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Catherine Fairbairn
Mackenzie Valley Environmental Impact Review Board
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Submitted to the registry

August 8th, 2024

Náhkale;

Re: Délı̨nę Got'ı̨nę Government Information Requests

Please find Délı̨nę Got'ı̨nę Government's (DGG) initial set of Information Requests for the Mackenzie Valley Highway Project (EA1213-02) as Appendix A. A second set, focusing on topics of interest for DGG's Community Wellness department will follow prior to the August 14th deadline. We ask the Review Board and other to treat these two files as one package.

Máhsı,



Todd Slack
Technical Team Consultant,
Lands, Resources, and Environment Department

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Catherine Fairbairn

Mackenzie Valley Environmental Impact Review Board

cfairbairn@reviewboard.ca

Submitted to the registry

August 12th, 2024

Náhkale,

Re: Délı̨nę Got'ı̨nę Government Information Requests

Submitted concurrent to this cover letter, please find Délı̨nę Got'ı̨nę Government's (DGG) second batch of Information Requests for the Mackenzie Valley Highway Project (EA1213-02). Please treat this file as a single package together with the first set submitted by Todd Slack on August 8, 2024.

Máhsı̨,

Jackie Siegel

Jackie Siegel

Technical Health Consultant

Community Wellness Department

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IR 10 - Financial Support for Working Groups

TOPIC: Corridor Working Group

ADDRESSED TO: GNWT

PREAMBLE: The Mackenzie Valley Highway Project - Developer's Assessment Report from October 2023 (DAR) states that "The GNWT has committed to develop and implement a Community Readiness Plan that includes several interconnected plans that are intended to address the adverse effects of the Project." Section 9.16 provides details on the structure and function of the Community Readiness Plans, outlining the role of Sub-Working Groups (Road Safety and Security, Training and Employment, and Social Monitoring and Adaptive Management) in developing and overseeing mitigation plans for the construction and operation of the MVH.

The proposed structure engages multiple organizations and GNWT departments, over an extended period (from one year pre-construction to five years post-construction). This will require significant financial and in-kind investments from the GNWT and a considerable amount of coordination across all parties. The responsibilities of the Sub-Working Groups are likewise significant and important, and DGG is concerned that the onus to complete necessary work to identify, research, and mitigate a broad set of effects will require an appropriate investment on their behalf. The scope is significant and the community staff in place already have heavy workloads. Furthermore, given the breadth and depth of plans to be completed, MVH will wholly consume staff time, leaving existing challenges and initiatives incomplete.

REQUEST:

1) DGG is looking for additional details around the Mackenzie Valley Highway Corridor Working Group (and its component groups). For the existing proposal of the Corridor Working Group, what are the anticipated fiscal and staff resources that GNWT will provide communities to complete this work? How will the CWG and all the sub-working groups be funded, and to what amount?
2) Will Délı̨nę specifically be provided sufficient funds to participate in the sub-working groups? What staffing resources will be made available?
3) What role will Délı̨nę have on the sub-working groups? How will GNWT ensure that our participation be equitable to that of other communities?

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IR 11 – Food Prices in Délı̨nę

TOPIC: Food Security

ADDRESSED TO: GNWT & Canada

PREAMBLE: The DAR states that there will be "greater variety of groceries (easier to access groceries in other communities as well ability for greater variety of fresh foods to be provided all-season)" due to the all-season operation of the highway (section 9.5.5). The DAR also outlines measurable parameters related to food security in section 9.2.4.1, including cost of food ($) and access to lower cost (high quality) food. As a community in the RAA, Délı̨nę is not likely to experience this benefit.

Contrary to some of the anticipated benefits for communities along the road route, DGG is concerned that landed prices in our community will be negatively affected. As Tulita and Norman Wells move to the road net, aerial freight delivery and passenger traffic levels will be significantly altered, with a potential negative economy of scale being imposed on the communities that are reliant on the air-supply net (Délı̨nę, Fort Good Hope, and Colville Lake). As a result, Délı̨nę is concerned that some of the positive themes of the project for the connected communities will be net negatives for our community – primarily cost of living.

REQUEST to GNWT:

1) To what degree, if at all, is it expected that Délı̨nę will see a change in food prices with the operation of the MVH? How does this compare to expected changes in other Sahtu communities?
    a. What parameters and assumptions have been made for these calculations? Please describe (and submit) the work that GNWT has done to understand the consequential impacts of the project on the cost of food for Délı̨nę and the other remote communities.
2) Given that DGG expects food prices to rise in Délı̨nę, has GNWT explored mitigations against this? How will GNWT ensure food prices do not rise in Délı̨nę?
3) What is/are the specific parameter/s that will be used to measure food cost and food access, i.e. a specific parameter available through the NWT Bureau of Statistics? DGG expects that this is going to be measured at the community level and not just at the regional level.
4) Please provide a discussion on the timing nature of these mitigations – Délı̨nę is interested in a responsive tool rather than something that requires years and repeated political decisions.

5) Please describe (and submit) the work that GNWT has done to understand the consequential impacts of the project on the cost of freight and passenger travel for Délı̨nę and the other remote communities.
6) If cost of living is observed to increase in the remote communities, what mitigations are GNWT willing to provide to offset the impacts of its road?

REQUEST to Canada:

1) What work has Canada done to understand the impacts to Délı̨nę's food mail program, as a result of this project?
2) Given that DGG expects food prices to rise in Délı̨nę, Canada (Nutrition North) explored mitigations against this? How will Canada ensure food prices do not rise in Délı̨nę? What mitigations are Canada willing to provide to offset the impacts of its road?

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IR 12 – Access to Traditional Foods

TOPIC: Food Security

ADDRESSED TO: GNWT

PREAMBLE: The DAR states that "Due to their distance from the Project, it is anticipated that the RAA communities will not experience any decreased access to wildlife resources" (section 9.9.5). However, DGG is concerned about the impacts on traditional food sources, particularly caribou and fishing, with the construction and operation of the highway.

REQUEST:

1) What is the expected impact on caribou population and behavior along the MVH corridor, particularly in proximity to Délı̨nę? We want GNWT to consider the road itself, vehicle traffic, and the increased access for recreational hunting.
    a. How will this affect food security in Délı̨nę, with consideration to the availability of traditional foods and the impact on nutrition for Délı̨nę residents?
2) What is the expected impact on fish populations in the Great Bear River? We want GNWT to consider the road itself and the increased access for recreational fishing and activities along the river.
    a. How will this affect food security in Délı̨nę, with consideration to the availability of traditional foods and the impact on nutrition for Délı̨nę residents?
3) Given the stated effects on traditional foods from the project in general, and DGGs concern for our community specifically, what measurements and mitigation processes is GNWT willing to engage in to minimize any adverse impact in a manner that is proactive?
4) Given Chapter 18 of the Sahtu Dene Metis Comprehensive Land Claim Agreement and the Sahtu Harvest Study, how will GNWT measure changes in caribou and other wildlife harvest for the purposes of assessing compensation under the Land Claim?
    a. Should caribou and other wildlife harvest drop below the minimum needs level threshold, as stated in the Land Claim and Sahtu Harvest Study, what mitigations are GNWT prepared to do to meet their legal obligations with reference to the Land Claim?

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IR 13 – Health Data

TOPIC: Community Health

ADDRESSED TO: GNWT

PREAMBLE: There is a general lack of community data available across the NWT, for understandable reasons such as small population numbers and low incidence rates of disease and other quantifiable health measures. This nevertheless makes planning for health programs, including addressing health outcomes as a result of this project, particularly challenging at the community level. It is not enough to rely on regional data as each community has a unique context and will be impacted differently by the highway.

REQUEST:

DGG wants GNWT to provide more resources towards increasing the capture, analysis and sharing of health data, particularly publicly available community health profiles. Given that substance use and mental health are explicitly stated as concerns in the DAR, DGG is asking the GNWT to develop stronger measurements around these areas.

1) Is GNWT willing to commit to additional resources for improved monitoring and sharing of substance use and mental health data at the community level at the outset of this project?
2) Understanding that current practice limits the collection and sharing of such data due to privacy concerns, but given that DGG, as an indigenous government, is granted ownership of the data of its citizens and members (see OCAP: https://fnigc.ca/ocap-training), will GNWT commit to proactively work with communities to make localized data easily available for the purposes of monitoring and responding to effects of the highway construction and operation?
    a. How will GNWT ensure that health data monitoring continues throughout and beyond the timeline of this project? How will GNWT ensure that communities are supported through relevant, timely, and available health data to monitor and respond to health concerns?

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IR 14 – Drugs and Alcohol

TOPIC: Community Health

ADDRESSED TO: GNWT

PREAMBLE: Substance use is already an area of great concern for Délı̨nę without introduction of the highway. The DAR states that "Health centre staff in Délı̨nę noted that more drugs and alcohol in Tulita would result in more drugs and alcohol in Délı̨ne, due to the proximity of the communities to each other" (section 9.5.6). Changes in community/social ties and social pressures due to the construction and operation of the highway will have an adverse effect on drugs and alcohol in Délı̨nę, and DGG must be confident that sufficient resources are committed to addressing these effects.

REQUEST:

1) Can GNWT provide community level data for alcohol and drug use in Sahtu communities? How often is this data collected and released?
2) As drug and alcohol use increases in LAA communities, how will Délı̨nę be affected? Please describe (and submit) the work that GNWT has done to understand the impacts and pathways of the project on drugs and alcohol in Délı̨nę and other remote communities.
3) Can the GNWT provide data on drug and alcohol use behavior changes from the TASR and Tuktoyaktuk highway projects? As Gameti is a similarly 'off-road' community, this might be a useful comparator for Délı̨nę.
    a. What lessons can GNWT take from other projects that it will apply to the MVH project to mitigate increases in drug and alcohol use in LAA and RAA communities?
4) DGG believes that drug and alcohol mitigation strategies need to be comprehensive and sufficiently resourced. How much funding and staffing is currently allocated in each community for drug and alcohol prevention and addictions treatment. What mental health services are available in each community (for substance use and more)?
    a. What resources and mandate will the Corridor Working Group and sub-working groups have to specifically monitor and mitigate drugs and alcohol? Will GNWT commit to responding to concerns raised by the working groups?
5) If the highway is built, what are the minimum steps necessary to provide prevention, treatment and mental health services in communities? Will GNWT commit to long-term funding of treatment programs? (Note, Community Readiness Strategy is funded until 5 years of operation).
    a. How long have similar road working groups been funded to Tlicho?

   b. Does GNWT believe this is sufficient time to measure and make changes? If so, why?
   c. For these programs, what were the funding levels before and after the construction of TASR?

6) What plan does the GNWT have to address drugs and alcohol enforcement (trafficking, bootlegging) along the MVH? If this strategy is meant to be developed by the sub-working groups, does GNWT believe there is sufficient time and resources to implement this upon the opening of the highway. DGG expects this plan to include at least the GNWT, RCMP, tow truck services, and other emergency services.
7) Given responses to all the above, does GNWT believe this is sufficient to address adverse effects on drugs and alcohol from the highway?

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IR 15 – Health Equity across the Region

TOPIC: Community Health

ADDRESSED TO: GNWT

PREAMBLE: DGG believes there is a significant likelihood that health equity will become a greater problem than already exists if the highway is built. Health services are lacking as is, and as LAA communities benefit from improved access to services, DGG expects that Délı̨nę, as an RAA community, will not experience these benefits at the same rate or level, if at all.

REQUEST:

1) What benefits vis-à-vis health services does GNWT expect LAA communities to experience as a result of the operation of the highway? What is the expected timeline of these benefits? For example, how long after the opening of the highway might health services be added or increased in LAA communities?
2) What adverse effects on health services does the GNWT expect RAA communities to experience as a result of the highway, considering factors such as reduced air traffic to the region and concentration of services in LAA communities?
3) Will the GNWT commit to taking a proactive approach to address any gaps in health services in RAA communities? Is the GNWT prepared to commit resources to ensure equitable health outcomes among all communities, regardless of their proximity to the highway?

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Appendix A: Délı̨nę Got'ı̨nę Government Information Requests for the Mackenzie Valley Highway Environmental Assessment

IR 1 – Mitigation effectiveness, Significant Impacts and the Purpose of Environmental Assessment

TOPIC: Nature of the assessment process

ADDRESSED TO: GNWT

PREAMBLE: In the response to Review Board Overarching IR 3 the GNWT noted that it "has not completed a systematic review of the effectiveness and limitations of each of its programs and plans".

This introduces a fundamental issue in the assessment process. The purpose of Measures is to bring impacts below a significance threshold. Without understanding if the past mitigations have been effective, it creates a great deal of uncertainty around the confidence of future mitigation effectiveness. Parties cannot be confident that the mitigations arrived at will be effective.

In short, it is not clear if the impacts from the Tłı̨chǫ Highway have been significant, with the supplementary question on whether that was incidental or due to the mitigations.

REQUEST: Please provide clear and complete answers to the following:

1) Understanding the contributing factors, does GNWT believe that any effects from the Tłı̨chǫ Highway have been significant?
2) Does GNWT believe that the monitoring and mitigations due to Measures were effective in reducing the impacts below the significance threshold?
3) Since 2021, please indicate:
    a. The total budget for the programs cited as part of the social and well-being 'net'
    b. The amount of funding provided to support monitoring and managing of affects specifically associated with the Tłı̨chǫ Highway.
4) In the three years prior to 2021, what was the total budget for:
    a. The programs cited as part of the social and wellbeing 'net'
    b. Any TASR specific monitoring projects.

IR 2 – Acknowledged Significant Impacts and the Need for Measures

TOPIC: Need for Measures

ADDRESSED TO: GNWT

PREAMBLE: GNWT has acknowledged that there are to be significant impacts as a consequence of this project. In addition to any other significant impacts found by the Board, these will require Measures (mitigations) to reduce their impact below the significance thresholds. DGG wishes to ensure that there is clarity amongst the proponent and the parties that this is a required outcome.

REQUEST:

1) Can GNWT confirm that Measures will be required for those areas where GNWT predicts significant impacts will occur.
2) GNWT has established that there will be a significant impact. Can they provide a narrative description of the significance threshold(s) that the mitigations must lower the impact below? If the project has a value (numeric or narrative) or monitoring in place, what effects within Délı̨nę represent a call for greater action (understanding that this is a work in progress)?
3) Does GNWT believe that Measures will be need for those areas that do not have plans, but are not yet acknowledged as having significant effects?

IR 3 – Ensuring sufficient information to complete the steps of an Environmental Assessment

TOPIC: Ability to Assess Impacts – Structural Needs/Provisions

ADDRESSED TO: GNWT

PREAMBLE: Given the EA Terms of Reference are quite explicit in terms of the Key Lines of Inquiry, the lack of information around social and economic considerations creates quite a limitation in the actual assessment of effects. When coupled with lack of proposed mitigations and the uncertainty of mitigation efficacy, it leaves Parties in a difficult position to be able to effectively utilize the EA process. MVH has had a decade with this project and has not yet developed the necessary plans – making the choice to do so *after* the EA. This is not acceptable.

Délı̨nę understands and supports that the project approach of working with the impacted communities to develop and deploy mitigations and monitoring. To undertake the development of these management steps after the EA creates a power imbalance in addition to the compromised assessment – should there be a conflict on the necessary mitigation post-EA, GNWT retains all decision-making authority.

At a minimum, the Proponent should create an outline, based on its experience with its other road projects, that provides clear commitments (stated and funding), goals/objectives, and criteria (where able) that will represent the initial ideal for the management effort. DGG doesn't believe that this is reinventing the wheel as we are learning from the successes and failures of the past - this may simply be porting over the management structure for TASR. This represents a minimum proposal that allows assessment and the creation of commitments in the EA process. Délı̨nę acknowledges that these are

drafts for consideration, to be worked on by the eventual Mackenzie Valley Highway Corridor Working Group

REQUEST: In order to facilitate assessment, please provide an initial framework that provides best management and monitoring practices developed from the Inuvik to Tuktoyaktuk Highway (ITH) and Tłı̨chǫ All-Season Road (TASR). DGG accepts that this represents only a base case for the MVH, with meaningful, collaborative, design work yet to come.

Specific Questions:

1) The creation and activation of the Corridor Working Group allows only one year (prior to construction) to create the sub-groups, approve plans, and provide all coordination. During this time there is only two meetings planned for this group. This feels like a monumental effort – given the standup and composition of the body is yet to be completed. For these plans or themes not to have a working draft or starting proposal, never mind not even being initiated, is troubling as it's the first KLOI and Délı̨nę 's largest concern.

   Given the pace of government initiatives can be quite slow (see GNWT 2023 Fire Review which just started), this feels inadequate given the significance. Given the political desire for this project to proceed makes the core question of its development a 'when' rather than an 'if', what rationale does GNWT have for not initiating this work immediately?

2) Similar to the time constraints around the Corridor Working Group, the sub-groups will have less than a year prior to construction (allowing for the larger group to meet and agree to sub-group membership) to collectively draft, review and approve drafts, issue them for the working group's consideration. This is to be done with only 4 meetings and with limited support and unclear processes. Is this reasonable?

3) Délı̨nę is not one of the local affected communities but will be exposed to indirect and community effects that DGG believes require monitoring and mitigation. Does GNWT accept that communities in the RAA have an important perspective and will be exposed to impacts in similar ways as other communities (i.e. drugs and alcohol will be much more accessible) and should be members of the steering committees created as part of the corridor working group?

4) DGG notes that there are two positions described in the DAR – one charged with coordination and one with SEIA monitoring.

   i) Relative to Construction start, when will these two positions be hired?

ii) Given the critical nature of the work (KLOI, significant concerns, primary community interests), this seems insufficient overall. If this project were approved, how many other staff does GNWT believe would be working on the project?
iii) If unknown, can the proponent anticipate the comparative level of staffing between socio-economic issues and others – would staff associated with avoiding, monitoring and managing impacts to communities amount to 1% of staff?

5) In the TASR process, DGG understands that TCG was the central body for the working groups. The current proposal has GNWT as the central coordinator.
   i) What was the rationale for the change?
   ii) Is GNWT open if other orders of government believed that a non-GNWT member should be the chair or coordinator?

6) Given the power imbalance between different orders of government post-EA (where GNWT has complete freedom of action in an area of public governance where it's the only real authority), what conflict resolution recourses will GNWT institute for the Corridor Working Group if there are strong disagreements in approach or needs?

   DGG does not believe that this is likely, but this is an issue introduced by the proponent's choice to develop core mitigations outside the environmental assessment process. If community and Indigenous governments cannot assess during the EA and satisfied with the mitigations, this will be moot, but it's a necessary requirement in case there are intractable disputes on the mitigations necessary to reduce impacts below significance.

IR 4 – Visual Timeline of Construction and Socio-Economic Programs

TOPIC: Timeline

ADDRESSED TO: GNWT

PREAMBLE: DGG is concerned that the project timeline lacks flexibility and as currently designed, will limit options and result in less than ideal outcomes. However, from our perspective, we have a limited comprehension as to how the different parts of the project come together.

REQUEST: Please provide a compiled timeline that looks are the activities of each of the sub-groups within the Corridor Working Group.

While we leave the key points to the developer, DGG's interest is in removing uncertainty around these matters. For instance, the timeline should include the project's RFP issuance, the awarding of principal contracts, any critical subcontracting dates, as well as notable construction dates.

- DGG understand that these dates are to be determined, so suggest that the project uses a nominal temporal scale based on the construction date, with all points referenced to that origin. Thus, the corridor working group start date is C-365 (one year prior).

IR 5 – Describing What a Successful Project Looks Like – Economic Benefits

TOPIC: Successful Economic Outcomes

ADDRESSED TO: GNWT

PREAMBLE: DGG believes that all parties would benefit from a narrative description that provides some details that expand on the project's goals or intentions with regard to economic benefits and how we know that they have been achieved. DGG leaves this to the proponent to write, though we ask for some simple metrics to be included. For example, the 50% northern hiring target is a useful, simple statement that addresses the interest of knowing what general positives can be expected out of the construction phase.

REQUEST:

1) Please provide a short general description of what benefits this project will result in from a community point of view, with regards to training, employment, and contracting.

IR 6 – Ensuring Benefits to Sahtu Residents from Project Construction – Skills/Training

TOPIC: Training

ADDRESSED TO: GNWT

PREAMBLE: DGG is deeply concerned that a significant portion of the envisioned benefits are at risk of not being delivered – through structural limitations and a lack of detailed planning and commitments.

DGG simply wants to ensure that all reasonable steps are being taken to prepare Sahtu residents to take advantage of the opportunities from the project. This means developing and deploying training and educational programs and where necessary, building infrastructure to support the delivery of programs, before the project commences.

REQUEST:

1) The Plan commitments (s. 9.16.2.2.1) largely indicate identification of gaps/barriers, local resources, as well as other information gathering efforts. It does not commit to deliver programs that will increase skills, trades experience or hours, or actually expand the labour resource. If properly understood, the outcome of this project, on or near the start of construction, is largely informational rather than actions or programs that would serve to improve or remedy the labour situation.
    a. Is the GNWT planning on delivery of any training or education programs that will improve the labour value in the Sahtu? For example, is the proponent intending to offer additional apprentice incentives targeted at the Sahtu? Are they providing improved higher education benefits for areas of study that may support the road construction? Is GNWT planning to work with local education authorities to improve grade school outcomes to broaden the pool of eligible students?
    b. If the project fails to meet its northern hiring targets, what consequences will occur to the GNWT project staff and project oversight? Is it just Sahtu and northern residents that bear the cost of failure?

2) Please describe and evaluate potential effects of the project on the following, at both the general and community specific level:

    Proposed education and training programs required for highway-related construction and operation employment, including:
        i. Local and regional training opportunities;
        ii. Timing and duration of programs, in relation to the highway development schedule;
        iii. Skills and experience gained in the highway workforce that could be applied to other available projects or sectors;
        iv. The number of people expected to be employable and available;
        v. The potential for local development of skills for senior professional positions (e.g. labourer/heavy equipment operator vs. supervisor/manager)
        vi. Proposed programs that would be provided by or sponsored by the developer.

3) How will GNWT ensure that this project is not like other large projects in the territory and that they will provide skills training and employment opportunities to Sahtúot'ine? What steps are they going to take that projects like Giant Mine did not benefit from?

4) Is the intent of the Contractor Training and Employment Plan to deliver training and improve northern employment?

5) Does the GNWT continue to believe that it can deliver on its socio-economic commitments, including the intent of Contractor Training and Employment Plan, within the year prior to construction starts?

   On the face of it, there seems to be significant reason to doubt this. For contrast, at Giant Mine, a large public contracting project which has a decade of lead-up and site management, GNWT and Canada (co-proponents) have delivered virtually no training or education programs, and have consistently not (perhaps never) met their northern employment targets, yet there seems to little consequence to any of the groups involved in the process (government staff, project staff, construction manager, contractors).

6) Délı̨nę currently lacks the infrastructure to deliver skills and trades training programs. Is the GNWT willing to make a commitment with DGG's education department to design, fund, and construct an appropriate facility?
   a. In the absence of an appropriate building, what steps/supports are the proponent taking to allow a broader range of potential students to attend schools/training outside their community?

7) What training targets or Key Performance Indicators does GNWT plan on establishing for this project? What does their research suggest are realistic and achievable goals for this project – what has been learned from other projects?
   a. TASR seemed to have successfully delivered the expected socio-economic benefits to the Tłı̨chǫ Region. Can the GWNT provide further information on that process and the lessons learned that will be used with this project? Details on the development timeline used for socio-economic agreements, monitoring and mitigations would be ideal information.

8) How will GNWT contracting recognize training as part of bid proposals? GNWT's own promotion materials for the Canyon Creek All-Season Access Road make it plain how important resources and planning for training and employment was at the *beginning* of the project

IR 7 – Ensuring Benefits to Sahtu Residents from Project Construction - Employment

TOPIC: Northern and Indigenous Employment

ADDRESSED TO: GNWT

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PREAMBLE: As with other areas in the DAR, assessing this Key Line of Inquiry is difficult as there is a lack of information – leaving parties to seek key details to even understand the initial commitment. Instead of analyzing a draft proposal, we are forced to seek the information just to understand the commitment and the facts around any mitigation. In this case, it does not seem that the project is intending to deploy programs to improve the probable outcomes. For DGG, failure to deliver meaningful training, employment, and/or contracting benefits as part of a generational construction program represents a significant failure.

REQUEST:

1) GNWT commits to having 50% of the workforce drawn from the NWT. What is not clear is the commitment to hiring Sahtu residents and particularly Indigenous Sahtu residents. Can the GNWT please provide clear information on what their goal is for local or regional hiring?

2) Within the contracting phase, when assessing/scoring proposals please describe the weight that the proponent will place on northern hiring. What penalties or corrective actions will be written into contracts if the proposed commitments are not met?

3) Please describe and evaluate potential effects of the project on the following, at both the general and community specific level:
    a. Direct and indirect employment opportunities generated by the development and the potential for uptake of these opportunities by Aboriginal peoples
    b. Employment and income opportunities for every year of construction and operation with particular reference to wage and salary employment by length and form of employment skills category
    c. Measures, plans, and commitments for maximizing local and Aboriginal Employment.

4) For any non-governmental employers involved in this project, please indicate how GNWT will require improvements and training to correct for failing to meet hiring targets and/or other Key Performance Indicators that are developed. What actions will the proponent take when they fail to meet their targets? Please provide examples of GNWT actions to this effect in other large public works projects.

5) Please provide a discussion on how GNWT will report on their socio-economic targets and the project performance.

IR 8 – Ensuring Benefits to Sahtu Residents from Project Construction - Contracting

TOPIC: Northern Contracting

ADDRESSED TO: GNWT

PREAMBLE: As with other areas in the DAR, assessing this Key Line of Inquiry is difficult as there is a lack of information – leaving parties to seek key details to even understand the initial commitment. Instead of analyzing a draft proposal, we are forced to seek the information just to understand the commitment and the facts around any mitigation. In this case, it does not seem that the project is intending to deploy programs to improve the probable outcomes. For DGG, failure to deliver meaningful training, employment, and/or contracting benefits as part of a generational construction program represents a significant failure.

Contracting is often the easiest aspect of Social Economic benefits to achieve (at the diamond mines, large infrastructure projects) but it requires planning and effort to ensure that the door is open enough for northern businesses who are at a competitive and scale disadvantage to southern outfits.

REQUEST:

1) Within the contracting phase, when assessing/scoring proposals please describe the weight that the proponent will place on northern based companies? Will the BIP program be applied to the evaluation process?

2) How will GNWT ensure that Joint Ventures meet the expectation of 'Joint' – that they are not simply shells where a southern company matches with a northern partner in name only?

3) How will GNWT structure contracts so that small businesses in the North can meaningfully bid and take advantage of potential opportunities? As an example of a past effort, at Giant Mine, the reclamation project heard the criticisms of its past efforts and has sought to provide breakdown packages at a variety of scales, providing a broader opportunity for northern businesses.

IR 9 – Community Disaster Response

TOPIC: Forest Fire Occurrence and Evacuation Support/Planning

ADDRESSED TO: GNWT

PREAMBLE: DGG has reviewed the GNWT response to LKFN IR 7.1 regarding forest fire occurrence. The statement that the road will not have any increase on the probability of fire occurrence seems poorly founded. Furthermore, the project is compared against two other scenarios – the current

winter road and the middle/upper Dempster Highway (unclear where the southern exclusion boundary is). The winter case is straightforward – the highway will pose increased risk; while the Dempster comparison requires additional consideration. With a lack of information, DGG asserts that the middle/upper Dempster represents a different environment with much different vegetation densities and complexes than that of the Mackenzie Valley Highway project area.

From the limited information, there is an incongruity in what GNWT thinks this road will provide. In the IR response, the anticipated use of the road can largely be described as a conduit for residents – with only a small amount of road-based harvesting access recognized beyond that. However, in the DAR, increased industrial use, tourism and local use seem to be recognized as possibilities. DGG believes the latter more likely – when we develop roads in the territory, increased use follows.

When we combine the fact that the use of this area is moving from winter only (aka zero risk) to all seasons with a higher intensity, the growing risk associated after fire ignition, and the ability of the community to continuously respond to emergency matters, DGG wants to ensure that there are appropriate supports for communities forced to deal with these situations.

DGG has accepted evacuees from Yellowknife and Fort Good Hope over the last two years, seeing our community grow 25% virtually overnight. This is work we are pleased to do – looking after family, elders and our neighbours is the Dene way. However, with this project, it is important that GNWT is prepared to support us as another order of government.

REQUEST:

1) Will the construction of the MVH alter GNWT fire management priorities?

2) As the threat increases, in the future, how does GNWT intend to provide improved community supports during emergency circumstances?

Pehdzeh Ki First Nation

Box 56
Wrigley, NT X0E 1E0
Phone: 867-581-3321
Toll Free: 1-855-813-5223
Fax: 867-581-3229
Band 756

August 14, 2024

cfairbairn@reviewboard.ca
Submitted to the Registry

Catherine Fairbairn, Senior Environmental Assessment Advisor
Mackenzie Valley Environmental Impact Review Board
5102 – 50th Ave,
Yellowknife, NT
X1A 2N7

Re Mackenzie Valley Highway – EA1213-02 – Information Requests

I write to provide Pehdzéh Kį First Nation's (PKFN's) Information Request.

PKFN has technical studies in progress. We intend to review our studies when they have been completed and participate in the second round of 2024 Information Requests.

We will also review the Department of Infrastructure's and other parties' responses to the MVEIRB's July 15, 2024, Information Requests in order to prepare our own further questions. For example, IRs 7, 8, 9, 12, 20, 21, 22, 27, 28, 29, 30, 41, 42, 58, 65, 66, 74, 76, 80, 81, and 82 relate directly to some of PKFN's key concerns. IR 66, in particular, addresses questions that we have repeatedly brought to the Department of Infrastructure's attention.

Do not hesitate to contact me with any questions.

Mahsi.

Chief Jesse (Jamie) Nekeneyia-Moses
Pehdzéh Kį First Nation

Pehdzéh Kį First Nation's Information Request

August 14, 2024

IR 1: Re how Infrastructure will integrate PKFN's TK Information into MVH planning

The GNWT Department of Infrastructure ("Infrastructure") states confidence that the information cited in the "Technical Data Report – Cultural and Traditional Land Use" in the DAR, is "adequate for the purposes of this assessment", taking into account that this assertion is made without access to PKFN's project-specific Traditional Land and Resource Use studies.[1] Infrastructure has stated that further TK received from PKFN will be reviewed "against the results of the DAR and incorporated in the regulatory process and project planning as appropriate",[2] and that Infrastructure will "review the information and consider it in the context of the Project in a supplemental report".[3]

Infrastructure has not fully responded to questions on this point from the MVEIRB:

> **Comment**
> The developer is expecting Pehdzéh Kį and Łíídlıı Kúé First Nation to submit their Traditional Land and Resource Use studies, but there are no details on how the developer plans to incorporate the findings of the study into the DAR in the same manner as the other Traditional Land Use Studies.
> **Recommendation**
> Please provide an update on the Pehdzéh Ki, Łíídlıı Kúé and any other TLRUs and when they can be expected for consideration. When the GWNT receives these studies, how does it plan to meaningfully and respectfully integrate the findings into the effects assessment? Will the GNWT validate its correct use of the information with Indigenous groups?
> **Response(s)**
> The GNWT-INF provided capacity funding for Pehdzéh Kį First Nation and Łíídlıı Kúé First Nation to complete project-specific traditional land and resource use (TLRU) studies for the Project. No TLRU reports have been received from Pehdzéh Kį First Nation as of March 2024. Łíídlıı Kúé First Nation's TLRU study report is anticipated in summer 2024.[4]

PKFN asks:

1. How will Infrastructure address the TDR's gaps and deficiencies?

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[1] *Developer's Assessment Report* at Section 11.7, p. 11.135.
[2] *Developer's Assessment Report* at Section 11.7, p. 11.135.
[3] *Developer's Assessment Report* at Section 3.2.2.3, p. 3-6.
[4] Comment 20 and Response between Catherine Fairbairn on behalf of the MVEIRB, and GNWT-Infrastructure, Feb. 9, 2024. MVEIRB Online Registry System. Accessed online May 15, 2024: https://new.onlinereviewsystem.ca/review/A2062718-6D85-EE11-8925-0022483C4492

2. How does Infrastructure plan to meaningfully integrate our traditional knowledge into the effects assessment?
3. How will Infrastructure validate its correct use of our information with us?
4. How will current timelines for the environmental assessment process allow for these steps to take place?

October 29, 2013

Mr. Jim Stevens
Director
Mackenzie Valley Highway
Department of Transportation
Government of the Northwest Territories
Yellowknife, NT

Dear Sir:

RE: Effect of Construction Timing on Mackenzie Valley Highway Impact Assessment Predictions

The Mackenzie Valley Environmental Impact Review Board (Review Board) is developing final terms of reference (ToR) for the preparation of the Developer's Assessment Report by the Government of the Northwest Territories. As a result of its review of Project Description Reports and the recent scoping meetings held in affected communities, the Review Board has identified several fundamental questions which it requires the Department of Transportation (developer) to answer so that the ToR can be finalized.

The Review Board understands the developer proposes to construct a highway from Wrigley to a point on the Dempster Highway near Inuvik. Further, the Mackenzie Highway will likely be constructed in segments and the schedule for each segment and for completing the entire highway is not known at this time. More specifically, the developer has described a construction schedule that may only involve constructing and then operating the highway from Wrigley to Norman Wells for an indeterminate period. Thus, the entire length of the highway may not be built at one time or on a schedule which facilitates the evaluation of the environmental impacts in a manner that enables the Review Board to determine the potential impacts of this staged development with confidence and advise the federal Minister accordingly.

To illustrate this concern, caribou and moose harvesting has been identified in community scoping sessions as an issue of some importance. Wildlife populations are dynamic and the Review Board is concerned that predictions of highway impacts based on current wildlife population levels may not be valid in 5, 10 or more years from now, when the more northern segments of the highway are actually built. Similar concerns exist in relation to the accuracy of impact predictions on other environmental variables, ranging from water resources to climate and permafrost and even socio-economic considerations.

In light of this concern, a supplementary submission is requested from the developer discussing how this staged construction schedule will affect the stated purpose(s) of constructing a through,

or loop highway, in light of each of the purposes of constructing the highway identified on page 2-1 of the Developer's Environmental Scoping Document.

The developer must also discuss how the extended time frame and sequential construction of this development will affect the accuracy and reliability of the impact predictions it must make during the environmental assessment process. This reliability analysis should be completed with respect to all key valued ecosystem components. The developer will indicate how these matters will affect its impact predictions should construction and operation of highway segments not take place for 5, 10 or 20 years after completion of the environmental assessment. The response to this question should be quantified to the extent possible and where professional judgment is applied, the individuals involved should be identified and their qualifications provided as part of the submission.

Depending on the outcome of this analysis, the Review Board will frame its approach to the temporal scope of the impact determinations necessary in this proceeding. The final ToR will be completed once the Board has your response to these questions and we have heard from the parties.

The developer's submission is requested by November 15, 2013.

Yours truly,

Vern Christensen
Executive Director

cc. MVEIRB Counsel
Public Registry

Northwest Territories Transportation

November 13, 2013

MVEIRB File: EA1213-02

Mr. Vern Christensen, Executive Director
Mackenzie Valley Environmental Review Board
5102-50th Avenue
200 Scotia Centre
PO BOX 938
YELLOWKNIFE NT X1A 2N7

Dear Mr. Christensen:

Effect of Construction Timing on the Mackenzie Valley Highway Impact Assessment Predictions

Thank you for your letter of October 29, 2013 requesting comment on issues related to the purpose of the development and the reliability of the impact predictions that will be included in the Developer's Assessment Report (DAR). I trust the following will address your questions.

While the Government of the Northwest Territories (GNWT) will be the developer of the Mackenzie Valley Highway (MVH), the federal government retains responsibility for funding the construction of new highways in the Northwest Territories. The GNWT has been advised by the federal government that funding for the construction of the MVH will not be available until completion of the environmental assessment by the Review Board. The GNWT has been consistent with this message throughout the Scoping stage of the assessment. The GNWT intends to construct the entire development as proposed in our Scoping Document; however, we are cognizant that funding arrangements with the federal government may necessitate a phased approach in which some sections of the proposed highway are constructed and operational before other sections.

The GNWT believes that a possible phased construction approach is consistent with the objectives of the development as identified on page 2-1 of our Scoping Document. A phased approach which provides all- weather access to some regions before the entire development is complete achieves many of the development's objectives.

.../2

The GNWT proposes to address the concerns raised by MVEIRB in relation to the reliability of the impact predictions in the following forms:

- Within the DAR document
- Pre-construction surveys

The GNWT will prepare a DAR which meets the Terms of Reference issued by the Review Board. The assessment of effects presented in the DAR will be based on current baseline conditions. However, in recognition that the development may require a phased schedule, the assessment will also include a review of best available data relating to predicted future potential changes to baseline conditions. For example, the potential effects of climate change. This data will be used in the assessment to discuss how baseline conditions may change and how that could affect the conclusions of the assessment.

Following completion of the environmental assessment the development will proceed through the permitting process, requiring provision of site specific baseline data to allow for the development of terms and conditions specific to each permit, licence or authorization. To support the information requirements of the permitting process the GNWT will conduct pre- development surveys to assess baseline conditions. Should these surveys result in findings that conditions differ to an extent that would affect the accuracy of the predicted effects in the DAR; the GNWT will commit to update the effects assessment for review by the appropriate agencies. We believe this approach will allow the MVEIRB to conduct a thorough and efficient environmental assessment providing for the protection of the environment and allowing for a possible staged construction schedule of the development.

It is the intent of the GNWT to develop the MVH in a manner which protects the environmental resources of the Mackenzie Valley and complies with all approvals issued for the development. Please do not hesitate to contact me should you have further questions.

Yours truly,



Jim Stevens

Mackenzie Valley Review Board

July 15, 2024

Seth Bohnet
Director, Strategic Infrastructure
Department of Infrastructure

Government of the Northwest Territories
P.O. Box 1320, Yellowknife, NT X1A 2L9

Via email: seth_bohnet@gov.nt.ca

Dear Mr. Bohnet,

RE: Mackenzie Valley Highway, Review Board information requests

The Mackenzie Valley Review Board (Review Board) has carefully reviewed your answers to parties' and Review Board's comments and questions about the Developer's Assessment Report (DAR), and answers to the Review Board's overarching information requests (IRs).

The Review Board recognizes the effort that went into the developer's responses to the three overarching IRs the Review Board asked in March. The Review Board found some aspects of the responses useful, but some responses lacked important details. The Review Board wants to understand what the optimal schedule and future conditions mean for impact predictions, as well as how the Government of the Northwest Territories (GNWT) can build on successes or learn from problems on similar highway projects. The Review Board has additional questions for the developer, many of which build on topics in the overarching IRs or questions parties asked in the review of the DAR.

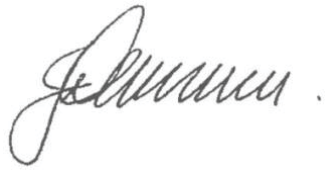
The Review Board understands that the GNWT is taking a whole-of-government approach for the Mackenzie Valley Highway project. The GNWT also has key responsibilities and expertise within specific departments and has responsibilities under Section 22 of the *Mackenzie Valley Resource Management Act* (the Act) to provide information to assist the Review Board in its assessment. The Review Board wants the views and analyses of expert departments in response to certain IRs that are within their field of expertise and responsibility. As such, the Review Board requires that each department with relevant expertise respond to the IRs as indicated, and that the developer clearly state: a) which information came from expert departments; and b) how that information was considered or applied in responding to the relevant IRs.

The Review Board requires the developer to fully respond to each IR. These IRs are intended to address relevant issues prior to public hearings. Thorough and thoughtful responses to IRs should lead to less complicated hearings with fewer issues. Please carefully consider the Review Board's detailed IRs on the online review system.

Parties can submit their own IRs until August 14, 2024. The developer is asked to respond to all the IRs directed to it by September 27, 2024.

If you have any questions or concerns, please contact Catherine Fairbairn at 867-766-7054 or cfairbairn@reviewboard.ca.

Respectfully,



Joanne Deneron
Chairperson

cc. Distribution List

Charles McNeely
Chairperson
Sahtu Secretariat Incorporated

Herb Norwegian
Grand Chief
Dehcho First Nations

Ken Kyikavichik
Grand Chief
Gwich'in Tribal Council

Erin Kelly
Deputy Minister
Environment and Climate Change

Steve Loutitt

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Assistant Deputy Minister
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Robert Jenkins
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Lorraine Seale
Director
Environment and Climate Change

Patricia Coyne
Manager
Mackenzie Valley Environmental Affairs Infrastructure

Mackenzie Valley Review Board

July 15, 2024

Seth Bohnet
Director, Strategic Infrastructure
Department of Infrastructure

Government of the Northwest Territories
P.O. Box 1320, Yellowknife, NT X1A 2L9

Via email: seth_bohnet@gov.nt.ca

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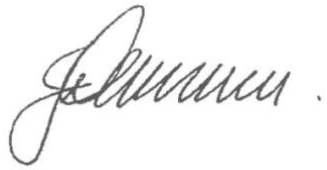
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Respectfully,



Joanne Deneron
Chairperson

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Patricia Coyne
Manager
Mackenzie Valley Environmental Affairs Infrastructure

esa

ECOSPHERE

Evaluating the road-effect zone on wildlife distribution in a rural landscape

COLIN S. SHANLEY[1,3,†] AND SANJAY PYARE[2]

[1]*Biology and Wildlife Department, University of Alaska, Fairbanks, Alaska 99775 USA*
[2]*Environmental Sciences and Geography Program, University of Alaska Southeast, Juneau, Alaska 99801 USA*

Abstract. The road-effect zone is the area in which ecological effects extend outward from a road. Dispersed off-highway vehicle (OHV; e.g., four-wheelers and snowmachines) activity on rural road networks creates a disturbance that reduces the effective amount of wildlife habitat and therefore has the potential for an extensive road-effect zone. Consequently, land managers must consider the trade-offs between rural road development and the conservation of habitat for species of concern. We conducted a spatially-explicit study of moose, *Alces alces*, occurrence in relation to rural roads and OHV routes in rural Alaska, U.S.A. We used logistic regression and AIC model selection criterion to develop resource selection functions (RSFs) for male and female moose at three spatial scales (250 m, 500 m, and 1000 m) in two seasons (summer and fall). To evaluate an ecological disturbance threshold from increasing route activity on the probability of animal occurrence, the RSFs were plotted against an index of route activity derived from interviews with OHV users, and fit with logarithmic functions. The variable for route activity improved the fit of RSF models for both sexes at all spatial scales and in both seasons. A negative relationship was found between moose occurrence and routes or areas in which routes were in close proximity to primary forage, with the exception of male moose at the 1000-m scale in the fall. Therefore, among the spatial scales of analysis, the road-effect zone for male moose was determined to be between 500 m and 1000 m, and >1000 m for female moose. Furthermore, route activity <0.25 km of vehicle travel/km^2/day was a threshold value at which moose sustained a high probability of occurrence (0.60 to 0.91). The results of our study suggest that the dispersed ecological effect of rural roads and OHV routes should be considered in transportation and land-management planning efforts. Relatively low levels of vehicular activity may create extensive road-effect zones for sensitive species.

Key words: Alaska; *Alces alces*; disturbance; ecological thresholds; habitat selection; moose; off-highway vehicles; resource selection function; road-effect zone; roads; rural landscape; wildlife distribution.

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INTRODUCTION

The growing network of roads in rural landscapes is creating new challenges and opportunities for transportation planning and the conservation of wildlife habitat (Trombulak and Frissell 2000, Forman et al. 2003, Fahrig and Rytwinski 2009). In the last four decades, the use of off-highway vehicles (OHVs; e.g., four-wheelers and snowmachines) on public lands across the U.S. has increased seven-fold (USFS 2004). As a result, illegal OHV use on public lands has been a growing problem across the U.S. (USFS 2004). OHVs have also been used for non-recreational

purposes that add another layer of complexity to access management plans in many rural areas. For example, OHVs have been used as the primary means of transportation for subsistence hunting and gathering of wild food resources in many rural communities (Berkes and Jolly 2001, Ford et al. 2006, Brinkman et al. 2007). OHV users have used existing infrastructure, such as old logging roads, in addition to creating an extensive informal network of dispersed routes in the process of searching for game (Mills and Firman 1986, Stedman et al. 2004, Schmidt et al. 2005).

One concept for evaluating the ecological footprint of rural road networks and establishing wildlife conservation measures is the "road-effect zone", which is a measure of the spatial extent of ecological effects that extend beyond the physical edge of roads (Forman et al. 1997). This zone was estimated to average approximately 600 m from roads in urbanized landscapes for a cross-section of ecological components, from altered streams to disrupted ungulate movements (Forman and Deblinger 2000). Extrapolating this impact zone across the 6.2 million-km road system of the U.S. resulted in estimates of ecological effects on 19% of the country, underscoring the large extent of road-affected lands (Forman 2000). Although Forman (2000) suggested this concept can be applied to rural landscapes and even showed the potentially disproportionate impact that vehicle activity on rural areas has (16.7% of the country) as compared to urban areas (2.5%), the 600-m estimate may not typify the road-effect zone in rural landscapes for several reasons. First, road-effects in rural areas may be underestimated due to the low detectability and high dispersion of OHV occurrence on landscapes (Preisler et al. 2006, Seip et al. 2007). Second, habituation to noise and visual disturbances of vehicles is less likely to occur when traffic frequency is lower and thus, OHVs putatively have a greater effect on wildlife in rural landscapes (Creel et al. 2002, Stankowich 2008). Third, whereas vehicular use may be more consistent in urban landscapes, rural use may be highly variable both temporally and spatially (Jaarsma and Willems 2002, Forman et al. 2003); suggesting that road-effect zones in rural areas must account for variability in vehicular frequency. And finally, whereas urban road networks occur in developed corridors that are relatively simple and patchy with respect to natural habitat, rural roads are juxtaposed with relatively undeveloped landscapes; suggesting a greater need to account for environmental covariates (e.g., habitat) when measuring road-effect zones in these areas (Fahrig and Rytwinski 2009).

Although the road-effect zone clearly has relevance, methods of actually estimating this parameter under the complex and dynamic conditions represented by OHVs on rural road networks has received scant attention. Spatially-explicit, multivariate modeling approaches have been applied to a number of animal resource-selection contexts (Johnson et al. 2006) and offer a solution to the problem of estimating the rural road-effect zone. Whereas previous studies on the road-effect zone that have been limited to observational data (Reijnen et al. 1995, Forman and Deblinger 2000, Boarman and Sazaki 2006, Semlitsch et al. 2007, Eigenbrod et al. 2009) and thus likely underestimated the extent of affected habitats, spatially-explicit models can incorporate large, high-frequency, and unbiased animal-tracking datasets to more fully realize impacts (Johnson et al. 2004, Gaines et al. 2005, Farmer et al. 2006, Ciarniello et al. 2007). For example, Sawyer et al. (2006) used three years of collar location-data to quantify the effective area of mule deer (*Odocoileus hemionus*) habitat lost to natural gas development.

In addition, spatially-explicit methods offer a practical benefit for managing OHV distribution: not only do these allow for mapping the maximum extent of a disturbance, e.g., the road-effect zone, but also allow for identification of disturbance thresholds (Huggett 2005, Groffman et al. 2006). An ecological disturbance threshold is a particularly useful and perhaps more ecologically-relevant metric, whereby vehicle activity causes an abrupt nonlinear animal response, rather than a gradual or linear response (Walker and Meyers 2004, Eigenbrod et al. 2009). Mapping portions of roaded landscapes that exceed a disturbance threshold yields an estimate of the effective amount of habitat lost by wildlife populations; a metric that is particularly valuable in situations when more direct evidence of impacts on animal fitness or population trends cannot be ascertained (Andren 1994, Fahrig 2001). Conversely, mapping areas falling below

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thresholds allows managers to identify potential zones where traditional levels and forms (e.g., subsistence hunting) of OHV use are more compatible with wildlife.

Our study objectives were to derive and evaluate a novel series of methods for evaluating the road-effect zone in rural landscapes. Specifically, we derived estimates of the road-effect zone on moose (*Alces alces*) in a rural landscape using a spatially-explicit, multivariate model approach that incorporated variability in vehicular frequency; conducted a follow-up exploratory analyses to identify ecological disturbance thresholds for OHV management; and finally, compared these estimates to previous estimates in urban areas and other landscapes where alternate analytical methods have been used.

Methods

Study area

Yakutat, Alaska is a rural community of approximately 800 residents located along the coast of southeastern Alaska in the northernmost portion of the Tongass National Forest (Fig. 1), a coastal temperate rainforest. The topography of Yakutat is a relatively flat strip of coastline abutting the Fairweather Range with a mosaic of wetlands, shrub lands, and forests (Shephard 1995). The area is bisected by several large glacial and rain-fed rivers. The forested areas are dominated by Sitka spruce (*Picea sitchensis*) interspersed with western hemlock (*Tsuga heterophylla*) and black cottonwood (*Populus trichocarpa*). The wetlands and shrub lands are composed of graminoids, forbs, and shrubs with several species of willows (Salix spp.) and Sitka alder (*Alnus sinuate*). The geographic bounds of the study area were defined by the availability of fine-scale (5 m) vegetation coverage data derived from remote sensing (SPOT) imagery; an area covering approximately 1000 km^2 (Fig. 1).

Animal location data

We used a three-year dataset of 30,825 locations from 20 GPS-collared moose during November 2002 to March 2005. The dataset was previously used to examine habitat selection and sightability of moose in the region (Oehlers 2007). The collars recorded a GPS location every six hours, an interval sufficient to maintain relative independence between consecutive locations and minimize spatial autocorrelation (Nielson et al. 2002). The dataset was formatted as follows: (1) for a season-specific comparison (Stankowich 2008), locations were separated into discrete five-week analysis periods corresponding to summer or fall (Table 1; Mills and Firman 1986, Franzmann and Schwartz 1997, USFS 2009). (2) To account for the possibility of behavioral differences, male and female moose were separated (Miquelle et al. 1992, Bowyer et al. 2001, Spaeth et al. 2004). (3) To minimize the influence of individual variation on pooled locations for modeling, an equal number of locations were selected from each individual (Thomas and Taylor 2006).

We conducted an analysis on a resulting dataset of 2,374 locations from five female and five male moose. 106 Locations per individual were randomly selected for the summer analysis period and 146 locations for fall (with one male vacating the study area during the fall) to produce individual seasonal home ranges (Girard et al. 2002). A matched use-availability design was employed to compare animal locations to random locations within seasonal home ranges (Design II; Manly et al. 2002, Johnson et al. 2006). Kernel home ranges (99.9%) were created for each individual with the Home Range Extension (Rodgers et al. 2007) in ArcGIS 9.2 (ESRI, Redlands, CA). The smallest whole kernel was found by lowering the h*ref* (smoothing parameter) in 0.1 increments until the home range polygon split or a hole formed inside the polygon. The individual home ranges were then pooled for different sexes and seasons to investigate third-order (Johnson 1980), sex-specific and season specific resource selection. To conservatively define available locations (Aebischer et al. 1993, Keating and Cherry 2004), lakes, rivers, and coastlines were also removed from these four combined home ranges before the available locations were randomly selected for analysis.

Route mapping and classification

The majority of existing route information was digitized from IKONOS remote sensing imagery in 2004 by the U.S. Forest Service Yakutat Ranger District. This information was supplemented and verified with ground-based GPS delineation of routes used by OHVs and by aerial survey from a

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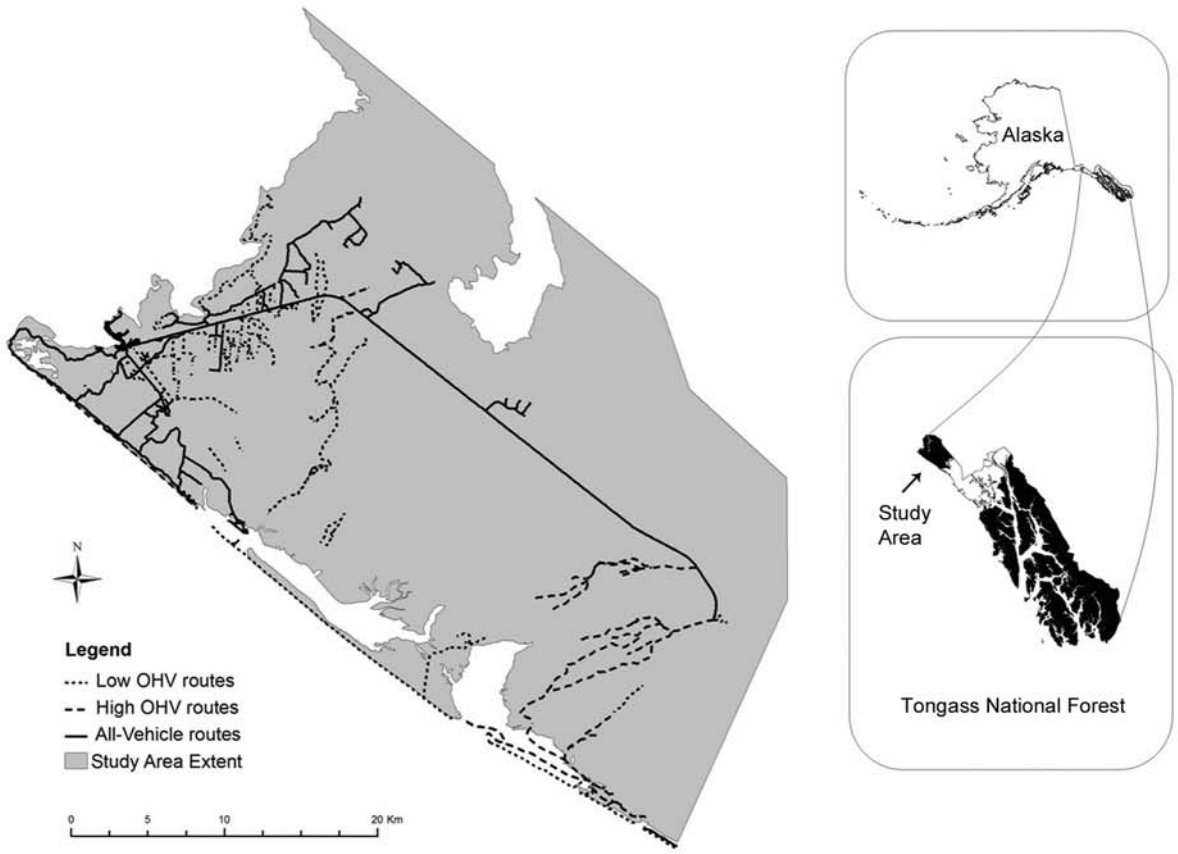


Fig. 1. The extent of remote sensing imagery covering the study area of Yakutat, Alaska, located on the northernmost coast of the Tongass National Forest, USA.

Table 1. Biological and anthropogenic factors used to justify the classification of GPS-collar data into seasonal analysis periods to evaluate a rural road-effect on moose in Yakutat, Alaska.

Season	Biological factors	Anthropogenic factors	Approx. time frame	Five-week analysis period
Summer	Summer forage/ Post-calving	Low terrestrial subsistence/ low OHV traffic	June 1–Sept. 15	July 1–Aug. 7
Late Fall	Fall forage/Post-rut	High terrestrial subsistence/ high OHV traffic	Oct. 8–Nov. 30	Oct. 8–Nov. 15

helicopter (Fig. 2). We then held a series of meetings with the land managers in 2006 to update and refine existing route information. Land managers did the following: (1) visually verified new routes observed on 2005 SPOT5 remote sensing imagery; (2) identified which routes were actively used over the study period; (3) categorized routes in three categories (Low OHV, High OHV, and All-Vehicles) according to perceived level of use as well as the visible wear and soil types (Table 2); and (4) selected three representative routes in each category to sample for route-use frequency in subsequent interviews with OHV users.

A total of 523 km of routes were mapped across the study area. The routes were composed of 184 km of Low OHV, 118 km High OHV, and 221 km of All-Vehicle routes. A random sample of approximately one-third ($n = 25$) of federally registered subsistence moose hunters were inter-

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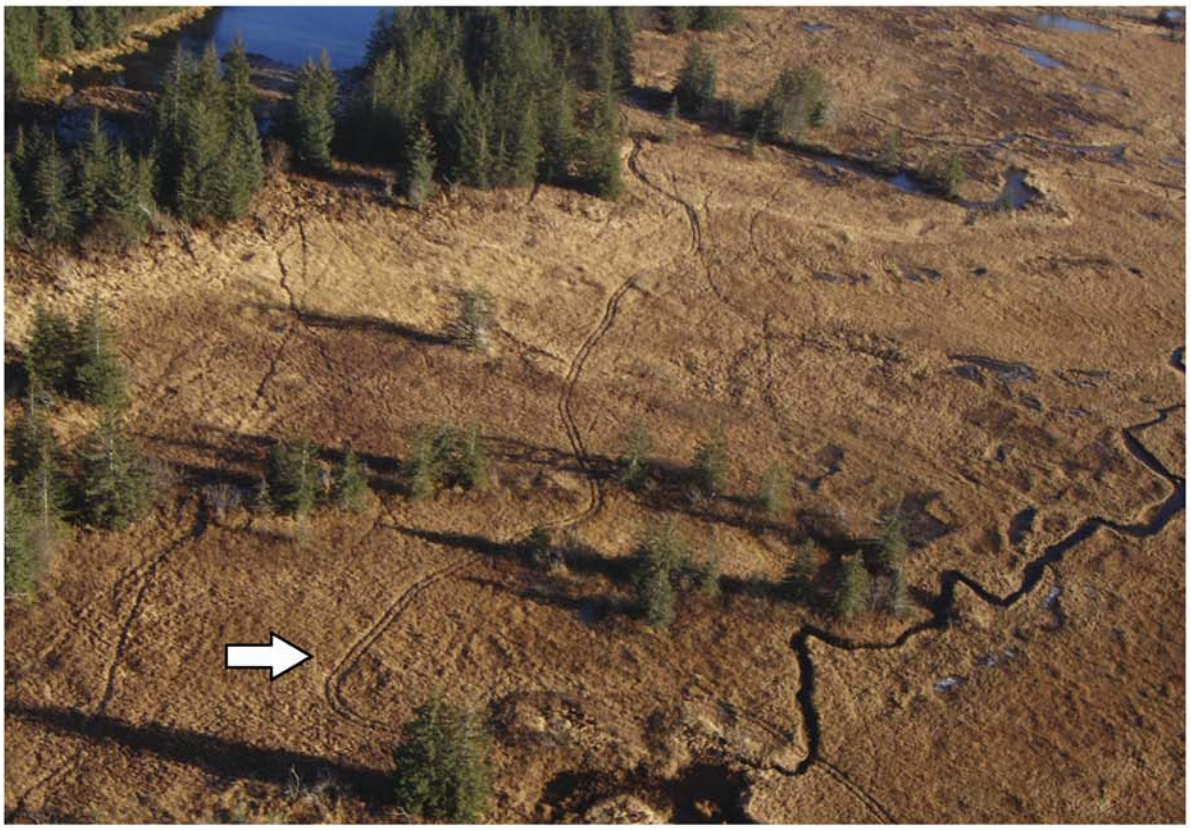


Fig. 2. A low-elevation aerial photograph showing a parallel wheel-track (indicated with an arrow) that typifies a dispersed off-highway vehicle (OHV) route through the mosaic of wetlands, shrub lands, and forests that compose the rural landscape of Yakutat, Alaska. Photo credit: U.S. Forest Service.

Table 2. The classification of vehicle routes based on vegetation displacement and soil types in Yakutat, Alaska.

Route type	Criteria
Low OHV	(a) Silt and clay soils: lack of incised ruts, wheel track is generally vegetated, one wheel track predominates, few parallel wheel tracks for short distances only (b) Beach and sand/gravel proximal outwash soils: not connected to the road system directly and not connected to high use trails through other soil types
High OHV	(a) Silt and clay soils: incised ruts, displaced soil, track denuded of vegetation, many parallel tracks, often in marginally passable areas (b) Beach or sand/gravel proximal outwash soils: connected to the road system directly or connected to high use trails through other soil types
All-Vehicles	Any route known to be driven by standard motor vehicles at any point in time that may also have OHV traffic

viewed in December 2007 to determine the frequency of route-use. Hunters were presented a 1.5 m $\times$ 1 m aerial photograph of the region with mapped roads and OHV routes. Without disclosing the preconceived route-use categories to hunters, hunters provided estimates of the number of one-way trips they traveled on the nine representative routes in each seasonal analysis period. Data were pooled for each of the three route categories, resulting in 75 route-use estimates for each category in each of the two seasonal analysis periods. Differences in the frequency of use among route-use categories were statistically significant (ANOVA; $p < 0.05$), so the average number of one-way trips observed in each route category was used as a weight in subsequent road-effect modeling (Table 3).

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Table 3. The total length of digitized routes as well as the results of a one-way ANOVA used to test for differences in the frequency of use among route-use categories.

Route type	Total (km)	Average ± SE	p
Summer			
Low OHV	184	0.03 ± 0.04	0.0116
High OHV	118	0.50 ± 0.26	<0.0001
All-Vehicles	221	14.1 ± 2.83	<0.0001
Fall			
Low OHV	184	0.75 ± 0.31	0.0126
High OHV	118	2.04 ± 0.66	<0.0001
All-Vehicles	221	13.1 ± 2.42	<0.0001

Road-effect modeling

We used an information-theoretic approach with multiple working hypotheses (Burnham and Anderson 2002) to investigate a road-effect on moose. We developed 10 a priori models to evaluate resource selection based on the following. First, we eliminated commonly employed habitat variables (e.g., elevation, slope, and aspect) due to the relatively flat terrain over the study area. Second, we were interested in evaluating specifically the effect of route activity on animal distribution so we developed models with and without a route activity variable. And third, we hypothesized that the primary predictors of moose occurrence in our study area during the snow-free summer and fall would be the proximity to high-quality forage, cover from predators, and riparian areas (Van Ballenberghe and Ballard 1998, Kunkel and Pletscher 2000, Dussault et al. 2005).

Table 4. Independent variables calculated for each used and random location at three spatial scales.

Variable	Description
Willow	Percent willow was created by adding the total area of cells the remote sensing imagery identified as willow, divided by the area of each scale buffer.
Edge	Edge density was created with the spatial statistics software FRAGSTATS (McGarigal and Marks 1995). The cells remote sensing imagery identified as trees were combined to create a tree canopy cover for the software to determine the average canopy edge density at each scale buffer.
Streams	Stream density was created by adding the total length of streams in each scale buffer, divided by the number of hectares in each scale buffer.
Routes	A measure of route activity was created from the average number of one-way trips in each route category. The total length of routes in each category were added within each scale buffer, and then multiplied by the average number of one-way trips for each category. These results for each scale buffer were combined across categories to represent the total vehicle travel in each scale buffer.

We produced three GIS raster datasets at a 20 m × 20 m cell resolution for spatial data consistency: (1) percent willow, (2) edge density (McGarigal and Marks 1995), and (3) stream density (Table 4). Select combinations of these variables were tested with and without a route variable and an interaction term for routes with willow to determine if inclusion of routes improved model fit (Table 4). Each variable was calculated at three spatial scales (250 m, 500 m, and 1000 m around each used and random point location) for each sex and for the two seasonal analysis periods. Spatial scales were chosen to represent a gradient in multi-scale habitat selection (Kie et al. 2002). Before variables were used in modeling, a Pearson's pair-wise correlation analysis was conducted at each scale to identify multi-collinearities among variables that were excluded from the analysis (Hosmer and Lemeshow 1989).

We then used logistic regression in SAS 9.1 (SAS, Cary, NC) on the 10 a priori models. Akaike's Information Criterion (AIC) was used for model selection, and the lowest ΔAIC scores and highest Akaike weights were used to select the most parsimonious best-fit models (Anderson 2008). We evaluated the predictive performance of the model with an area-corrected *k*-fold cross validation procedure (Boyce et al. 2002). This technique involved dividing animal locations into five datasets, applying the resource selection function (RSF) of the final model to one dataset, and evaluating model performance with the remaining four datasets. The range of logistic regression probability scores resulting from each dataset was divided into 10 equal-interval probability bins. The bins were area-corrected by dividing the middle probability score by the mapped area of the probability range occurring on the landscape. The average score across the 10 area-corrected probability bins was ranked, and Spearman rank analysis (r_s) was used to analyze the correlation between the ordinal rank and observed rank of probability bins.

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The best-fit RSFs were used in an exploratory analysis to identify an ecological disturbance threshold of vehicle activity on the probability of animal occurrence. We chose the 500-m scale because RSFs at this scale exhibited consistent patterns across sex and season for moose. A space and time-explicit metric of route activity was calculated in the GIS with the following formula, Eq.1, which converted the route-use area (km^2) of the 500-m buffer, and incorporated the sample size and the sampling period:

$$\left\{\left[(\text{Total km of vehicle travel in 500 m buffer}) \times \left(\frac{1.27\,\text{km}^2}{500\,\text{m buffer}}\right) \times (3\,\text{user samples in population})\right] \div (35\,\text{day sampling period})\right\} = \text{Total km of vehicle travel/km}^2\text{/day}. \quad (1)$$

Point locations (n = 1000) were randomly sampled from portions of the landscape with 0.01 km to 2 km vehicle travel/km^2/day to represent a gradient of areas with route activity. Route-activity values at sample locations were plotted against the corresponding probability of use derived from the RSF; and fit with a logarithmic function. This was performed for both sexes and both seasons.

Results

All the RSF models with the Route variable yielded the lowest ΔAIC score and highest Akaike weights (Table 5). This trend suggests that rural roads and OHVs influence moose distribution. The most frequently selected best-fit model for both sexes and both seasons included all four main variables: Willow + Edge + Streams + Routes. In two cases, comparable models resulted with a $\Delta AIC \leq 2$, which indicated these models had approximately equivalent explanatory power. The most parsimonious models were selected for each scale, sex, and season (Anderson 2008).

For female moose, Route coefficients in the best-fit models were consistently negative in the summer and fall at all three spatial scales. This pattern suggests that female moose avoided rural roads and OHV routes at multiple spatial scales (Table 6). Route coefficients were also statistically significant in all models, except in the summer at the 250-m scale. The non-significant Route variable at the 250-m scale in the summer suggests that a larger spatial scale of analysis was more appropriate to evaluate a road-effect on female moose in the summer. The four main variables were included as the best-fit for most female models, with the exception of the 250-m scale in the summer and fall. At the 250-m scale in summer, the four main and Willow × Routes interaction variables had the best-fit, although the interaction term was not statistically significant. The non-significant interaction term also suggests that a larger spatial scale of analysis was more appropriate to evaluate a road-effect on female moose in the summer. At the 250-m scale in the fall, Willow + Streams + Routes had the best-fit, suggesting edge density was of less importance to females at the 250-m scale in the fall or, again, that a larger spatial scale of analysis was more appropriate to evaluate a road-effect on female moose in the summer.

For male moose, Route coefficients or the interaction term Willow × Routes, were negative in best-fit models, with the exception of the 1000-m scale in the fall (Table 6). These results suggest male moose avoid rural roads and OHV routes or areas with willow in close proximity to routes. The positive relationship between males and routes at the 1000-m scale also suggests male moose may be less sensitive to routes than female moose at larger spatial scales. All the Route coefficients were statistically significant, with the exception of the 250-m scale in the summer. The exceptions to the inclusion of the main four variables as the best-fit model were in the summer at the 1000-scale and in the fall at the 250-m and 500-m scales. In the summer at the 1000-m scale, the best-fit model included the interaction term for Willow × Routes with a negative coefficient. In the fall at the 250-m and 500-m scale, the best-fit models were Willow + Edge + Routes + Willow × Routes. The lack of selection for stream density suggested riparian areas were of less importance at finer spatial scales for male moose in the fall.

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Table 5. Differences in AIC scores (ΔAIC), weights (w), and number of model parameters (k) used to evaluate rural roads and OHV routes effect on moose habitat selection with resource selection functions; male and female moose were evaluated separately during the summer and fall at three spatial scales.

Model	k	250 m		500 m		1000 m	
		ΔAIC	AICw	ΔAIC	AICw	ΔAIC	AICw
Summer Female							
Willow	1	43.1	0.000	35.2	0.000	36.8	0.000
Willow + Edge	2	44.0	0.000	36.1	0.000	37.2	0.000
Willow + Edge + Routes	3	26.1	0.000	23.3	0.000	23.2	0.000
Willow + Edge + Routes + Willow × Routes	4	22.1	0.000	24.9	0.000	25.0	0.000
Willow + Streams	2	19.3	0.000	12.2	0.001	14.6	0.000
Willow + Streams + Routes	3	9.0	0.009	8.1	0.011	12.4	0.001
Willow + Streams + Routes + Willow × Routes	4	4.3	0.095	9.2	0.006	14.4	0.000
Willow + Edge + Streams	3	17.5	0.000	7.2	0.018	6.1	0.031
Willow + Edge + Streams + Routes	4	4.4	0.088	0.0	0.642	0.0	0.649
Willow + Edge + Streams + Routes + Willow × Routes	5	0.0	0.808	1.4	0.321	1.4	0.318
Summer Male							
Willow	1	62.4	0.000	68.3	0.000	68.8	0.000
Willow + Edge	2	50.4	0.000	62.1	0.000	66.3	0.000
Willow + Edge + Routes	3	16.5	0.000	9.1	0.007	18.1	0.000
Willow + Edge + Routes + Willow × Routes	4	17.9	0.000	10.4	0.004	6.9	0.031
Willow + Streams	2	40.2	0.000	50.1	0.000	51.3	0.000
Willow + Streams + Routes	3	19.2	0.000	16.0	0.000	22.6	0.000
Willow + Streams + Routes + Willow × Routes	4	21.0	0.000	17.6	0.000	12.3	0.002
Willow + Edge + Streams	3	26.3	0.000	39.8	0.000	43.7	0.000
Willow + Edge + Streams + Routes	4	0.0	0.693	0.0	0.703	8.7	0.012
Willow + Edge + Streams + Routes + Willow × Routes	5	1.6	0.307	1.8	0.286	0.0	0.954
Fall Female							
Willow	1	51.7	0.000	63.9	0.000	111.5	0.000
Willow + Edge	2	48.5	0.000	53.1	0.000	101.4	0.000
Willow + Edge + Routes	3	32.0	0.000	19.9	0.000	11.8	0.002
Willow + Edge + Routes + Willow × Routes	4	33.9	0.000	20.8	0.000	8.6	0.008
Willow + Streams	2	5.2	0.032	21.7	0.000	59.1	0.000
Willow + Streams + Routes	3	0.0	0.425	3.5	0.098	10.6	0.003
Willow + Streams + Routes + Willow × Routes	4	2.0	0.157	3.9	0.080	10.9	0.003
Willow + Edge + Streams	3	12.1	0.001	20.1	0.000	57.4	0.000
Willow + Edge + Streams + Routes	4	0.8	0.281	0.0	0.561	1.0	0.372
Willow + Edge + Streams + Routes + Willow × Routes	5	2.8	0.104	1.5	0.261	0.0	0.613
Fall Male							
Willow	1	24.2	0.000	33.0	0.000	54.7	0.000
Willow + Edge	2	7.3	0.017	17.5	0.000	25.3	0.000
Willow + Edge + Routes	3	5.2	0.050	6.0	0.026	2.5	0.159
Willow + Edge + Routes + Willow × Routes	4	0.0	0.663	0.7	0.372	4.0	0.075
Willow + Streams	2	26.0	0.000	32.4	0.000	51.9	0.000
Willow + Streams + Routes	3	24.9	0.000	27.5	0.000	38.7	0.000
Willow + Streams + Routes + Willow × Routes	4	20.5	0.000	23.6	0.000	38.2	0.000
Willow + Edge + Streams	3	9.2	0.007	11.8	0.001	15.2	0.000
Willow + Edge + Streams + Routes	4	7.2	0.018	3.9	0.075	0.0	0.555
Willow + Edge + Streams + Routes + Willow × Routes	5	2.0	0.245	0.0	0.526	1.9	0.210

Model validation suggested that best-fit models had a high level of predictive power (Table 7). The highest Spearman rank correlation model for females in the summer was the same at the 250-m and 1000-m scales. In the fall, the female model with the highest correlation was at the 250-m scale. For male moose in the summer and fall, the model with the highest Spearman rank correlation was at the 250-m scale.

The mapped RSFs show a reduced probability of use by moose in areas of increasing route-use and route density, with the exception of male moose in the fall (Fig. 3). This disturbance pattern was accentuated for female moose in the fall season when route-use in Low OHV and High OHV categories increased. These data also exhibit a nonlinear relationship between moose occurrence and route activity (Fig. 4). Based on logarithmic fitting to this relationship, a high probability of moose occurrence (0.60 to 0.91)

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Table 6. Coefficients (β) and 95% confidence intervals of the most parsimonious RSF models used to evaluate rural roads and OHV routes effect on moose habitat selection; male and female moose were evaluated separately during the summer and fall at three spatial scales.

	250 m		500 m		1000 m	
Variable	β	95% CI	β	95% CI	β	95% CI
Summer Female						
Willow	0.019*	0.011, 0.026	0.022*	0.013, 0.032	0.019*	0.007, 0.031
Edge	0.004*	0.001, 0.008	0.008*	0.003, 0.012	0.013*	0.006, 0.019
Streams	0.01*	0.006, 0.014	0.013*	0.008, 0.018	0.016*	0.01, 0.022
Routes	−0.001	−0.003, 0.0003	−0.00004*	−0.0001, −0.00001	−0.00001*	−0.00002, −0.000002
Willow × Routes	0.00004	−0.00001, 0.0001				
Summer Male						
Willow	0.021*	0.014, 0.028	0.026*	0.016, 0.035	0.039*	0.027, 0.052
Edge	0.007*	0.004, 0.01	0.009*	0.005, 0.014	0.012*	0.006, 0.018
Streams	0.009*	0.005, 0.013	0.008*	0.003, 0.013	0.009*	0.003, 0.015
Routes	−0.0001	−0.002, 0.001	−0.0002*	−0.0003, −0.0001	0.00003	−0.00001, 0.0001
Willow × Routes					−0.00001*	−0.00001, −0.000001
Fall Female						
Willow	0.016*	0.01, 0.022	0.008	−0.001, 0.017	−0.006	−0.017, 0.005
Edge			−0.004*	−0.008, −0.001	−0.009*	−0.014, −0.004
Streams	0.011*	0.007, 0.015	0.011*	0.006, 0.016	0.01*	0.004, 0.016
Routes	−0.001*	−0.001, −0.0002	−0.0002*	−0.0003, −0.0001	−0.0002*	−0.0002, −0.0001
Willow × Routes						
Fall Male						
Willow	0.02*	0.012, 0.027	0.026*	0.016, 0.035	0.042*	0.029, 0.055
Edge	−0.007*	−0.01, −0.004	−0.011*	−0.015, −0.006	−0.022*	−0.029, −0.015
Streams					−0.007*	−0.013, −0.0004
Routes	0.001*	0.0003, 0.001	−0.0001*	−0.0002, −0.0001	0.00004*	0.00002, 0.0001
Willow × Routes	−0.00002*	−0.00004, −0.00001	0.00001*	0.00001, 0.000002		

Note: *Coefficients (β) significant at 5%

Table 7. Spearman rank correlations (r_s) of cross validated and area-corrected RSF-bin ranks for male and female moose during the summer and fall at three spatial scales.

	Summer		Fall	
Scale (m)	r_s	p	r_s	p
Female				
250	0.988	<0.0001	0.952	<0.0001
500	0.976	<0.0001	0.794	0.0061
1000	0.988	<0.0001	0.879	0.0008
Male				
250	0.988	<0.0001	0.988	<0.0001
500	0.912	0.0002	0.733	0.0158
1000	0.891	0.0005	0.903	0.0003

was observed where route frequency was less than approximately 0.25 km of vehicle travel/km^2/day (Table 8).

Discussion

The results of our analysis suggest rural roads and OHV traffic created an ecological road-effect zone that displaced moose and altered use of potential habitat near roads. The size of the road-effect zone was different for male and female moose. Among the spatial scales of our analyses, male moose were found to be negatively impacted to at least a 500-m distance from rural roads and OHV routes, whereas for female moose, the road-effect zone may extend >1000 m. These results suggest rural roads and OHV routes have a greater impact on wildlife in rural landscapes

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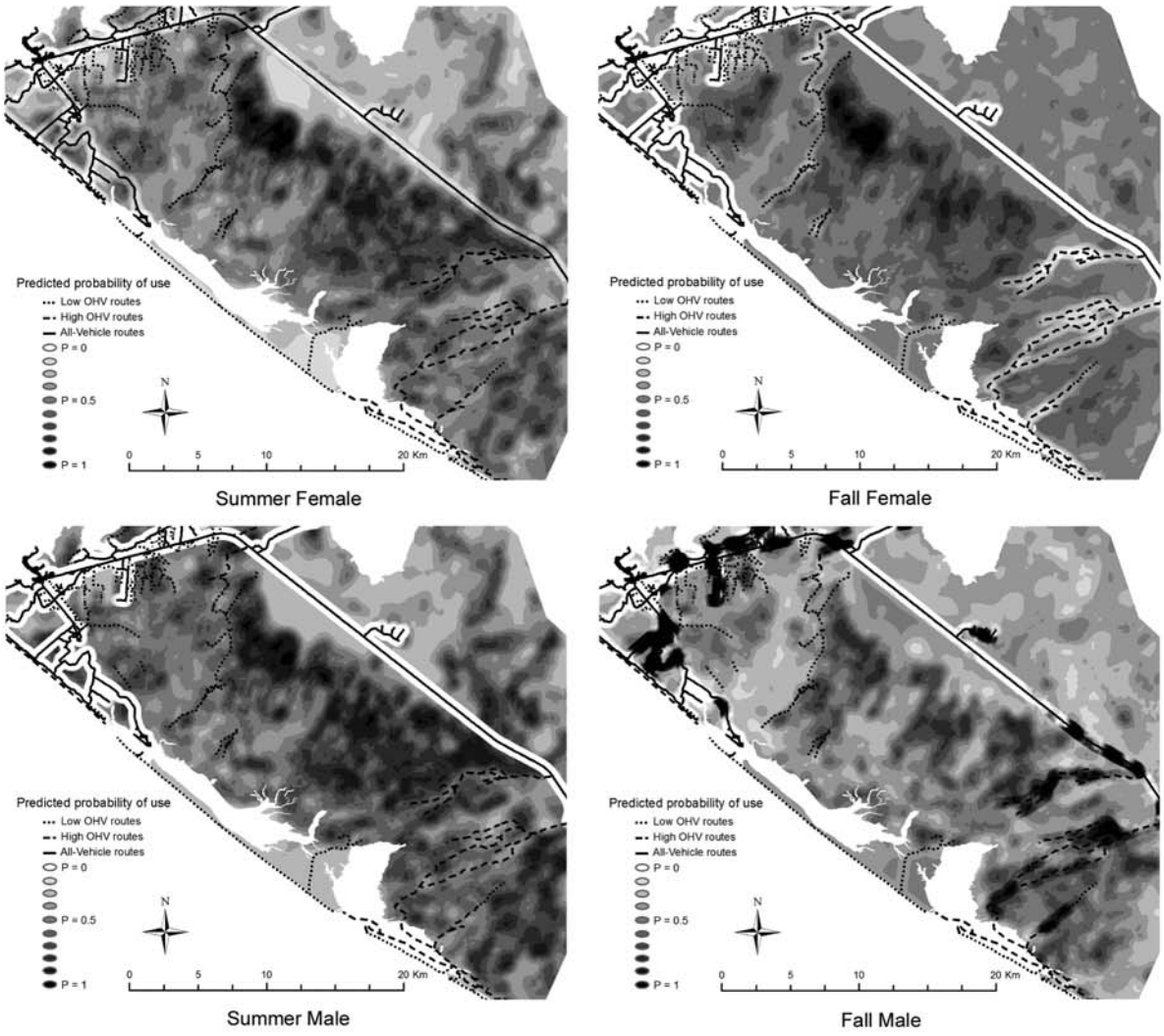


Fig. 3. Resource selection functions for male and female moose at the 500-m scale in the summer and fall; illustrating the road-effect zone created by rural roads and OHV routes in Yakutat, Alaska.

than the 600 m extent that Forman and Deblinger (2000) observed from urban roads. In addition, route activity less than 0.25 km of vehicle travel/km^2/day is an approximate space and time-explicit metric that land managers could use to reduce the probability of moose disturbance in our study area, when and where OHV access is necessary (e.g., subsistence hunting). We calculated that 13.2% of the study area in the summer and 23.5% in the fall exceeded this disturbance threshold, suggesting a substantial loss of effective wildlife habitat. Should future vehicle activity double on the current road network, >15% of the study area in the summer and >30% of the study area in the fall would exceed the disturbance threshold (Table 9).

Typically land management agencies lack long-term wildlife demographic data to evaluate disturbance effects on population trends or persistence (Jaeger et al. 2005). The change in effective habitat as a result of disturbance, however, is a type of ecological indicator that provides a sound alternative basis for establishing habitat conservation measures (Andren 1994, Fahrig 2001). For example, road avoidance and resulting habitat loss was attributed to a four-fold decrease in grizzly bear (*Ursus arctos*) density using spatially-explicit modeling inde-

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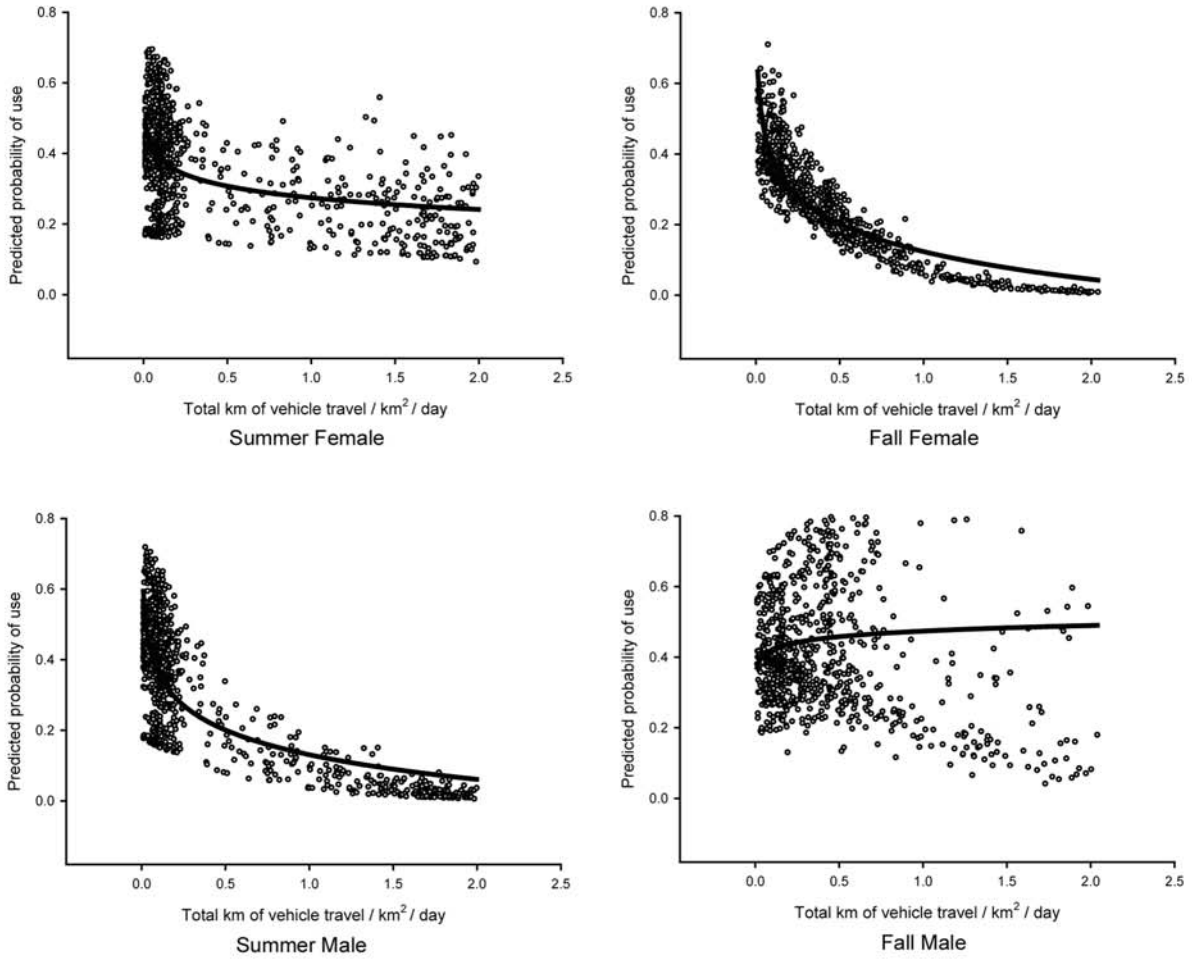


Fig. 4. Scatter plots with logarithmic regressions showing the probability of moose occurrence (500-m scale RSF) relative to the total km of vehicle travel/km^2/day in Yakutat, Alaska: Female, Summer $y = -0.0478\text{Ln}(x) + 0.2741$ ($R^2 = 0.2171$, $p < 0.0001$); Female, Fall $y = -0.1134\text{Ln}(x) + 0.1235$ ($R^2 = .7524$, $p < 0.0001$); Male, Summer $y = -0.101\text{Ln}(x) + 0.1306$ ($R^2 = 0.5378$, $p < 0.0001$); Male, Fall $y = 0.0229\text{Ln}(x) + 0.474$ ($R^2 = 0.0133$, $p = 0.0003$).

Table 8. Range of vehicle travel/km^2/day and resulting probability scores for male and female moose derived from logarithmic regressions.

Total km of vehicle travel/ km^2/day	Probability of moose occurrence		
	Summer Female	Fall Female	Summer Male
0.001	0.60	0.91	0.83
0.25	0.34	0.28	0.27
0.50	0.31	0.20	0.20
0.75	0.29	0.16	0.16
1.00	0.27	0.12	0.13
1.25	0.26	0.10	0.11
1.50	0.25	0.08	0.09
1.75	0.25	0.06	0.07
2.00	0.24	0.04	0.06

Table 9. Percent increase in vehicle activity effect on the percent of the landscape with a low probability of moose occurrence (i.e., exceeding the disturbance threshold).

Percent increase in vehicular activity	Percent of landscape with low probability of use	
	Summer	Fall
10	13.3	24.1
20	13.6	24.7
30	13.9	25.2
40	14.3	25.8
50	14.6	26.6
60	15.0	28.6
70	15.3	29.9
80	15.5	30.8
90	15.8	31.5
100	16.1	32.2

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pendently verified with DNA-based mark-recapture techniques (Ciarniello et al. 2007). We estimated habitat loss >20% in the fall, a critical period during which moose are typically building overwinter fat reserves (Van Ballenberghe and Ballard 1998). Displacement and loss of effective habitat in this small and isolated population of moose (Schmidt et al. 2008) therefore may have important consequences for animal fitness and demographics, suggesting a need for proactive access management (Seip et al. 2007).

The impact of roads and OHV routes on moose habitat selection was clearly evident from the consistently lowest ΔAIC scores for models with Routes and predominantly negative coefficients for the Route variable or the interaction term for Willow × Routes. The only exception to a negative association with Routes or the interaction for Willow × Routes, males at the 1000-m scale in the fall, could be explained by the fact that many OHV routes were specifically created by hunters to access concentrations of male moose for the fall hunting season (Mills and Firman 1986, USFS 2009). This pattern could also explain the positive association observed in models of male habitat selection at the fall 500-m scale for Willow × Routes and Routes at the summer 1000-m and fall 250-m scale. Or, perhaps, male moose are less sensitive to disturbance than female moose at broader spatial scales. In general, female moose appeared to be more sensitive to disturbance, with no statistically significant positive associations with Routes or Willow × Routes. This could be explained possibly by a female's higher levels of vigilance necessary for protecting calves (Bowyer et al. 1998, Stankowich 2008).

Our model-validation process suggested a high level of model accuracy at multiple spatial scales. This illustrates the importance of a multi-scale approach in wildlife habitat studies because disturbance effects may be exhibited at multiple spatial scales and be undetectable at other spatial scales (Johnson 1980, Bowyer and Kie 2006, Boyce 2006). All models at the 500-m scale had a statistically significant negative coefficient for specifically the Route variable, whereas the Route variable and statistical significance in models at other scales were inconsistent across male and female moose. In the subsequent exploratory analysis of an ecological disturbance threshold at the 500-m scale, the only exception to an avoidance pattern beyond approximately 0.25 km of vehicle travel/km^2/day was for male moose in the fall. This was likely due to the positive association seen with the interaction term for Willow × Routes in the 500-m scale model. The strong nonlinear negative response observed in the probability of female moose occurrence to increasing vehicle traffic in the summer and fall suggests a low avoidance-threshold within the range of vehicular frequency that occurred in Yakutat. A low avoidance threshold suggests that managers would be warranted to keep OHV traffic at lower levels than has traditionally occurred on this landscape; but because enforcement of such low OHV levels on a remote landscape could also be a challenge (Karasin 2003, Buckley 2004), restricting OHV access entirely could, in some instances, be defensible.

Previous studies on the indirect effect of roads on moose distribution have demonstrated mixed results relative to our study and may not be comparable due to differences in the resolution of data and the scale of analysis. For instance, coarser scale analyses have shown a positive association between moose and roads while finer scale analyses have shown a negative association between moose and roads. Schneider and Wasel (2000) suggested that while access is generally assumed to have a negative effect on moose locally, the regional density of moose was positively associated with roads in northern Alberta, Canada. Likewise, Remm and Luud (2003) found that the density of moose was positively associated with roads at a regional scale in Estonia. In contrast, the number of moose observed within 100 m of roads in Denali National Park, Alaska declined by >50% when visitor use increased eight-fold (Burson et al. 2000). Yost and Wright (2001) also found that moose sightings were less than expected up to 1200 m from a road in Denali, but the spatial configuration of habitats was not considered. For example, the availability of preferred moose habitat occurred closer to roads in Sweden, suggesting that an analysis that does take into account the spatial pattern of habitats could produce misleading results (Ball and Dahlgren 2002, Seiler 2005). The conflicting results of these

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studies indicate that the spatial configuration of habitats must be taken into consideration to more accurately investigate the potential effect of roads on wildlife distribution. Roads may interact with habitat to influence the observed distribution of wildlife (Maier et al. 2005). The value of incorporating habitat information has been demonstrated in previous road-impact studies involving grizzly bears (*Ursus arctos*) (Mace et al. 1996, Ciarniello et al. 2007, Roever et al. 2008), mule deer (*Odocoileus hemionus*) (Sawyer et al. 2006), and elk (*Cervus elaphus*) (Sawyer et al. 2007). These studies collectively illustrate that animals avoided preferred habitats with increasing levels of traffic, with potential repercussions on forage availability, individual fitness, and ultimately population productivity.

We suspect that the road-effect detected in moose is at least partially due to noise produced by vehicular traffic, as well as the perceived risk to hunting that is observed among many ungulates (Stankowich 2008). Ungulates in rural landscapes that experience low-levels of disturbance are less likely to habituate and therefore have a stronger tendency to show disturbance effects (Stankowich 2008). Noise could also inhibit predator detection by ungulates in rural landscapes, in contrast to ungulates in urban landscapes where primary predators (i.e., grizzly bears and wolves) are rare (Forman and Alexander 1998).

These findings should be treated within the context of assumptions made in our analyses. The limited sample size of moose individuals could have increased the chance that atypical disturbance behavior influenced resource selection patterns (Thomas and Taylor 2006). To help reduce this possibility, however, we used an equal number of locations from each animal. Furthermore, our reliance on social interviews to derive route activity levels could have influenced modeling results; and the use of infrared or magnetic trail-counters (e.g., Shephard and Whittington 2006) would have potentially provided a less biased measurement of route use. However, these data were not attainable at the time of the study. Nonetheless, we believed our approach was better than simply treating all route types equally with respect to levels of activity when clearly, the width and soil wear of routes indicated different levels of use.

Conclusion

The results of our study suggest that even dispersed vehicular activity on rural road networks significantly affects moose distribution. Therefore, rural road networks should be incorporated into transportation planning scenarios to most accurately estimate the road-effect zone on target species. Road-effect zones with extents like that observed in this study (>1000 m) could have a substantial impact on the effective amount of habitat available for target species on landscapes. Furthermore, our exploratory analysis to determine an ecological disturbance threshold suggests that moose exhibit a relatively low threshold to such dispersed activity. Although it may be difficult to limit vehicular activity below such a threshold on well established road networks, land managers should carefully consider the trade-offs between new rural road development and the conservation of wildlife habitat: even new rural routes with infrequent use can measurably displace sensitive species.

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Literature Cited

Aebischer, N. J., P. A. Robertson, and R. E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313–1325.

Anderson, D. R. 2008. Model Based Inference in the Life Sciences: A Primer on Evidence. Springer, New York, New York, USA.

Andren, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71:355–366.

Ball, J. P., and J. Dahlgren. 2002. Browsing damage on

21508925, 2011, 2, Downloaded from https://esajournals.onlinelibrary.wiley.com/doi/10.1890/ES10-00093.1. By Northwest Provincial, Wiley Online Library on [16/07/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

pine (*Pinus sylvestris* and *P-contorta*) by a migrating moose (*Alces alces*) population in winter: relation to habitat composition and road barriers. Scandinavian Journal of Forest Research 17:427–435.

Berkes, F., and D. Jolly. 2001. Adapting to climate change: social-ecological resilience in a Canadian western arctic community. Conservation Ecology 5:18.

Boarman, W. I., and M. Sazaki. 2006. A highway's road-effect zone for desert tortoises. Journal of Arid Environments 65:94–101.

Bowyer, R. T., and J. G. Kie. 2006. Effects of scale on interpreting life-history characteristics of ungulates and carnivores. Diversity and Distributions 12:244–257.

Bowyer, R. T., B. M. Pierce, L. K. Duffy, and D. A. Haggstrom. 2001. Sexual segregation in moose: effects of habitat manipulation. Alces 37:109–122.

Bowyer, R. T., V. Van Ballenberghe, and J. G. Kie. 1998. Timing and synchrony of parturition in Alaskan moose: long-term versus proximal effects of climate. Journal of Mammalogy 79:1332–1344.

Boyce, M. S. 2006. Scale for resource selection functions. Diversity and Distributions 12:269–276.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281–300.

Brinkman, T. J., G. P. Kofinas, F. S. Chapin III and D. K. Person. 2007. Influence of hunter adaptability on resilience of subsistence hunting systems. Journal of Ecological Anthropology 11:1–6.

Buckley, R. 2004. Environmental impacts of motorized off-highway vehicles. Pages 83–97 *in* R. Buckley, editor. Environmental Impacts of Ecotourism. CABI Publishing.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Inference: A Practical Information-Theoretic Approach. Springer-Verlag, New York, New York, USA.

Burson, S. L., J. L. Belant, K. A. Fortier, and W. C. Tomkiewicz. 2000. The effect of vehicle traffic on wildlife in Denali National Park. Arctic 53:146–151.

Ciarniello, L. M., M. S. Boyce, D. C. Heard, and D. R. Seip. 2007. Components of Grizzly Bear habitat selection: density, habitats, roads, mortality risk. Journal of Wildlife Management 71:1446–1457.

Creel, S., J. E. Fox, A. Hardy, J. Sands, B. Garrott, and R. O. Peterson. 2002. Snowmobile activity and glucocorticoid stress responses in wolves and elk. Conservation Biology 16:809–814.

Dussault, C., J. P. Ouellet, R. Courtois, J. Huot, L. Breton, and H. Jolicoeur. 2005. Linking moose habitat selection to limiting factors. Ecography 28:619–628.

Eigenbrod, F., S. J. Hecnar, and L. Fahrig. 2009. Quantifying the road-effect zone: threshold effects of a motorway on anuran populations in Ontario, Canada. Ecology and Society 14:24.

Fahrig, L. 2001. How much habitat is enough? Biological Conservation 100:65–74.

Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecology and Society 14:21.

Farmer, C. J., D. K. Person, and R. T. Bowyer. 2006. Risk factors and mortality of Black-Tailed Deer in a managed forest landscape. Journal of Wildlife Management 70:1403–1415.

Ford, J. D., B. Smit, and J. Wandel. 2006. Vulnerability to climate change in the Arctic: a case study from Arctic Bay, Canada. Global Environmental Change 16:145–160.

Forman, R. T. T. 2000. Estimate of the area affected ecologically by the road system in the United States. Conservation Biology 14:31–35.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and C. Winter. 2003. Road ecology: science and solutions. Island Press, Washington, D.C., USA.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207–231.

Forman, R. T. T., and R. D. Deblinger. 2000. The ecological road-effect zone of a Massachusetts (USA) suburban highway. Conservation Biology 14:36–46.

Forman, R. T. T., D. S. Friedman, D. Fitzhenry, J. D. Martin, A. S. Chen, and L. E. Alexander. 1997. Ecological effects of roads: toward three summary indices and an overview for North America. Pages 40–54 *in* K. Canters, editor. Habitat Fragmentation and Infrastructure. Ministry of Transport, Public Works and Water Management, Delft, Netherlands.

Franzmann, A. W., and C. C. Schwartz. 1997. Ecology and management of the North American moose. Smithsonian Institution Press, Washington, D.C., USA.

Gaines, W. L., A. L. Lyons, J. F. Lehmkuhl, and K. J. Raedeke. 2005. Landscape evaluation of female black bear habitat effectiveness and capability in the Northern Cascades, Washington. Biological Conservation 125:411–425.

Girard, I., J. P. Ouellet, R. Courtois, C. Dussault, and L. Breton. 2002. Effects of sampling effort based on GPS telemetry on home-range size estimations. Journal of Wildlife Management 66:1290–1300.

Groffman, P., J. Baron, T. Blett, A. Gold, I. Goodman, L. Gunderson, B. Levinson, M. Palmer, H. Paerl, G. Peterson, N. Poff, D. Rejeski, J. Reynolds, M. Turner, K. Weathers, and J. Wiens. 2006. Ecological thresholds: The key to successful environmental management or an important concept with no practical application? Ecosystems 9:1–13.

21508925, 2011, 2, Downloaded from https://esajournals.onlinelibrary.wiley.com/doi/10.1890/ES10-00093.1. By Northwest Provincial, Wiley Online Library on [16/07/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Hosmer, D. W., and S. Lemeshow. 1989. Applied Logistic Regression. John Wiley and Sons, New York, New York, USA.

Huggett, A. J. 2005. The concept and utility of 'ecological thresholds' in biodiversity conservation. Biological Conservation 124:301–310.

Jaarsma, C. F., and G. P. A. Willems. 2002. Reducing habitat fragmentation by minor rural roads through traffic calming. Landscape and Urban Planning 58:125–135.

Jaeger, J. A. G., J. Bowman, J. Brennan, L. Fahrig, D. Bert, J. Bouchard, N. Charbonneau, K. Frank, B. Gruber, and K. T. von Toschanowitz. 2005. Predicting when animal populations are at risk from roads: an interactive model of road avoidance behavior. Ecological Modelling 185:329–348.

Johnson, C. J., S. E. Nielsen, E. H. Merrill, L. L. McDonald, and M. S. Boyce. 2006. Resource selection functions based on use-availability data: theoretical motivation and evaluation methods. Journal of Wildlife Management 70:347–357.

Johnson, C. J., D. R. Seip, and M. S. Boyce. 2004. A quantitative approach to conservation planning: using resource selection functions to map the distribution of mountain caribou at multiple spatial scales. Journal of Applied Ecology 41:238–251.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

Karasin, L. N. 2003. All-Terrain Vehicles in the Adirondacks: Issues and Options. Wildlife Conservation Society, Working Paper No. 21.

Keating, K. A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. Journal of Wildlife Management 68:774–789.

Kie, J. G., R. T. Bowyer, M. C. Nicholson, B. B. Boroski, and E. R. Loft. 2002. Landscape heterogeneity at differing scales: effects on spatial distribution of mule deer. Ecology 83:530–544.

Kunkel, K. E., and D. H. Pletscher. 2000. Habitat factors affecting vulnerability of moose to predation by wolves in southeastern British Columbia. Canadian Journal of Zoology 78:150–157.

Mace, R. D., J. S. Waller, T. L. Manley, L. Jack Lyon, and H. Zuuring. 1996. Relationships among grizzly bears, roads, and habitat in the Swan Mountains, Montana. Journal of Applied Ecology 33:1395–1404.

Maier, J. A. K., J. M. Ver Hoef, A. D. McGuire, R. T. Bowyer, L. Saperstein, and H. A. Maier. 2005. Distribution and density of moose in relation to landscape characteristics: effects of scale. Canadian Journal of Forest Research 35:2233–2243.

Manly, B. F. J., L. L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource Selection by Animals: Statistical Design and Analysis for Field Studies. Kluwer Academic Publishers, The Netherlands.

McGarigal, K., and B. J. Marks. 1995. FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. Gen. Tech. Report PNW-GTR-351. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon, USA.

Mills, D. D., and A. S. Firman. 1986. Fish and Wildlife Use Patterns in Yakutat, Alaska: Contemporary Patterns and Changes. Alaska Department of Fish and Game, Division of Subsistence, Douglas, Alaska, USA.

Miquelle, D. G., J. M. Peek, and V. Vanballenberghe. 1992. Sexual segregation in Alaskan moose. Wildlife Monographs 122:1–57.

Nielson, S. E., M. S. Boyce, G. B. Stenhouse, and R. H. M. Munro. 2002. Modeling grizzly bear habitats in the Yellowhead Ecosystem of Alberta: taking autocorrelation seriously. Ursus 13:45–56.

Oehlers, S. A. 2007. Habitat Selection and Sightability of Moose in Southeast Alaska. MS Thesis. University of Alaska Fairbanks, Fairbanks, Alaska, USA.

Preisler, H. K., A. A. Ager, and M. J. Wisdom. 2006. Statistical methods for analyzing responses of wildlife to human disturbance. Journal of Applied Ecology 43:164–172.

Reijnen, R., R. Foppen, C. ter Braak, and J. Thissen. 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. Journal of Applied Ecology 32:187–202.

Remm, K., and A. Luud. 2003. Regression and point pattern models of moose distribution in relation to habitat distribution and human influence in Ida-Viru County, Estonia. Journal for Nature Conservation 11:197–211.

Rodgers, A. R., A. P. Carr, H. L. Beyer, L. Smith, and J. G. Kie. 2007. HRT: Home Range Tools for ArcGIS. Ontario Ministry of Natural Resources, Center for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada.

Roever, C. L., M. S. Boyce, and G. B. Stenhouse. 2008. Grizzly bears and forestry I: road vegetation and placement as an attractant to grizzly bears. Forest Ecology and Management 256:1253–1261.

Sawyer, H., R. M. Nielson, F. Lindzey, and L. L. McDonald. 2006. Winter habitat selection of mule deer before and during development of a natural gas field. Journal of Wildlife Management 70:396–403.

Sawyer, H., R. M. Nielson, F. G. Lindzey, L. Keith, J. H. Powell, and A. Abraham. 2007. Habitat selection of Rocky Mountain Elk in a nonforested environment. Journal of Wildlife Management 71:868–874.

Schmidt, J. I., J. M. V. Hoef, J. A. K. Maier, and R. T. Bowyer. 2005. Catch per unit effort for moose: a new approach using weibull regression. Journal of

21508925, 2011, 2, Downloaded from https://esajournals.onlinelibrary.wiley.com/doi/10.1890/ES10-00093.1. By Northwest Provincial, Wiley Online Library on [16/07/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Wildlife Management 69:1112–1124.

Schmidt, J. I., K. J. Hundertmark, R. T. Bowyer, and K. G. McCracken. 2008. Population structure and genetic diversity of moose in Alaska. Journal of Heredity 100:170–180.

Schneider, R. R., and S. Wasel. 2000. The effect of human settlement on the density of moose in northern Alberta. Journal of Wildlife Management 64:513–520.

Seiler, A. 2005. Predicting locations of moose-vehicle collisions in Sweden. Journal of Applied Ecology 42:371–382.

Seip, D. R., C. J. Johnson, and G. S. Watts. 2007. Displacement of Mountain Caribou from winter habitat by snowmobiles. Journal of Wildlife Management 71:1539–1544.

Semlitsch, R. D., T. J. Ryan, K. Hamed, M. Chatfield, B. Drehman, N. Pekarek, M. Spath, and A. Watland. 2007. Salamander abundance along road edges and within abandoned logging roads in Appalachian forests. Conservation Biology 21:159–167.

Shephard, M. E. 1995. Plant Community Ecology and Classification of the Yakutat Foreland, Alaska. R10-TP-56 USDA Forest Service, Alaska Region, Juneau, Alaska, USA.

Shephard, B., and J. Whittington. 2006. Response of wolves to corridor restoration and human use management. Ecology and Society 11:1.

Spaeth, D. F., R. T. Bowyer, T. R. Stephenson, and P. S. Barboza. 2004. Sexual segregation in moose *Alces alces*: an experimental manipulation of foraging behaviour. Wildlife Biology 10:59–72.

Stankowich, T. 2008. Ungulate flight responses to human disturbance: a review and meta-analysis. Biological Conservation 141:2159–2173.

Stedman, R., D. R. Diefenbach, C. B. Swope, J. C. Finley, A. E. Luloff, H. C. Zinn. G. J. San Julian, and G. A. Wang. 2004. Integrating wildlife and human-dimensions research methods to study hunters. Journal of Wildlife Management 68:762–773.

Thomas, D. L., and E. J. Taylor. 2006. Study designs and tests for comparing resource use and availability II. Journal of Wildlife Management 70:324–336.

Trombulak, S. C., and C. A. Frissell. 2000. Review of the ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18–30.

USFS. 2004. Managing the National Forest System: Great Issues and Great Divisions. USDA Forest Service, Washington, D.C., USA.

USFS. 2009. Yakutat Access Travel Management Plan. USDA Forest Service, Yakutat, Alaska, USA.

Van Ballenberghe, V., and W. B. Ballard. 1998. *Population dynamics*. Pages 223–245 *in* A. W. Franzmann and C. C. Schwartz, editors. Ecology and Management of the North American Moose. Smithsonian Institution Press, Washington, D.C., USA.

Walker, B. and J. Meyers. 2004. Thresholds in ecological and social-ecological systems: a developing database. Ecology and Society 9:3.

Yost, A. C., and R. G. Wright. 2001. Moose, caribou, and grizzly bear distribution in relation to road traffic in Denali National Park, Alaska. Arctic 54:41–48.

21508925, 2011, 2, Downloaded from https://esajournals.onlinelibrary.wiley.com/doi/10.1890/ES10-00093.1. By Northwest Provincial, Wiley Online Library on [16/07/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

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Research paper

Balancing the conservation of wildlife habitat with subsistence hunting access: A geospatial-scenario planning framework

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HIGHLIGHTS

- Contemporary subsistence hunting increasingly relies on motorized access.
- Motorized access used for subsistence hunting may effect wildlife habitat.
- Habitat conservation and hunting access can be spatially integrated with GIS.
- Scenario planning can evaluate wildlife habitat and hunting access quantitatively.

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ABSTRACT

Increased motorized access used for subsistence hunting has created a challenge for land managers trying to balance the conservation of wildlife habitat with the greater environmental impact of motorized access. We used an interdisciplinary approach to evaluate this challenge in a case study of subsistence moose (*Alces alces*) hunters who used off-highway vehicles (OHVs; e.g., four-wheelers) to access remote harvest areas in Yakutat, Alaska, USA, and the conservation needs to sustain moose. We developed a resilience-based planning framework that combined methods from wildlife ecology, land-use mapping, and scenario planning. The study started at the community level by working with local hunters to evaluate their values and goals for subsistence moose hunting, and to identify thresholds of undesired change. This process served as the basis for evaluating how four road closure scenarios would effect the distribution of moose and hunters' access to moose harvest areas. The effect of roads and OHV routes on moose distribution was quantified in a previous study with a GIS-based resource selection function model. An index of access was quantified on a digitized map of harvest areas. The results of the scenario analyses suggest that a balance in the conservation of wildlife habitat and subsistence hunting access could be found in the spatial arrangement of routes that are outside of important moose habitat, but within reach of preferred harvest areas. This spatially explicit planning framework may prove useful in northern communities experiencing an increased use of motorized access for contemporary subsistence hunting practices.

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1. Introduction

1.1. Background

Subsistence hunting communities across high latitude regions of the world are experiencing increased social, economic, and ecological changes that require rapid adaptation (Berkes & Jolly, 2001; Brinkman, Kofinas, Chapin, & Person, 2007; Condon, Collings, & Wenzel, 1995; Ford, Smit, & Wendel, 2006; Gordon et al., 2007; Kofinas et al., 2010). One such adaptation is the increased use of motorized access for more efficient hunting (e.g., four-wheelers and snowmachines). The increased use of motorized access for hunting has created new challenges for land management efforts that seek to balance the conservation of wildlife habitat with the need for subsistence access (Ahlstrand & Racine, 1993; Mills & Firman, 1986; Sowl & Poetter, 2004).

The conservation of wildlife habitat and subsistence hunting with motorized vehicles are often considered mutually exclusive (Gordon et al., 2007; Mills & Firman, 1986; Sowl & Poetter, 2004). A challenge in interdisciplinary research on ecosystem stewardship is to develop new and creative approaches to meet both these

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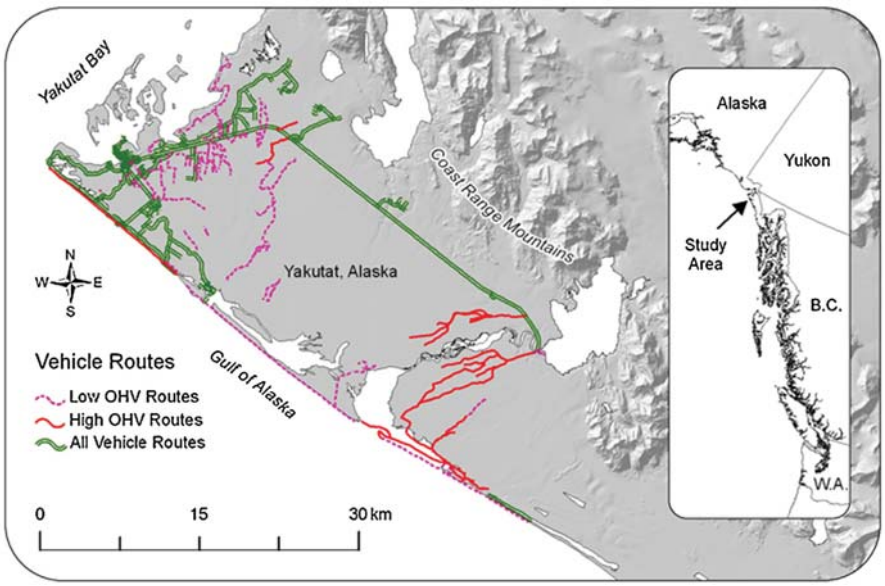


Fig. 1. A map of the study area, Yakutat, Alaska, USA and the network of existing vehicle routes. Yakutat is located along the Gulf of Alaska in the northernmost corner of the Tongass National Forest.

social and ecological goals (Chapin et al., 2006; Chapin, Kofinas, & Folke, 2009). For example, a resilience-based approach that uses road and trail closure scenarios could provide an effective framework to identify balanced solutions. Simultaneously considering both the social values of stakeholders and the ecological properties of a system increases the likelihood for more robust management decisions and resilience to unforeseen events (Berkes, Colding, & Folke, 2003; Chapin et al., 2009; Cordell & Bergstrom, 1999). Using a resilience-based approach, in abstract, one searches for ways to maintain valued attributes while avoiding thresholds to change in which valued attributes are lost (Walker et al., 2002). In this study, for instance, the valued attributes were identified as the conservation of wildlife habitat and access to subsistence resources. The ecological threshold was defined as the point in which wildlife habitat is effectively lost due to high levels of motorized disturbance (Shanley & Pyare, 2011). The associated social threshold is the point at which subsistence hunters do not have sufficient access to meet subsistence resources needs (Berman & Kofinas, 2004; Brinkman, Chapin, Kofinas, & Person, 2009).

Scenario analysis can be used in an interdisciplinary manner to address resource management questions about future conditions, which ultimately builds resilience into the sustainability of valued ecosystem services (Ascher, 2009; Carpenter, Bennett, & Peterson, 2006; Peterson, Cumming, & Carpenter, 2003). In general, the objective is to generate an understanding of plausible (not necessarily likely) future conditions that provide the basis for discussions about the costs and benefits associated with alternative actions or policies (Carpenter et al., 2006). Scenario analysis has been undertaken to explore a wide variety of natural resource questions. For example, Peterson, Douglas Beard, et al. (2003) used a scenario planning approach on a regional scale in the Northern Highlands Lake District, Wisconsin, to explore the future consequences of urbanization and ecological vulnerability to undesired change, such as the loss of valued fishing opportunities. Focusing on the sustainability of arctic subsistence communities, Kruse et al. (2004) used scenario analysis to explore the multiple effects of climate change, oil development, and tourism on caribou hunting. Researchers in these and other projects have taken different approaches to scenario planning based on the central question, scope of the project, and availability of data.

To balance the conservation of moose habitat with off-highway vehicles (OHVs; e.g., four-wheelers), we developed spatially explicit scenarios to evaluate effects on both moose disturbance and subsistence hunting access. We used this geospatial approach for three reasons: (1) spatially explicit scenarios with GIS improves the evaluation and analysis of potential sources of disturbance on wildlife (Johnson, Nielsen, Merrill, McDonald, & Boyce, 2006); (2) many subsistence hunters have a strong spatial and visual orientation (Tobias, 2000); and (3) GIS allowed us to integrate and synthesize a variety of data types (i.e., wildlife distribution and land-use).

The use of GIS technology for evaluating social and ecological data has become increasingly important for land-use planning. For example, Sawyer, Nielson, Lindzey, and McDonald (2006) used collar location data from mule deer (*Odocoileus hemionus*) and GIS to evaluate the trade-offs between deer habitat and natural gas development in Wyoming, U.S. Similarly, Braund (2007) used community interviews and participatory mapping with residents to create a geodatabase of traditional land-use near Tyonek and Beluga, Alaska, to evaluate potential industrial development conflict. However, new approaches are needed to combine these types of social and ecological analyses for more integrated assessments and adaptive management (Beier, Patterson, & Chapin, 2008). In this study, we illustrate how a resilience-based approach with spatially explicit scenario planning could provide an effective framework to achieve both the goals of habitat conservation and resource access.

1.2. Case study

Our case study occurred on the Yakutat Ranger District of the Tongass National Forest in southeastern Alaska, USA (Fig. 1). The location and timing of subsistence hunting has traditionally been unregulated (Mills & Firman, 1986). With the advent of OHVs, subsistence hunters incorporated them into subsistence hunting strategies because OHVs allowed more ground to be covered in search of game and greater efficiency in transporting large game species from remote harvest areas (Mills & Firman, 1986). The continual use of OHVs has visibly affected the landscape with ruts in wetland areas that remain for years, even after a single event. The prevalence of such ruts became a concern for regional land

Table 1
The study framework used to conduct an integrative geospatial-scenario analysis of subsistence hunting access and wildlife habitat conservation.

1. Identify values, goals, and thresholds to undesired change with respect to subsistence hunting access and wildlife habitat conservation.
2. Develop and map feasible multiuse access scenarios (e.g., road closures) with land managers using input and review from public hearings.
3. Interview resident subsistence hunters to map preferred harvest areas, elicit access constraints, and digitize results in a GIS.
4. Develop wildlife distribution models that include a variable(s) that quantifies the spatially explicit impact of access scenarios.
5. Quantitatively evaluate and rank the scenario's effect on the extent of accessible harvest areas and the extent of high value wildlife habitat.
6. Determine if the results of any one scenario are acceptable for subsistence hunting access and wildlife habitat conservation, as well as any other criteria (e.g., ecosystem functions, cost, etc.). If not, apply lessons learned to develop and evaluate a new suite of alternative scenarios.

managers when anadromous (salmon) streams were affected and the wildlife species were potentially displaced due to disturbance (e.g., noise) (USDA Forest Service, 2007).

Regulated access on the Tongass National Forest was mandated by the 1997 Tongass Land and Resources Management Plan (TLMP). Initial public meetings that introduced an Environmental Assessment revealed that residents were concerned that restricted motorized access would impede subsistence hunting practices. The subsistence activity of greatest concern with regards to access was the harvest of moose (*Alces alces*). Moose have historically been harvested in remote areas and these large animals (>500 kg) can be difficult to transport before the meat spoils. However, the large amount of meat forms a significant portion of a families' diet, making as successful hunt important. Moose were also a species that land managers were concerned would be affected by unregulated access, given OHV damage had increased in areas thought to contain the region's best moose habitat (USDA Forest Service, 2007).

Our study objective was to develop and test a geospatial-scenario planning framework (Table 1) with the goal of balancing the conservation of wildlife habitat and subsistence-hunting access. This study was conducted by evaluating the effect of four road-closure scenarios on both social and ecological goals of maintaining sufficient access and conserving moose habitat. Moose distribution models (Shanley & Pyare, 2011) that accounted for OHV impact on moose habitat were used to compare moose distribution among scenarios. Likewise, parameters of subsistence-hunting practices, elicited through moose hunter interviews, were extrapolated in GIS to compare the spatial extent of subsistence hunting access.

2. Methods

2.1. Social-ecological system

Yakutat, Alaska, has approximately 800 residents with a mixed cash-subsistence economy. Approximately 60% of the residents are Alaska Native, primarily Tlingit. Tlingit subsistence activities were traditionally focused around marine resources with salmon as the main source of protein (Mills & Firman, 1986). During the early 1930s, moose migrated into the Yakutat area from interior Canada and were opportunistically harvested from river shores with fishing vessels to supplement marine protein sources. There was no evidence of moose in the area prior to that time. By the late 1980s, moose was the primary source of red meat with 70% of households consuming moose, either through direct harvest or sharing networks (Mills & Firman, 1986).

In the 1960s, the Yakutat area was heavily vegetated with high-quality moose forage (i.e., willow) and the moose population grew steadily (Mills & Firman, 1986). During this period, the moose

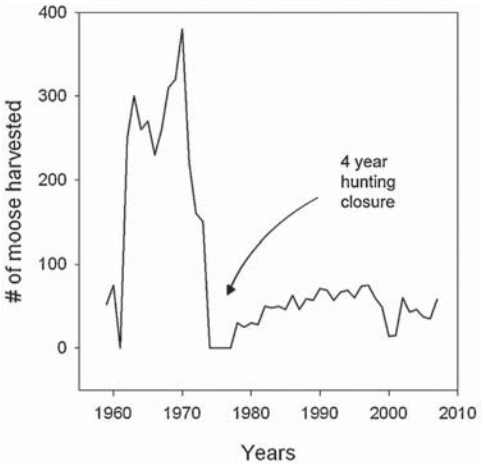


Fig. 2. The number of reported moose harvested in Yakutat, Alaska, USA from 1959 to 2007 (ADFG, 2008).

population size was believed to be >2000 (Smith & Franzmann, 1979) and the human population of Yakutat was approximately 300 residents with over 80% Alaska Native (U.S. Census, 1960). The road system was limited and hunting of moose was conducted primarily from fishing vessels along river outwash areas where a harvested moose could easily be transported. In the late 1960s, the road network expanded with logging activities, allowing increased hunting opportunities, new job opportunities and a concomitant increase in the human population (Mills & Firman, 1986). Competition also increased among residents of Yakutat and other communities (e.g., Juneau, Alaska), with hunters increasingly using OHVs to access remote harvest areas (Mills & Firman, 1986).

The peak harvest of 380 moose occurred in 1970 (Fig. 2). Moose became a highly valued source of protein to indigenous and non-indigenous groups, and liberal harvest limits continued despite the belief of biologists that the moose population was declining (Mills & Firman, 1986). In the early 1970s, a series of severe winters with snowfalls >7 m (NOAA, 1983) resulted in high moose mortality levels. By the mid-1970s, the moose population declined to the point that hunting was closed between 1974 and 1977 (Fig. 2). Since then, the moose population has never returned to pre-1960s levels. Captured female moose in the late-1970s showed normal pregnancy rates, although they were shown to be nutritionally stressed (Smith & Franzmann, 1979). Long-term residents suggested the nutritional stress arose from the rapid change in the region's vegetation composition, from higher quality moose-forage communities with willow (*Salix* spp.) and alder (*Alnus sinuate*) to lower quality communities like cottonwood (*Populus trichocarpa*) and spruce (*Picea sitchensis*) (Larsen, Motyka, Freymueller, Echelmeyer, & Ivins, 2005; Mills & Firman, 1986; Shephard, 1995). A similar pattern of successional change with an increase and decline in moose population was documented in an adjacent coastal area of the Copper River Delta, Alaska (Stephenson, Van Ballenberghe, Peek, & MacCracken, 2006). The moose population of Yakutat has remained relatively stable in recent history, utilizing early successional habitats created from natural disturbance events such as spring river flooding and avalanches, with approximately 800–1000 individuals estimated by aerial surveys during 2003 and 2004 (Oehlers, 2007).

2.2. Identifying values, goals, and thresholds

In the spring of 2007, we held a series of informal meetings separately with land managers and resident moose hunters, with follow-up discussions for review of findings and clarification. The purpose of the meetings was to define each group's respective

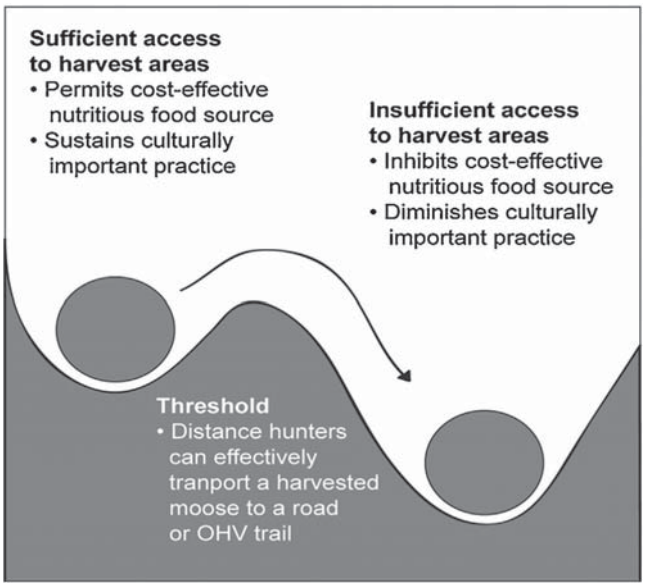


Fig. 3. A ball-and-cup diagram illustrating the multiple stability states and threshold in which subsistence moose hunters can have sufficient – or insufficient – access to subsistence resources to meet their household needs in Yakutat, Alaska, USA.

values, management goals, and perceived thresholds to undesired changes with respect to moose conservation and harvesting access (e.g., Berkes, Mathias, Kislalioglu, & Fast, 2001). Land managers identified their goal as the management of habitat on the Yakutat landscape to support a healthy moose population. Due to the reduced population counts of moose on the portion of the region heavily used by OHVs, they suspected OHVs were effectively lowering the region's carrying capacity for moose (USDA Forest Service, 2007). Managers were therefore primarily interested in whether or not there was a reduced probability of moose occurrence relative to OHV activity.

Resident moose hunters emphasized the importance of using OHVs to retrieve large game species from remote harvest areas, since these species were critical to meeting their economic, nutritional, and cultural needs. Hunters indicated there was a maximum or threshold distance they were willing to travel by foot to transport a moose from a harvest site to an OHV route or road. This threshold distance can be illustrated with an adapted ball-and-cup diagram from the resilience literature (e.g., Walker, Holling, Carpenter, & Kinzig, 2004) that shows alternate stability states with more or less desirable outcomes (Fig. 3). Hunters also noted that this distance was dynamic: this study would be a "snapshot" in time that represents the current social and ecological conditions. For example, with new forms of hunting innovation and technology this distance would likely change. Nevertheless, moose hunters stated for the foreseeable future they were primarily interested in maintaining sufficient OHV access to important harvest areas.

2.3. Road closure scenarios

Four road-closure scenarios under consideration by the Yakutat Ranger District to meet multiple objectives (e.g., wildlife values, stream restoration, and maintenance costs) were used for comparative analyses (USDA Forest Service, 2007; Table 2). Scenario 1 maintained the status quo with unlimited OHV access. All main roads (221 km) and the extensive network of hunter-created OHV routes (302 km) across inland meadows and beaches would remain available to search for moose and transport a harvested moose back to the community. Scenario 2 retained most of the main roads (182 km) and restricted many of the hunter created OHV routes to a select few (85 km) routes that could be maintained and monitored to National Forest standards (Table 2). A seasonal closure would also be put on OHV routes near tern (*Onychoprion aleuticus* and *Sterna paradisaea*) nesting habitat (May to mid-August). Hunters would be allowed to use an OHV to retrieve a harvested moose from open roads and OHV routes by obtaining a permit from the Yakutat Ranger District prior to hunting, and if they could do so without causing resource damage. Resource damage was defined as "soil displacement or cutting of living vegetation to create a path" from the road or OHV route to a harvested moose (USDA Forest Service, 2007). Hunters would also have to attain a permit from the Alaska Department of Natural Resources to cross streams used by anadromous salmon. Scenario 3 was similar to Scenario 2 in terms of the total amount of main roads (185 km), however subsistence hunting access was not given priority over national transportation planning standards (Table 2). Therefore, Scenario 3 retained fewer OHV routes than any of the other scenarios (39 km). Perhaps most importantly, hunters would also not be able to use OHVs to retrieve moose from open roads or OHV routes. Finally, Scenario 4 incorporated public comments on Scenario 2 from a meeting with the Yakutat Ranger District in 2005. This scenario resulted in fewer main roads (182 km), many of which lacked utility (e.g., old logging roads), and a greater number of designated OHV routes (55 km) (Table 2). Hunters in Scenario 4 were also allowed to use OHVs to transport a harvested moose to open roads and OHV routes, if they could do so without causing resource damage and obtain a permit prior to hunting. Seasonal closure in areas of nesting terns and a permitting process for crossing of salmon streams would also apply to Scenario 4.

Table 2
Categorized route lengths (km) and sum for each of the four road closure scenarios in Yakutat, Alaska, USA.

Routes (km)	Scenarios			
	I	II	III	IV
Low OHV	184	54	18	21
High OHV	118	31	21	34
All-vehicles	221	182	185	182
Total OHV	302	85	39	55
All routes	523	267	224	237

2.4. Evaluating subsistence access

A random sample of one-third ($n = 25$) of the federally registered subsistence moose hunters were interviewed to document their land-use patterns in 2007. During these 45-min interviews, hunters ($n = 21$ of 25) mapped their preferred harvest areas and estimated ($n = 25$) how far they were willing to transport a harvested moose on foot to an OHV route or road. A preferred harvest area was defined as an area currently valued for hunting moose. Each hunter delineated harvest areas with dry erase markers on a transparency over a 1.5 m x 1 m high-resolution aerial photograph of the region (approximately 2 cm = 1 km). Harvest areas for each hunter were manually digitized into GIS in the form of grids of cells (50 m resolution) designated with 1 of 2 values: 1 for harvest and 0 non-harvest. These 21 grids were collectively summed to create one grid for the sampled hunter population. For example, if the harvest areas of three hunters overlapped, cells in the composite harvest surface acquired a value of three, indicating that 14% (3 hunters/21 total hunters) used the cell area for hunting.

The distance that each hunter was willing to transport a harvested moose without motorized assistance to a road or OHV route was elicited during interviews. The mean (1.5 km), lower 95% CI (0.6 km), and upper 95% CI (2.4 km) transport distances were used for comparative analysis to represent the range of hunting

Table 3
Overlapping harvest area (km^2) categories and access score in the four road closure scenarios for Yakutat, Alaska, USA. The access score was derived from multiplying the km^2 of access by the percent use category, and then summing across categories for each scenario and distance. The hunter access distances are 0.6 km ("Short"), 1.5 km ("Average"), and 2.4 km ("Long").

Hunter harvest area percent use category	Scenarios											
	I			II			III			IV		
	Distance			Distance			Distance			Distance		
	Short	Average	Long	Short	Average	Long	Short	Average	Long	Short	Average	Long
5%	272.5	423.6	495.1	164.4	274.0	346.7	162.3	259.3	319.8	171.3	294.6	383.2
10%	206.7	325.8	379.6	68.5	151.0	226.8	56.2	126.0	197.5	72.6	161.5	243.1
14%	76.9	144.2	196.0	16.8	41.7	66.0	12.4	33.4	50.5	18.3	50.0	80.4
19%	37.0	72.9	96.8	10.0	17.0	29.2	4.0	8.1	12.8	10.1	17.4	31.9
24%	10.8	17.1	22.2	4.2	6.8	10.0	2.2	4.3	6.4	4.2	6.8	10.0
29%	3.5	3.5	4.2	0.0	0.5	1.4	0.0	0.0	0.8	0.0	0.5	1.4
33%	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Access score	54.4	90.8	112.7	19.7	38.4	55.9	16.1	31.7	45.4	20.6	41.6	61.7

zones around roads and OHV routes in each scenario. These zones represented portions of the landscape that were considered accessible by the of resident-hunter population.

An access score was then derived for each scenario and transport distance by overlaying the scenario-specific access zones on the cumulative harvest grid. First, harvest grid-cell values occurring within access zones for each road closure scenario were summed for each percent-use category. Then, we assumed a linear relationship between the relative importance of cells and the percent of hunters using the hunting area on the cumulative harvest grid. This assumption was made to weight the relative importance of harvest areas to the subsistence hunting community as a whole for scenario analysis. To calculate each scenario's final access score, the total cell area of each percent-use category was multiplied by the percentage of hunters that used the area those cells represented, and summed across all percent-use categories.

2.5. Evaluating moose habitat

A comparison of the cumulative impact of road-closure scenarios on the amount of high-probability female moose habitat (Shanley & Pyare, 2011) was developed using a cumulative habitat score for each scenario. To do this, we used GIS to map the proposed configuration of roads and OHV routes for each of the four scenarios. Each route was categorized as either Low OHV, High OHV, and All-Vehicles by size and surface wear, and then weighted with the mean number of seasonal one-way trips for each route category (Shanley & Pyare, 2011); a parameter estimated from hunter interviews.

A female moose distribution model (Shanley & Pyare, 2011) was used to evaluate the effect of the four road closure scenarios on moose distribution. A female distribution model was selected due to their reproductive importance and higher likelihood of disturbance (Shanley & Pyare, 2011). The model was a spatially explicit resource selection function (RSF Design II; Johnson et al., 2006; Manly, McDonald, Thomas, McDonald, & Erickson, 2002) that incorporated a parameter for OHV activity derived from interviews, as well as habitat composition and configuration. The resulting RSF for each scenario was a mapped surface of 20 m × 20 m grid cells representing the probability of moose occurrence across the study area. We utilized an average predicted probability/suitability approach (Liu, Berry, Dawson, & Pearson, 2005) where the mean probability of occurrence was used to determine a 0.4 threshold probability value for delineating species occurrence across the study area. Cells above the threshold probability value were classified into 0.1 probability intervals (e.g., 0.4–0.5, 0.5–0.6, etc.) for scenario analysis. We assumed a linear relationship between the probability of moose occurrence and the relative importance of habitat, and the total area of habitat in each probability interval was multiplied by the average probability of the interval. This assumption was made to weight the relative importance of habitats for scenario analysis. The final habitat score was calculated from the sum of the probability-corrected habitat intervals for each road closure scenario.

Table 4
Moose habitat (km^2) by probability interval and habitat score in the four road closure scenarios for Yakutat, Alaska, USA. The habitat score was derived by multiplying the km^2 of habitat by the probability of use interval mid-point, and then summing across probability-corrected intervals for each scenario.

Moose habitat probability intervals	Scenarios			
	I	II	III	IV
0.4–0.5	231.4	263.5	263.9	262.8
0.5–0.6	196.0	218.6	222.4	218.6
0.6–0.7	72.9	75.4	75.7	75.4
0.7–0.8	23.3	23.4	23.4	23.4
0.8–0.9	7.9	7.9	7.9	7.9
0.9–1.0	0.2	0.2	0.2	0.2
Habitat score	283.7	312.3	314.7	312.0

3. Scenario results

Scenario 1 maintained the status quo and included the greatest number of roads and OHV routes; and consistently resulted in the best scores for subsistence hunting access across the range of short, average, and long-distance hunter categories (Table 3 and Fig. 4). It also resulted in the lowest score for female moose habitat (Table 4 and Fig. 5), primarily seen in the 0.4–0.6 probability categories, because female moose were influenced by this larger road network. Scenario 2 (the U.S. Forest Service-preferred alternative) resulted in the second lowest scores for subsistence hunting access (Table 3) and a habitat score for female moose similar to Scenario 4 (Table 4). The closing of many roads and OHV routes would approximately halve the access scores of Scenario 1, but result in greater habitat area for female moose. Scenario 3, which met minimum policy requirements, resulted in the lowest score for subsistence hunting access (Table 3) and the greatest habitat score for female moose (Table 4). The low access scores and the high habitat score were the result of fewer roads and OHV routes. Scenario 4 was based on public comments on Scenario 2 and yielded the second highest scores for subsistence hunting access (Table 3) and a habitat score for female moose similar to Scenario 2 (Table 4). Scenario 4 had fewer roads but more OHV routes, which could explain why it provided for greater hunter access (Fig. 4).

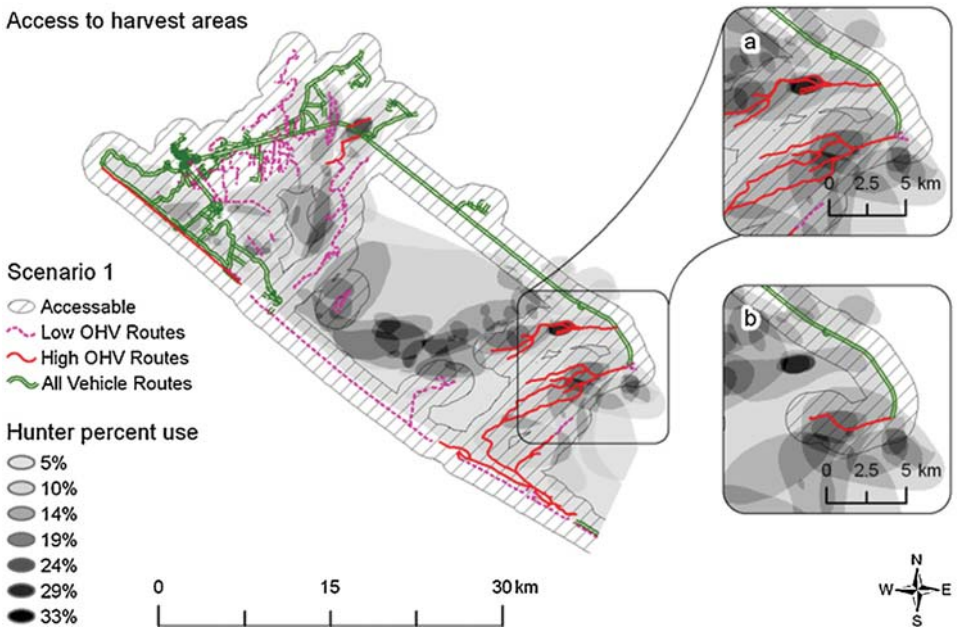


Fig. 4. Map of subsistence moose hunters' preferred harvest areas by percent use categories in Yakutat, Alaska, USA and the average distance (hashed areas) hunters are willing to transport a harvested moose from the existing network of vehicle routes in Scenario 1. Increasingly darker harvest areas represent increased hunter use. An inset (a) shows an area of extensive OHV routes in Scenario 1 and (b) shows the same visual extent and access to preferred harvest areas with fewer OHV routes in Scenario 4.

4. Discussion

The results of the road closure scenarios illustrate a social-ecological dynamic created by the spatial configuration of routes on moose habitat and subsistence hunting access. Comparison of the results of Scenario 1 with Scenario 4 illustrates how public comments incorporated in Scenario 4 consistently improved hunting access for short, average, and long-distance hunter categories (Table 3) with minimal impact on moose habitat (Table 4). The existing network in Scenario 1 yielded a greater degree of access but also had a noticeable disturbance effect on female moose (Table 4 and Fig. 5). Scenario 4 had fewer total routes but more harvest areas within reach of roads and OHV routes than any of the other scenarios. Maintaining the status quo in Scenario 1 without enacting new regulations would also allow future OHV route expansion that could pose a future impact to female moose habitat. The proposed regulations for Scenario 4 would ban the creation of new OHV routes but allow the retrieval of a harvested moose from designated routes, therefore limiting future impact on female moose habitat and allowing for more efficient transportation of a harvested moose. Additionally, the closure of main roads (All-Vehicle routes) seen in Scenario 1 illustrates how, kilometer-for-kilometer, the

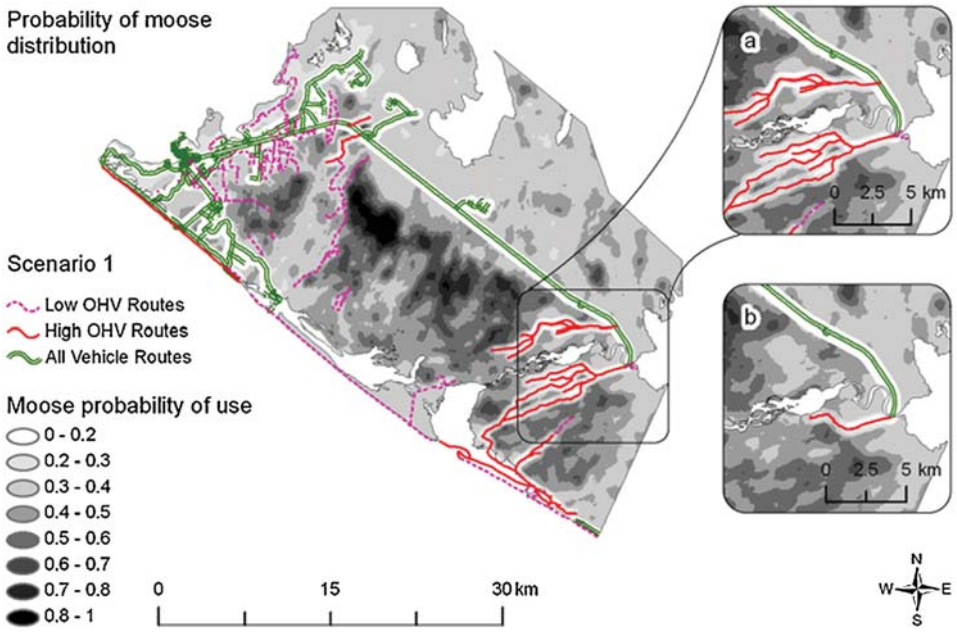


Fig. 5. Resource selection function model of female moose distribution with the existing network of vehicle routes in Scenario 1; illustrating the impact of roads and OHV routes on female moose habitat selection in Yakutat, Alaska, USA. Increasingly darker areas represent a higher probability of moose occurrence. An inset (a) shows an area of extensive OHV routes in Scenario 1 and (b) shows the same visual extent with fewer OHV routes in Scenario 4.

closure of main roads would have resulted in greater habitat gains for moose than the closure of OHV routes (Fig. 5) due to the higher disturbance effect caused by main roads (Shanley & Pyare, 2011).

Scenario 4 was ultimately selected by the Yakutat Ranger District as the adopted plan (USDA Forest Service, 2009a, 2009b). Although Scenario 4 showed promise through the incorporation of public comments, no clear "winner" emerged as the best scenario for the conservation of moose habitat and subsistence hunting access. Indeed, it may be too simplistic to utilize a linear relationship to score the extent of moose habitat and hunting access as proxies for evaluating planning scenarios. Rather, a balance in the conservation of wildlife habitat and subsistence hunting access may be achieved via the precise spatial configuration of transportation networks. More specifically, a balance could be achieved by the strategic closure of roads and OHV routes in specific areas with high probability moose habitat and the maintenance of routes that are within reach of important harvest areas. The methodology demonstrated here – the spatial integration of ecological and subsistence access – could likewise be applied to finer-scale scenario planning involving individual routes and specific harvest areas.

Follow-up interviews with the Yakutat Ranger District in 2012 suggest the implementation of Scenario 4 has had successes and challenges that will likely require future amendments and finer-scale analysis. While Scenario 4 has allowed for improved habitat protection in closed areas, the provision to allow OHV use for moose harvest retrieval has presented a challenge for assessing fine-scale environmental impacts adjacent to open roads and OHV routes. New studies are underway to quantify the environmental impacts using a system of hunter reporting and harvest site surveys. The land managers suggested the results of these studies will likely result in additional OHV route closings and in turn new trail openings to achieve a balance in the conservation of wildlife habitat and subsistence hunting access.

The results of the scenario analyses to date should be treated within the context of the assumptions made in our spatial analyses. The distance hunters were willing to transport a harvested moose to an OHV route or road was clearly identified as an important management consideration, but simplifying it to a range of three distances for our analyses should not overshadow the complexity of this metric that depends on yearly hunting conditions (e.g., weather), and will likely change as hunters adapt to new social and ecological conditions. Similarly, the disturbance of female moose will depend on the spatial configuration of habitats (Shanley & Pyare, 2011) that will also likely change with continued successional processes (Larsen et al., 2005; Shephard, 1995; Stephenson et al., 2006). Nevertheless, the resilience-based approach using a geospatial-scenario framework provided a quantitative and interdisciplinary process for assessing future management iterations. Indeed, increased social and ecological change, e.g., climate change, will necessitate flexibility as a crucial management consideration in the development of regulations that manage subsistence hunting access.

A review of other land-use studies suggests a geospatial-scenario framework may prove useful in many other regions where motorized subsistence access is increasing and the conservation of wildlife habitat is a concern. Some of the first subsistence land-use studies occurred in the Canadian Arctic, documenting Native land claims in the face of industrial development (Freeman, 1976). The results of these studies demonstrated how subsistence mapping could elicit detailed use of the landscape and the distance hunters traveled to reach harvest areas. Subsequent studies have also produced species-specific harvest maps, demonstrating high-value harvest areas that have stayed in the same locations for generations or alternatively, where social and ecological conditions have changed and required adaptation through, for instance, motorized vehicles to hunt more efficiently (Berkes et al., 1995; Natcher, 2004; Pedersen & Coffing, 1984). The variety of subsistence land-use patterns depends on the region and species of interest, and underscores the importance of time and place specific analyses. For example, Berman and Kofinas (2004) showed that the subsistence caribou hunters of Old Crow, Yukon preferred to harvest caribou on time-tested accessible migration routes in order to save resources (i.e., time and money), when possible. When the migrations changed, additional resources had to be used on extended trips with motorboats and snowmachines to secure a sufficient harvest. A similar pattern of harvest in local areas mixed with long-distance motorized travel was shown by Natcher (2004) in the Yukon Flat communities of interior Alaska. Moose hunters of Birch Creek preferred to hunt local wetland areas, but changing interior fire regimes (natural and prescribed) caused a time lag in moose-forage availability between burns in these wetland areas. The changing distribution of moose required an additional investment of time and money to search for moose with motorboats or snowmachines. In addition to the variety of land-use patterns described in subsistence studies, it is clear that accessing and securing subsistence resources is changing, and motorized access is shaping how hunters perceive and use the landscape (Brinkman et al., 2009).

5. Conclusion

The use of motorized access for the harvest of subsistence resources is likely to increase in Yakutat (USDA Forest Service, 2007), as it is in many northern subsistence communities (Berkes et al., 1995; Condon et al., 1995; Ford et al., 2006; Gordon et al., 2007). Increased integration of subsistence harvesting practices with the cash economy is likely to mean contemporary subsistence hunters will have less time to spend on the land than past generations, requiring more efficient means of accessing hunting areas. In addition, the expense of modern equipment such as snowmachines, OHVs, rifles, ammunition, and fuel, will result in an even greater involvement in the cash economy (Berman & Kofinas, 2004; Fast & Berkes, 1998). Furthermore, shifts in regional climate regimes will compound social-ecological changes due to greater investment in locating and securing the shifting distribution of resources (Chapin et al., 2004). In some regions or with some species, the influence of motorized access on wildlife habitat may be negligible (i.e., highly dispersed wildlife) or ecological changes will improve hunting opportunities. However, as this study suggests, access management plans in some regions need to be updated to better reflect changing social and ecological conditions. A resilience-based approach that incorporates geospatial-scenarios with integrative quantitative and qualitative components may provide an effective framework to balance the conservation of wildlife habitat with contemporary subsistence hunting practices.

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References

ADFG (2008). *Community Subsistence Information System (CSIS)*. Alaska Department of Fish and Game, Division of Subsistence, Juneau, Alaska. Retrieved from <http://www.adfg.alaska.gov/sb/CSIS/> Accessed 24.05.12.

Ascher, W. (2009). *Bringing in the future: Strategies for farsightedness and sustainability in developing countries*. Chicago: University of Chicago Press.

Ahlstrand, G. M., & Racine, C. H. (1993). Response of an Alaska, U.S.A., shrub-tussock community to selected all-terrain vehicle use. *Arctic and Alpine Research*, *25*, 142–149.

Beier, C. M., Patterson, T. M., & Chapin, F. S. (2008). Ecosystem services and emergent vulnerability in managed ecosystems: a geospatial decision-support tool. *Ecosystems*, http://dx.doi.org/10.1007/s10021-008-9170-z

Berkes, F., Hughes, A., George, P. J., Preston, R. J., Cummings, B. D., & Turner, J. (1995). The persistence of Aboriginal land use: fish and wildlife harvest areas in the Hudson and James Bay Lowland, Ontario. *Arctic*, *48*, 81–93.

Berkes, F., & Jolly, D. (2001). Adapting to climate change: social-ecological resilience in a Canadian western arctic community. *Conservation Ecology*, *5*, Retrieved from <http://www.consecol.org/vol5/iss2/art18/> Accessed 24.05.12.

Berkes, F., Mathias, J., Kislalioglu, M., & Fast, H. (2001). The Canadian arctic and the Oceans Act: the development of participatory environmental research and management. *Ocean and Coastal Management*, *44*, 451–469.

Berkes, F., Colding, J., & Folke, C. (2003). *Navigating social-ecological systems: Building resilience for complexity and change*. Cambridge: Cambridge University Press.

Berman, M., & Kofinas, G. (2004). Hunting for models: grounded and rational choice approaches to analyzing climate effects on subsistence hunting in an Arctic community. *Ecological Economics*, *49*, 31–46.

Braund, S. R. (2007). PacRim Coal Chuitna Coal Project subsistence use areas and traditional knowledge study for Tyonek and Beluga, Alaska. In *Prepared for DRven Corporation* Anchorage, AK,

Brinkman, T. J., Kofinas, G. P., Chapin, F. S., III, & Person, D. K. (2007). Influence of hunter adaptability on resilience of subsistence hunting systems. *Journal of Ecological Anthropology*, *11*, 1–6.

Brinkman, T. J., Chapin III, F. S., Kofinas, G. P., & Person, D. K. 2009. Linking hunter knowledge with forest change to understand changing deer harvest opportunities in intensively logged landscapes. *Ecology and Society*, 141, Retrieved from <http://www.ecologyandsociety.org/vol14/iss1/art36/> Accessed 24.05.12.

Carpenter, S. R., Bennett, E. M., & Peterson, G. D. (2006). Editorial: special feature on scenarios for ecosystem services. *Ecology and Society*, 11, Retrieved from <http://www.ecologyandsociety.org/vol11/iss2/art32/> Accessed 24.05.12.

Chapin, F. S., III, Kofinas, G. P., & Folke, C. (2009). *Principles of ecosystem stewardship: Resilience-based natural resource management in a changing world*. New York: Springer.

Chapin, F. S., III, Peterson, G., Berkes, F., Callaghan, T. V., Angelstam, P., Apps, M., et al. (2004). Resilience and vulnerability of northern regions to social and environmental change. *Ambio*, *33*, 344–349.

Chapin, F. S., III, Robards, M. D., Huntington, H. P., Johnstone, J. E., Trainor, S. E., Kofinas, G. P., et al. (2006). Directional changes in ecological communities and social-ecological systems: A framework for prediction based on Alaskan examples. *American Naturalist*, *168*, S36–S49.

Condon, R. G., Collings, P., & Wenzel, G. (1995). The best part of life: Subsistence hunting, ethnicity, and economic adaptation among young adult Inuit males. *Arctic*, *48*, 31–46.

Cordell, K. H., & Bergstrom, J. C. (1999). *Integrating social sciences with ecosystem management*. Champaign, IL: Sagamore Publishing.

Fast, H., & Berkes, F. (1998). *Chapter 8: Climate change, northern subsistence and land based economies*. Canada Country Study: Climate Impacts and Adaptation. Natural Resources Institute, Manitoba, Winnipeg. Retrieved from <http://www.dfo-mpo.gc.ca/Library/242932.pdf> Accessed 24.05.12.

Ford, J. D., Smit, B., & Wandel, J. (2006). Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. *Global Environmental Change*, *16*, 145–160.

Freeman, M. M. R. (1976). . *Report of the Inuit land use and occupancy project* Ottawa, Canada: Department of Indian and Northern Affairs.

Gordon, A. B., Andre, M., Kaglik, B., Cockney, S., Allen, M., Snowshoe, A., et al. (2007). *Arctic borderlands ecological knowledge co-op community reports 2005–2006*. Borderlands Society, Whitehorse, Yukon. Retrieved from <http://www.taiga.net/coop/community/2005-06/2005-06Community.pdf> Accessed 24.05.12.

Johnson, C. J., Nielsen, S. E., Merrill, E. H., McDonald, L. L., & Boyce, M. S. (2006). Resource selection functions based on use-availability data: Theoretical motivation and evaluation methods. *Journal of Wildlife Management*, *70*, 347–357.

Kofinas, G. P., Chapin, F. S., III, BurnSilver, S., Schmidt, J. I., Fresco, N. L., Kielland, K., et al. (2010). Resilience of Athabascan subsistence systems to interior Alaska's changing climate. *Canadian Journal of Forest Research*, *40*, 1347–1359.

Kruse, J. A., White, R. G., Epstein, H. E., Archie, B., Berman, M., Braund, S. R., et al. (2004). Modeling sustainability of arctic communities: an interdisciplinary collaboration of researchers and local knowledge holders. *Ecosystems*, *7*, 815–828.

Larsen, C. F., Motyka, R. J., Freymueller, J. T., Echelmeyer, K. A., & Ivins, E. R. (2005). Rapid viscoelastic uplift in southeast Alaska caused by post-Little Ice Age glacial retreat. *Earth and Planetary Science Letters*, *237*, 548–560.

Liu, C., Berry, P. M., Dawson, T. P., & Pearson, R. G. (2005). Selecting thresholds of occurrence in the prediction of species distributions. *Ecography*, *28*, 385–393.

Manly, B. F. J., McDonald, L. L., Thomas, D. L., McDonald, T. L., & Erickson, W. P. (2002). *Resource selection by animals: Statistical design and analysis for field studies*. The Netherlands: Kluwer Academic Publishers.

Mills, D. D., & Firman, A. S. (1986). *Fish and wildlife use patterns in Yakutat, Alaska: contemporary patterns and changes.* Alaska Department of Fish and Game, Division of Subsistence, Douglas, Alaska. Retrieved from <http://www.subsistence.adfg.state.ak.us/TechPap/tp131.pdf> Accessed 24.05.12.

Natcher, D. C. (2004). Implications of fire policy on Native land use in the Yukon Flats, Alaska. *Human Ecology*, *32*, 421–441.

NOAA (1983). *Local climatological data annual summary Yakutat, Alaska.* National Oceanic and Atmospheric Administration. U.S. Department of Commerce.

Oehlers, S. A. (2007). *Habitat Selection and Sightability of Moose in Southeast Alaska.* MS Thesis. University of Alaska Fairbanks, Fairbanks, AK.

Pedersen, S., & Coffing, M. (1984). *Caribou hunting: land use dimensions and recent harvest patterns in Kaktovik, northeast Alaska.* Alaska Department of Fish and Game, Division of Subsistence, Fairbanks, Alaska. Retrieved form <http://www.subsistence.adfg.state.ak.us/TechPap/tp092.pdf> Accessed 24.05.12.

Peterson, G. D., Cumming, G. S., & Carpenter, S. R. (2003). Scenario planning: a tool for conservation in an uncertain world. *Conservation Biology*, *17*, 358–366.

Peterson, G., Douglas Beard, T., Jr., Beisner, B. E., Bennett, E. L., Carpenter, S. R., Cumming, G. S., et al. (2003). Assessing future ecosystem services: a case study of the Northern Highlands Lake District, Wisconsin. *Conservation Ecology*, *7*, Retrieved from <http://www.consecol.org/vol7/iss3/art1/> Accessed 24.05.12.

Sawyer, H., Nielson, R. M., Lindzey, F., & McDonald, L. L. (2006). Winter habitat selection of mule deer before and during development of a natural gas field. *Journal of Wildlife Management*, *70*, 396–403.

Shanley, C. S., & Pyare, S. (2011). Evaluating the road-effect zone on wildlife distribution in a rural landscape. *Ecosphere*, 2, Retrieved from <http://www.esajournals.org/doi/pdf/10.1890/ES10-00093.1> Accessed 24.05.12.

Shephard, M. E. (1995). *Plant community ecology and classification of the Yakutat Foreland, Alaska*. Juneau, Alaska: USDA Forest Service.

Smith, C.A., & Franzmann, A.W. (1979). *Productivity and physiology of Yakutat Forelands moose.* Final Report W-17-10 and W-17-11. Alaska Department of Fish & Game.

Sowl, K., & Poetter, R. (2004). *Impact analysis of off-road vehicle use for subsistence purposes on refuge lands and resources adjacent to King Cove access project*. U.S. Fish & Wildlife Service, Izembek National Wildlife Refuge, Alaska. Retrieved from <http://izembek.fws.gov/pdf/impanalysis.pdf> Accessed 24.05.12.

Stephenson, T. R., Van Ballenberghe, V., Peek, J. M., & MacCracken, J. G. (2006). Spatio-temporal constraints on moose habitat and carrying capacity in coastal Alaska: Vegetation succession and climate. *Rangeland Ecology & Management*, *59*, 359–372.

Tobias, T. N. (2000). *Chief Kerry's moose: a guidebook to land use and occupancy mapping, research design and data collection.* Union of BC Indian Chiefs and Ecotrust Canada. Retrieved from <http://www.ecotrust.org/publications/Chief_Kerrys_Moose.pdf> Accessed 24.05.12.

U.S. Census (1960). *U.S. Census. Bureau of the Census.* U.S. Department of Commerce.

USDA Forest Service. (2007). *Yakutat access travel management plan*. Yakutat, AK: USDA Forest Service.

USDA Forest Service. (2009a). *Access and Travel Management on the Yakutat Ranger District: Environmental Assessment*. Tongass National Forest R10-MB-619a. Retrieved from: <http://www.fs.fed.us/nepa/nepa_project_exp.php?project=5247> Accessed 29.10.12.

USDA Forest Service (2009b). *Access and Travel Management on the Yakutat Ranger District: Decision Notice*. Yakutat, AK. Retrieved from: <http://www.fs.fed.us/nepa/nepa_project_exp.php?project=5247> Accessed 29.10.12.

Walker, B., Carpenter, S.R., Anderies, J., Abel, N., Cumming, G., Janssen, M., et al. (2002). Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation Ecology*, 6, Retrieved from <http://www.consecol.org/vol6/iss1/art14> Accessed 24.05.12.

Walker, B., Holling, C. S., Carpenter, S. R., Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. Ecology and Society, 9, Retrieved from <http://www.ecologyandsociety.org/vol9/iss2/art5/> Accessed 29.10.12.

Species at Risk Act
Recovery Strategy Series

Amended Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada

Woodland Caribou, Boreal population



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Note: The Woodland Caribou, Boreal population is referred to as "boreal caribou" in this document.

For copies of the recovery strategy, or for additional information on species at risk, including the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) Status Reports, residence descriptions, action plans, and other related recovery documents, please visit the Species at Risk (SAR) Public Registry[1].

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[1] www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html

AMENDED RECOVERY STRATEGY FOR THE WOODLAND CARIBOU (*RANGIFER TARANDUS CARIBOU*), BOREAL POPULATION, IN CANADA (2020)

The Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada was posted on the Species at Risk Public Registry in October 2012 (Environment Canada, 2012a).

Under Section 45 of the *Species at Risk Act* (SARA), the competent Minister may amend a recovery strategy at any time. This Amended Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada (hereafter, "amended recovery strategy") is for the purposes of:

- Identifying critical habitat in northern Saskatchewan's Boreal Shield range (SK1).
- Updating population and habitat condition information, based on information previously published in the 5-Year Progress Report (Environment and Climate Change Canada, 2017).
- Other minor edits to update factual information and/or to improve internal consistency within the document.

At the time of final posting, this amended recovery strategy replaces the 2012 Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada (Environment Canada, 2012a).

PREFACE

The federal, provincial, and territorial government signatories under the Accord for the Protection of Species at Risk (1996)[2] agreed to establish complementary legislation and programs that provide for effective protection of species at risk throughout Canada. Under the *Species at Risk Act* (S.C. 2002, c.29) (SARA), the federal competent ministers are responsible for the preparation of recovery strategies for listed Extirpated, Endangered, and Threatened species and are required to report on progress within five years after the publication of the final document on the Species at Risk (SAR) Public Registry.

The Minister of Environment and Climate Change and Minister responsible for the Parks Canada Agency is the competent minister under SARA for the Woodland Caribou, Boreal population, and has prepared both the 2012 Recovery Strategy and this amended recovery strategy, as per section 37 of SARA.

Environment and Climate Change Canada's Canadian Wildlife Service led the development of the 2012 Recovery Strategy. Seven provinces, two territories, one Indigenous government, four wildlife management boards and the Parks Canada Agency contributed information for the recovery strategy. Additional effort was made by Environment and Climate Change Canada to engage Indigenous communities that the minister considered directly affected by the recovery strategy. These efforts included two rounds of engagement, one before and the second one after the proposed recovery strategy was posted on the SAR Public Registry, to gather information on boreal caribou and to provide communities with an opportunity to comment on the proposed recovery strategy. In the first round, 271 Indigenous communities were contacted and 161 engaged, and in the second round, 265 Indigenous communities were contacted and 87 engaged. In addition, 25 formal submissions were received from Indigenous communities and organizations.

Following the posting of the proposed recovery strategy on August 26, 2011, the standard 60-day public comment period was extended by 120 days to February 22, 2012 as a result of Environment and Climate Change Canada's desire to consult Indigenous communities prior to finalizing the recovery strategy. The high level of interest in boreal caribou resulted in the submission of 19,046 comments during and subsequent to the public comment period. The majority of these were received as copies of form letters initiated by environmental group's campaigns. A total of 192 more detailed and/or technical submissions were received from governments, wildlife management boards, Indigenous communities and organizations, industry stakeholders, environmental organizations and academia.

The recovery strategy sets the strategic direction to arrest or reverse the decline of the species, including identification of critical habitat to the extent possible. It provides all Canadians with information to help take action on species conservation. When critical habitat is identified, either in a recovery strategy or an action plan, SARA requires that critical habitat then be protected. Environment and Climate Change Canada's Canadian Wildlife Service also led the development of this amended recovery strategy in order to identify critical habitat in northern Saskatchewan's Boreal Shield range (SK1). The work completed for the amended recovery strategy was done in

[2] www.canada.ca/en/environment-climate-change/services/species-risk-act-accord-funding.html#2

collaboration with the Government of Saskatchewan, the Science and Technology Branch of Environment and Climate Change Change, and the Parks Canada Agency. Prior to posting the proposed amended recovery strategy on the Species at Risk Public Registry, 34 Indigenous communities and 31 Indigenous organizations/governments located within and adjacent to SK1 were invited to share information, comments and dialogue on the draft amendment to the recovery strategy. At the time of posting the proposed amendment, 11 communities and five organizations/governments participated in information sessions and/or meetings.

Landscape level planning is essential for the recovery of boreal caribou. Provinces and territories have the primary responsibility for management of lands, natural resources and wildlife within boreal caribou ranges; however, this responsibility does vary in some parts of the country. For example, in the Northwest Territories, the Tłı̨chǫ Government manages land and resources (including wildlife) within Tłı̨chǫ Lands, as described in the Tłı̨chǫ Agreement (a combined comprehensive land claims and self-government agreement). There are also wildlife management boards that have been established under land claims agreements as the primary instrument for wildlife management in some regions of the country.

Success in the recovery of this species depends on the commitment and cooperation of many different constituencies that are or will be involved in implementing the directions set out in this strategy and will not be achieved by Environment and Climate Change Canada and the Parks Canada Agency, or any other jurisdiction alone. All Canadians are invited to join in supporting and implementing this strategy for the benefit of boreal caribou and Canadian society as a whole.

This recovery strategy is being followed by range plans or other similar documents and/or action plans that provide information on recovery measures that are being or will be taken by provinces and territories, Environment and Climate Change Canada and the Parks Canada Agency, other federal departments, wildlife management boards, Indigenous communities, stakeholders, and other organizations, to achieve the survival and recovery of boreal caribou. Environment and Climate Change Canada, for its part, released its Action Plan for boreal caribou in February 2018, which sets out the measures that the Government of Canada is taking and will take to support the recovery of boreal caribou (Environment and Climate Change Canada, 2018). In addition to this Action Plan, Parks Canada Agency site-specific Action Plans that address boreal caribou conservation and recovery efforts on lands administered by the Agency can be found on the SAR Public Registry. Implementation of this recovery strategy is subject to appropriations, priorities, and budgetary constraints of the participating jurisdictions and organizations.

ACKNOWLEDGEMENTS

Environment and Climate Change Canada would like to express its gratitude to the Indigenous people who shared their knowledge about boreal caribou in support of the recovery of this species. Knowledge was shared by Indigenous Knowledge holders and Indigenous communities and organizations on boreal caribou life history, habitat use, population status, threats facing the species and conservation measures, and this information has been used in the development of this recovery strategy (see Appendices B and C). Indigenous people consistently indicated that conservation of boreal caribou is essential, as this species is integral to the culture, identity and survival of their communities. The Indigenous Knowledge that was shared may also be used to support the development of range plans and/or action plans for boreal caribou, where consent for such use is granted. Environment and Climate Change Canada appreciates that so many Indigenous people were willing to share their knowledge and experiences to help in the recovery of this species.

Gratitude is also extended to federal, provincial and territorial jurisdictions, the Tłı̨chǫ Government, and wildlife management boards with management responsibility for boreal caribou, for generously sharing information and providing expertise to develop this recovery strategy. The Boreal Caribou Working Group, comprised of Environment and Climate Change Canada staff from across Canada, contributed extensively by working with Canadians to gather information and support processes to collect Indigenous Knowledge used to inform the development of this recovery strategy, and by compiling material and drafting the recovery strategy. Appreciation is extended to Environment and Climate Change Canada's Wildlife and Landscape Science Directorate (WLSD), the boreal caribou Science Management Committee and boreal caribou science advisors, for their extensive efforts and contribution to the recovery strategy through the provision of the 2008 Scientific Review for the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada, and the Scientific Assessment to Inform the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada, 2011 Update. Thanks are also given to the National Boreal Caribou Technical Committee for providing advice and feedback on the science work that was undertaken by WLSD as part of the schedule of studies to inform the identification of critical habitat in northern Saskatchewan's Boreal Shield range (SK1). Acknowledgement and thanks are given to all other parties that provided advice and input used in the development of this recovery strategy, including the Species at Risk Advisory Committee (SARAC), Indigenous governments, communities and organizations, industry stakeholders, non-government organizations and academia.

EXECUTIVE SUMMARY

This recovery strategy is for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population herein referred to as "boreal caribou", assessed in May 2002 as threatened and re-examined and confirmed as threatened in November 2014 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). This document is an amended version of the boreal caribou recovery strategy published by Environment and Climate Change Canada under the title Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada (Environment Canada, 2012a). At the time of final posting, the final version of this amended recovery strategy will replace the 2012 Recovery Strategy.

Boreal caribou are distributed broadly throughout the boreal forest, occurring in seven provinces and two territories and extending from the northeast corner of Yukon east to Labrador and south to Lake Superior. Boreal Caribou require large areas comprised of continuous tracts of undisturbed habitat rich in mature to old-growth coniferous forest, lichens, muskegs, peat lands, and upland or hilly areas. Large areas with suitable quality habitat allow boreal caribou to disperse across the landscape when conditions are unfavorable (e.g. natural fire disturbance, anthropogenic disturbance) and to maintain low population densities to reduce their risk of predation.

The geographic area occupied by a group of boreal caribou that are subject to similar factors affecting their demography and used to satisfy their life history processes (e.g. calving, rutting, wintering) over a defined time frame is referred to as a range. There are 51 boreal caribou ranges in Canada. Information available to delineate boreal caribou ranges varies in certainty and therefore ranges are categorized into three types: conservation units, improved conservation units and local population units. In this recovery strategy, the group of boreal caribou occupying any of the three types of ranges is referred to as a "local population" of boreal caribou.

Due to the specific life history characteristics they possess, boreal caribou are limited in their potential to recover from rapid, severe population declines. Habitat alteration (i.e. habitat loss, degradation, and fragmentation) from both anthropogenic and natural sources, and increased predation as a result of habitat alteration have led to local population declines throughout their distribution. Some local populations of boreal caribou are at risk because of other factors, mainly over-harvest. Threats are closely interrelated and act cumulatively to have direct or indirect impacts on boreal caribou and their habitat. Recovery of all boreal caribou local populations across Canada is technically and biologically feasible.

The recovery goal for boreal caribou is to achieve self-sustaining local populations in all boreal caribou ranges throughout their current distribution in Canada, to the extent possible. Achieving the recovery goal would allow for local population levels sufficient to sustain traditional Indigenous harvesting activities, consistent with existing Aboriginal and treaty rights. Ranges that are highly disturbed will take decades to recover from habitat alteration, as boreal caribou occur in mature boreal forest ecosystems that have evolved over centuries. Achieving this recovery goal for all local populations will take a number of decades.

To guide recovery efforts, the population and distribution objectives for boreal caribou across their distribution in Canada are, to the extent possible, to:

- Maintain the current status of the 15 existing self-sustaining local populations; and
- Stabilize and achieve self-sustaining status for the 36 not self-sustaining local populations.

Performance indicators are identified as a means by which progress towards achieving the population and distribution objectives can be measured. The critical habitat necessary to achieve the population and distribution objectives for the recovery and survival of boreal caribou is now fully identified within this amended recovery strategy, as critical habitat is identified for all 51 boreal caribou ranges.

Critical habitat was not identified in the Boreal Shield range (SK1) in the 2012 Recovery Strategy due to a lack of data on population size and trend, and the uniqueness of the disturbance regime (i.e. high fire and very low anthropogenic disturbance). As required under the *Species at Risk Act* (SARA), a schedule of studies was developed to identify critical habitat in SK1. That schedule of studies for SK1 is now complete.

Critical habitat for boreal caribou is identified as: i) the area within the boundary of each boreal caribou range that provides an overall ecological condition that will allow for an ongoing recruitment and retirement cycle of habitat, which maintains a perpetual state of a minimum of 65% of the area as undisturbed habitat in all ranges other than SK1, and a minimum of 40% undisturbed habitat in SK1; and ii) biophysical attributes required by boreal caribou to carry out life processes.

With the exception of SK1, this recovery strategy identifies 65% undisturbed habitat in a range as the disturbance management threshold, which provides a measurable probability (60%) for a local population to be self-sustaining. This threshold is considered a minimum threshold because at 65% undisturbed habitat there remains a significant risk (40%) that local populations will not be self-sustaining.

The disturbance management threshold for SK1 is 40% undisturbed habitat in the range, which provides a measurable probability (71%) for the local population to be self-sustaining. This threshold is considered a minimum threshold because at 40% undisturbed habitat there remains a risk (29%) that the SK1 local population will not be self-sustaining. Based on the best available information, SK1 is the first local population that is currently self-sustaining below the 65% undisturbed habitat threshold (based on 3 years of data). For this reason, and because of the uniqueness of the disturbance regime in SK1, a lower undisturbed habitat threshold has been identified for this range.

Environment and Climate Change Canada (2019) demonstrated that the SK1 local population is sensitive to small increases in anthropogenic disturbance and small decreases in adult survival. The analyses also showed that anthropogenic disturbance is not equivalent to fire, with the former having a stronger negative effect on population condition. Therefore, caution is warranted with respect to additional anthropogenic disturbance in this range. For SK1 critical habitat, activities that pertain specifically to increasing the level of anthropogenic disturbance in SK1 above 5% (while maintaining a minimum of 40% undisturbed habitat in the range) has been added to the list of factors that increase the likelihood that critical habitat will be destroyed. The range plan for SK1 should outline how total anthropogenic disturbance in the range will be maintained at or below 5%. In addition, the SK1 local population should continue to be

monitored to ensure that future changes in range condition (fire and anthropogenic disturbance) do not compromise the ability of the range to support a self-sustaining local population.

The recovery of boreal caribou requires actions that will vary according to both the habitat and population conditions within each boreal caribou range. This recovery strategy provides broad strategies and general approaches to achieve the population and distribution objectives, which will assist in the development of range plans and action plans. The suite of actions needed to maintain or recover the self-sustaining status of a boreal caribou local population will be determined and managed by the responsible jurisdictions in collaboration with Environment and Climate Canada, and consistent with this recovery strategy. The recovery actions most appropriate for a specific range will be governed by local opportunities and constraints, and the level of urgency for a given recovery action will be determined by both the population and habitat conditions within the range.

To guide the protection of critical habitat and the recovery of boreal caribou, range plans or other similar documents and/or action plans are being prepared by provincial and territorial jurisdictions. These plans provide detailed information on recovery measures that are being or will be implemented by provinces and territories, Environment and Climate Change Canada, other federal departments, wildlife management boards, Indigenous communities, stakeholders, and other organizations involved in the conservation, survival and recovery of boreal caribou. Success in recovering boreal caribou will depend on the commitment, collaboration and cooperation among all interested parties.

RECOVERY FEASIBILITY SUMMARY

Recovery of boreal caribou is considered to be both technically and biologically feasible across the species' distribution in Canada based on the following four criteria that Environment and Climate Change Canada uses to establish recovery feasibility.

Current evidence supports the conclusion that the recovery of all local populations is biologically and technically feasible. However, small local populations, and particularly those isolated from the core distribution of the national boreal caribou population, are at greater risk of not becoming self-sustaining. In these situations, a local population may have greater difficulty withstanding stochastic events, and may not experience enough immigration to maintain genetic diversity and therefore will be at greater risk of not persisting in the long-term. There may be other situations where recovery of a particular local population proves to be, over time and through unforeseen circumstances, not biologically or technically feasible and, as such, may affect the likelihood of achieving the population and distribution objectives.

1. Individuals of the wildlife species that are capable of reproduction are available now or in the foreseeable future to sustain the population or improve its abundance.
Yes. According to current best estimates, there are approximately 34,000 (see Section 3.2.2) boreal caribou across nine provinces and territories in Canada capable of successful reproduction and available to improve local population growth rates and abundance to achieve self-sustainability (Environment Canada, 2011b).

2. Sufficient suitable habitat is available to support the species or could be made available through habitat management or restoration.
Yes. Some boreal caribou local populations have sufficient suitable habitat within their ranges. For other boreal caribou local populations where sufficient suitable habitat is currently unavailable to support local populations at a self-sustaining level, sufficient habitat could be made available through habitat management or restoration.

3. The primary threats to the species or its habitat (including threats outside Canada) can be avoided or mitigated.
Yes. The primary threat to most boreal caribou local populations is unnaturally high predation rates as a result of human-caused and natural habitat loss, degradation, and fragmentation. These habitat alterations support conditions that favour higher alternate prey densities (e.g. moose (*Alces alces)*, deer (*Odocoileus spp.*)), resulting in increased predator populations (e.g. wolf (*Canis lupus*), bear (*Ursus spp.*)) that in turn increase the risk of predation to boreal caribou. This threat can be mitigated through coordinated land and/or resource planning, and habitat restoration and management, in conjunction with predator and alternate prey management where local population conditions warrant such action. In some ranges, over-exploitation through hunting can also be an issue. This threat can be avoided or mitigated through regulations and stewardship.

4. Recovery techniques exist to achieve the population and distribution objectives or can be expected to be developed within a reasonable timeframe.
Yes. Recovery techniques (e.g. protection and management of boreal forest habitat, habitat restoration, predator and alternate prey management, hunting regulations, stewardship initiatives)

are available to achieve the population and distribution objectives for boreal caribou, although there is uncertainty with regard to the effectiveness of some of these techniques, as they have not yet undergone a sufficiently long trial period.

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1 COSEWIC SPECIES ASSESSMENT INFORMATION

Date of Assessment: November 2014

Common Name (population): Caribou (Boreal population)

Scientific Name: *Rangifer tarandus*

COSEWIC Status: Threatened

Reason for Designation: This population occurs at naturally low densities in mature boreal forest habitats from Labrador to Yukon, with small, isolated populations at the southern part of the range, including along the Lake Superior coastline and in the Charlevoix region of Québec. Over the past century, local subpopulations have been lost; range contraction has proceeded from the south by up to 50% of historical range in some areas. Despite considerable conservation efforts, range-wide declines have continued since the last assessment in 2002, particularly in Alberta, northeastern British Columbia, and Labrador. Some populations remain poorly monitored, particularly those in the northern portion of the range. For 37 of 51 subpopulations where trend data are available, 81% are in decline, as indicated by negative population growth rates. Some of the most intensively managed subpopulations may remain critically imperiled. Reasons for decline are mainly due to increased predation and habitat loss, the latter stemming from the combination of anthropogenic (natural resource extraction) and natural (fires) disturbance. The proliferation of linear landscape features such as roads and seismic lines facilitates predation by wolves, and the conversion of mature – old conifer stands to younger seral stages promotes increases in alternate prey such as Moose and White-tailed Deer. Shifts in the northern distribution of White-tailed Deer, mediated by landscape change, also bring novel parasites into parts of the range of this population. In some regions, overhunting poses a threat to long-term conservation. Threats are closely interrelated and act cumulatively to impact this population. Population increases do not appear likely in one-third of subpopulations where disturbances exceed a threshold of viability. A >30% decline in population is projected in the near term.

Canadian Occurrence: Yukon, Northwest Territories, British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Newfoundland and Labrador.

COSEWIC Status History: The Boreal population was designated threatened in May 2000. Status re-examined and confirmed in May 2002 and November 2014.

* COSEWIC (Committee on the Status of Endangered Wildlife in Canada)

In 2000, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, as threatened. The species was added to the List of Wildlife Species at Risk (Schedule 1) under SARA, at Proclamation, in 2003. In 2011, COSEWIC adopted new "Designatable Units" (DU) for caribou (*Rangifer tarandus*) in Canada using a number of variables to classify the different herds or groups of herds

(COSEWIC, 2011). These DU descriptions provided a clear and consistent scheme for identifying DUs due to the complexity of *Rangifer tarandus* in Canada. Woodland Caribou (*Rangifer tarandus caribou*), Boreal population is equivalent to COSEWIC's DU6, which is called Caribou (*Rangifer tarandus*), Boreal population. The 2014 COSEWIC assessment for the species was completed under this new DU structure/name (COSEWIC, 2014). However, until such time as Schedule 1 of SARA is amended to reflect the new common and scientific names changes, the species remains Woodland Caribou (*Rangifer tarandus caribou*), Boreal population under SARA. In this recovery strategy, the Woodland Caribou, Boreal population is referred to as simply "boreal caribou".

2 SPECIES STATUS INFORMATION

Boreal caribou are listed as threatened under Canada's *Species at Risk Act* (SARA), based on an observed, estimated, inferred or suspected reduction in population size of > 30% over three caribou generations (approximately 20 years). Boreal caribou have been provincially/territorially ranked in most jurisdictions (see Table 1). Boreal caribou have not been ranked globally by NatureServe.

Table 1. Canadian status and provincial/territorial designations for boreal caribou.

Canadian Status	Provincial/Territorial Designation
SARA – Schedule 1 (Threatened)	NT – Threatened YT – Not Listed BC – Red Listed (Threatened – Endangered) AB – Threatened SK – Not Listed MB – Threatened ON – Threatened QC – Vulnerable (Special Concern – Threatened) NL – Threatened

3 SPECIES INFORMATION

Caribou and reindeer are members of a single species, *Rangifer tarandus*. The term "caribou" is used to describe the various subspecies present in North America, whereas "reindeer" refers to the domesticated, semi-domesticated or wild subspecies found in Eurasia (Hummel and Ray 2008). Although there is considerable variation in phenotypic traits in this species (e.g., body size, pelage colour, morphology), caribou and reindeer are able to interbreed and produce fertile, viable offspring (Hummel and Ray 2008). It should be noted that reindeer occur in North America, particularly Newfoundland, as a result of human introductions.

Banfield (1974) recognized four existing subspecies of caribou in Canada, including Peary Caribou (*Rangifer tarandus pearyi*), Barren-ground Caribou (*R. t. groenlandicus*), Grant's Caribou (*R. t. granti*), and Woodland Caribou (*R. t. caribou*). A fifth subspecies, the Dawson's Caribou (*R. t. dawsoni*), which occurred in Haida Gwaii (i.e. Queen Charlotte Islands, BC) is extinct. Each subspecies displays differences in morphology, behaviour, and areas of geographic

occurrence. Boreal caribou are among those caribou populations that were classified by Banfield (1974) as Woodland Caribou.

Boreal caribou are endemic to Canada, and are distributed across nine provinces and territories, including British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, Newfoundland and Labrador, Northwest Territories, and Yukon (see Figure 1) (DU6; COSEWIC 2011).

3.1 Species Description

Like all Woodland Caribou, boreal caribou are a medium-sized (1.0-1.2 m shoulder height and weighing 110-210 kg) member of the deer family (*Cervidae*) (Thomas and Gray, 2002). Adults have a dark brown coat with a creamy white neck, mane, shoulder stripe, underbelly, underside of the tail, and patch above each hoof (Banfield, 1974; Boreal Caribou ATK Reports, 2010-2011). A distinctive characteristic of all caribou is large crescent-shaped hooves that provide flotation in snow and soft ground (e.g. peat lands), and assist in digging through snow to forage on lichens and other ground vegetation (Thomas and Gray, 2002). Antlers of boreal caribou are flattened, compact, and relatively dense. As a unique feature among the deer family, both male and female boreal caribou have antlers during part of the year, although some females may have only one antler or no antlers at all (Thomas and Gray, 2002; Boreal Caribou ATK Reports, 2010-2011). In comparison to Barren-ground Caribou, boreal caribou antlers are thicker and broader, and their legs and heads are longer.

3.2 Population and Distribution

Boreal caribou are forest-dwelling, sedentary caribou that occur only in Canada and are distributed broadly across the boreal forest (Thomas and Gray, 2002; Festa-Bianchet, 2011). The Canadian distribution of boreal caribou stretches from the northeast corner of Yukon east to Labrador, and extends as far south as Lake Superior (see Figure 1) (Environment Canada, 2008; Environment Canada, 2011b). Across Canada, the southern limit of boreal caribou distribution has progressively receded northward since the early 1900s (see Figure 1), a trend that continues today (Thomas and Gray, 2002; Schaefer, 2003; Festa-Bianchet et al., 2011). Indigenous Knowledge indicates that boreal caribou have moved northward as a result of habitat loss in the south (Boreal Caribou ATK Reports, 2010-2011).



Figure 1. Distribution (i.e. extent of occurrence) of boreal caribou in Canada. The current distribution of boreal caribou is shown in brown. The estimated southern extent of historical Woodland Caribou distribution is indicated by the dashed line.

3.2.1 Boreal Caribou Ranges

The geographic area occupied by a group of boreal caribou that are subject to similar factors affecting their demography and used to satisfy their life history processes (e.g. calving, rutting, wintering) over a defined time frame is referred to as a range (Environment Canada, 2011b). Boreal caribou are distributed across 51 ranges (see Figure 2 and Table 2) based on the best available information provided by the provincial and territorial jurisdictions, including observational and telemetry data, and biophysical analyses (Environment Canada, 2011b).

In this recovery strategy, "local population" refers to a group of boreal caribou occupying any of the three types of boreal caribou ranges (conservation unit, improved conservation unit, local population unit).

Environment and Climate Change Canada (2011b) identified three types of boreal caribou ranges, categorized based on the degree of certainty in the delineated boundaries. Eight ranges have been identified as "conservation units" (low certainty), 20 ranges as "improved conservation units" (medium certainty), and 23 ranges as "local population units" (high certainty) (see Appendix F). It is anticipated there will be changes to conservation units and improved conservation units as more information becomes available. In this recovery strategy, "local population" refers to a group of boreal caribou occupying any of the three types of boreal caribou ranges (conservation unit, improved conservation unit, local population unit).

As a result of limited information on many of the ranges in Canada, only three transboundary ranges (a range that extends across a provincial or territorial boundary) have been defined: Northwest Territories range (NT1), Chinchaga range (AB1), and Lac Joseph range (NL1). As new and more refined information is continually being collected by jurisdictions, range delineation and population demographic information will be updated and may result in revisions to range boundaries and possibly more transboundary ranges.

Ranges can and do vary greatly in size; some cover very large areas (e.g. Northwest Territories range (NT1): 44,166,546 ha), whereas others are much smaller (e.g. Charlevoix range (QC2): 312,803 ha). Whether a range can support a self-sustaining local population is a function of both the amount and quality of habitat available for boreal caribou.

Of the 51 boreal caribou local populations, 15 are "self-sustaining", 26 are "not self-sustaining" and 10 are "as likely as not self-sustaining", based on Environment and Climate Change Canada's (2011b) methodology and data from provincial and territorial jurisdictions (see Figure 3 and Appendix F). In the population and distribution objectives, "not self-sustaining" local populations refers to both the local populations assessed as "as likely as not self-sustaining" and those assessed as "not self-sustaining". The assessment of the likelihood of self-sustainability may change when ranges that cross jurisdictional boundaries are combined. Range boundaries and integrated risk assessments will be updated annually based on new or more refined evidence provided by the provincial and territorial jurisdictions.

In some cases, there are discrepancies between the range boundaries as presented in Figure 2, which were based on information provided by provincial and territorial jurisdictions, and the information that was provided by Indigenous Knowledge holders. These will be addressed in

range plans and/or action plans (see Sections 7.3 and 9) where provinces and territories, Indigenous communities, and other people with knowledge of a particular boreal caribou range can work together to ensure range boundaries are based on the best available information.

Boreal caribou use of a range may change over time as a result of variation in ecological conditions (e.g. vegetation change as a result of natural disturbances, predator/prey dynamics) and patterns of human disturbance (e.g. industrial development) affecting the landscape. Variation in habitat conditions, resource availability, and the amount and arrangement of disturbance on the landscape, influences patterns of boreal caribou range use that result in either: a) a discrete range, where boreal caribou occupy a clearly defined area with little exchange with other ranges (e.g. Coastal range (ON6), Charlevoix range (QC2)); or b) a continuous range where boreal caribou are dispersed over a large area and may move more freely and over greater distances within the area characterized by common biophysical attributes (e.g. Northwest Territories range (NT1)).



Figure 2. Geographic distribution of the 51 known ranges of boreal caribou in Canada as of June 2012.

Table 2. Range identification and range names for the 51 known ranges of boreal caribou in Canada.

Range ID	Range Name
NT1	Northwest Territories
BC1	Maxhamish
BC2	Calendar
BC3	Snake-Sahtahneh
BC4	Parker
BC5	Prophet
AB1	Chinchaga (incl. BC portion)
AB2	Bistcho
AB3	Yates
AB4	Caribou Mountains
AB5	Little Smoky
AB6	Red Earth
AB7	West Side Athabasca River
AB8	Richardson
AB9	East Side Athabasca River
AB10	Cold Lake
AB11	Nipisi

Range ID	Range Name
AB12	Slave Lake
SK1	Boreal Shield
SK2	Boreal Plain
MB1	The Bog
MB2	Kississing
MB3	Naosap
MB4	Reed
MB5	North Interlake
MB6	William Lake
MB7	Wabowden
MB8	Wapisu
MB9	Manitoba North
MB10	Manitoba South
MB11	Manitoba East
MB12	Atikaki-Berens
MB13	Owl-Flinstone
ON1	Sydney

Range ID	Range Name
ON2	Berens
ON3	Churchill
ON4	Brightsand
ON5	Nipigon
ON6	Coastal
ON7	Pagwachuan
ON8	Kesagami
ON9	Far North
QC1	Val d'Or
QC2	Charlevoix
QC3	Pipmuacan
QC4	Manouane
QC5	Manicouagan
QC6	Quebec
NL1	Lac Joseph
NL2	Red Wine Mountain
NL3	Mealy Mountain

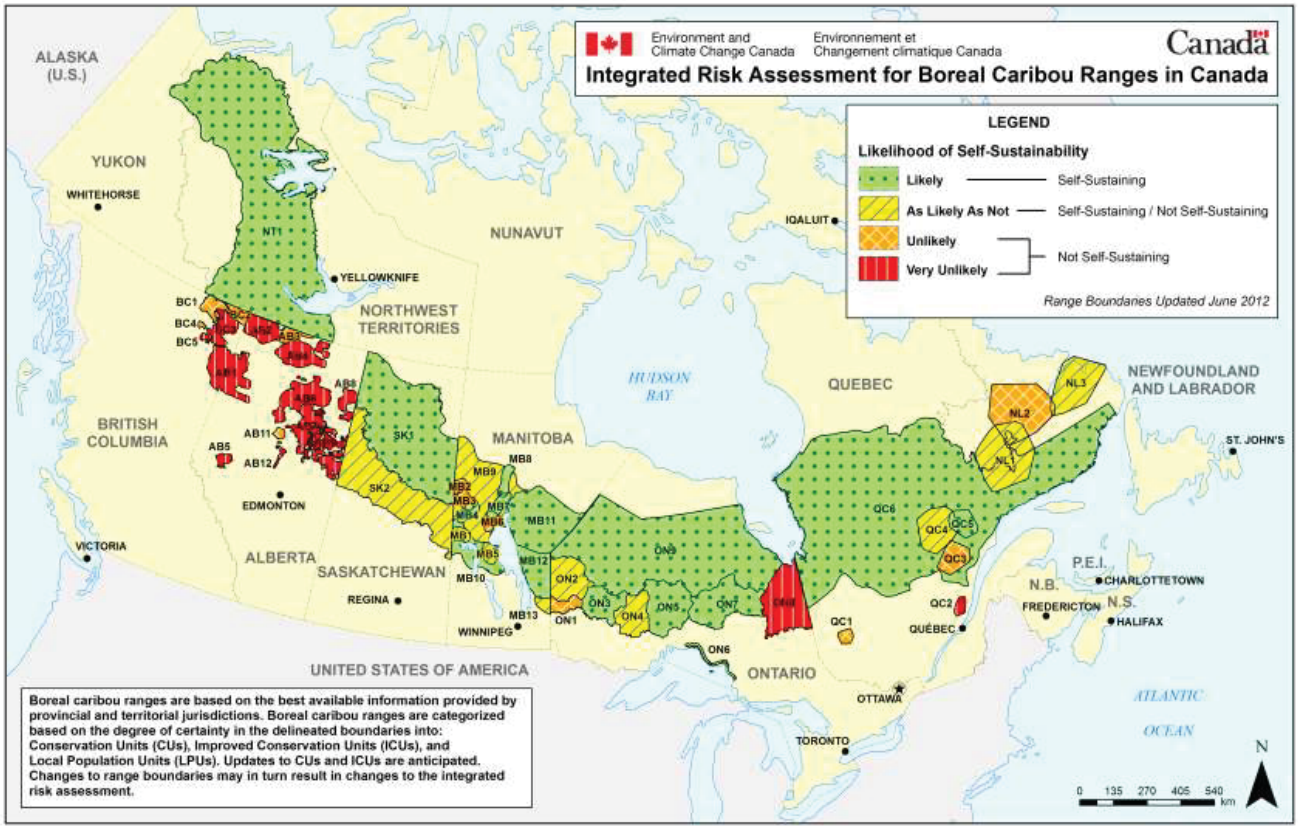


Figure 3. Integrated risk assessment for boreal caribou ranges in Canada as of June 2012, reflecting the capacity of each range to maintain a self-sustaining local population of boreal caribou. The likelihood of self-sustainability for the Boreal Shield range (SK1) has been updated from "unknown" to "likely" in this amended recovery strategy. The integrated risk assessments for the remaining ranges have not been updated.

3.2.2 Local Populations

Precise enumeration of the size of a boreal caribou local population is a challenge due to the large areas that boreal caribou occupy (often over thousands of square kilometres), the low densities at which they occur (making survey from aircraft challenging), and their relatively solitary habits (Environment Canada, 2008; Callaghan et al., 2010). Across Canada, densities average two to three animals per 100 km^2, but densities vary regionally and can be higher in areas with high quality habitat (Environment Canada, 2011b). The literature also reports that more than 300 boreal caribou are needed for self-sustaining local populations, thereby requiring ranges of at least 10,000 to 15,000 km^2 in size subject to type and quality of habitat (Environment Canada, 2011b).

Within ranges, boreal caribou are often found in small groups of fewer than 15 individuals. This will vary seasonally in accordance with life processes (e.g. calving, rutting, wintering) and based on local conditions within the range (Boreal Caribou ATK Reports, 2010-11). Boreal caribou typically form relatively mixed-sex groups; however, during calving periods females are generally solitary (Boreal Caribou ATK Reports, 2010-2011; Nagy et al., 2011).

Based on the best available information, the current overall number of boreal caribou in Canada is estimated to be approximately 33,000-34,000 individuals (Environment Canada, 2011b; COSEWIC, 2014). This number is based on mean local population size estimates as provided by the provincial and territorial jurisdictions. It is important to note that the overall national population size estimate is only a crude approximation, as population estimates over time are unavailable in most regions. Appendix F outlines the current population size and trend information for each of the 51 ranges, as provided by provincial and territorial jurisdictions (Environment and Climate Change Canada, 2017).

3.3 Needs of the Boreal Caribou

3.3.1 Habitat and Biological Needs

Boreal caribou require large range areas comprised of continuous tracts of undisturbed habitat. In general, boreal caribou prefer habitat consisting of mature to old-growth coniferous forest (e.g. jack pine (*Pinus banksiana*), black spruce (*Picea mariana*)) with abundant lichens, or muskegs and peat lands intermixed with upland or hilly areas (Stuart-Smith et al., 1997; Rettie and Messier, 2000; Courtois, 2003; Brown et al., 2007; Boreal Caribou ATK Reports, 2010-2011). Large range areas reduce the risk of predation by allowing boreal caribou to maintain low population densities throughout the range and by allowing them to avoid areas of high predation risk, such as areas with high densities of alternate prey species (e.g. moose and deer) and predators (e.g. wolf and bear) (Rettie and Messier, 2001; Brown et al., 2003; Whittington et al., 2011) (see Section 4.2). Boreal caribou use a variety of habitats to avoid predators, including muskegs and bodies of water, as well as mature and old-growth forests (Boreal Caribou ATK Reports, 2010-2011).

Boreal caribou select habitat that provides food, particularly terrestrial and arboreal lichens, during late winter and early spring, and avoid early stage, successional forests and recently disturbed areas (Schaefer and Pruitt, 1991; Stuart-Smith et al., 1997; Rettie and Messier, 2000;

Dunford et al., 2006; Boreal Caribou ATK Reports, 2010-2011), which have poor feeding options, impede movement, and attract other ungulates (Whitefeather Forest, 2006). In order to access forage during winters with deep or crusted snow, boreal caribou require habitat that has arboreal lichens and shallower snow (such as mature coniferous stands with closed canopies and upland or hilly areas exposed to wind), where it is easier to dig for ground lichens (Vandal and Barrette, 1985; Thomas and Armbruster, 1996; Courbin et al., 2009; Boreal Caribou ATK Reports, 2010-2011; Moreau et al., 2012).

Boreal caribou have specific habitat requirements during calving and post-calving periods. To calve, pregnant cows travel to isolated, relatively predator-free areas where nutritious forage is available, such as islands in lakes, peat lands or muskegs, lakeshores and forests (Boreal Caribou ATK Reports, 2010-2011). Unavailable, inadequate or degraded habitat affects the reproductive success of females as well as the survival of calves, and can result in population decline (Thomas and Gray, 2002; McCarthy et al., 2011; Pinard et al., 2012).

Boreal caribou shift their use of habitat and their distribution within the range in response to various natural processes (e.g. forest fire, food availability, weather conditions) and human activities (e.g. development, logging, recreation) (Boreal Caribou ATK Reports, 2010-2011; Environment Canada, 2011b). For example, any mature and old-growth forest stands lost to fire or tree removal practices will result in the degradation of suitable habitat in the short-term. In response to such changing environmental conditions, boreal caribou will shift within their range. Over time, a disturbed area may recover and become suitable for use by boreal caribou.

3.3.2 Connectivity

Connectivity of habitat both within a range and between ranges is essential for boreal caribou persistence on the landscape. Within a range, habitat connectivity allows for seasonal movement among habitats with the different resources needed by boreal caribou to satisfy their life history requirements (see Appendix H for examples of biophysical attributes), and for boreal caribou to use different areas as they respond to disturbance or as disturbed habitat recovers (Saher and Schmiegelow, 2005).

Connectivity between boreal caribou ranges allows for immigration and emigration between local populations, which increases gene flow, thereby helping to maintain genetic diversity and the species' subsequent resilience to environmental stressors (e.g. disease, severe weather). Studies have demonstrated that isolation of local populations as a result of disturbance to the landscape (i.e. any form of anthropogenic or natural habitat alteration), can result in a significant reduction in genetic diversity (Courtois et al., 2003; Weckworth et al., 2012). Connectivity between ranges also maintains recovery or rescue effects between boreal caribou ranges. Finally, connectivity within and between boreal caribou ranges will allow for movement in response to changing environmental conditions (e.g. climate change) (Racey and Armstrong, 2000; Courtois et al., 2003; McLoughlin et al., 2004; Pither et al., 2006; Boreal Caribou ATK Reports, 2010-2011).

3.3.3 Limiting Factors

Boreal caribou possess certain life history characteristics that limit their potential to recover from rapid, severe population declines. As a primary anti-predator survival strategy, boreal caribou spatially separate themselves from predators and alternate prey, maintaining low population densities across their range (Bergerud, 1988; Bergerud, 1996; Johnson et al., 2001; Environment Canada, 2008). Accordingly, continuous tracts of undisturbed habitat of suitable quality (i.e. with the required biophysical attributes) are needed to ensure self-sustaining local populations.

Boreal caribou have a low reproductive output relative to other ungulates and therefore are vulnerable to higher rates of mortality whether caused by predation or over-harvesting. Females typically do not produce young until three years of age and then have only one calf per year (Bergerud, 2000). In addition, while all age classes of boreal caribou are vulnerable to predation, calf mortality can be especially high, particularly within the first thirty days after birth (Bergerud and Elliot, 1986; Gustine et al., 2006). Calves disperse themselves over the landscape as an anti-predator tactic. In most cases predation is the main proximate factor limiting boreal caribou population growth, since the survival of calves to one year of age is usually low and is often insufficient to compensate for annual adult mortality in declining populations (Bergerud, 1974; Stuart-Smith et al., 1997; DeMars et al., 2011).

Small local populations with few adult females (and hence few births) and low calf survival have a low potential for population growth (Bergerud, 1980; Bergerud, 2000; McCarthy et al., 2011). In addition to being affected by reproductive and mortality rates related to their age distribution, small local populations can be disproportionately affected by stochastic events (e.g. environmental events such as winter icing or heavy snowfalls, fire, disease). Consequently, population growth is likely to be highly variable in small local populations, with an increased probability of extirpation (Caughley, 1994; Courtois et al., 2007).

4 THREATS

4.1 Threat Assessment

There are a variety of threats that directly and/or indirectly affect boreal caribou and their habitat across Canada. A summary of these threats and their national level of concern are provided below (see Table 3). The level of concern was determined using best available information, including Indigenous Knowledge and comments received through engagement with Indigenous communities. Threats and their level of concern differ between regions and local populations. For example, the level of concern for the effect of hunting on local populations is high in Labrador, while it remains medium nationally. Actions to mitigate threats are being or will be addressed in range plans and/or action plans (see Sections 7.3 and 9).

Many of the threats to boreal caribou and their habitat are related and may interact, in which case they can have cumulative impacts that may not be evident when threats are examined individually (Weclaw and Hudson, 2004; Boreal Caribou ATK Reports, 2010-2011; Badiou et al., 2011). Additionally, the impacts of threats on the size and distribution of boreal caribou local populations have a lag effect, which can take years to manifest (Vors et al., 2007).

Table 3. Threat assessment table for boreal caribou.

Threat	Level of Concern[1]	Extent	Occurrence	Frequency	Severity[2]	Causal Certainty[3]
Habitat Alteration (Disturbance)						
Habitat alteration (loss, degradation or fragmentation) as a result of human land-use activities	High	Widespread across Canada	Current	Continuous	High	High
Habitat alteration (loss, degradation or fragmentation) as a result of forest fire	Medium	Widespread across Canada	Current	Recurrent	Moderate	High
Natural Processes						
Predation	High	Widespread across Canada	Current	Continuous	High	High
Parasites and disease	Low	Localized across Canada	Anticipated	Unknown	Unknown	Low

Threat	Level of Concern[1]	Extent	Occurrence	Frequency	Severity[2]	Causal Certainty[3]
Biological Resource Use						
Hunting	Medium	Localized across Canada	Current	Seasonal	Moderate	Medium
Climate and Natural Disasters						
Climate change and severe weather	Medium	Widespread across Canada	Current	Unknown	Unknown	Low-Med
Other Threats						
Noise and light disturbance	Low-Med	Localized across Canada	Current	Recurrent	Unknown	Low
Vehicle collisions	Low	Localized across Canada	Current	Recurrent	Low	Low
Pollution	Low	Localized across Canada	Unknown	Unknown	Unknown	Low

1 Level of concern: qualifies the level of concern for managing the threat for the recovery of the species, consistent with the population and distribution objectives. This criterion considers all other criteria in the table.

2 Severity: reflects the population-level effect (i.e. high means a very large population-level effect; low means a limited population-level effect).

3 Causal certainty: reflects the degree of evidence that is known for the threat (i.e. high: available evidence strongly links the threat to stresses on population viability; medium: there is a correlation between the threat and population viability according to best available information; low: the threat is assumed or plausible).

4.2 Description of Threats

The threats to boreal caribou and their habitat identified in Table 3 are described below.

4.2.1 Habitat Alteration (Disturbance)

Habitat alteration occurs when changes are made on the landscape that adversely impact the ecosystem, either temporarily or permanently, reducing the overall function of habitat within the range for boreal caribou. Habitat loss is a change to a landscape that results in areas with no immediate or long-term future value to boreal caribou (e.g. conversion to agriculture, development of industrial facilities) whereas habitat degradation refers to a reduced but not total loss of habitat value for boreal caribou (e.g. reduction in the availability or quality of habitat following timber harvesting or seismic line development). Habitat fragmentation is the dissection of habitat by human-made linear features (e.g. roads, seismic lines, pipelines, hydroelectric

corridors) and polygonal features (e.g. forestry cut blocks) that may affect how boreal caribou use habitat or may result in a negative impact on the overall condition of a local population.

Environment and Climate Change Canada mapped total disturbance levels on boreal caribou ranges across their distribution in Canada as a predictor of self-sustainability for boreal caribou local populations. The total disturbance footprint was measured as the combined effects of fire that has occurred in the past 40 years and buffered (500 m) anthropogenic disturbance defined as any human-caused disturbance to the landscape that could be visually identified from Landsat imagery at a scale of 1:50,000. Although the effect of anthropogenic disturbance varies for individual ranges (i.e. in some ranges extending up to 14 km), Environment and Climate Change Canada (2011b) demonstrated that the application of a 500 m buffer to mapped anthropogenic features best represents the combined effects of increased predation and avoidance on caribou population trends at the national scale (Environment Canada, 2011b).

Data and approaches used to measure disturbance in Environment and Climate Change Canada's meta-analysis (2011b) were consistently applied across all provinces and territories. Disturbance data have been used for the purposes of this recovery strategy. Provinces and territories may have updated information and tools (e.g. Lidar remote sensing, detailed field sampling, other inventory techniques) to measure disturbance that were not considered in the national-level integrated risk assessment. Strong evidence validated by Environment and Climate Change Canada may be used to update disturbance measures and the integrated risk assessment.

Environment and Climate Change Canada (2011b) developed a methodology for consideration of disturbance management thresholds, which is described in more detail in Appendix E. With the exception of the Boreal Shield range (SK1), this amended recovery strategy identifies 65% undisturbed habitat in a range as the disturbance management threshold, which provides a measurable probability (60%) for a local population to be self-sustaining. This threshold is considered a minimum threshold because at 65% undisturbed habitat there remains a significant risk (40%) that a local population will not be self-sustaining.

For SK1, this amended recovery strategy identifies 40% undisturbed habitat in the range as the disturbance management threshold, which provides a measurable probability (71%) for the local population to be self-sustaining. This threshold is considered a minimum threshold because at 40% undisturbed habitat there remains a risk (29%) that the SK1 local population will not be self-sustaining (see Appendices D and E).

In any given range, habitat disturbance reduces the suitability of adjacent habitat, increase rates of predation, increase access to the land for hunting opportunities, and can act as barriers to boreal caribou movement (Chubbs et al., 1993; Smith et al., 2000; Dyer et al., 2001; Lander, 2006; Boreal Caribou ATK Reports, 2010-2011; Environment Canada, 2011b). In some cases boreal caribou may use areas of inadequate or degraded habitat (e.g. remnant habitat following certain types of forest fires, buffer habitat surrounding certain types of development), particularly in highly disturbed ranges where opportunities for movement to suitable undisturbed habitat are limited or unavailable. In these situations boreal caribou are at a higher mortality risk. In addition, large-scale disturbances to the landscape (e.g. intense forest fire, widespread forest harvest) can cause boreal caribou to cease their use of portions of the range.

4.2.1.1 Habitat Alteration (Loss, Degradation or Fragmentation) as a Result of Human Land-use Activities

Indigenous Knowledge and science identify disturbance primarily associated with the following human land-use activities as having a negative effect on boreal caribou local populations across Canada: forestry; oil and gas exploration and development; mining and mineral exploration and development; hydro-electric development; and tourism. These activities affect boreal caribou through a combination of direct and functional habitat loss, decreased habitat quality (i.e. habitat degradation), and development of linear features such as roads and seismic lines (i.e. habitat fragmentation) (Thomas and Gray, 2002; Vors et al., 2007; Boreal Caribou ATK Reports, 2010-2011).

The effects of habitat alteration may reduce the viability of a boreal caribou local population through the reduction of habitat quality and quantity, possibly leading to a reduction in the size of the range, and potentially resulting in the extirpation of a local population.

4.2.1.2 Habitat Alteration (Loss, Degradation or Fragmentation) as a Result of Forest Fire

Forest fires are required for boreal forest regeneration and have historically played a significant role in the local population size and distribution of boreal caribou within their range and across their Canadian distribution (Thomas and Gray, 2002; Dzus et al., 2010). Natural processes such as forest fires can directly alter habitat, making it unsuitable for boreal caribou (e.g. loss of mature conifer stands, loss of lichens and other forage plants, barriers to movement) (Environment Canada, 2011b). Boreal caribou generally do not return to burned areas for several decades until the forest is old enough to support lichens and other food sources, although they may make limited use of burned areas to feed on new growth (Boreal Caribou ATK Reports, 2010-2011).

Historically, when a forest fire occurred, boreal caribou would shift their use of habitat from the burned areas to areas that are more suitable. However, with the increase of industrial exploration and development, in a number of ranges there are fewer available suitable areas into which boreal caribou can move. When combined with human-caused disturbance, forest fires can threaten boreal caribou recovery even though they are a natural component of the boreal forest ecosystem. In some areas, forest fires have been reported as occurring more frequently than in the past (Whitefeather Forest, 2006; Boreal Caribou ATK Reports, 2010-2011).

4.2.2 Natural Processes

4.2.2.1 Predation

Across most of the distribution of boreal caribou, human-induced habitat alterations have caused an imbalance in predator-prey relationships resulting in unnaturally high predation rates. This is the major factor affecting the viability of most boreal caribou local populations (Bergerud, 1988; Stuart-Smith et al., 1997; Rettie and Messier, 1998; Schaefer et al., 1999; James and Stuart-Smith, 2000; Wittmer et al., 2005; Chabot, 2011). Based on the weight of evidence coming from science and Indigenous Knowledge, increased wolf and/or bear predation is the main proximate cause of boreal caribou decline across Canada (Bergerud, 1988; Edmonds, 1988; Seip, 1992;

Boertje et al., 1996; Boreal Caribou ATK Reports, 2010-2011; Pinard et al., 2012). However, in some parts of Canada, cougar (*Puma concolor*), coyotes (*Canis latrans*), lynx (*Lynx canadensis*), and eagles (*Haliaeetus leucocephalus* and *Aquila chrysaetos*) have also been identified as predators of boreal caribou, particularly calves (Thomas and Gray, 2002; Boreal Caribou ATK Reports, 2010-2011; McCarthy et al., 2011).

Human-caused habitat alterations have been shown to facilitate movement of predators within the boreal forest and hence can increase the abundance, distribution and hunting efficiency of species that prey on boreal caribou (James and Stuart-Smith, 2000; Neufeld, 2006; Boreal Caribou ATK Reports, 2010-2011). Additionally, although boreal caribou may not be the target prey species, they are taken opportunistically when encountered. In boreal caribou ranges with habitat alterations that provide favorable conditions for prey species such as deer and moose, predators such as wolves can increase in number, which can significantly reduce or even eliminate boreal caribou local populations (Seip, 1991; Seip, 1992; Wittmer et al., 2005; Courtois and Ouellet, 2007; Courbin et al., 2008; Boreal Caribou ATK Reports, 2010-2011). In addition to deer and moose, elk (*Cervus canadensis*), bison (*Bison bison*), and beaver (*Castor canadensis*) are other species that predators of boreal caribou commonly hunt and that have increased in number within the distribution of boreal caribou (Boreal Caribou ATK Reports, 2010-2011).

4.2.2.2 Parasites and Diseases

Viral, parasitic, and bacterial diseases can affect individual boreal caribou and may have effects at the local population level in certain parts of the country, although it is not thought to be one of the major threats affecting boreal caribou at the national level.

Other natural processes such as forest insects and disease can leave large areas of forest defoliated, and eventually dead, and may have an effect on boreal caribou habitat. In particular the mountain pine beetle (*Dendroctonus ponderosae*), which covers large areas of northeastern British Columbia and northern Alberta and threatens to move into Saskatchewan, could indirectly affect boreal caribou (Richie, 2008; Environment Canada, 2011a).

4.2.3 Biological Resource Use

4.2.3.1 Hunting

Hunting has and continues to contribute to the decline of boreal caribou (Bergerud, 1967; Kelsall, 1968; Bergerud, 1974; Bergerud, 1978; Courtois et al., 2007; Boreal Caribou ATK Reports, 2010-2011). Both targeted hunting and incidental harvest (when boreal caribou intermingle seasonally with legally hunted migratory caribou ecotypes) of boreal caribou are of concern in several areas, and may be contributing to local population declines and/or preventing recovery (Environment Canada, 2011a).

Although the extent of hunting is poorly understood in most areas, analyses of historical population trends, data from radio-collared animals, and current demographic information suggest that hunting remains a significant component of adult female boreal caribou mortality and hence is a primary threat in some ranges (Dzus, 2001; Schmelzer et al., 2004; Courtois et al., 2007). Hunting of boreal caribou is facilitated by the construction of roads and other linear

features and by the use of off-road vehicles that enable access to previously inaccessible areas (Boreal Caribou ATK Reports, 2010-2011). Moreover, Indigenous Knowledge indicates that technological advances in hunting tools (e.g. high-powered rifles and scopes) and in methods used to locate and access hunting sites (e.g. GPS, satellite tracking, aircraft, snowmobiles, trucks) have facilitated the chase of boreal caribou, resulting in a greater number of caribou being taken (Boreal Caribou ATK Reports, 2010-2011; Environment Canada, 2011a).

4.2.4 Climate and Natural Disasters

4.2.4.1 Climate Change and Severe Weather

Climate change has been identified by Indigenous Knowledge holders and scientists as a threat to boreal caribou and their habitat. Both groups indicate that there are many uncertainties surrounding the impacts of climate change and how climate change may interact with other threats. The long-term effects of climate change and the implications on boreal caribou habitat are unknown.

Greater weather variability and severe weather events, which are expected to increase with climate change, are likely to increase the frequency and severity of wildfires and cause more freeze-thaw cycles, freezing rain, deep snow, hot summer temperatures, and changes in the forest composition and food supply (Thomas and Gray, 2002; Vors and Boyce, 2009; Boreal Caribou ATK Reports, 2010-2011). In some areas, a shift in the timing and length of seasons, with earlier spring thaws and later freeze-ups, has been observed by many Indigenous Knowledge holders (Boreal Caribou ATK Reports, 2010-2011). Climate change will likely also lead to changes in habitat which, in the Northwest Territories, can increase permafrost melting.

Climate related changes in habitat favour deer and other prey species, which expand into boreal caribou range, increasing predator populations and predation of boreal caribou, and facilitating the spread of disease. Climate change may result in habitat change for boreal caribou, as it drives boreal forest composition to shift northwards, and results in other factors including the spread of forest insects that cause tree mortality (e.g. mountain pine beetle) (Johnston, 2009; Johnston, 2010).

4.2.5 Other Threats

Other threats that have a lower level of concern at the national scale (although they may be of greater concern for individual ranges) include:

Noise and Light Disturbance: Noise and light disturbance result in short-term behavioural and physiological responses of individual boreal caribou, including a startle response, elevated heart rate, and production of glucocorticoids. Sustained or repeated disturbance can result in avoidance of areas and the reduction in use of suitable habitat (Sapolsky, 1992; Creel et al., 2002).

Vehicle Collisions: In some areas, boreal caribou are vulnerable to mortality from vehicle or rail collisions (Brown and Hobson, 1998); however, on a national scale, vehicle collisions are not thought to pose a major threat to boreal caribou (Boreal Caribou ATK Reports, 2010-2011).

Pollution: The threat of pollution (e.g. from oil and gas, chemical spraying for forestry, pesticides, hydro, salt, dust and litter coming from the creation of roads) was identified as a concern through meetings held with Indigenous communities (Environment Canada, 2011a) and by Indigenous Knowledge holders (Boreal Caribou ATK Reports, 2010-2011). Very little is known about the severity of this threat to boreal caribou local populations.

5 POPULATION AND DISTRIBUTION OBJECTIVES

The national population of boreal caribou is currently made up of local populations distributed across 51 ranges in Canada (see Figure 2 and Table 2). Boreal caribou ranges are the fundamental units of conservation and management for boreal caribou recovery planning and actions (Thomas and Gray, 2002). The range is the appropriate unit of analysis for identifying critical habitat and other requirements for self-sustaining local populations of boreal caribou. The range represents the geographic area occupied by a group of individuals that are subject to similar factors affecting their demography and is used to satisfy their life history processes (e.g. calving, rutting, wintering) over a defined time frame.

5.1 Recovery of Boreal Caribou

5.1.1 Varying Ecological Conditions

Indigenous Knowledge and comments received through engagement with Indigenous communities identifies the need for continued presence of self-sustaining local populations in all boreal caribou ranges across Canada (Boreal Caribou ATK Reports, 2010-2011; Environment Canada, 2011a). This is reflected in the knowledge that all animals are connected to each other and that boreal caribou are essential to the balance of nature and for their role in the boreal ecosystem.

Boreal caribou encounter a wide variety of ecological conditions across their distribution. Taken together, all boreal caribou ranges contribute to ensuring that the full ecological gradient is represented and captures local adaptations to change. This allows for maintenance of the evolutionary potential of the species and accounts for the full spectrum of ecological interactions boreal caribou can have within the full array of ecological settings (Redford et al., 2011).

Science supports that conservation of a species such as boreal caribou is achieved by maintaining multiple local population units across a species' geographical range, in representative ecological settings, with replicate local populations in each setting that are self-sustaining, genetically robust, ecologically functional, and resilient to climate and other changes (Environment Canada, 2011b). Without connectivity, redundancy and representivity across several ecological scenarios there is an increased risk to the survival and recovery of boreal caribou.

Small local populations, particularly those isolated from the core distribution of the national population of boreal caribou, are at greater risk of not becoming self-sustaining or maintaining self-sustaining status. In these situations, a local population may have greater difficulty withstanding stochastic events, and may not experience enough immigration to maintain genetic diversity or adequate population size, and therefore will be at greater risk of not persisting in the long-term. Accordingly, different recovery actions (e.g. translocation, captive breeding) may be necessary to maintain and recover small local populations, and particularly those that are declining. There may be considerable uncertainty regarding the effectiveness of such recovery tools. It will be important to assess feasibility and conduct a risk assessment prior to undertaking any such activities.

There are several small local populations including Parker (BC4) and Prophet (BC5) in British Columbia, Nipisi (AB11) and Slave Lake (AB12) in Alberta, The Bog (MB1), Kississing (MB2), North Interlake (MB5), William Lake (MB6) and Owl-Flinstone (MB13) in Manitoba, and Red Wine Mountain (NL2) in Newfoundland and Labrador. Small isolated local populations include Little Smoky (AB5) in Alberta, Coastal (ON6) in Ontario, and Val D'Or (QC1) and Charlevoix (QC2) in Quebec (see Figure 2).

5.1.2 Connectivity Between and Within Boreal Caribou Ranges

Maintaining a long-term self-sustaining status for boreal caribou ranges depends on connectivity within and between ranges. Connectivity between ranges enables immigration and emigration between neighbouring boreal caribou local populations, which allows for the maintenance of local population size and genetic diversity. Maintaining genetic diversity is needed to maintain the resilience of a local population as described in Section 3.3.2.

Connectivity also allows wide ranging mammals like boreal caribou to adapt to changes in their natural environment (e.g. climate change, disturbance), recognizing that a contiguous population does not mean that each range must be physically connected to other ranges or that areas of habitat within a range must be physically connected to other areas. However, it does mean that the distance between ranges and between core habitat areas within a range should not be so large that no movement of boreal caribou could occur, though it may not be their preferred habitat type. Connectivity between ranges benefits gene flow and helps to maintain or increase population size. Connectivity within a range is important for seasonal movement and the use of habitat as boreal caribou respond to disturbance or as disturbed habitat recovers (Saher and Schmiegelow, 2005).

5.2 Objectives

5.2.1 Recovery Goal

The recovery goal for boreal caribou is to achieve self-sustaining local populations in all boreal caribou ranges throughout their current distribution in Canada, to the extent possible.

The recovery goal reflects the best available information, including scientific knowledge, Indigenous Knowledge and comments received through engagement with Indigenous communities. The goal is informed by the scientific principles of conservation and reflects the intent to recover all local populations. Achieving the recovery goal would allow for local population levels sufficient to sustain traditional Indigenous harvesting activities, consistent with existing Aboriginal and treaty rights. Feedback received from Indigenous communities indicated a strong support for this recovery goal.

Recovery for boreal caribou is the achievement of self-sustaining local populations, which are demographically and genetically viable connected local populations across the species' distribution. Current evidence supports the conclusion that the recovery of all local populations is biologically and technically feasible. As noted in Sections 3.3.3 and 5.1.1, small and isolated local populations are at greater risk of not becoming self-sustaining or maintaining self-sustaining status. There may be situations where recovery of a particular local population proves

to be, over time and through unforeseen circumstances, not biologically or technically feasible. Each boreal caribou local population contributes to the biodiversity, ecological functionality, and resilience of the species to environmental change, reducing the risk of species' extinction (Ray, 2011).

5.2.2 Population and Distribution Objectives

To guide recovery efforts, the population and distribution objectives (see Figure 4) are, to the extent possible, to:

- Maintain the current status of the 15 existing self-sustaining local populations (green dotted ranges); and
- Stabilize and achieve self-sustaining status for the 36 not self-sustaining local populations (blue hatched ranges).

"Not self-sustaining" local populations refers to the local populations assessed as "as likely as not self-sustaining" and those assessed as "not self-sustaining". The population and distribution objective for the Boreal Shield (SK1) local population has been changed from "stabilize and achieve self-sustaining status" to "maintain self-sustaining status" in this amended recovery strategy, based on work carried out by P.D. McLoughlin (University of Saskatchewan, personal communications) and Environment and Climate Change Canada (2019) that indicates that the SK1 local population is self-sustaining.

5.3 Timelines to Recovery

Boreal caribou exist in mature boreal forest ecosystems that evolved over centuries, and in turn take decades to recover from disturbance. Reversing ecological processes detrimental to boreal caribou (e.g. habitat degradation and loss, the increase in predator and alternate prey populations), and instituting changes to management frameworks and ongoing land use arrangements, will often require time frames in excess of 50 to 100 years. Given these realities, while it is currently biologically and technically feasible to recover all local populations, under the best efforts of all parties, some local populations will not return to a self-sustaining status for a number of decades.

For several boreal caribou local populations, immediate actions to avoid extirpation are needed such that recovery can be achieved over time. Recovery will be monitored continuously and reported every five years (see Section 8).

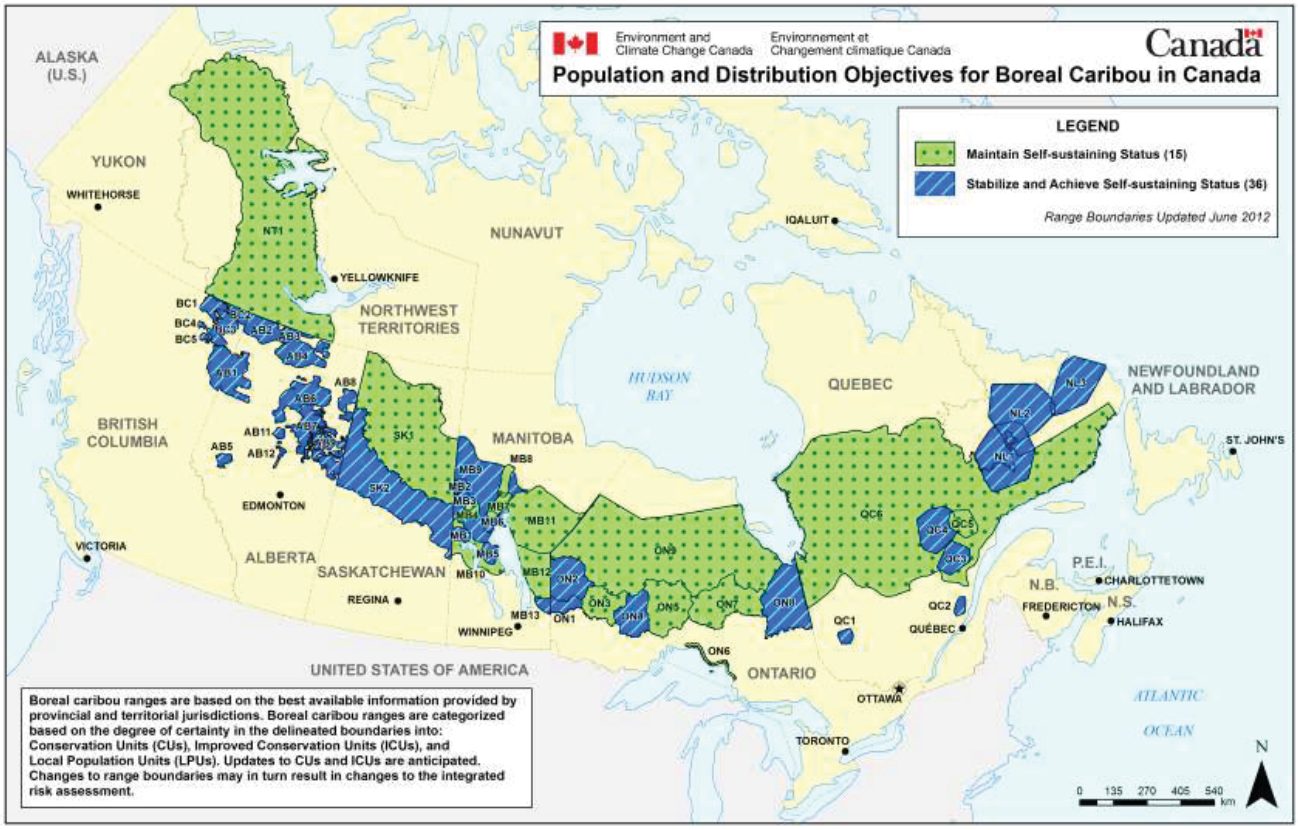


Figure 4. Population and distribution objectives for boreal caribou in Canada. The population and distribution objective for the Boreal Shield range (SK1) has been updated from "stabilize and achieve self-sustaining status" in the 2012 Recovery Strategy to "maintain self-sustaining status" in this amended recovery strategy.

5.4 Prioritizing Recovery Actions and Managing Risk

All local populations are included in the goal for the recovery of boreal caribou based on their contributions to connectivity, representivity and redundancy. Each local population also faces different challenges to maintain or achieve self-sustaining status. Successful recovery of boreal caribou will require practical considerations and implementation of recovery actions tailored for each range. Prioritization of recovery actions is being addressed at the range and/or action planning stage where the allocation of effort and the rate of risk reduction for individual ranges can best be determined.

Range and/or action planning considers a multitude of information and factors, such as regional ecological conditions, local population size and trend, boreal caribou movement between ranges, habitat condition between ranges, distribution of resources for restoration efforts, and others. In prioritizing recovery actions, consideration should be given to the current risk of extirpation of a local population, the length of time to achieve a self-sustaining status, ecological needs of connectivity, representivity and redundancy, as well as population and habitat conditions.

5.5 Achieving Recovery for Self-Sustaining Local Populations

Recovery is achieved for the 15 self-sustaining local populations by maintaining population and range conditions that support their self-sustaining status.

5.6 Achieving Recovery for Not Self-Sustaining Local Populations

Recovery is achieved for the 36 not self-sustaining local populations through a combination of coordinated habitat restoration and population management actions applied over time to return a local population to a self-sustaining status. For each not self-sustaining local population, the timeframe for achieving recovery will vary depending on whether the habitat condition and/or the population condition is/are a limiting factor.

For boreal caribou ranges where local populations are declining, stabilizing the local population by halting its decline will require immediate action. For all ranges wherein the local population size is small, achieving a stable population trend and recovering the population to a minimum of 100 animals[3] will be necessary to mitigate risk of quasi-extinction. Although certain local populations with fewer than 100 animals may be stable and persist over the short-term where adequate suitable habitat supply is available, the long-term persistence of those populations is less certain. In some instances, continued human intervention may be required to achieve the minimum population size target.

In addition to managing local population size, habitat management will also be necessary. This recovery strategy identifies 65% undisturbed habitat in all ranges except SK1, and 40% undisturbed habitat in SK1, as the disturbance management threshold. This provides a

[3] 100 animals provides a 0.7 probability of not reaching a quasi-extinction threshold of less than 10 reproductively active females under stable conditions over 50 years (Environment Canada, 2011b).

measurable probability (60% for all ranges with the exception of SK1, which has a 71% probability) for a local population to be self-sustaining (see Appendix E).

For boreal caribou ranges with undisturbed habitat below the threshold:

- Restoration of disturbed habitat to a minimum of 65% undisturbed habitat will be necessary in all ranges except SK1, where the threshold is set at 40% undisturbed habitat.

For boreal caribou ranges with undisturbed habitat equal to or above the threshold:

- Maintenance of a minimum of 65% undisturbed habitat will be necessary in all ranges except SK1, where maintenance of a minimum of 40% undisturbed habitat will be necessary.

There are 31 ranges that do not meet the disturbance management threshold of 65% undisturbed habitat (40% undisturbed habitat for SK1) (see Section 7.1). Of these ranges, local population trends are declining (16 local populations), stable (eight local populations) or unknown (seven local populations).

There are 20 ranges where the habitat condition meets or exceeds the disturbance management threshold. Of these ranges, four local populations are declining, two local populations are stable, and the trend of 14 local populations is unknown.

6 BROAD STRATEGIES AND GENERAL APPROACHES TO MEET OBJECTIVES

6.1 Actions Already Completed or Currently Underway

Federal, provincial and territorial governments, wildlife management boards, Indigenous people, non-government organizations, and affected industries across Canada have taken and continue to take a range of actions to manage and protect boreal caribou and their habitat. Environment and Climate Change Canada's 5-Year Progress Report, published in October 2017, highlights progress made by governments, Indigenous people, and other partners and stakeholders in implementing the 2012 Recovery Strategy (Environment and Climate Change Canada, 2017). Examples of actions already completed or currently underway vary across Canada, and include:

- Identification and delineation of boreal caribou ranges and habitats within ranges;
- Assessment of the population size and/or trend and/or distribution of local populations of boreal caribou across Canada;
- Consideration of boreal caribou habitat requirements when planning and implementing forest harvesting and other industrial activities;
- Development and implementation of operating guidelines for industrial development within boreal caribou ranges;
- Land-use planning to identify areas within boreal caribou ranges where boreal caribou conservation is prioritized;
- Closed, restricted, and/or managed hunting by Indigenous and non-Indigenous people, on a voluntary basis or through regulations;
- Predator and alternate prey management in some ranges where local populations of boreal caribou are rapidly declining;
- Development of cooperative stewardship agreements and activities to support the engagement of Indigenous organizations and stakeholders in the monitoring, management, and conservation of boreal caribou;
- Preparation of outreach materials on boreal caribou and dissemination to interest groups and the general public;
- Research on boreal caribou ranges, habitat, ecology and limiting factors; and
- Continue to implement the Action Plan for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada – Federal Actions, including as it relates to the development of conservation agreements (Environment and Climate Change Canada, 2018).

Collectively, these actions, and the level of commitment associated with these actions, are an encouraging foundation upon which to build. Table 4 outlines the status of provincial and territorial recovery planning for boreal caribou.

Table 4. Status of boreal caribou recovery planning, as of April 2019, in provincial and territorial jurisdictions where boreal caribou occur.

Provincial/ Territorial Jurisdiction	Recovery Document	Recovery Goal/Objective
Northwest Territories	• Recovery Strategy for the Boreal Caribou (*Rangifer tarandus caribou*) in the Northwest Territories, 2017	• Ensure a healthy and sustainable boreal caribou population across their territorial range that offers harvesting opportunities for present and future generations.
British Columbia	• Implementation Plan for the Ongoing Management of Boreal Caribou in British Columbia, 2011 • An updated recovery planning document is being collaboratively developed	• Decrease the expected rate of decline • Significantly reduce the risk of extirpation for four populations within 50 years
Alberta	• A Woodland Caribou Policy for Alberta, June 2011 • Alberta Woodland Caribou Recovery Plan, 2004/05 – 2013/14	• Achieve self-sustaining woodland caribou herds and maintain the distribution of caribou in the province • Ensure long-term habitat requirements throughout caribou ranges in the province
Saskatchewan	• Conservation Strategy for Boreal Woodland Caribou (*Rangifer tarandus caribou*) in Saskatchewan, 2013	• Sustain and enhance woodland caribou populations, and maintain the ecosystems they require, throughout their current range
Manitoba	• Manitoba's Boreal Woodland Caribou Recovery Strategy, 2015	• Self-sustaining local populations of boreal caribou across all management units • Management and protection of caribou habitat to sustain boreal caribou populations
Ontario	• Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*)(Forest-dwelling, Boreal Population) in Ontario, 2008 • Ontario's Woodland Caribou Conservation Plan, 2009	• Maintain self-sustaining, genetically-connected local populations of Woodland Caribou (forest-dwelling boreal population) where they currently exist, improve security and connections among isolated mainland local populations, and facilitate the return of caribou to strategic areas near their current extent of occurrence
Quebec	• Quebec Recovery Plan for Woodland Caribou, 2013-2023	• Maintain suitable habitat for caribou • Maintain current distribution • Achieve and maintain uniform distribution (> 11,000 caribou)
Newfoundland and Labrador	• Recovery Strategy for Three Woodland Caribou Herds (*Rangifer tarandus caribou*; Boreal population) in Labrador, 2004 • Updated Recovery Plan is being prepared	• Prevent extinction and improve status of current herds • Determine and achieve viable, self-sustaining wild populations distributed throughout their available current and historical ranges for each of the three herds

6.2 Strategic Direction for Recovery

The following table (see Table 5) and narrative describe, at a national level, the broad strategies and general approaches to be taken and the research and management activities needed to address the threats to boreal caribou and achieve the population and distribution objectives for each range. Many strategies and approaches are interrelated and details on their implementation and their level of priority will differ across the country and by local population and habitat conditions. Sequencing and timing of specific recovery actions and their level of priority will be outlined and addressed in range plans and/or action plans (see Sections 7.3 and 9).

Table 5. Recovery planning table for boreal caribou

Threat or Limitation	Priority[5]	Broad Strategy to Recovery	General Description of Research and Management Approaches
Landscape Level Planning			
Habitat alteration as a result of human land-use activities Habitat alteration as a result of natural processes	Urgent	Undertake landscape level planning that considers current and future boreal caribou habitat requirements	• Develop range plans (see Section 7.3) that outline range-specific population and habitat management activities with measurable targets to achieve recovery goal. • Undertake coordinated land and/or resource planning to ensure that development activities are planned (type, amount, and distribution) and implemented at appropriate spatial and temporal scales (e.g. consider sensitive periods/areas such as calving). • Plan to maintain habitat within and between boreal caribou ranges, to maintain connectivity where required. • Undertake coordinated planning among provincial and territorial jurisdictions that jointly manage ranges (i.e. transboundary ranges) to reach agreement on the overall strategic direction for local population recovery. • Develop range-appropriate cumulative effects assessment approaches. Very large ranges (Northwest Territories (NT1), Far North (ON9), and Quebec (QC6)) will require different approaches. • Communicate among governments, wildlife management boards, Indigenous communities and organizations, non-governmental organizations, and other organizations responsible for land and/or resource management and/or conservation within the boreal forest to ensure coordination of planning and management and, where applicable, facilitate cross-jurisdictional cooperation and implementation.
Habitat Management			
Habitat alteration as a result of human land-use activities Habitat alteration as a result of natural processes	Urgent	Manage habitat to meet current and future habitat requirements of boreal caribou	• Protect key areas for boreal caribou through appropriate habitat management and protection mechanisms (e.g. legislated protected areas, no development zones, mixed use zones, and conservation agreements). • Undertake coordinated actions to reclaim boreal caribou habitat through restoration efforts (e.g. restore industrial landscape features such as roads, old seismic lines, pipelines, cut-lines, temporary roads, cleared areas; reconnect fragmented ranges).

Threat or Limitation	Priority[5]	Broad Strategy to Recovery	General Description of Research and Management Approaches
			• Measure and monitor disturbance on the landscape (see Section 4.2.1). Update range plans to reflect changes in habitat condition. • Where ranges are highly disturbed, identify areas that will be prioritized for boreal caribou recovery and targeted for early habitat reclamation. Incorporate management guidelines and actions into permitting conditions for activities identified as affecting boreal caribou or their habitat. • For ranges that are jointly managed (i.e. transboundary), undertake collaborative habitat management among responsible provincial and territorial jurisdictions to ensure equitable efforts are underway. • Encourage stewardship of boreal caribou habitat among industries, interest groups, and Indigenous communities and organizations. • Assess the impact of natural disturbance (e.g. forest fire) on the long-term habitat management of boreal caribou ranges. Where necessary, incorporate short- and long-term boreal caribou habitat considerations, along with other considerations, into forest fire management. • Monitor habitat and use adaptive management to assess progress and adjust management activities as appropriate.
Mortality and Population Management			
Predation	High	Manage predators and alternate prey	• Where necessary, apply predator management as an interim management tool, in conjunction with other management approaches (e.g. habitat restoration and management), to achieve boreal caribou local population growth. Alternate prey management may also be applied in conjunction with predator management. • Where applicable, consider effective indirect predator management techniques as an alternative to direct predator management (e.g. limiting predator access, penning of boreal caribou). • Where mortality and/or population management are implemented, monitor boreal caribou local populations and consider monitoring the effects on other impacted species.
Hunting	Medium	Manage direct human-caused mortality of boreal caribou	• Determine the extent of current hunting, and the effects of hunting on boreal caribou local populations. • In consultation with Indigenous people, develop and implement harvest strategies, where required to achieve boreal caribou recovery. • Assess and address impacts of hunting regulations for all boreal caribou ranges that overlap with other legally hunted Woodland Caribou ecotypes. • Reduce illegal hunting through stewardship, education and enforcement.

Threat or Limitation	Priority[5]	Broad Strategy to Recovery	General Description of Research and Management Approaches
Population Monitoring			
Knowledge gaps: Population dynamics (trends, size, structure, and distribution)	High	Conduct population studies to better understand population structure, trends and distribution	• Where necessary, refine understanding of the structure and functioning of boreal caribou local populations. • Monitor population size and/or trend, as well as changes in boreal caribou distribution over time and in relation to habitat condition and disturbance. • Coordinate data collection, data-sharing, and planning between or among neighbouring provincial and territorial jurisdictions to establish transboundary ranges where appropriate. • Revise boreal caribou range delineations based on updated population information from science and Indigenous Knowledge.
Knowledge gaps: boreal caribou health and condition	Low - Medium	Monitor boreal caribou health and condition	• Gather information, monitor and manage the health and body condition of individual boreal caribou.
Knowledge gaps: boreal caribou sensory disturbance	Low - Medium	Monitor and manage sensory disturbance of boreal caribou	• Assess the extent, distribution, and possible consequences of sensory disturbance (e.g. aircraft traffic, snowmobiles, all-terrain vehicles, tourism, research, and equipment associated with oil and gas or forestry) on boreal caribou, and where required reduce its effects, particularly during sensitive periods (e.g. calving). • Minimize disturbance to boreal caribou during monitoring and research programs, and select monitoring and research techniques that are the least intrusive.

[5] *Priority: reflects the level of priority of the broad strategy on a national level. This priority for each local population may differ.*

6.3 Narrative to Support the Recovery Planning Table

Recovery of boreal caribou will require the commitment, collaboration and cooperation among federal, provincial and territorial jurisdictions, wildlife management boards, Indigenous people, local communities, landowners, industry and other interested parties. It will be important to monitor habitat conditions, size and/or trend, and the distribution of boreal caribou local populations so that the effectiveness of individual range management regimes can be evaluated, and adjusted as necessary. It should also be recognized that it takes time for the impact of human developments and natural disturbances on boreal caribou to become evident. Therefore, range plans and/or action plans must take into account the likelihood of a delayed boreal caribou population and distribution response to anthropogenic or natural habitat alterations.

6.3.1 Landscape Level Planning

As the range has been identified as the most relevant scale at which to plan for the conservation of boreal caribou, undertaking landscape level land and/or natural resource planning is appropriate for effective management of cumulative effects of habitat disturbance within boreal

caribou ranges and for managing disturbance over time to ensure sufficient habitat is available for boreal caribou, both of which are more difficult in the context of individual project approvals. Range-level planning for boreal caribou should consider current and future human developments and determine detailed management activities that are tailored to the conditions of the range and the local population in question. Range plans and/or action plans should take into account natural disturbances and cumulative effects of development within and between boreal caribou ranges.

It will be important to undertake coordinated land and/or resource planning to ensure that development activities are planned and approved, taking into consideration the cumulative impacts of all current and future developments within a range. Assessing cumulative effects will require a different approach for large continuous ranges than for smaller discrete ranges. The impact of disturbance that may be concentrated in part of a large continuous range may be masked given the size of the range. Dividing the large areas into smaller management units may allow land managers to better understand where the disturbance is occurring and plan accordingly, in order to avoid irreversible range retraction and permanent breaks in range connectivity.

In light of the impacts that actions taken in neighbouring ranges have on boreal caribou, it will be important that provinces and territories take a collaborative approach to land and/or resource planning, particularly in ranges that are jointly managed (i.e. transboundary), to ensure an agreed upon direction to boreal caribou recovery is attained.

6.3.2 Habitat Management

Boreal caribou ranges will need to be managed to ensure their current and future ability to support self-sustaining local populations. The effectiveness of various management activities may vary between and within ranges due to differences in population condition and specific local conditions.

Management of the amount, type and distribution of human developments will be necessary. Both anthropogenic and natural disturbances will need to be monitored and measured. Methods may vary in accordance with the information and tools available to the provinces and territories. Anthropogenic disturbance (i.e. industrial and other human activities) will need to be managed in a manner consistent with land and/or resource planning that has taken into account the current and future habitat requirements of boreal caribou. Disturbed areas may need to be improved or restored to support population and distribution objectives within each boreal caribou range. Maintaining connectivity within and between habitat patches and ranges will be particularly important for boreal caribou. In certain cases, it may be necessary to identify and designate protected areas with biophysical attributes for boreal caribou. For ranges that are jointly managed by provinces and territories (i.e. transboundary), collaborative habitat management approaches will be necessary to ensure that equitable recovery efforts are underway. Though ranges may cross provincial and territorial boundaries, each jurisdiction remains accountable for activities carried out in their own range.

6.3.3 Mortality and Population Management

6.3.3.1 Manage Predators and Alternate Prey

Human-induced habitat alterations have upset the natural balance between boreal caribou and their predators, resulting in unnaturally high predation rates in some boreal caribou ranges. As a result, in some ranges, a population management approach involving management of other wildlife species (i.e. predators and alternate prey) may be required to stop boreal caribou declines and stabilize the local population in order to prevent their extirpation in the short-term. Where the condition of the local population warrants such measures, predator and in some cases alternate prey management may be applied as interim management tools, recognizing that a punctuated approach to mortality management may be necessary over a period of time while habitat conditions in the range recover. Where mortality management is applied, concurrent application of other management tools will be needed to achieve boreal caribou recovery. In particular, habitat restoration and management will be necessary to recover the range conditions to provide an adequate habitat supply system to support boreal caribou local populations. Predator and alternate prey management should be considered simultaneously. Alternate prey management applied in the absence of concurrent predator management has the potential to be harmful to boreal caribou conservation.

6.3.3.2 Manage Direct Human-Caused Mortality of Boreal Caribou

The extent of hunting and its effect on boreal caribou local populations is largely unknown across most of the distribution of boreal caribou. Therefore, it is important to first determine the level of hunting within a range in order to understand the potential impact of hunting on the viability of a local population. Attention should also be given to areas where boreal caribou ranges overlap with legally hunted caribou ecotypes, and hunting regulations for the legally hunted caribou ecotypes should be modified as appropriate. In areas where hunting is shown to have a negative effect on local population viability, harvest strategies should be developed, in consultation with Indigenous people, to achieve boreal caribou recovery.

6.3.4 Population Monitoring

6.3.4.1 Conduct Population Studies to Better Understand Boreal Caribou Population Structure, Trends and Distribution

There is considerable variation in the level of understanding of boreal caribou local population structure and trends across their distribution. While accurate population size and trend estimates are available for some local populations, for others, size and trend estimates are based primarily on professional judgement and limited data. For local populations where little is known, baseline population ecology studies such as boreal caribou collaring, aerial observations/counting, and on the ground monitoring activities are required to establish a baseline from which to plan and measure recovery progress. For all local populations, size and/or trend, and distribution should be monitored over time to test the efficacy of management actions and adapt those management actions as appropriate.

6.3.4.2 Monitor Boreal Caribou Health and Condition

Parasites and disease can affect individual boreal caribou and may have effects at the local population level in certain parts of the country. Pollution from oil and gas contaminated sites has also been shown to negatively affect the health of boreal caribou and may result in mortality if individuals consume toxins at waste sites. However, little is known about the severity of parasites, disease and pollution to individual boreal caribou or to boreal caribou local populations. Therefore, information on the health and body condition of boreal caribou should be monitored to better understand the relationship between these threats and the viability of local populations, and whether there is a need for additional recovery actions.

6.3.4.3 Monitor and Manage Sensory Disturbance of Boreal Caribou

The extent, distribution and effects of various sources of sensory disturbance (e.g. low-flying aircraft, snowmobiles, equipment associated with various industries) on individual boreal caribou and boreal caribou local populations should be assessed. Where required, management actions to reduce the effects of sensory disturbance on boreal caribou should be implemented and the effectiveness of the management actions should be monitored over time and adapted as necessary.

7 CRITICAL HABITAT

Under SARA, critical habitat is defined as "the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species". For boreal caribou, critical habitat identification describes the habitat that is necessary to maintain or recover self-sustaining local populations throughout their distribution. In some of the areas identified as critical habitat, the quality of habitat will need to be improved for recovery to be achieved.

Boreal caribou shift in their use of range over space and time, in accordance with changes in the location of biophysical attributes within the range as areas of disturbed and undisturbed habitat cycle on the landscape. For a local population to be self-sustaining over time, this habitat supply system (i.e. critical habitat) must function perpetually.

7.1 Identification of Critical Habitat for Boreal Caribou

7.1.1 Critical Habitat for All Ranges Except the Boreal Shield Range

Based on the foregoing, critical habitat for boreal caribou is identified for all boreal caribou ranges, except for northern Saskatchewan's Boreal Shield range (SK1), (see Figure 5) as:

- The area within the boundary of each boreal caribou range that provides an overall ecological condition that will allow for an ongoing recruitment and retirement cycle of habitat, which maintains a perpetual state of a minimum of 65% of the area as undisturbed habitat; and
- Biophysical attributes required by boreal caribou to carry out life processes (see Appendix H).

Based on methodology developed by Environment and Climate Change Canada (2011b), a disturbance management threshold of 65% has been identified, which provides a measurable probability (60%) for a local population to be self-sustaining (see Appendix E). The precise location of the 65% undisturbed habitat within the range will vary over time. The habitat within a range should exist in an appropriate spatial configuration such that boreal caribou can move throughout the range and access required habitat when needed. The key to this identification is achieving and maintaining an overall, ongoing range condition that allows for the dynamic habitat supply system, containing the biophysical attributes upon which boreal caribou depend, to operate. It is this dynamic habitat supply system within the range boundaries that is the habitat condition necessary for the recovery of boreal caribou.

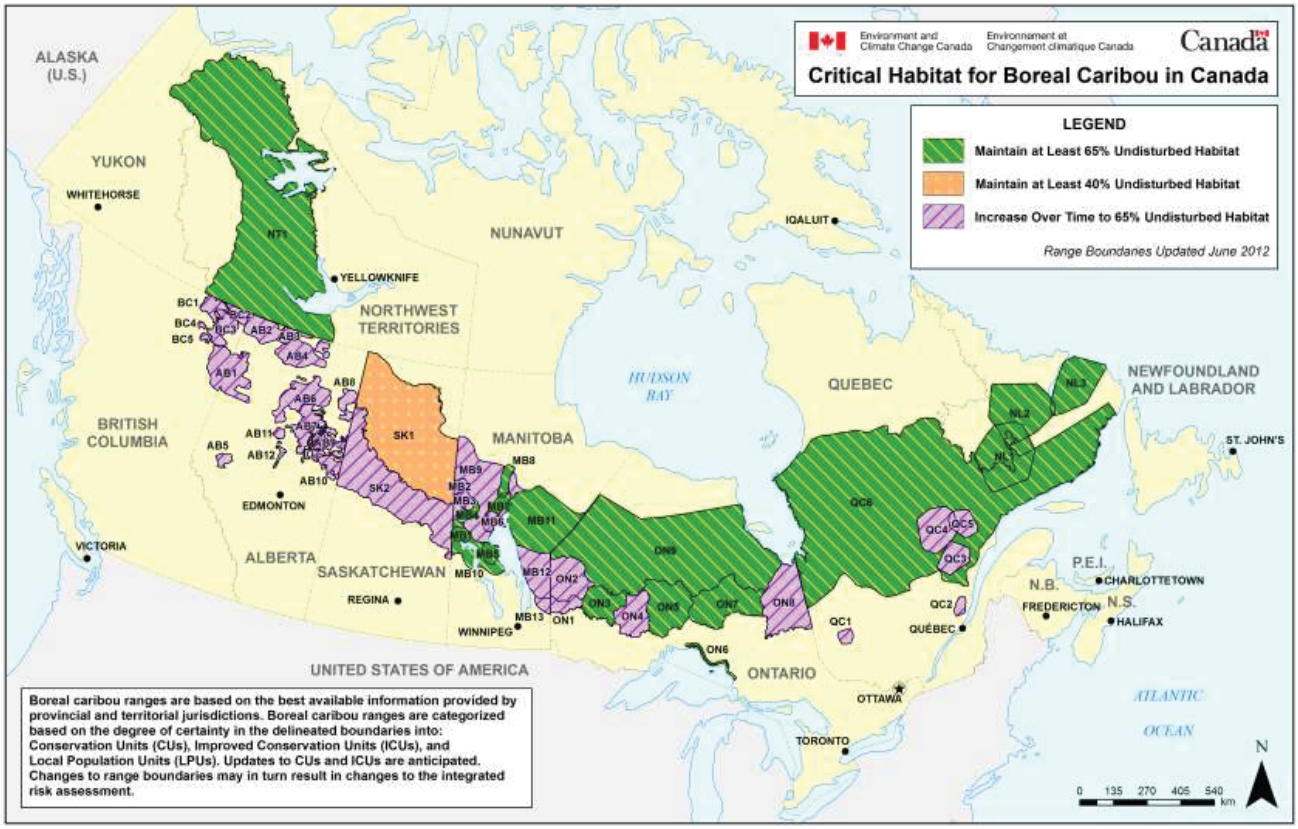


Figure 5. Critical habitat for boreal caribou in Canada as of 2019. Updated information includes the identification of critical habitat in SK1. MB6 and QC5 have also been updated from green to mauve based on habitat condition information previously published in the 5-Year Progress Report (Environment and Climate Change Canada, 2017).

7.1.2 Critical Habitat in Northern Saskatchewan's Boreal Shield Range (SK1)

Critical habitat was not identified in SK1 in the 2012 Recovery Strategy due to a lack of data on population size and trend, and the uniqueness of the disturbance regime (i.e. high fire and very low anthropogenic disturbance). As required under SARA, a schedule of studies was developed to identify critical habitat in SK1 and the schedule of studies is now complete (see Appendix D).

Critical habitat for boreal caribou in northern Saskatchewan's Boreal Shield range (SK1), (see Figure 5) is identified as:

- The area within the boundary of the SK1 boreal caribou range that provides an overall ecological condition that will allow for an ongoing recruitment and retirement cycle of habitat, which maintains a perpetual state of a minimum of 40% of the area as undisturbed habitat; and
- Biophysical attributes required by boreal caribou to carry out life processes (see Appendix H).

Based on three years of demographic data collected in SK1 between 2015 and 2017 by P.D. McLoughlin (University of Saskatchewan, personal communication), as part of the schedule of studies to identify critical habitat, additional analyses were completed by Environment and Climate Change Canada that indicate the SK1 local population is likely self-sustaining at current levels of disturbance (60% total disturbance), with a 71% probability of persistence (see Figure 3 and Appendix E). Environment and Climate Change Canada's analyses also show that the SK1 local population is sensitive to small increases in anthropogenic disturbance and sensitive to small decreases in adult survival. For these reasons, a higher probability of persistence was selected for critical habitat identification in SK1 (71%) than was selected for the other 50 ranges across Canada (60%) (Environment and Climate Change Canada, 2019).

The precise location of the 40% undisturbed habitat within the range will vary over time. The habitat within the SK1 range should exist in an appropriate spatial configuration such that boreal caribou can move throughout the range and access required habitat when needed. The key to this identification is achieving and maintaining an overall, ongoing range condition that allows for the dynamic habitat supply system, containing the biophysical attributes upon which boreal caribou depend, to operate. It is this dynamic habitat supply system within the SK1 range boundary that is the habitat condition necessary for the recovery of boreal caribou.

7.1.3 Components of Critical Habitat

The identification of critical habitat for boreal caribou is comprised of three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat. Appendix J provides critical habitat component information for each boreal caribou range.

Location

Location describes where critical habitat is found. For boreal caribou the relevant scale to identify critical habitat is the range, which delineates the area within which critical habitat is located. There are 51 ranges within the current distribution of the boreal caribou (see Figure 2 and Table 2).

Amount

Amount describes the quantity of critical habitat.

A strong relationship exists between habitat disturbance and whether a local population is stable, increasing or decreasing. As the quantity and/or severity of disturbance increases, there is increasing risk that a local population will be in decline (Environment Canada, 2011b), as further described in Appendix E.

Amount for all ranges except the Boreal Shield range: With the exception of the Boreal Shield range (SK1), this recovery strategy identifies a minimum of 65% undisturbed habitat in a range as the disturbance management threshold, which provides a measurable probability (60%) for a local population to be self-sustaining. This threshold is considered a minimum threshold because at 65% undisturbed habitat there remains a significant risk (40%) that local populations will not be self-sustaining.

Amount for the Boreal Shield range: For SK1, this recovery strategy identifies a minimum of 40% undisturbed habitat in the range as the disturbance management threshold, which provides a measurable probability (71%) for the local population to be self-sustaining. This threshold is considered a minimum threshold because at 40% undisturbed habitat there remains a risk (29%) that the local population will not be self-sustaining.

Habitat disturbance within a range needs to be managed by the responsible jurisdiction at a level that will allow for a local population to be self-sustaining. As there is variation in habitat and population conditions between boreal caribou local populations across their distribution, for some ranges it may be necessary to manage the range above the 65% undisturbed habitat threshold, while for other ranges, such as SK1, it may be possible to manage the range below the 65% undisturbed habitat threshold. However, there must be strong evidence, validated by Environment and Climate Change Canada, from population data collected over an extended period of time to support the management decision to establish a lower range-specific threshold (i.e. the lag effects of disturbance on a local population have been considered and accounted for).

In the absence of strong evidence to support lowering the undisturbed habitat threshold below 65%, the amount of critical habitat for all ranges, except SK1, is at least 65% undisturbed habitat. For management purposes, the amount of critical habitat may need to be maintained or restored, depending on the level of disturbance in a range.

- In ranges with undisturbed habitat below the threshold, initially, critical habitat is the existing habitat that over time would contribute to the attainment of 65% undisturbed habitat (40% undisturbed habitat for SK1).
- In ranges with undisturbed habitat equal to or above the threshold, critical habitat is at least 65% undisturbed habitat in a range (40% undisturbed habitat for SK1).
- The habitat that is included in the 65% undisturbed habitat (40% undisturbed habitat for SK1) will change over time given the dynamic nature of the boreal forest.

As previously reported in the 5-Year Progress Report, two ranges – the William Lake range (MB6) and the Manicouagan range (QC5) – changed from having greater than 65% undisturbed habitat to having less than 65% undisturbed habitat (Environment and Climate Change Canada, 2017). This change is reflected in both Figure 5 and Appendix J, where the amount of critical habitat for these two ranges changed from green ("maintain at least 65% undisturbed habitat") to mauve ("increase over time to 65% undisturbed habitat").

Section 4.2.1 describes the methodology used to measure disturbance for each range.

Type

Type describes the biophysical attributes of critical habitat.

Biophysical attributes are the habitat characteristics required by boreal caribou to carry out life processes necessary for survival and recovery. Biophysical attributes within and adjacent to core habitat areas of boreal caribou use will be more important to a local population than those that are isolated and less accessible to boreal caribou (i.e. spatially separated by a disturbance). The biophysical attributes for boreal caribou will vary over space and time with the dynamic nature of the boreal forest. In addition, particular biophysical attributes will be of greater importance to boreal caribou at different points in time. Certain biophysical attributes are required more by a local population during different life processes, seasons or at various times over the years.

Information from Indigenous Knowledge (Boreal Caribou ATK Reports, 2010-2011), habitat selection analyses, and scientific published reports (Environment Canada, 2011b) were used to summarize the biophysical attributes necessary for boreal caribou. Results are categorized by the habitat type (e.g. calving habitat, winter habitat) and are provided by ecozone in order to capture the ecological variation across the current distribution of boreal caribou (see Appendix H). In addition to variation across ecozones, the biophysical attributes necessary for boreal caribou will vary both between and within ranges. For certain ranges, more specific information was made available to describe biophysical attributes and this has been included in Appendix H.

7.2 Activities Likely to Result in the Destruction of Critical Habitat

SARA requires that a recovery strategy identify examples of activities likely to destroy critical habitat. Destruction is determined on a case by case basis. Destruction would result if part of the critical habitat were degraded, either permanently or temporarily, such that it would not serve its function when needed by boreal caribou. Destruction may result from a single activity, multiple activities at one point in time, or from the cumulative effects of one or more activities over time.

Activities that are likely to result in the destruction of critical habitat, include, but are not limited to, the following:

- Any activity resulting in the direct loss of boreal caribou critical habitat. Examples of such activities include: conversion of habitat to agriculture, forestry cut blocks, mines, and industrial and infrastructure development.

- Any activity resulting in the degradation of critical habitat leading to a reduced, but not total loss of both habitat quality and availability for boreal caribou. Examples of such activities include: pollution, drainage of an area, and flooding.
- Any activity resulting in the fragmentation of habitat by human-made linear features. Examples of such activities include: road development, seismic lines, pipelines, and hydroelectric corridors.

7.2.1 Likelihood of Critical Habitat Destruction for All Ranges Except the Boreal Shield Range

The likelihood that critical habitat will be destroyed is increased if any one of the above activities, or combination thereof, were to occur in such a manner, place and time, that after appropriate mitigation techniques (see Appendix I) any one of the following were to occur:

- Compromise the ability of a range to be maintained at 65% undisturbed habitat;
- Compromise the ability of a range to be restored to 65% undisturbed habitat;
- Reduce connectivity within a range;
- Increase predator and/or alternate prey access to undisturbed areas; or
- Remove or alter biophysical attributes necessary for boreal caribou.

7.2.2 Likelihood of Critical Habitat Destruction for the Boreal Shield Range

For the Boreal Shield range (SK1), the likelihood that critical habitat will be destroyed is increased if any one of the above activities, or combination thereof, were to occur in such a manner, place and time, that after appropriate mitigation techniques (see Appendix I) any one of the following were to occur:

- Compromise the ability of the range to be maintained at 40% undisturbed habitat;
- Increase total anthropogenic disturbance within the range above 5% (while maintaining a minimum of 40% undisturbed habitat);
- Reduce connectivity within the range;
- Increase predator and/or alternate prey access to undisturbed areas; or
- Remove or alter biophysical attributes necessary for boreal caribou.

Based on Environment and Climate Change Canada's 5-Year Progress Report, and as reported in Appendix F, the SK1 range currently has 40% undisturbed habitat (or 60% disturbed habitat) (Environment and Climate Change Canada, 2017). The 60% total non-overlapping disturbance is comprised of 58% fire and 3% anthropogenic disturbance[4]. Analyses conducted by Environment and Climate Change Canada, using population data provided by the University of Saskatchewan, indicates that based on the three years of available population data there is a 71% probability that

[4] When calculating total disturbance for a range, anthropogenic disturbance and fire disturbance that overlap are not counted twice in the total.

the SK1 location population is self-sustaining at the current levels of disturbance (P.D. McLoughlin, University of Saskatchewan, personal communication; Environment and Climate Change Canada, 2019). Environment and Climate Change Canada's analyses also investigated the changes in the probability of persistence with increasing levels of anthropogenic disturbance in the range. Results show that with an additional 2.5–3.0% anthropogenic disturbance, the probability of persistence of the SK1 local population drops from 71% to 60%, and to 50% when the additional anthropogenic disturbance reaches 5% (Environment and Climate Change Canada, 2019). The analyses did not consider the additional effects of fire disturbance due to the difficulties in managing wildfires.

Additional analyses by Environment and Climate Change Canada (2019) demonstrated that anthropogenic disturbance is not equivalent to fire, with the former having a stronger negative effect on population condition. This result, coupled with the analyses that showed that the local population is sensitive to small increases in anthropogenic disturbance and sensitive to small decreases in adult survival, indicates that caution is warranted with respect to additional anthropogenic disturbance in this range (see Appendix D) (Environment and Climate Change Canada, 2019). Therefore, for SK1 critical habitat, activities that pertain specifically to increasing the level of anthropogenic disturbance in SK1 has been added to the list of factors that increase the likelihood that critical habitat will be destroyed.

7.2.3 Cumulative Effects

A single project/activity may or may not result in the destruction of critical habitat; however, when considered in the context of all current and future development activities within and among ranges, the cumulative impacts may result in the destruction of critical habitat.

Mitigation of adverse effects from individual projects/activities will require a coordinated approach and management of cumulative effects within and among ranges. A cumulative effects assessment is essential to position the proposed project/activity in the context of all current and future development activities. The cumulative effects assessment will:

- Assess the impact of all disturbances (anthropogenic and natural) at the range-scale;
- Monitor habitat conditions, including the amount of current disturbed and undisturbed habitat (see Section 4.2.1), and amount of habitat being restored;
- Account for planned disturbances; and
- Assess the distribution of disturbance in large ranges for risk of range retraction in parts of the range.

For large continuous ranges, a different approach for assessing cumulative effects will be required than for smaller discrete ranges. Dividing the large areas into smaller management units will allow land managers to understand where the disturbance is occurring and avoid irreversible range retraction and a permanent break in range connectivity.

Determination of whether an activity is likely to result in the destruction of critical habitat will be facilitated by a range plan. For example, a range plan would identify activities that are likely to result in direct loss, degradation, and/or fragmentation of habitat, relevant to specific local

circumstances. Any development that does not align with the range plan would be considered an activity likely to destroy critical habitat.

7.3 Range Plans

Given the dynamic nature of boreal caribou habitat requirements, the landscape scale at which those requirements operate, and the highly variable present-day land management and ecological conditions that exist among all boreal caribou ranges, range-specific approaches to protecting critical habitat, and in many cases improving the condition of critical habitat for this species, are needed.

In light of jurisdictional responsibilities for land and natural resource management, it is expected that they will develop range plans. In areas where the responsibility for land and natural resource management varies, range plans will be developed collaboratively between all responsible authorities. Range plans may be stand-alone documents, or part of other planning documents including action plans. In September 2016, Environment and Climate Change Canada published the Range Plan Guidance for Woodland Caribou, Boreal Population to assist provincial and territorial jurisdictions in their preparation of range plans (Environment and Climate Change Canada, 2016). The Range Plan Guidance provides general guidance on the development of range plans and is consistent with the guidance provided in this recovery strategy.

Range plans will outline how the given range will be managed to maintain or attain a minimum of 65% undisturbed habitat in all ranges other than SK1, and 40% undisturbed habitat in the SK1 range, over time. Specifically each range plan should reflect disturbance patterns on the landscape, as measured and updated by the provinces and territories, and outline measures and steps that will be taken to manage the interaction between human disturbance and natural disturbance.

Difference between a range plan and an action plan

Action plans, which are required under SARA, provide the public and stakeholders with details on how the recovery strategy will be implemented. Action plans include a broad spectrum of subjects, such as: measures to address threats and to achieve population and distribution objectives; an evaluation of socio-economic costs and benefits to be derived from its implementation; and an approach for monitoring and reporting, etc. An action plan is not necessarily range-specific; it could cover multiple ranges or even specific recovery measures within a range. Range plans are documents that outline how a given range will be managed to ensure that critical habitat is protected from destruction.

Purpose of a range plan

The main purpose of a range plan is to outline how range-specific land and/or resource activities will be managed over space and time to ensure that critical habitat is protected from destruction. As such, each range plan should reflect disturbance patterns on the landscape, as measured and updated by the provinces and territories, and outline the measures and steps that will be taken to manage the interaction between human disturbance, natural disturbance, and the need to maintain or establish an ongoing, dynamic state of a minimum of 65% of the range as undisturbed habitat

in all ranges other than SK1, and 40% undisturbed habitat in the SK1 range, at any point in time to achieve or maintain a self-sustaining local population. While the general ecological principles and critical habitat dynamics described in the recovery strategy apply to all ranges, individual ranges also possess a unique mix of ecological and land use conditions (e.g. population condition, habitat condition and configuration, social and legal arrangements) that must be factored into decision making.

The range plans, consistent with this recovery strategy, will be one factor considered by the Minister of Environment and Climate Change in forming an opinion on whether the laws of the province or territory effectively protect critical habitat within each boreal caribou range. As such, range plans should contain the background information necessary for the Minister of Environment and Climate Change to make an informed assessment of whether critical habitat protection is in place or is being realistically pursued throughout the range. Specifically, range plans should indicate what laws of the province or territory, legislative and/or regulatory provisions, licences or other instruments issued under an Act or regulation, or contractually binding agreements the jurisdiction intends to use to protect critical habitat. In the absence of range plans, the minister will use the best available information and consult with the jurisdiction to determine whether critical habitat is effectively protected. If the minister is of the opinion that there are no provisions in or measures under SARA or another Act of Parliament that protect the critical habitat (including a section 11 agreement) and the laws of the provinces and territories do not effectively protect their critical habitat, the Minister of Environment and Climate Change is required to recommend that a protection order be made to the to the Governor in Council.

Range plans may form part of an action plan under SARA. However, in order to be adopted in whole or in part as an action plan by the Minister of Environment and Climate Change, the range plan and the process used to develop it will need to meet the requirements of section 48 (cooperation) and section 49 (content) of SARA. In addition, range plans will be used to inform reporting that is required under SARA on implementation and progress toward meeting the population and distribution objectives of this recovery strategy. Finally, range plans may be used to inform decisions related to environmental assessments, issuance of permits (either under SARA or other applicable legislation), and other similar approval processes.

Process for developing a range plan

The development of each range plan will be led by the responsible provincial or territorial jurisdiction. In areas where the management responsibility for land and natural resource management varies, range plans will likely be multi-jurisdictional led between all responsible authorities. Range plans should be developed in a collaborative manner with directly affected stakeholders and should also engage local land users. Jurisdictions are encouraged to use Indigenous Knowledge when developing range plans and should also apply the appropriate level of cooperation with Indigenous peoples as they would in any other resource management planning process that is undertaken within their province or territory. The exact process of collaboration that is used is the responsibility of each jurisdiction and may vary between jurisdictions.

Range plans may be updated by the jurisdictions over time to reflect changes in habitat and

population conditions for any given range. In particular, range plans should be updated following any significant natural disturbance event (e.g. forest fires).

Timelines for the development of range plans

Given the variation in management contexts, population and habitat information, and levels of risk across the geographic distribution of boreal caribou, the 2012 Recovery Strategy called for range plans to be completed by the responsible jurisdiction(s) within 3-5 years of the posting of the 2012 Recovery Strategy. Environment and Climate Change Canada continues to seek commitments to develop jurisdictional range plans or other similar documents through the development of conservation agreements.

For the Boreal Shield range (SK1), the Government of Saskatchewan should complete the range plan by June 2021.

What should be included in a range plan?

There is no single prescriptive approach to developing a range plan, and jurisdictions may select those approaches they consider most appropriate. Range plans should include such things as:

- Demonstration of how at least 65% undisturbed habitat (40% undisturbed habitat in SK1), will be achieved and/or maintained over time;
- For SK1, demonstration of how total anthropogenic disturbance in the range will be maintained at or below 5% (while maintaining a minimum of 40% undisturbed habitat) (see section 7.2.2);
- List of the laws of the province or territory (including any corresponding regulations, permits, licenses, etc.) and conservation measures (such as agreements, programs, compliance incentives, conservation leases, etc.) that will be used to prevent activities likely to destroy critical habitat;
    - include land tenure assessment for all areas of critical habitat within each range
    - where protection measures do not exist, the range plan should indicate the steps being taken to put them in place and the expected timeline for implementation
- Information on range-specific activities likely to destroy critical habitat within each range. This will involve identifying and assessing current projects/activities as well as any foreseeable future projects/activities, and should include a cumulative effects analysis;
- An approach for measuring disturbance to the landscape and monitoring critical habitat to ensure that protection mechanisms are in place and are working to prevent the destruction of boreal caribou critical habitat;
- An approach for monitoring population trends to ensure that local populations are responding positively to management techniques;
- An approach for monitoring natural disturbances, and habitat quality and quantity; and
- Identification of information needs and plans for addressing information gaps.

8 MEASURING PROGRESS

Under SARA, the competent minister must report on the implementation of a recovery strategy and the progress towards meeting its objectives every five years. Population and habitat conditions for boreal caribou will change over time given the changes to population demographics, the dynamic nature of the boreal ecosystem and the manner in which the species shifts in its use of the landscape over time. Accordingly, the five-year time frame for reporting on implementation allows for these changes to be included in an updated recovery strategy, and for subsequent range plans and action plans to be updated under an adaptive management framework.

Monitoring of boreal caribou local populations based on performance indicators will be essential to have the information necessary to evaluate the effectiveness of management actions and to make necessary adjustments through an adaptive management process over time.

8.1 Adaptive Management

The process of adaptive management planning and implementation acknowledges and supports the adjustment of management actions in light of new or more refined knowledge. Through adaptive management, knowledge gaps and uncertainties are identified, evaluated and reported as information needs, addressed through monitoring and research, and then implemented through revised and improved management actions.

The challenge of achieving the recovery goal of self-sustaining local populations of boreal caribou will vary by boreal caribou range given the habitat and population conditions and management context associated with each range. In order to ensure adaptive management is applied to boreal caribou recovery, cooperation with federal, provincial and territorial jurisdictions, wildlife management boards, Indigenous people, and others involved in the conservation, survival and recovery of boreal caribou is required.

8.2 Performance Indicators

The performance indicators presented below provide a way to define and measure progress toward achieving the population and distribution objectives.

The ultimate performance indicator of boreal caribou recovery is self-sustaining local populations throughout the entirety of their distribution in Canada. Performance indicators for this recovery strategy are that the population and distribution objective is met for each boreal caribou range, and that boreal caribou become less at risk. Recovery of all boreal caribou local populations is technically and biologically feasible; however given the challenges of recovery for boreal caribou, some local populations that are currently not self-sustaining will likely require a number of decades to return to a recovered state.

The performance indicators described below are provided as national guidelines to gauge the successful implementation of the recovery strategy. More detailed performance indicators that

reflect the specific local conditions (e.g. population condition, habitat condition, alternate prey/predator dynamics, mortality rates) of each boreal caribou range will need to be developed at the range plan and/or action plan stage.

General:

a) Complete range plans for each range within 3-5 years of the posting of the 2012 Recovery Strategy (see Section 7.3).

b) For SK1, complete the range plan by June 2021 (see Section 7.3).

Population Condition (population trend and size):

a) Maintain current distribution of boreal caribou across Canada.

b) Achieve and/or maintain a stable to increasing population trend as measured over five years (i.e. $\lambda \geq$ stable) or other empirical data that indicates population trend is stable or increasing.

c) Achieve a minimum of 100 animals[5] for boreal caribou ranges with population estimates of less than 100 animals, or show progress towards this goal every five years.

Habitat Condition (amount and type of undisturbed habitat):

a) For ranges that meet or exceed the undisturbed habitat threshold, maintain the undisturbed habitat that includes the biophysical attributes needed for boreal caribou to carry out life processes at a minimum of 65% (40% for SK1) of the total range.

b) For ranges below the 65% undisturbed habitat threshold (40% for SK1), identify in a range and/or action plan specific areas of existing undisturbed habitat, as well as those areas where future habitat is to be restored to an undisturbed condition over reasonable, gradual increments every five years.

c) Provide measurements of disturbance for each range that reflect the best available information, as provided by the provinces and territories, to update the recovery strategy accordingly every five years.

[5] 100 animals provides a 0.7 probability of not reaching a quasi-extinction threshold of less than 10 reproductively active females under stable conditions over 50 years (Environment Canada, 2011b).

9 STATEMENT ON ACTION PLANS

As required by SARA, the Minister of Environment and Climate Change published the Action Plan for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada – Federal Actions on the Species at Risk Public Registry on February 13, 2018 (Environment and Climate Change Canada, 2018). The Action Plan presents the recovery measures that the federal government is taking or plans to take to help achieve the recovery goal and population and distribution objectives for the species, as identified in the 2012 Recovery Strategy (Environment Canada, 2012a). In addition to this Action Plan, Parks Canada Agency site-specific Action Plans that address boreal caribou conservation and recovery efforts on lands administered by the Agency can be found on the SAR Public Registry.

Action plans provide information on recovery measures that should be taken by Environment and Climate Change Canada and other federal government departments and agencies including Parks Canada Agency, Crown-Indigenous Relations and Northern Affairs Canada, Department of National Defence and the Canadian Forces among others, provincial and territorial jurisdictions, wildlife management boards, Indigenous people, stakeholders and other organizations involved in the conservation, survival and recovery of boreal caribou. Action plans provide the public and stakeholders with details on how the recovery strategy will be implemented. Action plans include a broad spectrum of subjects, such as: measures to address threats and to achieve population and distribution objectives; an evaluation of socio-economic costs and benefits to be derived from its implementation; and, an approach for monitoring and reporting. An action plan is not necessarily range-specific; instead it could cover multiple ranges.

Range plans are documents that outline how the habitat condition within a given range will be managed over time and space to ensure that critical habitat for boreal caribou is protected from destruction and therein, that each local population will either continue to be self-sustaining or become self-sustaining over time. In September 2016, Environment and Climate Change Canada published the Range Plan Guidance for Woodland Caribou, Boreal Population to assist provincial and territorial jurisdictions in their preparation of range plans (Environment and Climate Change Canada, 2016).

The Minister of Environment and Climate Change may adopt or incorporate parts of a range plan, an existing provincial or territorial plan, or other relevant planning documents that meet the requirements of SARA as an action plan. Where the Minister of Environment and Climate Change proposes to adopt an existing plan or a portion of it as a SARA action plan, it will be posted on the Species at Risk Public Registry for the prescribed 60-day comment period. Within 30 days after the expiry of the comment period, and considering the comments received, the minister will publish a final action plan.

9.1 Coordinated Approach

9.1.1 Provincial and Territorial Jurisdictional Leadership

Provinces and territories have the primary responsibility for management of lands and wildlife within boreal caribou distribution, however this responsibility does vary in some parts of the country. For example, in the Northwest Territories, the Tłı̨chǫ Government manages land and resources (including wildlife) within Tłı̨chǫ Lands, as described in the Tłı̨chǫ Agreement (a combined comprehensive land claims and self-government agreement). There are also wildlife management boards that have been established under land claims agreements as the primary instrument for wildlife management in some regions of the country. In addition, Parks Canada Agency has a significant role to play where boreal caribou exist within national parks and historic sites.

Range plans and/or action plans inform broader land-use planning and decision making, and require substantial inter-agency communication and cooperation. Coordination is particularly important for range and/or action plans that address boreal caribou recovery in transboundary ranges, and for ensuring connectivity within ranges and across the species current distribution is maintained.

9.1.2 Indigenous Involvement

The Minister of Environment and Climate Change must cooperate with affected Indigenous organizations for recovery strategies and action plans. Across Canada, cooperation with Indigenous people is key to the success in developing and implementing action plans.

In acknowledgement of existing Aboriginal and treaty rights, to the extent possible, details of harvesting plans for local populations, consistent with the principles of conservation, will be addressed in range and/or action plans. When applicable, harvesting plans will follow the required process under Land Claim Agreements or provincial/territorial laws. Indigenous involvement will be required to determine population targets that ensure stable boreal caribou local populations are maintained and recovery of local populations that are not self-sustaining is achieved, while providing for traditional Indigenous harvesting practices consistent with conservation and existing Aboriginal and treaty rights. A description of Environment and Climate Change Canada's approach to engaging with Indigenous people in the development of both the 2012 Recovery Strategy and the 2020 Amended Recovery Strategy for boreal caribou is provided in Appendix B.

9.1.3 Stakeholder Engagement

Success in the recovery of this species depends on the commitment, collaboration, and cooperation of many different constituencies that are or will be involved in implementing the broad strategies and general approaches set out in this recovery strategy and will not be achieved by Environment and Climate Change Canada, or any other jurisdiction, alone. All stakeholders, including the industry sector, environmental organizations, and private landowners should be engaged where appropriate in developing and implementing action plans.

9.2 Range Specific Actions

The recovery of boreal caribou requires actions that will vary by individual boreal caribou range based on the population and habitat conditions. Each range will require a range-specific path forward for the recovery of boreal caribou. As described under Section 7.3, range plans and/or action plans are needed to guide protection and management of critical habitat, and overall recovery actions, in each boreal caribou range.

Range plans describe how critical habitat will be protected. The 2012 Recovery Strategy called for these jurisdictionally-led range plans to be produced for each range within 3-5 years of the posting of the 2012 Recovery Strategy. Environment and Climate Change Canada continues to seek commitments to develop jurisdictional range plans or other similar documents through the development of conservation agreements for the species.

For the Boreal Shield range (SK1), the Government of Saskatchewan should complete the range plan by June 2021.

In the absence of range plans, the Minister of Environment and Climate Change will use the best available information and consult with the jurisdiction to make a determination on the state of protection of critical habitat for boreal caribou.

9.2.1 Habitat and Population Management

The broad strategies and general approaches to meet the population and distribution objectives (see Section 6), as set out in this recovery strategy, will inform the development of range plans and action plans, where detailed local-level planning will occur to guide the implementation of recovery actions.

The broad strategies and general approaches are designed to guide range and action planning based on the state of each boreal caribou range. Many approaches and strategic directions are inter-related and should be implemented as described in the range plans and action plans. Generally, for self-sustaining local populations, minimal management actions may be necessary, and strategically planned development could take place without threatening boreal caribou and the status of the local population. Where local populations are not self-sustaining, specific management action is needed, in some cases for many decades, until sufficient habitat is restored and the population condition is improved. Mortality management, including predator and alternate prey management, may be needed to help prevent extirpation of a boreal caribou local population in the interim while habitat management efforts are underway to restore the ecological conditions of the range necessary to support a self-sustaining local population.

Jurisdictions are accountable for the long-term planning and management of boreal caribou ranges with the implementation of different habitat and population management tools available at their discretion, depending on the specific local conditions. The implementation of habitat management practices, such as fire suppression, and mortality management practices, such as predator control, are at the discretion of jurisdictions, and the application of these tools will vary in accordance with jurisdictional policies and procedures.

10 GLOSSARY

Note: The following terms are defined in accordance with their use in this document.

Anthropogenic: caused by human activity.

Biological feasibility: recovery is determined to be biologically feasible under the following circumstances: individuals of the wildlife species that are capable of reproduction are available now or in the foreseeable future to sustain the population or improve its abundance; sufficient suitable habitat is available to support the species or could be made available through habitat management or restoration; and primary threats to the species or its habitat can be avoided or mitigated.

Biophysical attributes: habitat characteristics required by boreal caribou to carry out life processes necessary for survival and recovery (see Appendix H).

Current distribution (extent of occurrence): the area that encompasses the geographic distribution of all known boreal caribou ranges, based on provincial and territorial distribution maps developed from observation and telemetry data, local knowledge (including in some cases Indigenous Knowledge), and biophysical analyses.

Disturbance management threshold: at the scale of boreal caribou range, the habitat disturbance point below which conditions are such that the recovery goal will likely be met (i.e. acceptable level of risk), and above which the outcome is either highly uncertain or unacceptable.

Disturbed habitat: habitat showing: i) anthropogenic disturbance visible on Landsat at a scale of 1:50,000, including habitat within a 500 m buffer of the anthropogenic disturbance; and/or ii) fire disturbance in the last 40 years, as identified in data from each provincial and territorial jurisdiction (without buffer).

Existing habitat: the entire boreal caribou range area minus permanent alterations. See also *permanent alterations.*

Indigenous Knowledge (IK): IK includes, but is not limited to, the knowledge Indigenous peoples have accumulated about wildlife species and their environment. Much of this knowledge has accumulated over many generations.

Local population: a group of boreal caribou occupying a defined area distinguished spatially from areas occupied by other groups of boreal caribou. Local population dynamics are driven primarily by local factors affecting birth and death rates, rather than immigration or emigration among groups.

In this recovery strategy, “local population” refers to a group of boreal caribou occupying any of the three types of boreal caribou ranges (i.e. conservation unit, improved conservation unit, local population unit). See also *range*.

Not self-sustaining local population: in the population and distribution objectives "not self-sustaining local population" includes both the local populations assessed as "as likely as not self-sustaining" and those assessed as "not self-sustaining".

Permanent alterations: existing features found within a range, such as industrial and urban developments, permanent infrastructure, and graded or paved roads that do not currently possess or have the potential to possess the biophysical attributes of critical habitat for boreal caribou.

Quasi-extinction: a population with less than 10 reproductively active females.

Range: the geographic area occupied by a group of individuals that are subject to similar factors affecting their demography and used to satisfy their life history processes (e.g. calving, rutting, wintering) over a defined time frame. Environment and Climate Change Canada (2011b) identified three types of boreal caribou ranges categorized based on the degree of certainty in the delineated range boundaries (i.e. conservation unit, improved conservation unit, local population unit).

Range plan: a document that demonstrates how the habitat condition within a given range will be managed over time and space to ensure that critical habitat for boreal caribou is protected from destruction and therein, that each local population will either continue to be self-sustaining or become self-sustaining over time.

Self-sustaining local population: a local population of boreal caribou that on average demonstrates stable or positive population growth over the short-term (≤20 years), and is large enough to withstand stochastic events and persist over the long-term (≥50 years), without the need for ongoing active management intervention.

Technical feasibility: recovery is determined to be technically feasible when recovery techniques exist to achieve the population and distribution objectives or can be expected to be developed within a reasonable timeframe.

To the extent possible: current evidence supports the conclusion that the recovery of all local populations is technically and biologically feasible. There may be situations where recovery of a particular local population proves to be, over time and through unforeseen circumstances, not biologically or technically feasible and as such may affect the likelihood of achieving the population and distribution objectives for some local populations.

Undisturbed habitat: habitat not showing any: i) anthropogenic disturbance visible on Landsat at a scale of 1:50,000, including habitat within a 500 m buffer of the anthropogenic disturbance; and/or ii) fire disturbance in the last 40 years, as identified in data from each provincial and territorial jurisdiction(without buffer). Disturbance within the 500 m buffer would result in a reduction of the undisturbed habitat.

11 REFERENCES

Adams, L.G., B.W. Dale, and L.D. Mech. 1995. Wolf predation on caribou calves in Denali National Park, Alaska. *In* Carbyn, L.N., S.H. Fritts and D.R. Seip (editors). Ecology and Conservation of Wolves in a Changing World. Canadian Circumpolar Institute, Occasional Publication no. 35, Edmonton, Alberta.

Badiou, P., S. Boutin, M. Carlson, M. Darveau, P. Drapeau, J. Jacobs, C. Johnson, J. Kerr, M. Manseau, P. McLoughlin, G. Orians, S. Pimm, P. Raven, D. Roberts, T. Root, N. Roulet, J. Schaefer, D. Schindler, M. St-Laurent, J. Strittholt, N. Turner, A. Weaver, and J. Wells. 2011. Keeping woodland caribou in the boreal forest: Big challenge, immense opportunity. International Boreal Conservation Science Panel. 12 pp.

Banfield, A.W.F. 1974. Mammals of Canada. University of Toronto Press. Toronto, Ontario. 438 pp.

Bergerud, A.T. 1967. Management of Labrador caribou. *Journal of Wildlife Management* 31: 626-642.

Bergerud, A.T. 1974. Decline of caribou in North America following settlement. *Journal of Wildlife Management* 38:757-770.

Bergerud, A.T. 1978. The status and management of Woodland Caribou in British Columbia. Report to Fish and Wildlife Branch, Government of British Columbia. Victoria, British Columbia. 138 pp.

Bergerud, A.T. 1980. A review of the population dynamics of caribou and wild reindeer in North America. *In* D. Reimers, E. Gaare, and S. Skenneberg (editors). Proceedings of the 2nd International Reindeer/Caribou Symposium, Roros, Norway.

Bergerud, A.T. 1988. Caribou, wolves and man. *Trends in Ecology & Evolution* 3:68-72.

Bergerud, A.T. 1996. Evolving perspectives on caribou population dynamics: have we got it right yet? *Rangifer Special Issue* No. 9. pp. 95–115.

Bergerud, A.T. 2000. Caribou. In S. *Demarais and P.R. Krausman (Editors). Ecology and Management of Large Mammals in North America*. Prentice Hall, Upper Saddle River, New Jersey.

Bergerud, A.T., R.D. Jakimchuk, and D.R. Carruthers. 1984. The buffalo of the north: caribou (*Rangifer tarandus*) and human developments. *Arctic* 37: 7-22.

Bergerud, A.T., and J.P. Elliot. 1986. Dynamics of caribou and wolves in northern British Columbia. *Canadian Journal of Zoology* 64: 1515-1529.

Bergerud, A.T., and R.E. Page. 1987. Displacement and dispersal of parturient caribou at calving as antipredator tactics. *Canadian Journal of Zoology* 62: 1566-1575.

Bergerud, A.T., R.S. Ferguson, and H.E. Butler. 1990. Spring migration and dispersion of Woodland Caribou at calving. *Animal Behaviour* 39: 360-368.

Boertje, R.D., P. Valkenburg, and M.E. McNay. 1996. Increases in moose, caribou, and wolves following wolf control in Alaska. *Journal of Wildlife Management* 60: 474-489.

Boreal Caribou Aboriginal Traditional Knowledge (ATK) Reports. 2010-2011. Compiled June 2011. Ottawa: Environment Canada.

Bradshaw, C.J.A., D. M. Hebert, A.B. Rippin, and S. Boutin. 1995. Winter peat land habitat selection by Woodland Caribou in northeastern Alberta. *Canadian Journal of Zoology* 73: 1567-1574.

Bradshaw, C.J.A., S. Boutin, and D.M. Hebert. 1998. Energetic implications of disturbance caused by petroleum exploration to Woodland Caribou 76: 1319-1324.

Brown, G.S., F.F. Mallory, and W.J. Rettie. 2003. Range size and seasonal movement for female Woodland Caribou in the boreal forest of northeastern Ontario. *Rangifer Special Issue* No. 14: 227-233.

Brown, G.S., W.J. Rettie, R.J. Brooks, and F.F. Mallory. 2007. Predicting the impacts of forest management on woodland caribou habitat suitability in black spruce boreal forest. *Forest Ecology and Management* 245: 137-147.

Brown, W.K., J. Huot, P. Lamothe, S.N. Luttich, M. Pare, G. St.Martin, and J.B. Theberge. 1986. The distribution and movement patterns of four Woodland Caribou herds in Québec and Labrador. *Rangifer Special Issue* No. 1: 43-49.

Brown, W.K., and J.B. Théberge. 1990. The effect of extreme snow cover on feeding-site selection by Woodland Caribou. *Journal of Wildlife Management* 54: 161-168.

Brown, W.K., and D.P. Hobson. 1998. Caribou in west-central Alberta - information review and synthesis. Terrestrial & Aquatic Environmental Managers, Calgary, Alberta.

Callaghan, C., S. Virc, and J. Duffe. 2010. Woodland Caribou, boreal population, trends in Canada. Technical Thematic Report No. 11. In *Canadian Biodiversity: Ecosystem Status and Trends 2010.*

Caughley, G. 1994. Directions in conservation biology. *Journal of Animal Ecology* 63: 15-244.

Caughley, G., and A. Gunn. 1996. Conservation Biology in Theory and Practice. Blackwell Science, Cambridge, Massachusetts, USA. 459 pp.

Chabot, A. 2011. Suivi télémétrique et stratégie générale d'aménagement de l'habitat des caribous forestiers du Nitassinan de la Première Nation innue d'Essipit. Rapport du Groupe-Conseil AGIR inc., présenté au Conseil de la Première Nation innue d'Essipit. 43 p. et 1 annexe.

Chubbs, T.E., L.B. Keith, S.P. Mahoney, and M.J. McGrath. 1993. Response of Woodland Caribou (*Rangifer tarandus*) to clear-cutting in east-central Newfoundland. *Canadian Journal of Zoology* 71: 487-493.

COSEWIC. 2011. Designatable Units for Caribou (*Rangifer tarandus*) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 88 pp.

COSEWIC. 2014. COSEWIC assessment and status report on the Caribou Rangifer tarandus, Newfoundland population, Atlantic-Gaspésie population and Boreal population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xxiii + 128 pp. (https://wildlife-species.canada.ca/species-risk-registry/document/default_e.cfm?documentID=2769)

Courbin, N., D. Fortin, C. Dussault, and R. Courtois. 2009. Landscape management for Woodland Caribou: the protection of forest blocks influences wolf-caribou co-occurrence. *Landscape Ecology* 24: 1375-1388.

Courtois, R. 2003. La conservation du caribou forestier dans un contexte de perte d'habitat et de fragmentation du milieu. Ph.D. thesis, Université du Québec à Rimouski. 350 pp.

Courtois, R., L. Bernatchez, J.-P. Ouellet, and L. Breton. 2003. Significance of caribou (*Rangifer tarandus*) ecotypes from a molecular genetics viewpoint. *Conservation Genetics* 4: 393-364.

Courtois, R., and J.-P. Ouellet. 2007. Modeling the impact of moose and wolf management on persistence of Woodland Caribou. *Alces* 43: 13-27.

Courtois, R., J.P. Ouellet, L. Breton, A. Gingras, and C. Dussault. 2007. Effects of forest disturbance on density, space use, and mortality of woodland caribou. *Écoscience*, 14: 491–498.

Creel, S., J.E. Fox, A. Hardy, J. Sands, B. Garrott, and R.O. Peterson. 2002. Snowmobile activity and glucocorticoid stress responses in wolves and elk. *Conservation Biology* 16(3): 809-814.

Cumming, H.G. 1992. Woodland Caribou: facts for forest managers. *Forestry Chronicles* 68: 481-491.

Cumming, H.G., and B.T. Hyer. 1998. Experimental log hauling through a traditional caribou wintering area. *Rangifer Special Issue* No. 10: 241-258.

Dale, B. W., L.G. Adams, and R.T. Bowyer. 1994. Functional response of wolves preying on barren-ground caribou in a multiple-prey ecosystem. *Journal of Animal Ecology* 63(3): 644-652.

Darby, W.R., and W.O. Pruitt, Jr. 1984. Habitat use, movements and grouping behaviour of Woodland Caribou, *Rangifer tarandus caribou*, in southeastern Manitoba. *Canadian Field Naturalist* 98: 184-190.

DeMars, C., C. Thiessen, and S. Boutin. 2011. Assessing Spatial Factors Affecting Predation Risk to Boreal Caribou Calves: Implications for Management. University of Alberta and BC Ministry of Natural Resource Operations 1-35.

Dunford, J.S., P.D. McLoughlin, F. Dalerum, and S. Boutin. 2006. Lichen abundance in the peatlands of Northern Alberta: implications for boreal caribou. *Ecoscience* 13:469–474.

Dyer, S.J., J.P. O'Neill, S.M. Wasel, and S. Boutin. 2001. Avoidance of industrial development by Woodland Caribou. *Journal of Wildlife Management* 65: 531-542.

Dyer, S.J., J.P. O'Neill, S.M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female Woodland Caribou in northeastern Alberta. *Canadian Journal of Zoology* 80: 839-845.

Dzus, E. 2001. Status of the Woodland Caribou (*Rangifer tarandus caribou*) in Alberta. Alberta Environment, Fisheries and Wildlife Division, and Alberta Conservation Association. Wildlife Status Report no. 30. Edmonton, Alberta. 47 pp.

Dzus, E., J. Ray, I. Thompson, and C. Wedeles, C. 2010. Caribou and the National Boreal Standard: Report of the FSC Canada Science Panel. Toronto, ON, Forest Stewardship Council of Canada.

Edmonds, E.J. 1988. Population status, distribution, and movements of Woodland Caribou in west central Alberta. *Canadian Journal or Zoology* 66: 815-826.

Environment Canada. 2008. Scientific Review for the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada. August 2008. Ottawa: Environment Canada. 72pp. plus 80 pp Appendices.

Environment Canada. 2010. Planning for a Sustainable Future: a Federal Sustainable Development Strategy for Canada. Ottawa: Environment Canada. 75pp.

Environment Canada. 2011a. Round 1: Report on the Engagement Process with Aboriginal Communities and Stakeholders in the Development of the Proposed Recovery Strategy for Boreal Caribou. Unpublished. Ottawa: Environment Canada. 62pp.

Environment Canada. 2011b. Scientific Assessment to Inform the Identification of Critical Habitat for Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population, in Canada: 2011 Update. Ottawa, ON. 102pp. plus appendices.

Environment Canada. 2012a. Recovery Strategy for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population, in Canada. *Species at Risk Act* Recovery Strategy Series. Environment Canada, Ottawa. xi + 138pp.

Environment Canada. 2012b. What People Have Said on the Proposed Recovery Strategy for Boreal Caribou: A summary of the engagement process, comments received and changes made. Ottawa: Environment Canada. 5pp.

Environment and Climate Change Canada. 2016. Range Plan Guidance for Woodland Caribou, Boreal Population. *Species at Risk Act:* Policies and Guidelines Series. Environment and Climate Change Canada, Ottawa. 26p.

Environment and Climate Change Canada. 2017. Report on the Progress of Recovery Strategy Implementation for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal population in Canada for the Period 2012-2017. *Species at Risk Act* Recovery Strategy Series. Environment and Climate Change Canada, Ottawa. ix + 94pp.

Environment and Climate Change Canada. 2018. Action Plan for the Woodland Caribou (*Rangifer tarandus caribou*), Boreal Population in Canada – Federal Actions. *Species at Risk Act* Action Plan Series. Environment and Climate Change Canada, Ottawa. xi + 28pp.

Environment and Climate Change Canada. 2019. Boreal Caribou Science to Inform Recovery: Science Summary Sheet #1. Ottawa, Ontario, Canada. 10p.

Festa-Bianchet, M., J.C. Ray, S. Boutin, S.D. Côté, and A. Gunn. 2011. Caribou conservation in Canada: an uncertain future. *Journal of Canadian Zoology* 89: 419-434.

Fortin, D., F. Barnier, P. Drapeau, T. Duchesne, C. Dussault, S. Heppell, M.-C. Prima, M.-H. St-Laurent and G. Szor. 2017. Forest productivity mitigates human disturbance effects on late-seral prey exposed to apparent competitors and predators. *Scientific Reports*. 7(6370):1-12.

Gillett, N.P., A.J. Weaver, F.W. Zwiers, and M.D. Flannigan. 2004. Detecting the effect of climate change on Canadian forest fires. *Geophysical Research Letters* 31 (18).

Gustine, D.D., K.L. Parker, R.J. Lay, N.P. Gillingham, and D. Heard. 2006. Calf survival of woodland caribou in a multipredator ecosystem. *Wildlife Monographs* 165:1–32

Harrington, F.H., and A.M. Veitch. 1991. Short-term impacts of low-level jet fighter training on caribou in Labrador. *Arctic* 44: 318-327.

Hummel, M. and J.C. Ray. 2008. Caribou and the North: a shared future. Dundurn. 288 pp.

James, A.R.C., and A.K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear features. *Journal of Wildlife Management* 64: 154-159.

Johnson, C.J., K. L. Parker, and D.C. Heard. 2001. Foraging across a variable landscape: behavioural decisions made by Woodland Caribou at multiple special scales. *Oecologia* 127(4): 590 – 602.

Johnston, M. 2009. Vulnerability of Canada's Tree Species to Climate Change and Management Options for Adaptation: An Overview for Policy Makes and Practitioners. Canadian Council of Forest Ministers. 44 pp.

Johnston, M. 2010. Tree Species Vulnerability and Adaptation to Climate Change: Final Technical Report. Saskatchewan Research Council, June 2010.

Kelsall, J.P. 1968. The migratory barren-ground caribou of Canada. Monograph no.3, Canadian Wildlife Service, Indian Affairs and Northern Development. Queen's Printer, Ottawa, Ontario. 339 pp.

Lander, C.A. 2006. Distribution and movement of Woodland Caribou on disturbed landscapes in Manitoba. M.Sc. Thesis, Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba.

Mahoney, S.P., and J.A. Schaefer. 2001. Hydroelectric development and the disruption of migration in caribou. Abstract, 9th North American Caribou Workshop. Kuujjuaq, Quebec, April 23-27, 2001.

McCarthy, S.C., R.B. Weladji, C. Doucet, and P. Saunders. 2011. Woodland caribou calf recruitment in relation to calving/post-calving landscape composition. *Rangifer Special Issue* 31: 35-47.

McLoughlin, P.D., D. Paetkau, M. Duda, and S. Boutin. 2004. Genetic diversity and relatedness of boreal caribou populations in western Canada. *Biological Conservation* 118: 593-598.

Moreau, G., D. Fortin, S. Couturier, and T. Duchesne. 2012. Multi-level functional responses for wildlife conservation: the case of threatened caribou in managed boreal forests. *Journal of Applied Ecology* 49: 611-620.

Nagy, J.A., D.L. Johnson, N.C. Larter, M.W. Campbell, A.E. Derocher, A. Kelly, M. Dumond, D. Allaire, and B. Croft. 2011. Subpopulation structure of caribou (Rangifer tarandus L.) in arctic and subarctic Canada. *Ecological Applications* 21:2334–2348.

Neufeld, L.M. 2006. Spatial dynamics of wolves and Woodland Caribou in an industrial forest landscape in west-central Alberta. M.Sc. Thesis. University of Alberta, Edmonton, Alberta.

Ontario Woodland Caribou Recovery Team. 2008. Woodland Caribou (*Rangifer tarandus caribou*) (Forest-dwelling, Boreal Population) in Ontario. Prepared for the Ontario Ministry of Natural Resources, Peterborough, Ontario. 93pp.

Pinard, V., C. Dussault, J. Ouellet, D. Fortin, and R. Courtois. 2012. Calving rate, calf survival rate, and habitat selection of forest-dwelling caribou in a highly managed landscape. *The Journal of Wildlife Management* 76: 189-199.

Pither, R., M. Manseau, J. Clark, M. Ball, P. Wilson, and A. Arsenault. 2006. Relating the population genetic structure of Woodland Caribou to landscape connectivity. 11th North American Caribou Workshop. Jasper, Alberta, Canada. April 23-27, 2006.

Pitt, W.C., and R.A. Jordan. 1994. A survey of the nematode parasite *Parelaphostrongylus tenuis* in the white-tailed deer, *Odocoileus virginianus*, in a region proposed for caribou, *Rangifer tarandus caribou*, re-introduction in Minnesota. *Canadian Field-Naturalist* 108: 341-346.

Podur, J., D. L. Martell, and K. Knight. 2002. Statistical quality control analysis of forest fire activity in Canada. *Canadian Journal of Forest Research* 32: 195- 205.

Racey, G.D. 2005. Climate change and Woodland Caribou in northwestern Ontario: A risk analysis. *Rangifer Special Issue* No. 16: 123-136.

Racey, G.D., and T. Armstrong. 2000. Woodland Caribou range occupancy in northwestern Ontario: past and present. *Rangifer Special Issue* No. 12:153-184.

Ray, J. 2011. Biological Considerations for Recovery Objectives for Boreal caribou in Canada. Wildlife Conservation Society Canada, Toronto, Ontario.

Redford, K.H., G. Amato, J. Baillie, P. Beldomenico, E.L. Bennett, N. Clum, R. Cook, G. Fonseca, S. Hedges, F. Launay, S. Lieberman, G.M. Mace, A. Murayama, A. Putnam, J.G. Robinson, H. Rosenbaum, E.W. Sanderson, S.N. Stuart, P. Thomas, and J. Thorbjarnarson. 2011. What does it mean to successfully conserve a (vertebrate) species? *BioScience* 61(1): 39-48.

Rettie, W.J., and F. Messier. 1998. Dynamics of Woodland Caribou populations at the southern limit of their range in Saskatchewan. *Canadian Journal of Zoology* 76:257-259.

Rettie, W.J., and F. Messier. 2000. Hierarchical habitat selection by Woodland Caribou: its relationship to limiting factors. *Ecography* 23: 466-478.

Rettie, W.J., and F. Messier. 2001. Range use and movement rates of Woodland Caribou in Saskatchewan. *Canadian Journal of Zoology* 79:1933-1936.

Richie, C. 2008. Management and challenges of the mountain pine beetle infestation in British Columbia. *Alces* 44: 127-135.

Saher, D.J., and F.K.A. Schmiegelow. 2005. Movement pathways and habitat selection by woodland caribou during spring migration. *Rangifer Special Issue* No.16: 143-154.

Sapolsky, R. 1992. Neuroendocrinology of the stress response. Pages 287-324 *in* J.B. Becker, S. M. Breedlove and D. Crews (Editors). *Behavioural Endocrinology*. MIT Press, Cambridge, Massachusetts.

Schaefer, J.A. 2003. Long-term range recession and the persistence of caribou on the taiga. *Conservation Biology* 15: 1435-1439.

Schaefer, J.A., and W.O. Pruitt, Jr. 1991. Fire and Woodland Caribou in southwestern Manitoba. *Wildlife Monographs* 116: 1-39.

Schaefer, J.A., A.M. Veitch, F.H. Harrington, W.K. Brown, J.B. Theberge, and S.N. Luttich. 1999. Demography of decline of the Red Wine Mountain caribou herd. *Journal of Wildlife Management* 63(2): 580-587.

Schmelzer, I., J. Brazil, T. Chubbs, S. French, B. Hearn, R. Jeffery, L. LeDrew, H. Martin, A. McNeill, R. Nuna, R. Otto, F. Phillips, G. Mitchell, G. Pittman, N. Simon, and G. Yetman. 2004. Recovery Strategy for Three Woodland Caribou Herds (*Rangifer tarandus caribou*;

Boreal Population) in Labrador. Newfoundland and Labrador Department of Environment and Conservation, Corner Brook, Newfoundland and Labrador.

Schwartz C.C., and A.W. Franzmann. 1989. Bears, wolves, moose, and forest succession, some management considerations on the Kenai Peninsula, Alaska. *Alces* 25: 1-10.

Seip, D.R. 1991. Predation and caribou populations. *Rangifer Special Issue* No.11: 46-52.

Seip, D.R. 1992. Factors limiting Woodland Caribou populations and their interrelationships with wolves and moose in southeastern British Columbia. *Canadian Journal of Zoology* 70: 1494-1503.

Skinner, W. R., B. J. Stocks, D. L. Martell, and A. Shabbar. 1999. The association between circulation anomalies in the mid-troposphere and area burned by wildland fire in Canada, *Theoretical and Applied Climatology* 63: 89-105.

Skinner, W. R., M. D. Flannigan, B. J. Stocks, D.L. Martell, B.M. Wotton, J.B. Todd, J.A. Mason, K.A. Logan, and E.M. Bosch. 2002. A 500 hPa synoptic wildland fire climatology for large Canadian forest fires, 1959– 1996. *Theoretical and Applied Climatology* 71: 157-169.

Smith, K.G., E.J. Ficht, D. Hobson, T.C. Sorensen, and D. Hervieux. 2000. Winter distribution of Woodland Caribou in relation to clear-cut logging in west-central Alberta. *Canadian Journal of Zoology* 78: 1433-1436.

Stocks, B.J., J. A. Mason, J. B. Todd, E. M. Bosch, B. M. Wotton, B. D. Amiro, M. D. Flannigan, K. G. Hirsch, K. A. Logan, D. L. Martell, and W. R. Skinner. 2003. *Journal of Geophysical Research* 108 (D1), 8149, doi:10.1029/ 2001JD000484.

Stuart-Smith, A.K, C.J.A. Bradshaw, S. Boutin, D.M. Hebert, and A.B. Rippin. 1997. Woodland Caribou relative to landscape pattern in northeastern Alberta. *Journal of Wildlife Management* 61: 622-633.

Telfer, E.S. 1978. Cervid distribution, browse and snow cover in Alberta. *Journal of Wildlife Management* 42: 352-361.

Thomas, D.C., and H.J. Armbruster. 1996. Woodland Caribou Habitat Studies in Saskatchewan: Second Annual Report Including Some Preliminary Recommendations. Environment Canada, Canadian Wildlife Service, Edmonton, Alberta.

Thomas, D.C., and D.R. Gray. 2002. Update COSEWIC status report on the Woodland Caribou *Rangifer tarandus caribou* in Canada, in COSEWIC assessment and update status report on the Woodland Caribou *Rangifer tarandus caribou* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-98 pp.

Toupin, B., J. Huot, and M. Manseau. 1995. Effect of insect harassment on the behaviour of the Rivière George caribou. *Arctic* 49(4): 375-382.

Tyler, N.C. 1991. Short-term behavioural responses of Svalbard reindeer (*Rangifer tarandus*) to direct provocation by a snowmobile. *Biological Conservation* 56: 159-194.

Vandal, D., and C. Barrette. 1985. Snow depth and feeding interaction at snow craters in Woodland Caribou. Pages 199–212 *in* T.C. Meredith and A.M. Martell (editors). Proceedings of the Second North American Caribou Workshop, Val Morin, Quebec, 15–20 October 1984. McGill Subarctic Research Papers no. 36, Centre for Northern Studies and Research, McGill University, Montreal, Quebec.

Van Wagner, C. E. 1988. The historical pattern of annual burned area in Canada. *Forestry Chronicle* 64: 182-185.

Vors, L.S., J.A. Schaefer, B.A. Pond, A.R. Rogers, and B.R. Patterson. 2007. Woodland Caribou extirpation and anthropogenic landscape disturbance in Ontario. *Journal of Wildlife Management* 71:1249-1256.

Vors, L.S., and M.S. Boyce. 2009. Global declines of caribou and reindeer. *Global Change Biology* 15: 2626-2633.

Weckworth, B.V., M. Musiani, A.D. McDevitt, M. Hebblewhite, and S. Mariani. 2012. Reconstruction of caribou evolutionary history in western North America and its implications for conservation. *Molecular Ecology* 21(14): 3610-3624.

Weclaw, P., and R.J. Hudson. 2004. Simulation of conservation and management of Woodland Caribou. *Ecological Modelling* 157: 75-94.

Whitefeather Forest. 2006. Keeping Woodland Caribou on the land: Cross-cultural research in the Whitefeather forest. Whitefeather Forest Management Corporation. Draft Report: June 16, 2006. pp.43.

Whittington, J., M. Hebblewhite, N.J. DeCesare, L. Neufeld, M. Bradley, J. Wilmshurst, and M. Musiani. 2011. Caribou encounters with wolves increase near roads and trails: a time-to-event approach. *Journal of Applied Ecology* 48**:** 1535–1542.

Wittmer, H.U., B.N. McLellan, D.R. Seip, J.A.Young, T.A. Kinley, G.S. Watts, and D. Hamilton. 2005. Population dynamics of the endangered mountain ecotype of Woodland Caribou (*Rangifer tarandus caribou*) in British Columbia, Canada. *Canadian Journal of Zoology* 83: 367-418.

APPENDIX A: EFFECTS ON THE ENVIRONMENT AND OTHER SPECIES

A strategic environmental assessment (SEA) is conducted on all SARA recovery planning documents, in accordance with the *Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals.* The purpose of a SEA is to incorporate environmental considerations into the development of public policies, plans, and program proposals to support environmentally sound decision-making, and to evaluate whether the outcomes of a recovery planning document could affect any component of the environment or any of the *Federal Sustainable Development Strategy's* (FSDS) goals and targets.

Recovery planning is intended to benefit species at risk and biodiversity in general. However, it is recognized that certain strategies may also inadvertently lead to environmental effects beyond the intended benefits, or have negative impacts upon other species. The planning process based on national guidelines directly incorporates consideration of all environmental effects, with a particular focus on possible impacts upon non-target species or habitats. The results of the SEA are incorporated directly into the strategy itself, but are also summarized below in this statement.

Boreal caribou are an umbrella species for the older-growth boreal forest at large. There are many species that share the same habitat requirements as boreal caribou and will benefit from the recovery actions outlined in this recovery strategy. This recovery strategy will benefit the environment and biodiversity as a whole by promoting the recovery of boreal caribou and by protecting and enhancing habitat.

The management measures outlined in this recovery strategy are those required to halt boreal caribou local population declines and to assist in stabilizing and recovering local populations. With respect to broader environmental impacts, certain management tools, most notably predator (e.g. wolves, bears) and alternate prey (e.g. moose, deer) management, may be required in areas with unnaturally high rates of predation on boreal caribou.

Short-term (i.e. 5–10 years) predator and alternate prey suppression has been used in wildlife management across North America over the past decades, with predator and alternate prey species generally demonstrating fairly rapid recovery once the measures have ceased.

The recovery strategy acknowledges that predator and alternate prey management may be required in some ranges to help stop boreal caribou declines and stabilize local populations that are at risk of extirpation. Where applied, predator and alternate prey management should be used as an interim management tool, in conjunction with other management tools (e.g. habitat restoration and management) to prevent extirpation and achieve population growth. Effective indirect predator management techniques (such as actions to limit the access of predators to boreal caribou) should be considered prior to undertaking direct predator and alternate prey management. When a predator or alternate prey management program is being planned, the conservation status of all affected species must be considered. Where implemented, the effects of mortality management activities on boreal caribou local populations should be monitored.

APPENDIX B: ENGAGEMENT WITH INDIGENOUS PEOPLE IN THE DEVELOPMENT OF THE RECOVERY STRATEGY FOR BOREAL CARIBOU

Once a species is listed as extirpated, endangered or threatened under SARA, a recovery strategy must be developed. Recognizing the important traditional, cultural, and spiritual role of boreal caribou in the lives of Indigenous people, Environment and Climate Change Canada sought engagement and input from Indigenous communities in the development of both the 2012 Recovery Strategy and the 2020 Amended Recovery Strategy for boreal caribou.

2012 Recovery Strategy (2009-2012)

Two rounds of engagement were undertaken, with a focus on seeking input and sharing information with Indigenous communities. In addition, Environment and Climate Change Canada supported processes to gather Indigenous Knowledge (see Appendix C). These two components were essential in the development of the 2012 Recovery Strategy. Nationally, Environment and Climate Change Canada contacted over 260 Indigenous communities located within and adjacent to the current distribution of boreal caribou during both rounds of engagement to invite them to participate in Environment and Climate Change Canada's process to develop the recovery strategy for boreal caribou.

Round 1 Meetings (2009-2011)

In the first round of engagement on the recovery strategy, Environment and Climate Change Canada contacted 271 Indigenous communities and 161 of them participated. Engagement at this early stage in the development of the recovery strategy provided Indigenous communities the opportunity to share comments, opinions, and information about boreal caribou. Environment and Climate Change Canada used this information to inform the development of the key elements of the recovery strategy, including: i) population and distribution objectives for boreal caribou; ii) threats to boreal caribou and their habitat; and iii) identification of boreal caribou critical habitat.

The information that Environment and Climate Change Canada received from Indigenous communities and from stakeholder meetings, meetings with the provinces and territories, scientific studies, and Indigenous Knowledge studies were used to draft the proposed recovery strategy (Environment Canada, 2011a).

Round 2 Meetings (2011-2012)

In the second round of engagement, Environment and Climate Change Canada contacted 265 [1] Indigenous communities and 87 of those participated; in addition, Environment and Climate Change Canada received 25 formal submissions from Indigenous communities and organizations. This round of engagement provided the opportunity for comments and dialogue

[1] During the first round of engagement, 6 Indigenous communities indicated they did not require any further follow-up throughout this process. This accounts for the discrepancy in the number of Indigenous communities contacted during round 1 and 2.

on the proposed recovery strategy that was posted on the Species at Risk Public Registry on August 26, 2011. The required 60-day public comment period was extended by an additional 120 days until February 22, 2012 to allow time for Indigenous communities to better participate in the engagement process and provide comments on the proposed recovery strategy prior to finalization.

Environment and Climate Change Canada considered all feedback received from Indigenous communities, along with the over 19,000 comments received from government, industry, environmental organizations, and the public when finalizing the 2012 Recovery Strategy (Environment Canada, 2012b). Changes made to the proposed recovery strategy were a direct result of the feedback received during the public comment period, including the input received from Indigenous communities and organizations.

2020 Amended Recovery Strategy (2018 – 2019)

Environment and Climate Change Canada contacted 34 Indigenous communities and 31 Indigenous organizations/governments located within and adjacent to northern Saskatchewan's Boreal Shield range (SK1) to invite them to participate in the process to develop an amendment to the 2012 Recovery Strategy for boreal caribou to identify critical habitat in SK1. At the time of posting the proposed amendment to the recovery strategy on the Species at Risk Public Registry, 11 communities and five organizations/governments participated in information sessions and/or meetings. This engagement provided the opportunity for participating groups to share information, comments, and dialogue on the draft amendment to the recovery strategy.

APPENDIX C: INDIGENOUS KNOWLEDGE SUMMARY REPORTS ON BOREAL CARIBOU

SARA specifies that "... the traditional knowledge of the Aboriginal peoples of Canada should be considered (...) in developing and implementing recovery measures." In the summer of 2009, Environment and Climate Change Canada made a commitment to ensure that Indigenous Knowledge from across the range of boreal caribou would inform the development of the recovery strategy. This commitment came from the recognition that Indigenous people possess significant and unique knowledge about boreal caribou biology, population trends, distribution, and threats facing the species, which could support recovery planning.

Environment and Climate Change Canada staff in each province/territory within the boreal caribou range began the process to have Indigenous Knowledge inform the recovery strategy by contacting Indigenous provincial and territorial organizations, Tribal Councils, and Indigenous consultants/facilitators to determine their interest in helping to gather Indigenous Knowledge. Additionally, each Indigenous community within and adjacent to the range of boreal caribou was contacted and followed up with, inviting them to participate in the process of developing the recovery strategy. As a result of these efforts, one of three basic processes was followed in the participating communities:

1. Local or regional Indigenous organizations interviewed knowledge holders;
2. Regional or local workshops coordinated by Indigenous facilitators were held; or
3. Indigenous Knowledge sharing was done in partnership with other initiatives (e.g. projects funded by Aboriginal Funds for Species at Risk).

All Indigenous contractors/communities/organizations that participated prepared summary reports based on interviews with knowledge holders. Environment and Climate Change Canada's Boreal Caribou Working Group received all summary reports and reviewed these in detail to highlight information that could inform the recovery strategy. Knowledge provided that would be more applicable at the action planning stage was also identified and flagged by Environment and Climate Change Canada's Boreal Caribou Working Group. The purpose of this step was to identify where and how the Indigenous Knowledge could support the recovery strategy and the subsequent range and/or action plans.

Each Indigenous Knowledge summary report received contains unique and geographically specific information that is representative of the knowledge and experiences shared by knowledge holders (Boreal Caribou ATK Reports, 2010-2011). Indigenous Knowledge with respect to boreal caribou life history, habitat use, population status, threats facing the species, and conservation measures was used to inform the recovery strategy. In addition, Indigenous Knowledge holders shared considerable detailed local knowledge about boreal caribou, which may be used to support range and/or action plans, if and where consent for such use is granted. In all cases, Environment and Climate Change Canada reconfirmed the intention of the use of Indigenous Knowledge in this document with knowledge holders.

APPENDIX D: SCIENTIFIC ASSESSMENTS OF CRITICAL HABITAT FOR BOREAL CARIBOU

2008 Scientific Review

In 2007, Environment and Climate Change Canada launched a science-based review with the mandate to identify boreal caribou critical habitat to the extent possible, using the best available information, and/or prepare a schedule of studies to complete this task. The results were summarized in a report entitled *Scientific Review for the Identification of Critical Habitat for Woodland Caribou (Rangifer tarandus caribou), Boreal Population, in Canada* (hereinafter referred to as the 2008 Scientific Review).

Identifying critical habitat for boreal caribou was framed as an exercise in decision analysis and adaptive management. Establishment of a systematic, transparent and repeatable process was central to the approach. The resultant Critical Habitat Framework was anchored by synthesis and analysis of available quantitative data and published scientific information on boreal caribou population and habitat ecology.

The 2008 Scientific Review established boreal caribou ranges as the appropriate scale at which to identify critical habitat, and applied a probabilistic approach to assessing the adequacy of the current range conditions to support a self-sustaining local population based on three lines of evidence: percent total disturbance, local population growth and local population size. Of the 57 local populations or units of analysis delineated at the time, 30 were assessed as 'Not Self-Sustaining' (integrated probability of less than 0.5), 17 as 'Self-Sustaining' (integrated probability of greater than 0.5), and 10 as "as likely as not self-sustaining" (integrated probability equal to 0.5).

Additional Scientific Activities

The 2008 Scientific Review established a foundation for the assessment of critical habitat; however, Environment and Climate Change Canada identified key areas for further exploration to improve the science foundation to inform the identification of critical habitat:

1. Implications to critical habitat identification of variation in approaches applied by provincial and territorial jurisdictions to delineate ranges.
2. Relative impacts of different disturbances and habitat types, and their configurations, on the ability of ranges to support self-sustaining local populations, and resultant critical habitat identification.
3. Identification of disturbance management thresholds for self-sustaining local populations.
4. Influence of future range conditions on disturbance management thresholds given the dynamic nature of disturbance in a given range.

The purpose of addressing these knowledge gaps was to further inform the identification of critical habitat for boreal caribou, using the best available information. To this end, Environment and Climate Change Canada undertook the work presented in the Scientific Assessment to Inform the Identification of Critical Habitat for Woodland Caribou *(Rangifer tarandus caribou),*

Boreal Population, in Canada: 2011 Update (herein referred to as the 2011 Scientific Assessment).

2011 Scientific Assessment: Concepts and Methodology

Similar to the 2008 Scientific Review, the 2011 Scientific Assessment was designed to provide a probabilistic evaluation of critical habitat relative to the set of conditions (demographic and environmental) for each range. The framework and components developed in the 2008 Scientific Review were expanded and enhanced through a suite of scientific activities including: enhanced disturbance mapping; habitat selection analysis; buffer analysis; meta-analysis of boreal caribou local population and habitat conditions; assessment of current conditions to support self-sustaining boreal caribou local populations using indicators of two ecological components of sustainability (stable or positive population growth and long-term persistence); representation of future conditions through application of a simple habitat dynamics model; and development of a methodology for establishing risk-based, range-specific disturbance management thresholds based on best available information.

Information to Support the Identification of Critical Habitat

The information to inform the identification of boreal caribou critical habitat provided in the 2011 Scientific Assessment for each range consists of the following four components:

1. The delineation and location of the range, and certainty in range delineation.
2. An integrated risk assessment based on multiple lines of evidence from three indicators, and application of hierarchical decision rules to evaluate the probability that current conditions on a range will support a self-sustaining local population. The result is expressed as a likelihood statement relative to achieving the population and distribution objectives.
3. Information to support the identification of disturbance management thresholds. Specifically, a consistent methodology for deriving such thresholds is provided, along with examples of their potential application, and discussion of their interpretation relative to the criteria and indicators evaluated.
4. A description of the biophysical attributes, defined as the habitat characteristics required by boreal caribou to carry out life processes necessary for survival and recovery. The results from the habitat selection analyses and other published reports were used to summarize biophysical attributes by ecozone.

The related goals of assessing the ability of ranges to support self-sustaining local populations, and establishment of disturbance management thresholds, must acknowledge uncertainties arising from the availability and reliability of information about current local population condition, as well as how local populations might respond to additional and often interacting stressors. The probabilistic approach applied in the 2011 Scientific Assessment explicitly incorporated the effects of uncertainties and data quality in the assessment process. This approach is consistent with the concept of adaptive management, which expresses probable outcomes as hypotheses. Monitoring and evaluation of realized outcomes informs adaptations of management strategies over time.

Key Findings

The information and analyses presented in the 2011 Scientific Assessment addresses limitations identified with implementation of the work presented in the 2008 Scientific Review. However, neither the approach nor the results of the 2011 assessment represent a fundamental shift from the 2008 Scientific Review's conclusion that range is the appropriate geographic delineation for critical habitat description. Further, the amount of total disturbance within a range remains the primary criteria for identifying critical habitat to meet a goal of self-sustaining local populations of boreal caribou.

Highlights of the application of the conceptual framework and associated analyses supporting the 2011 assessment include:

1. Nearly 70% of the variation in boreal caribou recruitment across 24 study areas spanning the full range of boreal caribou distribution and range condition in Canada was explained by a single composite measure of total disturbance (fire + buffered anthropogenic), most of which could be attributed to the negative effects of anthropogenic disturbance.
2. Of the 57 identified boreal caribou ranges in Canada at the time, 17 (30%) were assessed in the 'self-sustaining' category, 7 (12%) in the "as likely as not self-sustaining category", and 33 (58%) in the 'not self-sustaining' category.
3. Range-specific disturbance management thresholds can be derived from a generalized disturbance-population growth function in conjunction with range-specific information. A methodology was developed to extend the critical habitat description for consideration of disturbance management thresholds when acceptable risks are defined by managers.

In addition to these highlights, several important observations related to the availability of information emerged, and recommendations related to these are advanced:

1. Most boreal caribou ranges in Canada have not been fully described owing to a lack of standardized animal location data and poor understanding of movement within and between ranges. While a total of 57 ranges were still recognized at the time by provincial and territorial jurisdictions in Canada, changes to the delineation of boreal caribou ranges have been made since the 2008 Scientific Review, by various jurisdictions, based on different criteria. The issue of appropriate delineation of transboundary ranges remains unresolved.
2. Demographic data are lacking for many boreal caribou ranges in Canada. Monitoring and assessment programs to provide data on local population size, local population trend, recruitment and adult mortality are required to improve understanding of factors affecting boreal caribou survival and recovery, to increase certainty in assessment results, and to monitor response of local populations to recovery actions and to assess progress towards meeting the population and distribution objectives for boreal caribou across Canada.

In conclusion, significant advances were made to the conceptual and methodological design in the 2011 Scientific Assessment to address some key uncertainties or limitations identified in the 2008 Scientific Review. These advances improved the robustness of the results with respect to providing a scientific basis to inform the identification of critical habitat for boreal caribou across Canada.

Scientific Research to Inform Critical Habitat in Saskatchewan's Boreal Shield Range

The 2012 Recovery Strategy used the scientific foundation of the 2008 Scientific Review and 2011 Scientific Assessment as the basis for critical habitat identification for all boreal caribou ranges in Canada, except for northern Saskatchewan's Boreal Shield range (SK1) (Environment Canada, 2008; Environment Canada, 2011b; Environment Canada, 2012a). Critical habitat for SK1 was not identified in 2012 because population size and trend were unknown, and the high fire (55%) and low anthropogenic (3%) disturbance represented conditions not well represented in the data used to identify 65% undisturbed habitat in each range as the disturbance management threshold. The 2012 Recovery Strategy identified this knowledge gap in the schedule of studies.

Since the 2012 Recovery Strategy, three years of demographic data have been collected for SK1 and a number of other jurisdictions have also acquired additional recruitment and adult survival data, with better representation of the spectrum of combinations between anthropogenic disturbance and fire. Environment and Climate Change Canada also updated the disturbance mapping, based on 2015 imagery, facilitating temporal correspondence with the new demographic data. This new and larger dataset facilitated additional scientific analysis including (Environment and Climate Change Canada, 2019):

1. An evaluation of a subset of the 2011 recruitment models to distinguish the effects of buffered anthropogenic disturbance from the effects of fire.
2. An evaluation of the newly collected demographic data from SK1 in the context of the national models that predict recruitment as a function of disturbance.
3. An evaluation of the subset of 2011 models to investigate the potential influence of anthropogenic disturbance and fire on adult female survival.
4. A scenario analysis exploring the potential impacts of additional levels of buffered anthropogenic disturbance using updated information.

Key Findings (Environment and Climate Change Canada, 2019)

1. The model separating the effects of anthropogenic disturbance (buffered by 500m) from fire received the highest level of support explaining 39% of the variation in recruitment. Both anthropogenic disturbance and fire had significant negative effects; however, anthropogenic disturbance had a larger effect.
2. Both the total disturbance model (top model in 2011) and the model separating anthropogenic disturbance from fire adequately predict recruitment for SK1 (average observed recruitment falls within 95% confidence intervals).
3. In the evaluation of adult female survival, the top model included anthropogenic disturbance (buffered by 500m) only, explaining about 12% of the variation. Additional analysis are required to understand other potential factors that may be influencing adult female survival. Currently, SK1 has one of the highest rates of boreal caribou adult female survival reported in Canada. Additional analyses indicate that the probability of maintaining a self-sustaining population in SK1 is sensitive to decreases in adult female

survival. For example, the probability that SK1 is self-sustaining would drop to less than 20% if adult female survival fell from 0.91 to 0.87 (assuming no change in recruitment).

4. At current disturbance levels, the probability that SK1 is self-sustaining is 71%; the probability is based on the three years of recruitment and adult survival collected for SK1. The scenario analyses suggest that SK1 would fall to 60% chance of maintaining a self-sustaining population with an additional 2.5-3.0% anthropogenic disturbance. Continued population monitoring will be important in order to reduce uncertainty in population condition over the longer term and to monitor population response to future landscape change.

APPENDIX E: IDENTIFYING DISTURBANCE MANAGEMENT THRESHOLDS

This Appendix is derived from Environment and Climate Change Canada's Scientific Assessment (2011b), and has been adapted for the purposes of this recovery strategy. A methodology was developed for consideration of disturbance management thresholds (Environment Canada, 2011b) and is herein described. Establishing disturbance management thresholds requires a recovery goal and an acceptable level of risk from a management perspective.

The recovery goal for boreal caribou is to achieve self-sustaining local populations in all boreal caribou ranges throughout their current distribution in Canada, to the extent possible. Environment and Climate Change Canada (2011b) expressed this recovery goal as the likelihood of observing a mean lambda (population growth) over a 20-year period of a stable or increasing population and the likelihood of the population size remaining above a quasi-extinction threshold of 10 reproductively active females over a 50 year period. The likelihood of the population remaining stable or increasing over 20 years was based on two indicators: population trend and disturbance level within a boreal caribou range. In order to assess the influence of disturbance level on the population trend, a study was completed to develop a relationship that expresses the probability of a population being stable or increasing at varying levels of total range disturbance (see Figure E-1). This relationship was derived by combining information on the negative effects of disturbance on boreal caribou recruitment with a national mean annual adult survival rate for mature females. This relationship was used to inform the range condition required to meet the recovery goal which is a core element of the identification of critical habitat in this recovery strategy.

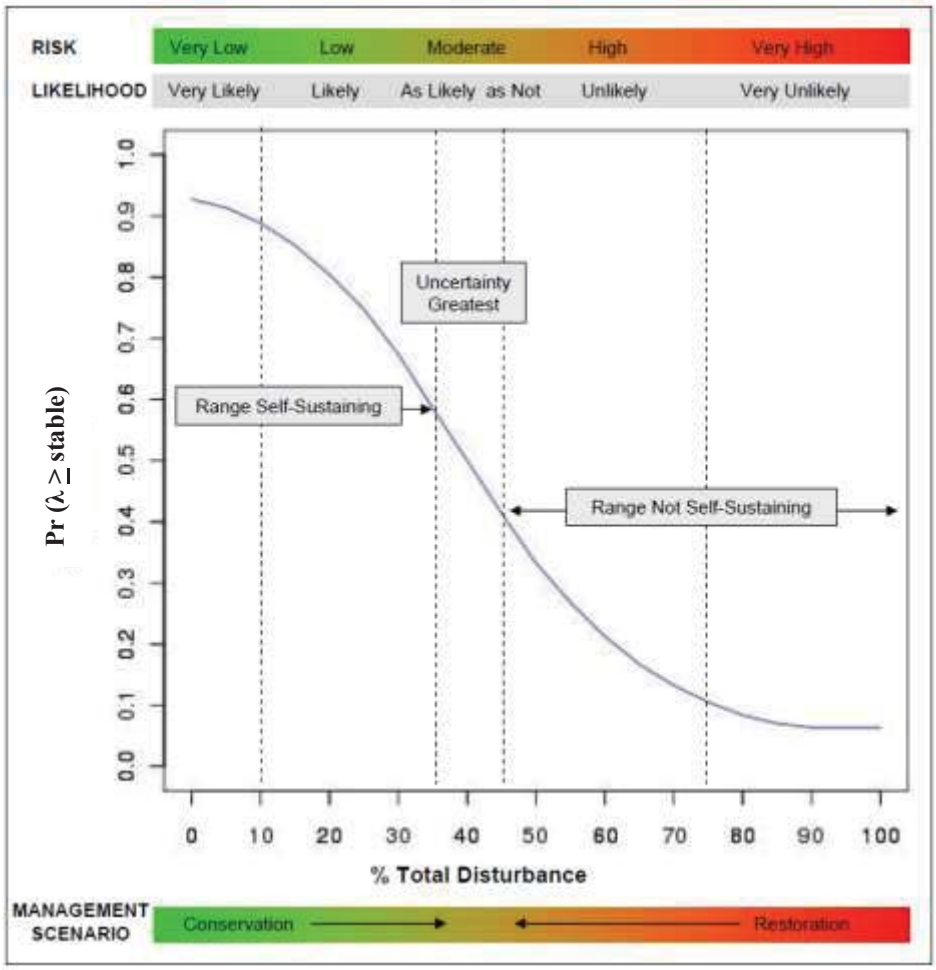


Figure E-1. Disturbance management thresholds: The probability of observing stable or positive growth ($\lambda \geq$ stable) of boreal caribou local populations over a 20-year period at varying levels of total range disturbance (fires $\leq$ 40 years + anthropogenic disturbances buffered by 500 m). Certainty of outcome, ecological risk, and management scenarios are illustrated along a continuum of conditions.

The disturbance values associated with the likelihood of achieving a self-sustaining local population can be used to express the relative risk of not achieving a self-sustaining local population (see Table E-1). At this point, a given management objective or target must be specified in order to determine what is an acceptable level of risk from a management perspective.

Table E-1. Intervals of total range disturbance associated with varying levels of certainty in outcome and assigned risk relative to achieving stable or positive population growth.

Probability of Sustained Stable or Positive Growth[1]	Likelihood of Desired Outcome	Disturbance Interval	Level of Risk
≥ 90%	Very Likely	≤ 10%	Very Low
< 90 to ≥ 60%	Likely	> 10 to 35%	Low
< 60 to ≥ 40%	As Likely as Not	> 35 to 45%	Moderate
< 40 to ≥ %10	Unlikely	> 45 to 75%	High
< 10%	Very Unlikely	>75%	Very High

[1] *Intervals adapted from the International Panel on Climate Change 2005; time frame for assessing mean growth rate is 20 years.*

A disturbance management threshold marks the point below which (i.e. at lower levels of disturbance) range conditions are likely to meet the recovery goal with an acceptable level of risk, and above which the outcome is either highly uncertain or unacceptable. In this recovery strategy a 0.6 or 60% probability of self-sustainability (i.e. population growth is stable/increasing) is applied resulting in a maximum disturbance management threshold of 35% total disturbance (or 65% undisturbed habitat as referenced throughout the recovery strategy) (see Figure E-1). A probability of 1.0 or 100 % is ideal, however, unrealistic since 0% total disturbance is virtually impossible even without anthropogenic disturbances. The maximum disturbance management threshold of 35% at 0.6 or 60% probability of self-sustainability is a reasonable starting point providing a likely certainty of recovery, given the available information on boreal caribou at this time. It is important to emphasize that this is a maximum disturbance management threshold because there is still a risk (0.4 or 40%) that local populations will not be self-sustaining. Local populations that have greater than 35% total disturbance (or less than 65% undisturbed habitat) will first be recovered to the 35% disturbance management threshold (i.e. to achieve 65% undisturbed habitat). The disturbance management threshold may be altered in the future as more information becomes available on the associated level of risk for boreal caribou local populations to meet the recovery goal outlined in this strategy.

For SK1, a minimum of 40% undisturbed habitat in the range is identified as the disturbance management threshold, which provides a measurable probability of 71% for the local population to be self-sustaining. Given that the analyses conducted by Environment and Climate Change Canada indicate that the population is sensitive to small increases in anthropogenic disturbance and sensitive to small decreases in adult survival, a higher probability of persistence was selected for critical habitat identification in SK1 (71%) than was selected for the other 50 ranges across Canada (60%) (Environment and Climate Change Canada, 2019). Continued population monitoring will be needed to reduce uncertainty in population condition over the longer term, particularly in light of future changes in range condition (e.g. increased fires associated with climate change).

APPENDIX F: SUMMARY OF BOREAL CARIBOU LOCAL POPULATION CONDITION AND HABITAT CONDITION

Table F-1 provides a summary of boreal caribou local population condition and habitat condition for each of the 51 boreal caribou ranges. Boreal caribou distribution (see Figure 2) and population and habitat condition information is based on the best available information including observational and telemetry data, and biophysical analyses, provided by provincial and territorial jurisdictions (Environment and Climate Change Canada, 2017). As a result of limited information on many of the ranges in Canada, only three transboundary ranges (a range that extends across a provincial or territorial boundary) have been defined: Northwest Territories range (NT1), Chinchaga range (AB1), and Lac Joseph range (NL1). As more refined information is being continually collected by jurisdictions, range delineation and population demographic information will be updated and may result in revisions to range boundaries and possibly more transboundary ranges. The assessment of self-sustainability may change when ranges that cross jurisdictional boundaries are combined. Range boundaries and integrated risk assessments will be updated annually based on new or more refined evidence provided by the provincial and territorial jurisdictions. In some cases, local population size estimates and trend data are based primarily on professional judgment and limited data, and not on rigorously collected field data.

The Range Type lists the different classification of local populations based on June 2012 range boundaries for boreal caribou provided by jurisdictions, which were subsequently classified into three types reflecting the level of certainty in range boundaries: Conservation Units (CU - low certainty), Improved Conservation Units (ICU- medium certainty), and Local Population (LP - high certainty).

Risk assessment is the status of self-sustainability of the local populations where SS=self-sustaining; NSS = not self-sustaining; NSS/SS = as likely as not self-sustaining.

Further explanation on disturbance is provided in Section 4.2.1.

Table F-1. Boreal caribou local population condition and habitat condition information. The population condition and habitat condition have been updated in this amended recovery strategy based on information previously published in the 5-Year Progress Report (Environment and Climate Change Canada, 2017).

Range Identification	Range Name	Range Type	Population Estimate relative to 100[1] (≥ 100, or < 100)	Population Trend	Disturbed Habitat (%)			Risk Assessment[5]
					Fire[2]	Anthropogenic[3]	Total[4]	
Northwest Territories								
NT1	Northwest Territories	ICU	≥ 100[6]	not available[7]	28	9	35	SS
British Columbia								
BC1	Maxhamish	LP	≥ 100	stable[8]	2	67	68	NSS
BC2	Calendar	LP	≥ 100	stable[8]	16	53	61	NSS

Range Identification	Range Name	Range Type	Population Estimate relative to 100[1] (≥ 100, or < 100)	Population Trend	Disturbed Habitat (%)			Risk Assessment[5]
					Fire[2]	Anthropogenic[3]	Total[4]	
BC3	Snake-Sahtahneh	LP	≥ 100	stable[8]	5	77	79	NSS
BC4	Parker	LP	< 100	declining[8]	3	57	57	NSS
BC5	Prophet	LP	< 100	declining[8]	10	78	78	NSS
Alberta								
AB1	Chinchaga (incl. BC portion)	LP	≥ 100	declining	9	79	80	NSS
AB2	Bistcho	LP	≥ 100	declining	40	58	75	NSS
AB3	Yates	LP	≥ 100	stable	42	20	55	NSS
AB4	Caribou Mountains	LP	≥ 100	declining	46	27	62	NSS
AB5	Little Smoky	LP	≥ 100	stable[9]	0.4	96	96	NSS
AB6	Red Earth	LP	≥ 100	declining	40	48	72	NSS
AB7	West Side Athabasca River	LP	≥ 100	declining	5	70	72	NSS
AB8	Richardson	LP	≥ 100	stable	74	23	88	NSS
AB9	East Side Athabasca River	LP	≥ 100	declining	28	78	84	NSS
AB10	Cold Lake	LP	≥ 100	declining	33	76	87	NSS
AB11	Nipisi	LP	< 100	not available[10]	9	75	77	NSS
AB12	Slave Lake	LP	< 100	not available[10]	39	74	87	NSS
Saskatchewan								
SK1	Boreal Shield	CU	≥ 100[11]	stable	58	3	60	SS
SK2	Boreal Plain	CU	≥ 100	not available[12]	30	20	45	NSS/SS
Manitoba								
MB1	The Bog	ICU	≥ 100[13]	not available[14]	6	14	19	NSS/SS
MB2	Kississing	ICU	≥ 100[13]	not available[14]	39	15	54	NSS
MB3	Naosap	ICU	not available[15]	not available[15]	28	28	52	NSS
MB4	Reed	ICU	not available[15]	not available[15]	7	20	26	SS

Range Identification	Range Name	Range Type	Population Estimate relative to 100[1] (≥ 100, or < 100)	Population Trend	Disturbed Habitat (%)			Risk Assessment[5]
					Fire[2]	Anthropogenic[3]	Total[4]	
MB5	North Interlake	ICU	< 100	not available[14]	4	14	18	NSS/SS
MB6	William Lake	ICU	< 100	not available[14]	25	17	36	NSS
MB7	Wabowden	ICU	≥ 100	not available[14]	10	20	28	SS
MB8	Wapisu	ICU	not available[15]	not available[15]	11	13	24	SS
MB9	Manitoba North	CU	not available[15]	not available[15]	23	11	33	NSS/SS
MB10	Manitoba South	CU	not available[15]	not available[15]	4	12	16	SS
MB11	Manitoba East	CU	not available[15]	not available[15]	26	3	29	SS
MB12	Atikaki-Berens	ICU	not available[15]	not available[15]	29	6	34	SS
MB13	Owl-Flinstone	LP	< 100	not available[14]	25	18	39	NSS/SS
Ontario								
ON1	Sydney	ICU	< 100	declining	27	25	49	NSS
ON2	Berens	ICU	≥ 100	declining	31	6	37	NSS/SS
ON3	Churchill	ICU	≥ 100	declining	8	28	34	SS
ON4	Brightsand	ICU	≥ 100	declining	19	26	41	NSS/SS
ON5	Nipigon	ICU	≥ 100	declining	7	25	30	SS
ON6	Coastal	CU	≥ 100	declining	0	15	15	SS
ON7	Pagwachuan	ICU	≥ 100	stable	0.7	27	27	SS
ON8	Kesagami	ICU	≥ 100	declining	3	37	40	NSS
ON9	Far North	CU	≥ 100[16]	declining[16]	15	1	16	SS
Quebec								
QC1	Val d'Or	LP	< 100	declining	0.2	65	65	NSS
QC2	Charlevoix	LP	< 100	declining	4	80	82	NSS
QC3	Pipmuacan	ICU	≥ 100	declining	11	60	68	NSS

Range Identification	Range Name	Range Type	Population Estimate relative to 100[1] (≥ 100, or < 100)	Population Trend	Disturbed Habitat (%)			Risk Assessment[5]
					Fire[2]	Anthropogenic[3]	Total[4]	
QC4	Manouane	ICU	≥ 100	stable	18	26	41	NSS/SS
QC5	Manicouagan	ICU	≥ 100[17]	stable[17]	3	36	37	SS
QC6	Quebec	CU	≥ 100[17]	not available[18]	20	13	32	SS
Newfoundland and Labrador[19]								
NL1	Lac Joseph	LP	≥ 100	not available[20]	12	2	14	NSS/SS
NL2	Red Wine Mountain	LP	≥ 100[21]	not available[22]	7	3	9	NSS
NL3	Mealy Mountain	LP	≥ 100	not available[23]	1	1	2	NSS/SS

[1] A minimum of 100 animals was used in the 2011 Scientific Assessment to evaluate when local populations might be vulnerable to extinction from stochastic events due to small size (Environment Canada, 2011b).
[2] Fire disturbance is any area where a fire has occurred in the past 40 years (without buffer).
[3] For anthropogenic disturbance, a 500 meter buffer is applied to all linear and polygonal disturbances.
[4] For total disturbance, both anthropogenic and fire disturbances that overlap are not counted twice in the total.
[5] With the exception of the Boreal Shield range (SK1), the integrated risk assessments have not been updated in this amended recovery strategy.
[6] The population size estimate for NT1 is 6000 to 7000 individuals.
[7] Sub-regional collar-based monitoring programs, and traditional and community knowledge, suggests that boreal caribou population trends differ in various part of NT1. Generally speaking, population trends seem to be increasing or stable in northern NT1, and stable or decreasing in southern NT1. More information is available in the Northwest Territories' Recovery Strategy published in 2017(http://www.nwtspeciesatrisk.ca/sites/default/files/nwt_boreal_caribou_recovery_strategy_2017_final_0.pdf).
[8] In 2013-2014 there was a bacterial pathogen outbreak which caused local population declines in BC. Parker and Prophet ranges have not recovered from the outbreak. The other local populations have been recovering, but the current trend information may not reflect equilibrium conditions for these populations.
[9] AB5 is stable in response to delivery of an annual wolf population reduction program.
[10] Population trend is not available for AB11 and AB12 due to low collared female sample size, resulting in unreliable estimates of annual adult female survival.
[11] The population size estimate for SK1 is >5000 individuals.
[12] Monitoring data are insufficient in SK2 to establish a population trend.
[13] The increase to ≥ 100 reflects an increased survey effort and does not necessarily indicate an improvement in overall status.
[14] Population trend data for Manitoba ranges are under review by the province of Manitoba and were not available to be included in this amended recovery strategy.
[15] The province of Manitoba delineated new range boundaries in 2015 (https://www.gov.mb.ca/sd/wildlife/sar/pdf/cariboustrategy_octfall2015.pdf). As a result, there are no updated population data available for these ranges. Population data for Manitoba's new provincial ranges are presented in the 5-Year Progress Report (Environment and Climate Change Canada, 2017).
[16] ON9 was delineated into 6 new ranges by the province of Ontario in 2013 (https://www.ontario.ca/document/range-management-policy-support-woodland-caribou-conservation-and-recovery). Population data for these new provincial ranges are presented in the 5-Year Progress Report (Environment and Climate Change Canada, 2017).

[17] The province of Quebec is in the process of updating range and population condition metrics for QC5 and QC6. Preliminary data are available in the 5-Year Progress Report for areas defined by Fortin et al. (2017) (Environment and Climate Change Canada, 2017).
[18] It is not possible to estimate population trend for QC6 as a whole because of insufficient survey data across the range. Preliminary population trends are available in the 5-Year Progress Report for areas defined by Fortin et al. (2017) that fall within the QC6 range (Environment and Climate Change Canada, 2017).
[19] The province of Newfoundland and Labrador is in the process of updating population condition metrics as part of an updated provincial recovery plan. The future reporting of survey results will be dependent on ongoing exercises to delineate subpopulations in Labrador.
[20] A recent survey was conducted in the NL1 range, but the data could not be analyzed in time for this amended recovery strategy.
[21] The understanding of population structure for NL2 has changed since the 2012 Recovery Strategy. The increase to ≥ 100 animals is due to a shift from minimum population counts (associated with collar deployment and other field activities) to systematic surveys in portions of the range.
[22] Preliminary data and expert opinion suggests that population trends in NL2 are generally increasing in the southern part of the range and declining in the northern part of the range.
[23] The understanding of population structure for NL3 has changed since the 2012 Recovery Strategy. A survey of NL3 is tentatively being planned during the next five years with Parks Canada Agency.

APPENDIX G: DETAILS ON THE IDENTIFICATION OF CRITICAL HABITAT FOR BOREAL CARIBOU

Table G-1 provides a summary of boreal caribou habitat condition for each of the 51 boreal caribou ranges. Boreal caribou distribution (see Figure 2) and habitat condition information is based on the best available information including observational and telemetry data, and biophysical analyses, provided by provincial and territorial jurisdictions (Environment Canada, 2011b). As a result of limited information on many of the ranges in Canada, only three transboundary ranges (a range that extends across a provincial or territorial boundary) have been defined: Northwest Territories range (NT1), Chinchaga range (AB1), and Lac Joseph range (NL1). As more refined information is being continually collected by jurisdictions, range delineation and population demographic information will be updated and may result in revisions to range boundaries and possibly more transboundary ranges. The assessment of self-sustainability may change when ranges that cross jurisdictional boundaries are combined. Range boundaries and integrated risk assessments will be updated annually based on new or more refined evidence provided by the provincial and territorial jurisdictions.

As described in Section 7.1, the identification of critical habitat for boreal caribou is comprised of three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

Table G-1. Boreal caribou critical habitat information. The habitat condition has been updated in this amended recovery strategy based on information previously published in the 5-Year Progress Report (Environment and Climate Change Canada, 2017).

Range Identification	Location	Amount					Type
	Range Name	Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Biophysical Attributes (see corresponding ecozone table in Appendix H)
			Fire[1]	Anthropogenic[2]	Total[3]		
Northwest Territories							
NT1	Northwest Territories	44,166,546	28	9	35	65	Taiga Plain Boreal Plain Southern Arctic Taiga Cordillera
British Columbia							
BC1	Maxhamish	710,105	2	67	68	32	Taiga Plain
BC2	Calendar	496,393	16	53	61	39	Taiga Plain
BC3	Snake-Sahtahneh	1,198,752	5	77	79	21	Taiga Plain
BC4	Parker	75,222	3	57	57	43	Taiga Plain
BC5	Prophet	119,396	10	78	78	22	Taiga Plain
Alberta							
AB1	Chinchaga (incl. BC portion)	3,162,612	9	79	80	20	Taiga Plain Boreal Plain

Range Identification	Location	Amount					Type
	Range Name	Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Biophysical Attributes (see corresponding ecozone table in Appendix H)
			Fire[1]	Anthropogenic[2]	Total[3]		
AB2	Bistcho	1,436,555	40	58	75	25	Taiga Plain
AB3	Yates	523,094	42	20	55	45	Taiga Plain
AB4	Caribou Mountains	2,069,000	46	27	62	38	Taiga Plain Boreal Plain
AB5	Little Smoky	308,606	0.4	96	96	4	Montane Cordillera Boreal Plain
AB6	Red Earth	2,473,729	40	48	72	28	Boreal Plain
AB7	West Side Athabasca River	1,572,652	5	70	72	28	Boreal Plain
AB8	Richardson	707,350	74	23	88	12	Boreal Shield (West) Boreal Plain
AB9	East Side Athabasca River	1,315,980	28	78	84	16	Boreal Plain
AB10	Cold Lake	672,422	33	76	87	13	Boreal Plain
AB11	Nipisi	210,771	9	75	77	23	Boreal Plain
AB12	Slave Lake	151,904	39	74	87	13	Boreal Plain
Saskatchewan							
SK1	Boreal Shield	18,034,870	58	3	60	40	Taiga Shield Boreal Shield (West)
SK2	Boreal Plain	10,592,463	30	20	45	55	Boreal Plain
Manitoba							
MB1	The Bog	446,383	6	14	19	81	Boreal Plain
MB2	Kississing	317,029	39	15	54	46	Boreal Shield (West)
MB3	Naosap	456,977	28	28	52	48	Boreal Shield (West) Boreal Plain
MB4	Reed	357, 425	7	20	26	74	Boreal Shield (West) Boreal Plain
MB5	North Interlake	489,680	4	14	18	82	Boreal Plain
MB6	William Lake	488,219	25	17	36	64	Boreal Plain
MB7	Wabowden	628,938	10	20	28	72	Boreal Shield (West) Boreal Plain
MB8	Wapisu	565,044	11	13	24	76	Boreal Shield (West)

Range Identification	Location	Amount					Type
	Range Name	Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Biophysical Attributes (see corresponding ecozone table in Appendix H)
			Fire[1]	Anthropogenic[2]	Total[3]		
MB9	Manitoba North	6,205,520	23	11	33	67	Boreal Shield (West) Boreal Plain
MB10	Manitoba South	1,867,255	4	12	16	84	Boreal Plain
MB11	Manitoba East	6,612,782	26	3	29	71	Boreal Shield (West and West Central)
MB12	Atikaki-Berens	2,387,665	29	6	34	66	Boreal Shield (West Central)
MB13	Owl-Flinstone	363,570	25	18	39	61	Boreal Shield (West Central)
Ontario							
ON1	Sydney	753,001	27	25	49	51	Boreal Shield (West Central)
ON2	Berens	2,794,835	31	6	37	63	Boreal Shield (West Central)
ON3	Churchill	2,150,490	8	28	34	66	Boreal Shield (West Central)
ON4	Brightsand	2,220,921	19	26	41	59	Boreal Shield (West Central)
ON5	Nipigon	3,885,026	7	25	30	70	Boreal Shield (West and West Central)
ON6	Coastal	376,598	0	15	15	85	Boreal Shield (West Central and Central)
ON7	Pagwachuan	4,542,918	0.7	27	27	73	Hudson Plain Boreal Shield (West, West Central and Central)
ON8	Kesagami	4,766,463	3	37	40	60	Hudson Plain Boreal Shield (Central)
ON9	Far North	28,265,143	15	1	16	84	Hudson Plain Boreal Shield (West and West Central)
Quebec							
QC1	Val d'Or	346,861	0.2	65	65	35	Boreal Shield (Central)
QC2	Charlevoix	312,803	4	80	82	18	Boreal Shield (Southeast)

Range Identification	Location	Amount					Type
	Range Name	Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Biophysical Attributes (see corresponding ecozone table in Appendix H)
			Fire[1]	Anthropogenic[2]	Total[3]		
QC3	Pipmuacan	1,376,899	11	60	68	32	Boreal Shield (East)
QC4	Manouane	2,716,449	18	26	41	59	Boreal Shield (East)
QC5	Manicouagan	1,134,129	3	36	37	63	Boreal Shield (East)
QC6	Quebec	62,156,186	20	13	32	68	Boreal Shield (Central, East and Southeast) Taiga Shield Hudson Plain
Newfoundland and Labrador							
NL1	Lac Joseph	5,802,491	12	2	14	86	Taiga Shield Boreal Shield (East)
NL2	Red Wine Mountain	5,838,594	7	3	9	91	Taiga Shield Boreal Shield (East)
NL3	Mealy Mountain	3,948,463	1	1	2	98	Taiga Shield Boreal Shield (East)

[1] Fire disturbance is any area where a fire has occurred in the past 40 years (without buffer).
[2] For anthropogenic disturbance, a 500 meter buffer is applied to all linear and polygonal disturbances.
[3] For total disturbance, both anthropogenic and fire disturbances that overlap are not counted twice in the total.

APPENDIX H: BIOPHYSICAL ATTRIBUTES FOR BOREAL CARIBOU CRITICAL HABITAT

Biophysical Attributes

Indigenous Knowledge (Boreal Caribou ATK Reports, 2010-2011), habitat selection analyses, and scientific published reports (Environment Canada, 2011b) were used to summarize biophysical attributes required by boreal caribou to carry out life processes necessary for survival and recovery. Results are provided by ecozone and ecoregion in order to capture the ecological variation across the distribution of boreal caribou.

Boreal Caribou Ranges by Ecozone and Ecoregion

Boreal caribou are distributed in the boreal forest across eight ecozones in Canada including: Taiga Plain, Montane Cordillera, Taiga Shield, Boreal Plain, Boreal Shield, Hudson Plain, Southern Arctic, and Taiga Cordillera. The largest ecozone, Boreal Shield, is further divided into five ecoregions: Boreal Shield West, Boreal Shield West Central, Boreal Shield Central, Boreal Shield East, and Boreal Shield South East (see Figure H-1).

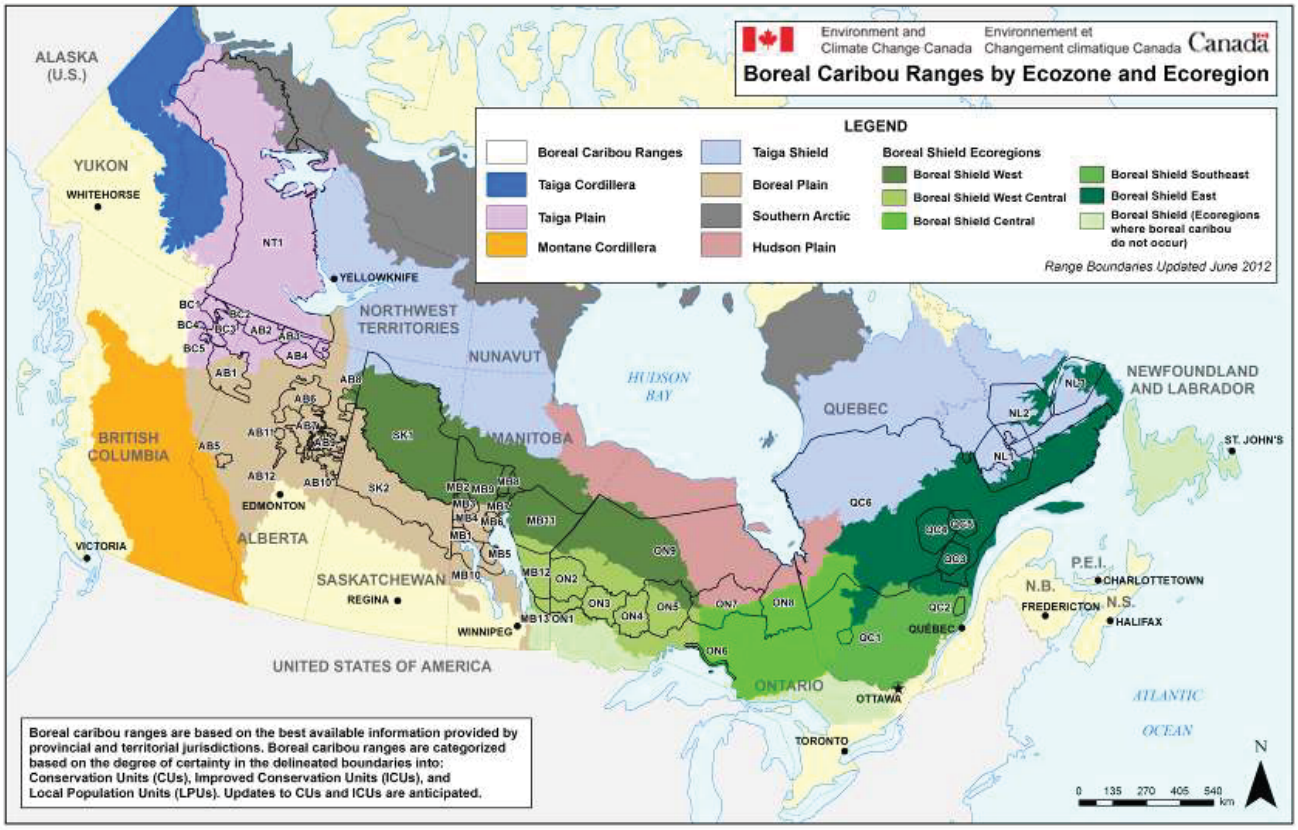


Figure H-1. Boreal caribou distribution across ecozones and ecoregions in Canada.

Biophysical Attribute Descriptions

The biophysical attributes for boreal caribou critical habitat are categorized by the types of habitat used by boreal caribou in accordance with seasonal and life-stage activity which include broad scale, calving, post-calving, rutting, wintering, and travel. This information is provided in the following tables by ecozone and ecoregion.

Biophysical attributes will vary both between and within boreal caribou ranges. As the biophysical attributes presented in this recovery strategy were developed at a national scale by ecozone and ecoregion, and not by local population, it is anticipated that each provincial and territorial jurisdiction may have or will develop over time, a more refined description of the biophysical attributes required for each range. Biophysical attributes specific to boreal caribou ranges in Labrador have been provided by the jurisdiction and are included in Table H-6 below.

Table H-1. Biophysical attributes for boreal caribou critical habitat in the Taiga Plain ecozone.

Type of habitat	Description
Broad scale	Mature forests (jack pine, spruce, and tamarack) of 100 years or older, and open coniferous habitat. Large areas of spruce peat land and muskeg with preference for bogs over fens and upland and lowland black spruce forests with abundant lichens, and sedge and moss availability. Flatter areas with smaller trees and willows, hills and higher ground.
Calving	Open coniferous forests, tussock tundra, low shrub, riparian, recent burned areas, south and west aspects and hills and higher locations. Muskegs, marshes, staying close to water sources. Caribou observed on small islands of mature black spruce or mixed forests within peat lands, in old burns at the edge of wetlands, in alder thickets with abundant standing water and on lake shores.
Post-calving	Muskegs or areas with access to muskegs, open meadows on higher ground, close to water (lakes and rivers) and mixed bush areas. Open coniferous forests with abundant lichens, low shrub, riparian, tussock tundra, sparsely vegetative habitat, recent burns and west aspects. Old burns and neighbouring remnant unburned forests selected in late spring and early summer.
Rutting	Open coniferous and mixed wood forests, low shrub, riparian, tussock tundra, recent burns and west aspect. Still use muskegs that harbor ground lichen and sedges, mixed bush areas, areas of higher ground. Regenerating burns and sparsely vegetated habitat.
Winter	Open coniferous forests (black spruce and pine) that provide adequate cover with abundant lichens, riparian areas. Caribou observed in muskeg areas in early winter. Spruce-lichen forests, fire regenerated, sparsely vegetated habitat, herbaceous and tall shrub habitat and sphagnum moss with scattered spruce. As snow depth increases, they remain more often in areas of dense pine or thickly wooded black spruce, with hanging lichen and remains access to open, mixed vegetation for ground forage.
Travel	Females show high fidelity to calving sites among years (i.e. within 14.5 km). Many caribou shift the pattern of use based on seasonal preferences, in large multi-habitat areas. Rates of movement increase during the rut and are greatest in winter.

Table H-2. Biophysical attributes for boreal caribou critical habitat in the Montane Cordillera ecozone.

Type of habitat	Description
Broad scale	Upland lodge pole pine, mixed conifer lodgepole pine/black spruce and treed muskeg areas with abundant lichens. Open, pine dominated stands of 80 years or more.
Calving	Areas closer to cut-blocks with a high proportion of larch are selected during calving. Lower mountain peaks.
Post-calving	Homogeneous areas of conifer dominated stands.
Rutting	No information on rutting habitat currently available.
Winter	Caribou use areas with a high proportion of larch and pine forests during winter.

Table H-3. Biophysical attributes for boreal caribou critical habitat in the Taiga Shield ecozone (see Table H-6 for biophysical attributes more specific to Labrador ranges).

Type of habitat	Description
Broad scale	Upland tundra dominated by ericaceous shrubs (*Ericaceae* spp.), lichen, grasses and sedges. Lowland tundra composed of peat land complexes (muskeg and string bogs), wetlands (swamps, marshes), lakes, rivers and riparian valleys. Dense mature jack pine and black spruce stands with balsam fir and tamarack present and open conifer forests with abundant lichens.
Calving	String bogs, treed bogs, small open wetlands (< 1 km^2), large muskeg, marshes along water bodies. Barren grounds. Calving on peninsulas and islands increases with amount of open water.
Post-calving	Forested wetlands. Hilly areas, coastal sites, along shorelines of water bodies (rivers, lakes, creeks), marshes with lichen availability.
Rutting	Open wetlands, swamps. Mature forests, mountainous terrain with forests of black spruce, tamarack and pine trees with abundant lichen.
Winter	Forested areas are used in years of low snow accumulation; otherwise winter habitat selection reflects general avoidance of deep snow, including use of tundra habitat at higher elevations in mountainous regions and bogs along lakes or oceans. Forested wetlands. Tundra uplands and sand flats in proximity to water. Barren grounds. Bog edges, glacial erratics and bedrock erratics with lichen and lakes. Some use of mature white spruce and fir stands as alternative to habitat with arboreal lichens. Mix of mature forest stands, mountainous terrain with forests of black spruce, tamarack and jack pine with abundant lichen.
Travel	Connectivity between selected habitat types important given reported patterns of movement among caribou. Some animals have been reported to travel up to distances of approximately 200 km, although the majority of animals appear to move shorter distances. Females show fidelity to post-calving sites returning to within 6.7 km of a given location in consecutive years.

Table H-4. Biophysical attributes for boreal caribou critical habitat in the Boreal Plain ecozone.

Type of habitat	Description
Broad scale	Late seral-stage (> 50 years old) conifer forest (jack pine, black spruce, tamarack), treed peat lands, muskegs or bogs, use dry islands in the middle of muskegs, with abundant lichens. Hilly or higher ground and small lakes. Restricted primarily to peat land complexes. Higher elevations (~1135 m). Selected old (>40 years) burns.
Calving	Bogs and mature forests selected for calving as well as islands and small lakes. Peat lands and stands dominated by black spruce and lowland black spruce stands within muskeg are used for calving.
Post-calving	Forest stands older than 50 yrs. Upland black spruce/jack pine forests, lowland black spruce, young jack pine and open and treed peat lands and muskeg are also selected during summer. Use lichen and low muskeg vegetation. In some areas, sites with abundant arboreal lichen are selected during summer.
Rutting	Mature forests. Upland black spruce/jack pine forests, lowland black spruce, young jack pine and open and treed peat lands and muskeg during summer.
Winter	Treed peat lands, treed bog and treed fen and open fen complexes with > 50% peat land coverage with high abundance of lichens. Use of small lakes, rock outcrops on lakes for lichen access. Mature forest > 50 years old. Upland black spruce/jack pine forests, lowland black spruce, young jack pine and open and treed peat lands.

Table H-4a. Biophysical attributes for boreal caribou critical habitat in the Boreal Shield West ecoregion.

Type of habitat	Description
Broad scale	Conifer/tamarack-dominated peat land complexes, muskegs or bogs, use dry islands in the middle of muskegs and upland moderate to dense mature conifer forests (jack pine, black spruce, tamarack) with abundant lichens. Hilly or higher ground, lots of smaller lakes in area.
Calving	Peat lands, stands dominated by black spruce, mature forest stands and treed muskeg all used for calving. Caribou will use islands, small lakes, lakeshores during calving.
Post-calving	Wooded lakeshores, islands, sparsely treed rock, upland conifer-spruce and treed muskeg are used in summer. Sites with a high abundance of arboreal lichen are important for foraging in some areas. Dense conifer and mixed forest are also used.
Rutting	Dense and sparse conifer and mixed forests. Open riparian habitats are also used during the rut.
Winter	Mature upland spruce, pine stands and treed muskeg. Jack pine dominated forests. Caribou select sparse and dense conifer, mixed forests and treed bogs. In some areas caribou will select habitat with greater visibility and further away from forest edges.
Travel	Some males move > 100 km during the rutting season. Traditional travel routes between summer and winter ranges occur in large peat land complexes. Caribou migrate in a north to south pattern.

Table H-4b. Biophysical attributes of boreal caribou habitat in the Boreal Shield West Central ecoregion.

Type of habitat	Description
Broad scale	Mature conifer uplands and conifer/tamarack dominated lowlands. Conifer/tamarack-dominated peat lands, muskegs with abundant arboreal lichens, upland mature conifer forests stands with abundant terrestrial lichen and rocky areas with sparse trees. Elevations of 300 m. Intermediate values of Normalized Difference Vegetation Index[1]. Selection for old (>40 years) burns.
Calving	Forested wetlands/treed bog, old burns, sparse conifer and dense spruce. Need lichen availability. Peat lands, raised hillrocks with large muskeg areas, forested islands and shorelines of large lakes selected during calving. Jack pine or jack pine/black spruce forests also used for calving.
Post-calving	Peat land with forested islands, islands, and shorelines selected during summer. Mature, dense forest stands.
Rutting	Semi-open and open bogs and mature conifer uplands selected during rutting. Terrestrial lichens and arboreal lichens, sedges and bog ericoids (*Andromeda glaucophylla, Chamaedaphne calyculata, Kalmia polifolia,* and *Ledum groenlandicum*) are important sources of forage.
Winter	Mature coniferous stands. Areas with a high proportion of lakes (> 5-100 ha) with convoluted shorelines. Caribou forage in areas with high lichen abundance and fewer shrubs in jack pine and black spruce stands with low tree densities, low basal areas and short heights. Caribou select open bogs, intermediate to mature jack pine rock ridges, jack pine habitats with lichens and lakes, but move to jack pine ridges in mature conifer stands with lichen when winter conditions prevent foraging in bogs. Arboreal lichens, terrestrial lichens, sedges and ericaceous species are an important source of forage.
Travel	Travel mainly in conifer forests, avoiding open habitats (e.g. lakes, disturbed areas, etc.) when migrating from summer to winter habitat. Use frozen lakes for travel during winter/spring, in some instances to reach islands for calving. Spring migration is not restricted to specific travel routes. Some move at a range of 100 km during the rutting season. Caribou moved 8-60 km away after logging operations were begun.

Table H-4c. Biophysical attributes for boreal caribou critical habitat in the Boreal Shield Central ecoregion.

Type of habitat	Description
Broad scale	Late seral-stage black spruce-dominated lowlands and jack pine dominated uplands. Open black spruce lowlands. Low-density late seral-stage jack pine or black spruce forests and black spruce/tamarack-dominated peat lands with abundant terrestrial and moderate arboreal lichens. Caribou also use areas with dry to moist sandy to loamy soils and shallow soils over bedrock. Elevations of 300 m. Intermediate values of Normalized Difference Vegetation Index[1]. Selection for old (>40 years) burns.
Calving	Open canopies of mature black spruce and mesic peat land with ericaceous species for calving are selected for calving in the Claybelt region. Females with calves selected areas with more abundant ericaceous shrubs and terrestrial lichens during the summer compared to females without calves.
Winter	Large areas of contiguous forests dominated by black spruce. Open conifer forests or forests with lower tree densities where terrestrial and arboreal lichen are abundant and there is significant less snow (e.g. shorelines) are also selected.

Table H-4d. Biophysical attributes for boreal caribou critical habitat in the Boreal Shield East ecoregion (see Table H-6 for biophysical attributes more specific to Labrador ranges).

Type of habitat	Description
Broad scale	Conifer-feather moss forests on poorly-drained sites and mature conifer uplands with abundant terrestrial lichen. Black spruce, jack pine and balsam fir stands present with abundant lichen. Water bodies and wetlands (swamps, marshy areas with tamarack). Mountains or rolling hills. Elevations of 300 m. Intermediate values of Normalized Difference Vegetation Index[1]. Selection for old (>40 years) burns.
Calving	Open wetlands, peninsulas and islands. Sedges, ericaceous species, bryophytes, alder and larch selected in spring. Balsam fir, dense black spruce stands, spruce-fir forests older than 40 years, and dry bare land with high lichen densities. Mature conifer stands, as well as wetlands (marshes, peat moss areas). Higher altitudes used for calving in this area rather than lake or water bodies.
Post-calving	Open and forested wetlands (marshes, swamps), and continued use of peninsulas and islands. Hilly areas, coastal sites, shorelines (rivers, lakes, creeks). Aquatic plants, dwarf birch (*Betula glandulosa*), deciduous shrubs, ericaceous species and moss.
Rutting	Open wetlands selected, swamps. Terrestrial and arboreal lichens, forbs, sedges, mosses and coniferous and deciduous shrubs. Balsam fir stands, dense spruce stands, mature and regenerating conifer stands, other forest stands (tamarack, pine) with abundant lichens, wetlands (swamps) and dry bare lands.
Winter	Forested wetlands. Some use of upland-tundra for loafing. Mountainous terrain. Dry bare land, wetlands, mature conifer forests with lichen, balsam fir stands, dense spruce stands, and mixed spruce-fir forests older than 40 years selected in southern areas. Observed along frozen bodies of water. Use of mature forests protected from harvesting increases probability of encounters with wolves that select the same habitats in winter. Shallow snow depths selected in late winter.
Travel	Caribou move greater distances during the rutting season.

Table H-4e. Biophysical attributes for boreal caribou critical habitat in the Boreal Shield Southeast ecoregion.

Type of habitat	Description
Broad scale	Late seral-stage black spruce-dominated lowlands and jack pine-dominated uplands, Balsam fir stands, marshlands and abundant lichen.
Calving	Open, medium-closed conifer forests. Elevations of 300 m. Intermediate values of Normalized Difference Vegetation Index[1]. Selection for old (>40 years) burns.
Rutting	Dense and open mature conifer forests of spruce, tamarack, jack pine and young conifer forests between 30 – 50 years old.
Winter	Open stands of balsam fir, balsam fir-black spruce, black spruce, black-spruce-tamarack and jack pine stands older than 70 yrs. Dry bare lands, 30-50 year old stands of balsam fir or fir-black spruce, as well as 50 year old jack pine stands, and arboreal and terrestrial lichens.

Table H-5. Biophysical attributes for boreal caribou critical habitat in the Hudson Plain ecozone.

Type of habitat	Description
Broad scale	Habitats selected generally to reduce predation risk. Shrub rich treed muskeg and mature conifer forests abundant in lichens. Shorelines of deep lakes and rivers (birch trees). Poorly drained areas dominated by sedges, mosses and lichens, as well as open black spruce and tamarack forests. Elevations of 150m. Intermediate levels of ruggedness[1] and Normalized Difference Vegetation Index[2].
Calving	Mature conifer stand with and without lichens and muskegs. Preference for higher altitudes compared to habitat use during other periods.
Post-calving	Fens, bogs and lakes.
Rutting	Wetlands and conifer stands with lichen. Mature and regenerating conifer stands are also used, albeit to a lesser degree. Caribou use hills in the lowlands, treed islands in muskegs with several different tree species.
Winter	Dense and mature conifer forests with lichens and wetlands. Peat lands dominated by open bogs and terrestrial lichens. Large patches of intermediate and mature black spruce, shrub-rich treed muskeg and mixed conifer stands all used in late winter.
Travel	Movements greatest in fall/winter when caribou transition from calving to winter habitat. Long range movements are greater in areas with high moose densities, presumably to reduce predation risk.

[1] Vector ruggedness is a metric used to capture variability in slope and aspect.
[2] Normalized Difference Vegetation Index (NDVI) is an index that provides a standardized method of comparing vegetation greenness between satellite images.

NOTE: A small portion of boreal caribou critical habitat in the northern portion of the Northwest Territories range falls within the Southern Arctic ecozone and the Taiga Cordillera ecozone. Currently, there is no information available on boreal caribou habitat use or biophysical attributes in either of these ecozones. Biophysical attributes in the Taiga Plain ecozone are used to describe the type of habitat needed for the identification of critical habitat for boreal caribou in the Southern Arctic and Taiga Cordillera ecozones.

Biophysical attributes specific to Labrador ranges, containing detailed information as made available by the jurisdiction.

Table H-6. Biophysical attributes of boreal caribou critical habitat in the Taiga Shield ecozone and Boreal Shield East ecoregion, specific to Labrador ranges.

Type of habitat	Description
Broad scale	Subarctic and boreal forests. Tundra and low shrubs at high elevations. Numerous lakes, peatlands (string, plateau and basin bogs, ribbed and ladder fens) and peatland complexes of several wetland types adjacent and contiguous to each other, broad river valleys. Lichen woodlands, new and regenerating burns. Intermediate values of Normalized Difference Vegetation Index[1]. <u>Lac Joseph (NL1)</u> Mid and low subarctic forests characterized by open coniferous forests, eskers and upland plateaus. Black spruce dominant; jackpine and trembling aspen occur sporadically. Poorly-drained sites characterized by extensive ribbed fen-string bog complexes bordered by black-spruce sphagnum stands. Well drained sites and river uplands often containing open lichen woodlands. Lakes comprising approximately 15%of range, including Lac Joseph, Lake Ashuanipi and Atikonak Lakes. <u>Red Wine Mountain (NL2)</u> High boreal forest and alpine areas in addition to low subarctic forest. Boreal forest portions contain productive, close-canopied boreal forests, with deep river valleys. Black spruce predominant, while some balsam fir, white birch, and trembling aspen also occur. Dominant topographical feature are the Red Wine Mountains (600m- 900m asl), and an extensive upland boreal plateau consisting of a mosaic of extensive string bogs and open conifer forest (400 m asl). Alpine areas with tundra vegetation; larch and black spruce on lower valley slopes. <u>Mealy Mountain (NL3)</u> Extensive tree-less coastal barrens and offshore islands with tundra-like vegetation, and extensive string bogs and open pools of water, with hummocks dominated by scrub spruce and Labrador tea on the Eagle River Plateau. Mid-boreal forest characterized by closed-canopied black spruce and balsam fir forests. Eskers which occasionally support ribbons of lichen woodland. Dominant topographical feature is the Mealy Mountain range (1000m asl), containing alpine areas with tundra vegetation.
Calving	Muskegs, lakes and islands, peninsulas of large lakes, or combinations of these features. Mature, dense conifer stands (>90 years) with a sphagnum, forb or shrub understory, particularly when in proximity to wetlands or lakes.
Post-calving and summer	Immediately post calving: wetlands and areas with open water, and adjacent areas of mature, dense coniferous forest. Summer (July through September) and early fall: broader array of vegetation communities in the vicinity of their calving areas, including mature coniferous forests with a shrub or moss/forb understory, treed bogs and some open-canopied woodlands with an extensive shrub understory. Open and forested wetlands (muskeg, treed bogs) and continued use of peninsulas and islands, shorelines (rivers, lakes, creeks). Riparian plants, dwarf birch (*Betula glandulosa*), willow, ericaceous shrubs, forbs grasses and sedges for forage.

Type of habitat	Description
Rutting	Wetlands and areas with open water, and adjacent areas of mature, dense coniferous forest. Mature coniferous forests with a shrub or moss/forb understory, treed bogs and some open-canopied woodlands with an extensive shrub understory. Open and forested wetlands (muskeg, treed bogs) and continued use of peninsulas and islands, shorelines (rivers, lakes, creeks). Riparian plants, dwarf birch (*Betula glandulosa*), willow, ericaceous shrubs, forbs and sedges for forage.
Winter	Early winter (November through January): lichen woodlands and lichen-shrub woodlands. Occasional use of wetlands. Late winter: lichen woodlands, ice-covered water bodies (for rest and as a refuge), and regenerating burns (with shrub and Cladina mitis understory) in some cases. Extensive use of coastal barrens in Mealy Mountain range. Some use of Alpine areas in Red Wine Mountain and Mealy Mountain range.
Travel	During spring and fall migration, select open habitats that are easy to travel through. In particular, during spring migration select for (frozen) wetlands and burns, and during fall migration added open lichen woodlands to the latter cover classes. Most females travel up to 20 km from winter areas to calving sites, but can move by as much as 120 km.

[1] Normalized Difference Vegetation Index (NDVI) is an index that provides a standardized method of comparing vegetation greenness between satellite images.

APPENDIX I: MITIGATION TECHNIQUES TO AVOID DESTRUCTION OF CRITICAL HABITAT

Mitigation of the adverse effects that may result from a proposed project on boreal caribou could include different techniques. These techniques include avoiding destruction of undisturbed habitat or biophysical attributes necessary for the species to carry out life processes, reducing noise or pollution, or minimizing disturbance by adapting its shape or adjusting the timing of the disturbance. Table I-1 provides examples of considerations and possible mitigation techniques when planning development within a boreal caribou range.

Table I-1. Examples of considerations when planning development within a boreal caribou range and possible mitigation techniques.

Considerations when planning development	Examples of possible mitigation techniques
Threshold of disturbance in the short- and long-term	Minimize the footprint of development, consider locations where habitat is already disturbed; restore habitat to provide continual availability of undisturbed habitat over time.
Ecological factors	Avoid destruction of biophysical attributes (see Appendix H).
Spatial configuration	Minimize disturbance by adapting its shape (small polygon vs. linear).
Sensory disturbances	Mitigation of noise, light, smells, vibrations to prevent harassment of boreal caribou.
Pollution	Mitigate pollution through scrubbers or other techniques. Some types of pollution may be especially of concern (e.g. air pollution that increases acidity may affect lichens on which boreal caribou depend for food).
Timing of disturbance	Certain types of disturbance could occur only in seasons when boreal caribou are not using the area or do not respond negatively to the activity.
Induced effects	New access roads in previously undisturbed areas may induce further disturbance by opening territory to more development, recreational users, etc. This could be prevented by an access management plan that could include limiting access, decommissioning roads, etc.
Corridors that support predator movement	Impact may be reduced by using techniques that prevent use of corridor by predators (no compaction of snow, immediate replanting of trees, etc.).
Increases in predator and/or alternate prey populations	Mortality management techniques may be considered where the killing of predators would be a final, necessary option implemented temporarily, along with habitat restoration.

APPENDIX J: CRITICAL HABITAT FACTSHEETS



Illustration © Judie Shore

CRITICAL HABITAT FACTSHEETS: NORTHWEST TERRITORIES

Critical Habitat Identification: Northwest Territories Range (NT1)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-1. Key map of the general location of the range.

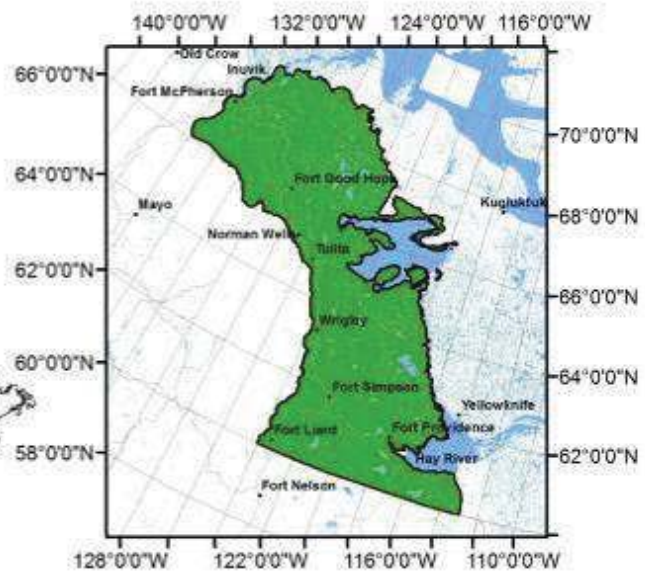


Figure J-2. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
44,166,546	28	9	35	65	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain
	Boreal Plain
	Southern Arctic
	Taiga Cordillera

[1] *See Appendix H*

CRITICAL HABITAT FACTSHEETS: BRITISH COLUMBIA

Critical Habitat Identification: Maxhamish Range (BC1)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-3. Key map of the general location of the range.

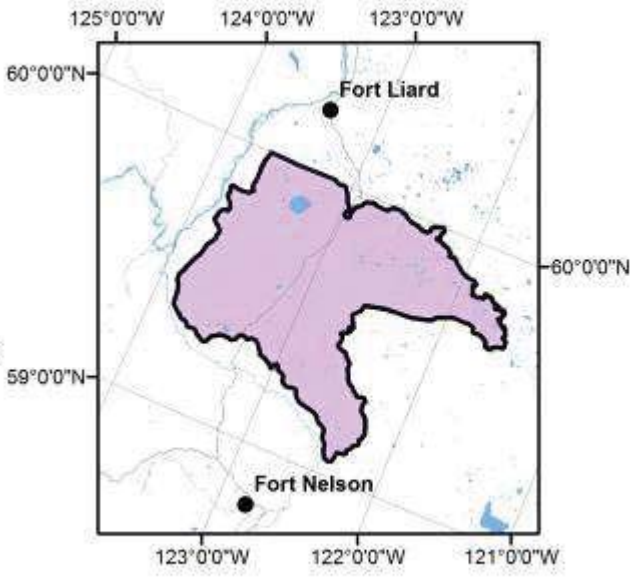


Figure J-4. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
710,105	2	67	68	32	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain

[1] *See Appendix H*

Critical Habitat Identification: Calendar Range (BC2)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-5. Key map of the general location of the range.

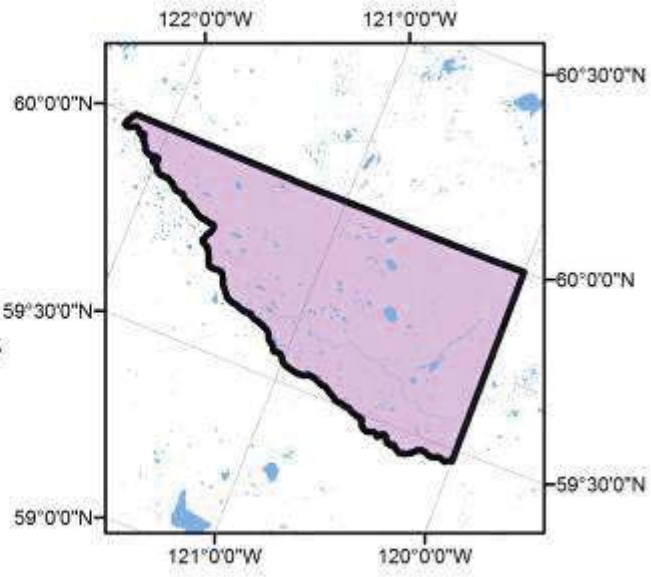


Figure J-6. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
496,393	16	53	61	39	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain

[1] *See Appendix H*

Critical Habitat Identification: Snake-Sahtahneh Range (BC3)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-7. Key map of the general location of the range.

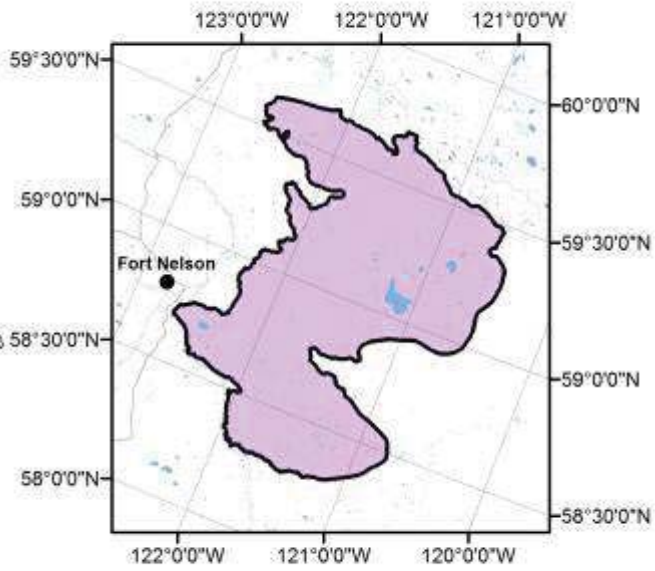


Figure J-8. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
1,198,752	5	77	79	21	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain

[1] *See Appendix H*

Critical Habitat Identification: Parker Range (BC4)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-9. Key map of the general location of the range.



Figure J-10. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
75,222	3	57	57	43	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain

[1] *See Appendix H*

Critical Habitat Identification: Prophet Range (BC5)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-11. Key map of the general location of the range.

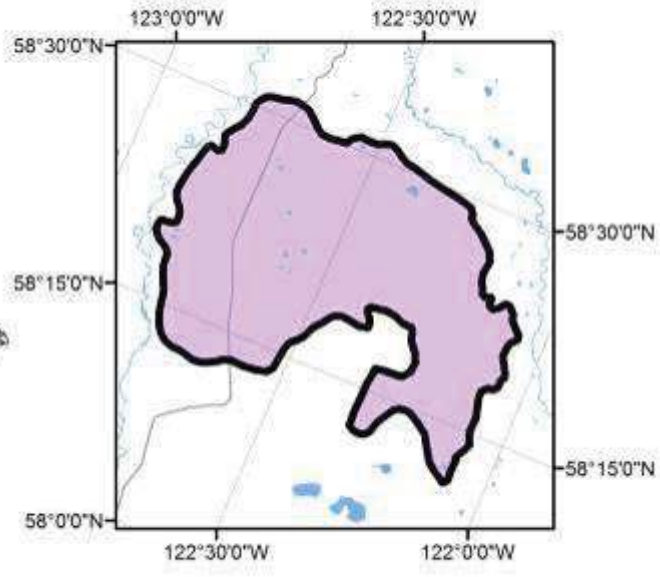


Figure J-12. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
119,396	10	78	78	22	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain

[1] *See Appendix H*

CRITICAL HABITAT FACTSHEETS: ALBERTA

Critical Habitat Identification: Chinchaga Range (incl. BC portion) (AB1)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-13. Key map of the general location of the range.



Figure J-14. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
3,162,612	9	79	80	20	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain
	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Bistcho Range (AB2)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-15. Key map of the general location of the range.

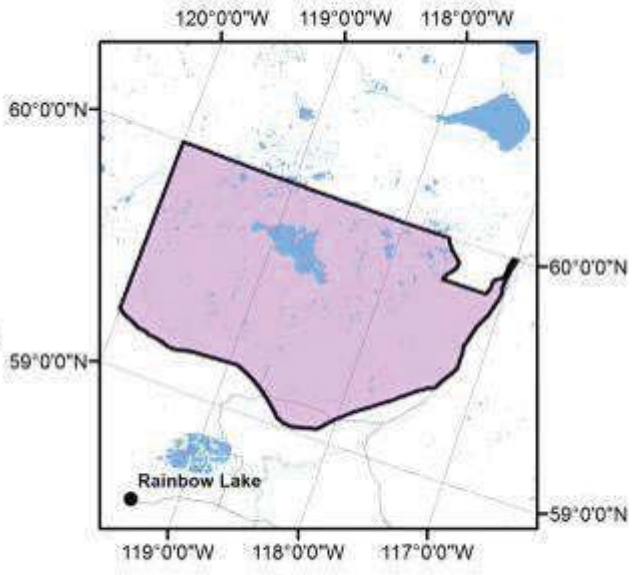


Figure J-16. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
1,436,555	40	58	75	25	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain

[1] *See Appendix H*

Critical Habitat Identification: Yates Range (AB3)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-17. Key map of the general location of the range.



Figure J-18. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
523,094	42	20	55	45	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain

[1] *See Appendix H*

Critical Habitat Identification: Caribou Mountains Range (AB4)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-19. Key map of the general location of the range.

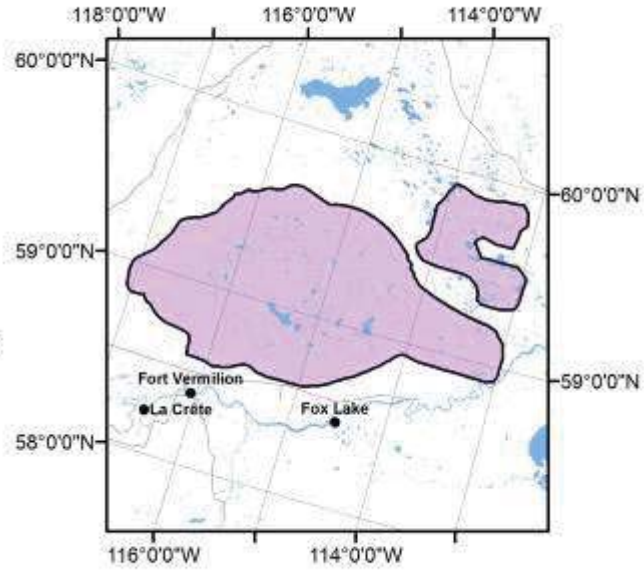


Figure J-20. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
2,069,000	46	27	62	38	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Plain
	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Little Smoky Range (AB5)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-21. Key map of the general location of the range.



Figure J-22. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
308,606	0.4	96	96	4	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Montane Cordillera
	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Red Earth Range (AB6)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-23. Key map of the general location of the range.



Figure J-24. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
2,473,729	40	48	72	28	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: West Side Athabasca River Range (AB7)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-25. Key map of the general location of the range.

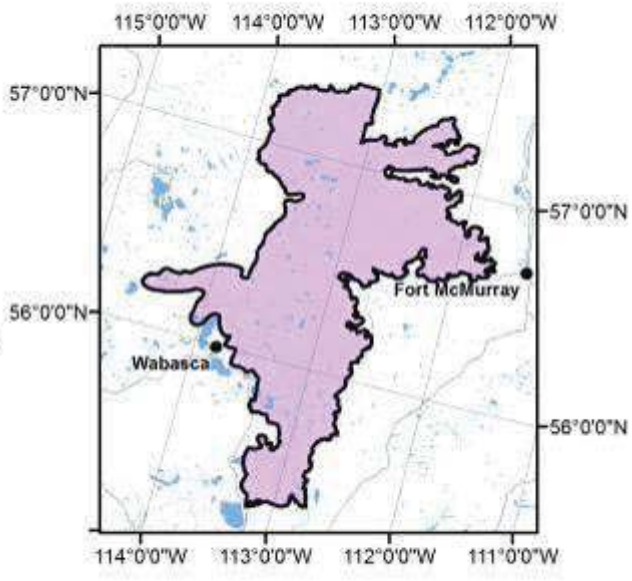


Figure J-26. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
1,572,652	5	70	72	28	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Richardson Range (AB8)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-27. Key map of the general location of the range.

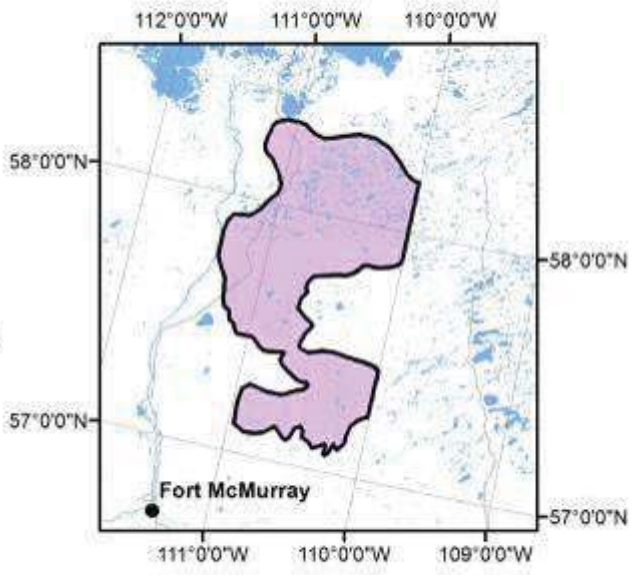


Figure J-28. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
707,350	74	23	88	12	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
	Boreal Plain
Ecoregion(s)[1]:	Boreal Shield (West)

[1] *See Appendix H*

Critical Habitat Identification: East Side Athabasca River Range (AB9)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-29. Key map of the general location of the range.

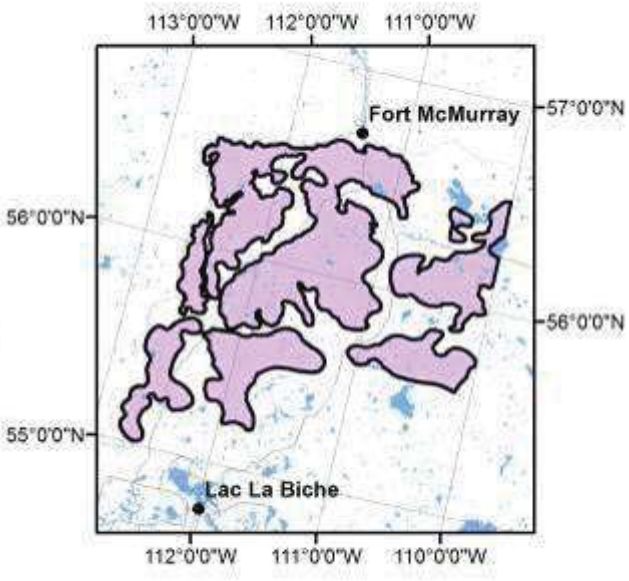


Figure J-30. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
1,315,980	28	78	84	16	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Cold Lake Range (AB10)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-31. Key map of the general location of the range.

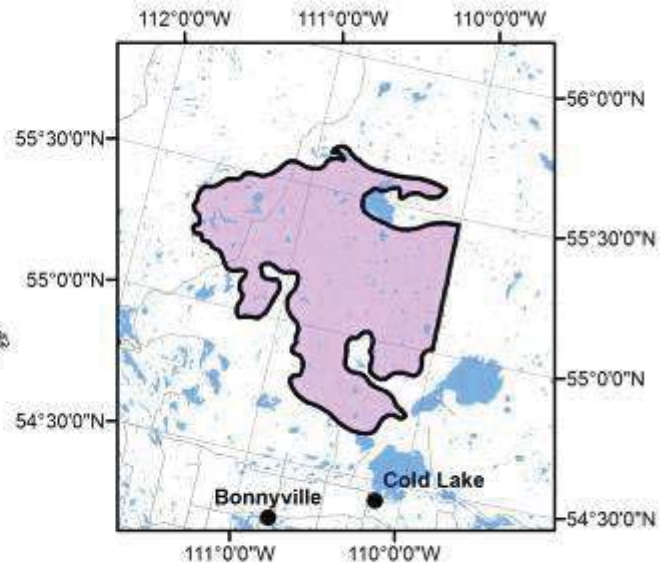


Figure J-32. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
672,422	33	76	87	13	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Nipisi Range (AB11)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-33. Key map of the general location of the range.



Figure J-34. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
210,771	9	75	77	23	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Slave Lake Range (AB12)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-35. Key map of the general location of the range.



Figure J-36. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
151,904	39	74	87	13	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

CRITICAL HABITAT FACTSHEETS: SASKATCHEWAN

Critical Habitat Identification: Boreal Shield Range (SK1)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-37. Key map of the general location of the range.

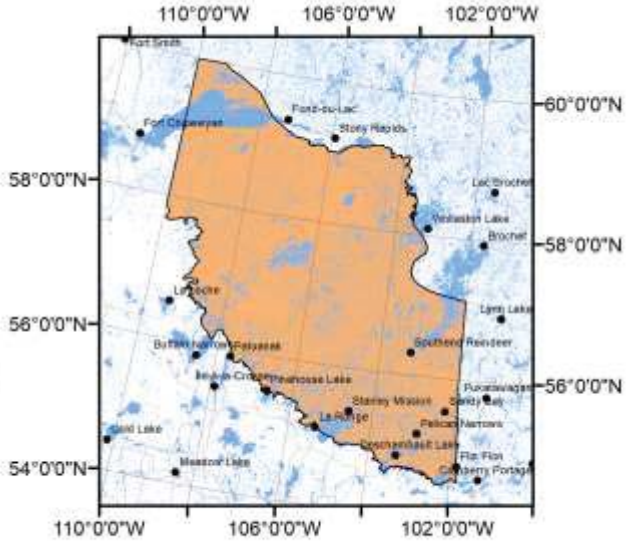


Figure J-38. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
18,034,870	58	3	60	40	At least 40% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Shield
	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West)

[1] *See Appendix H*

Critical Habitat Identification: Boreal Plain Range (SK2)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-39. Key map of the general location of the range.



Figure J-40. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
10,592,463	30	20	45	55	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

CRITICAL HABITAT FACTSHEETS: MANITOBA

Critical Habitat Identification: The Bog Range (MB1)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-41. Key map of the general location of the range.

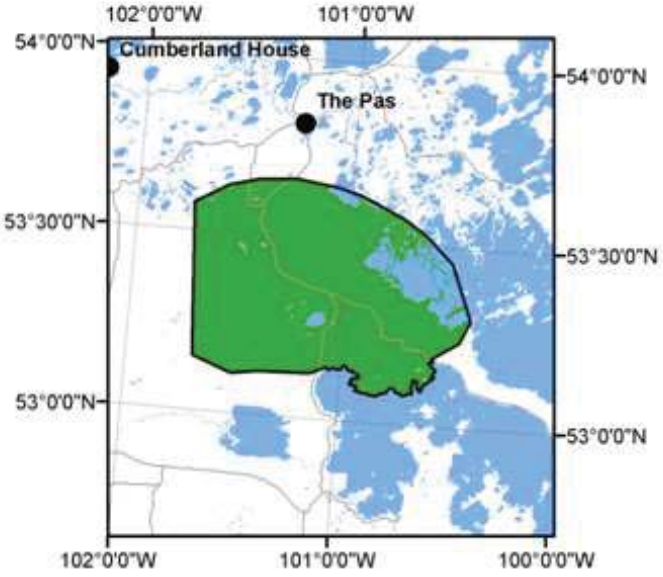


Figure J-42. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
446,383	6	14	19	81	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Kississing Range (MB2)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-43. Key map of the general location of the range.

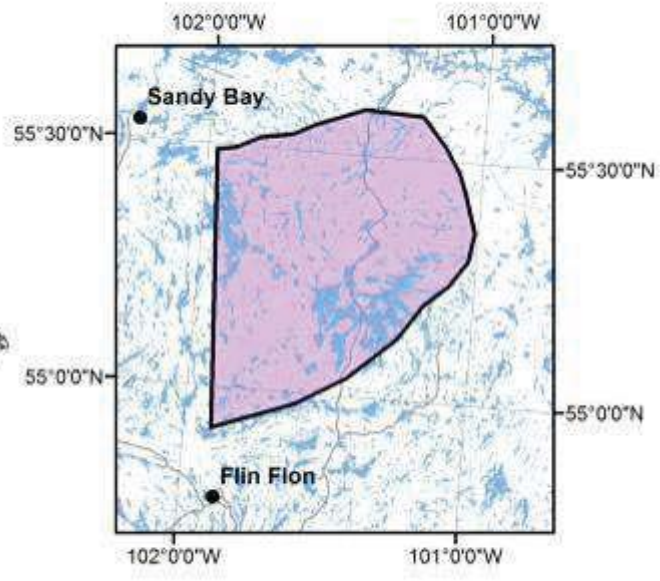


Figure J-44. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
317,029	39	15	54	46	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West)

[1] *See Appendix H*

Critical Habitat Identification: Naosap Range (MB3)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-45. Key map of the general location of the range.

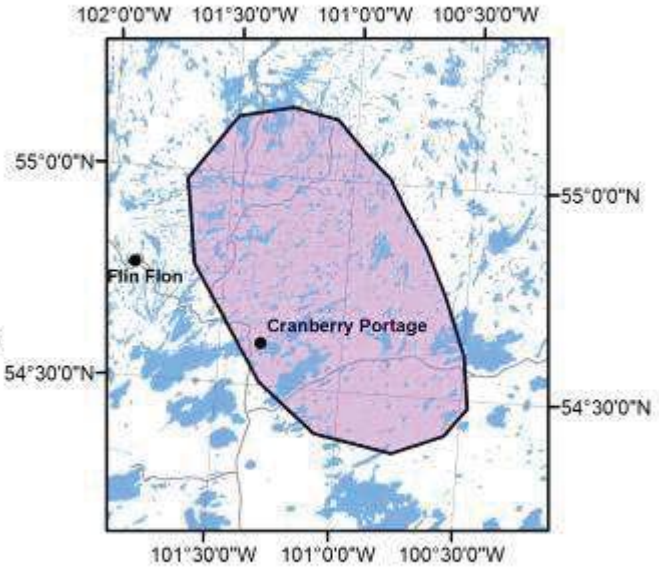


Figure J-46. The geographic boundary within which critical habitat is located

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
456,977	28	28	52	48	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
	Boreal Plain
Ecoregion(s)[1]:	Boreal Shield (West)

[1] *See Appendix H*

Critical Habitat Identification: Reed Range (MB4)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-47. Key map of the general location of the range.

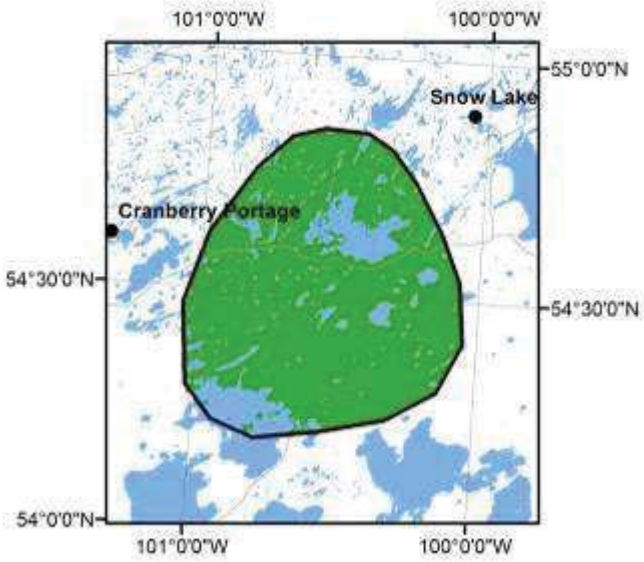


Figure J-48. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
357, 425	7	20	26	74	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
	Boreal Plain
Ecoregion(s)[1]:	Boreal Shield (West)

[1] *See Appendix H*

Critical Habitat Identification: North Interlake Range (MB5)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-49. Key map of the general location of the range.

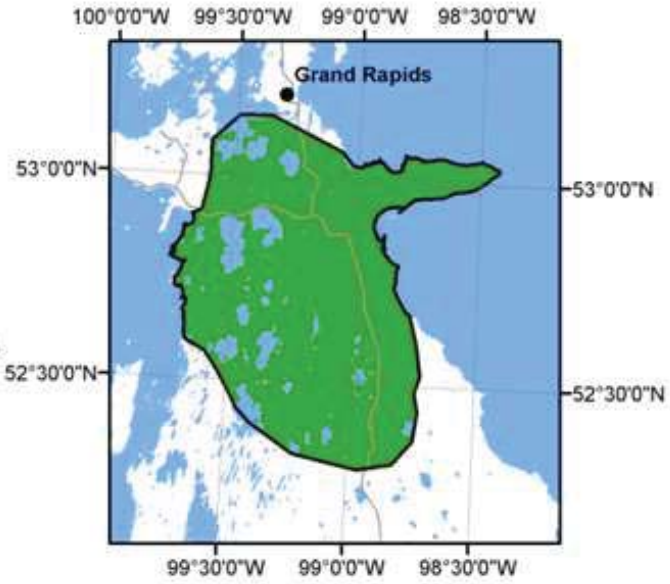


Figure J-50. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Critical Habitat Undisturbed
	Fire	Anthropogenic	Total		
489,680	4	14	18	82	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: William Lake Range (MB6)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-51. Key map of the general location of the range.

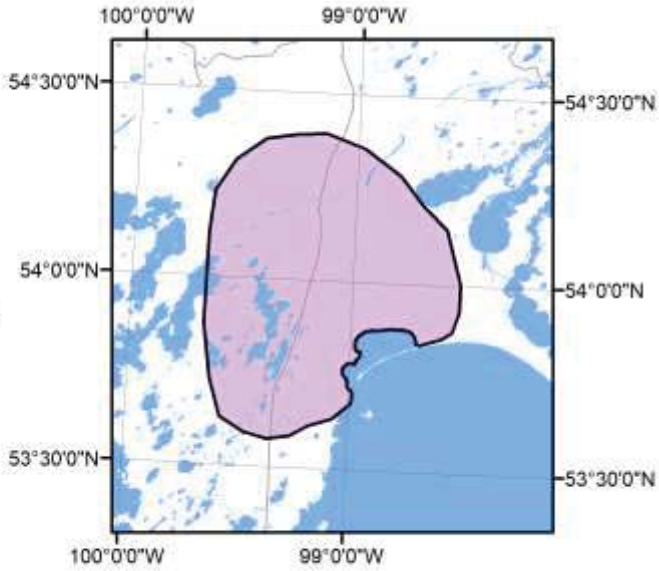


Figure J-52. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
488,219	25	17	36	64	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Wabowden Range (MB7)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-53. Key map of the general location of the range.

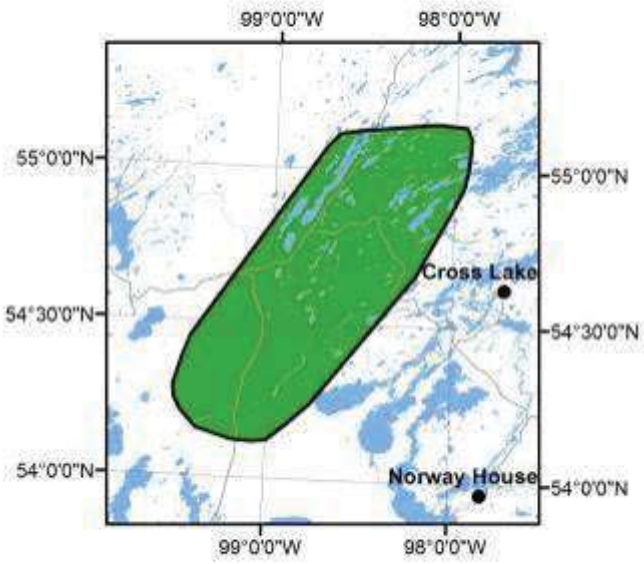


Figure J-54. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
628,938	10	20	28	72	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozones(s)[1]:	Boreal Shield
	Boreal Plain
Ecoregion(s)[1]:	Boreal Shield (West)

[1] *See Appendix H*

Critical Habitat Identification: Wapisu Range (MB8)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-55. Key map of the general location of the range.

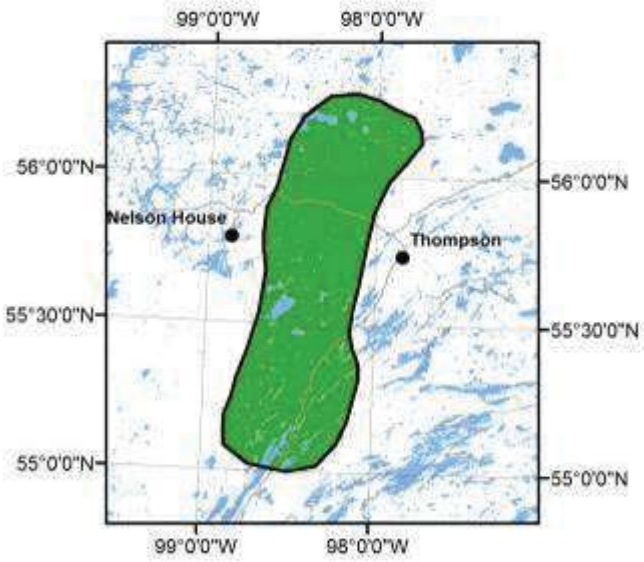


Figure J-56. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
565,044	11	13	24	76	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West)

[1] *See Appendix H*

Critical Habitat Identification: Manitoba North Range (MB9)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-57. Key map of the general location of the range.

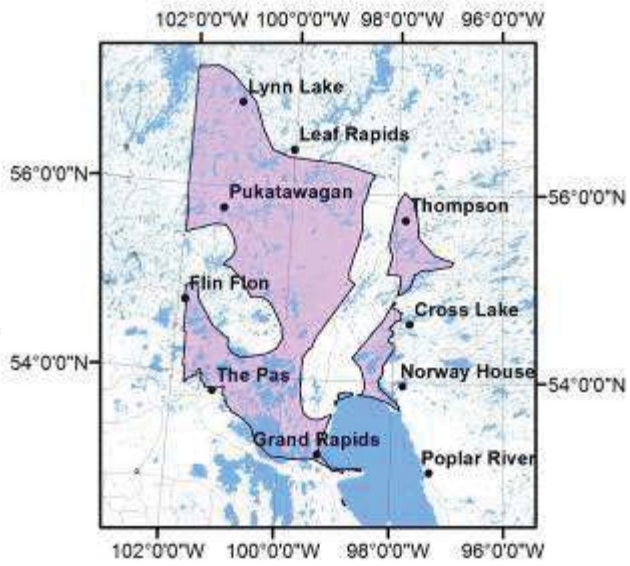


Figure J-58. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
6,205,520	23	11	33	67	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
	Boreal Plain
Ecoregion(s)[1]:	Boreal Shield (West)

[1] *See Appendix H*

Critical Habitat Identification: Manitoba South Range (MB10)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-59. Key map of the general location of the range.

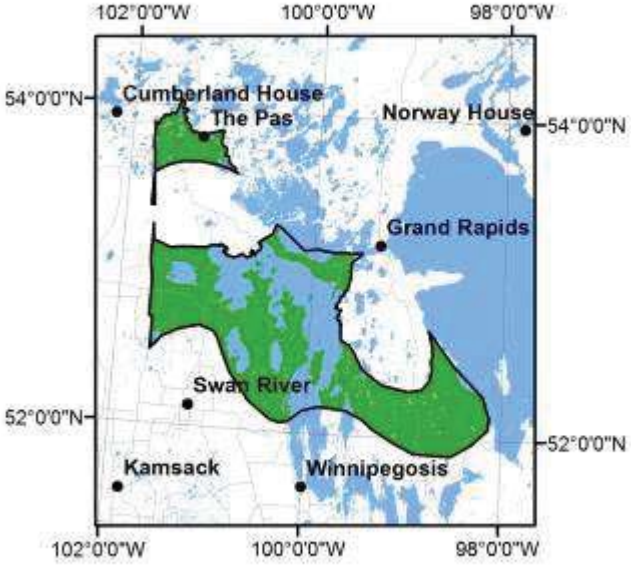


Figure J-60. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
1,867,255	4	12	16	84	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Plain

[1] *See Appendix H*

Critical Habitat Identification: Manitoba East Range (MB11)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-61. Key map of the general location of the range.

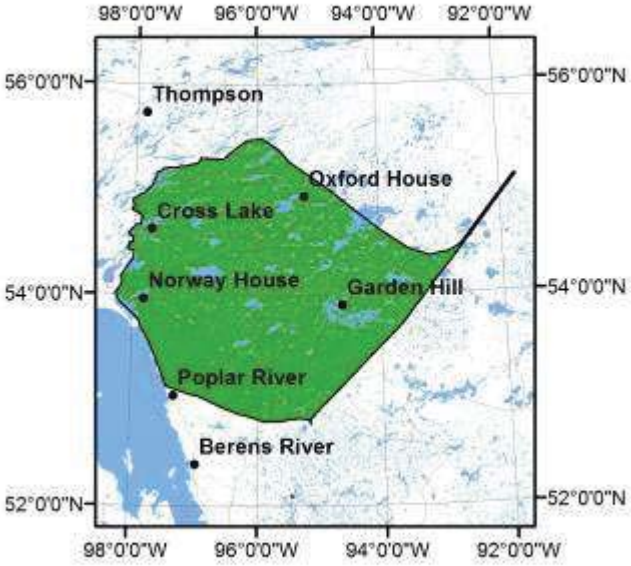


Figure J-62. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
6,612,782	26	3	29	71	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West)
	Boreal Shield (West Central)

[1] *See Appendix H*

Critical Habitat Identification: Atikaki-Berens Range (MB12)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-63. Key map of the general location of the range.



Figure J-64. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
2,387,665	29	6	34	66	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West Central)

[1] *See Appendix H*

Critical Habitat Identification: Owl-Flinstone Range (MB13)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-65. Key map of the general location of the range.



Figure J-66. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
363,570	25	18	39	61	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West Central)

[1] *See Appendix H*

CRITICAL HABITAT FACTSHEETS: ONTARIO

Critical Habitat Identification: Sydney Range (ON1)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-67. Key map of the general location of the range.

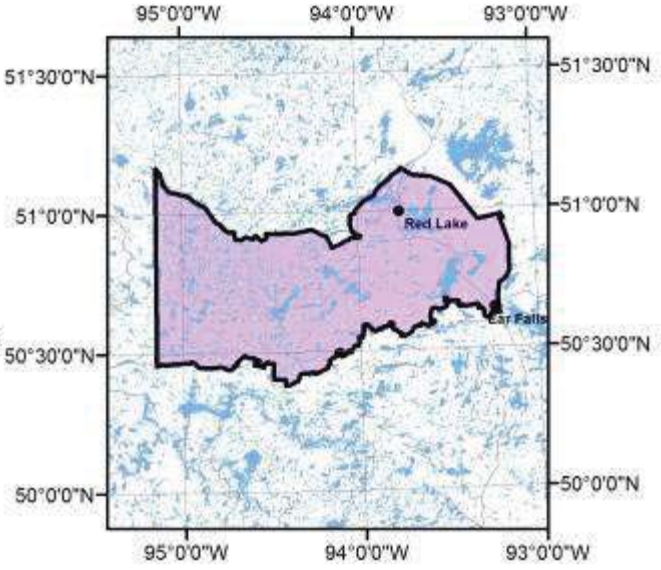


Figure J-68. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
753,001	27	25	49	51	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West Central)

[1] *See Appendix H*

Critical Habitat Identification: Berens Range (ON2)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-69. Key map of the general location of the range.



Figure J-70. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
2,794,835	31	6	37	63	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West Central)

[1] *See Appendix H*

Critical Habitat Identification: Churchill Range (ON3)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-71. Key map of the general location of the range.



Figure J-72. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
2,150,490	8	28	34	66	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West Central)

[1] *See Appendix H*

Critical Habitat Identification: Brightsand Range (ON4)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-73. Key map of the general location of the range.



Figure J-74. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
2,220,921	19	26	41	59	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West Central)

[1] *See Appendix H*

Critical Habitat Identification: Nipigon Range (ON5)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-75. Key map of the general location of the range.



Figure J-76. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
3,885,026	7	25	30	70	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West)
	Boreal Shield (West Central)

[1] *See Appendix H*

Critical Habitat Identification: Coastal Range (ON6)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-77. Key map of the general location of the range.



Figure J-78. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
376,598	0	15	15	85	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West Central)
	Boreal Shield (Central)

[1] *See Appendix H*

Critical Habitat Identification: Pagwachuan Range (ON7)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-79. Key map of the general location of the range.



Figure J-80. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
4,542,918	0.7	27	27	73	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Hudson Plain
	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (West)
	Boreal Shield (West Central)
	Boreal Shield (Central)

[1] *See Appendix H*

Critical Habitat Identification: Kesagami Range (ON8)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-81. Key map of the general location of the range.



Figure J-82. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
4,766,463	3	37	40	60	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Hudson Plain
	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (Central)

[1] *See Appendix H*

Critical Habitat Identification: Far North Range (ON9)[1]

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-83. Key map of the general location of the range.

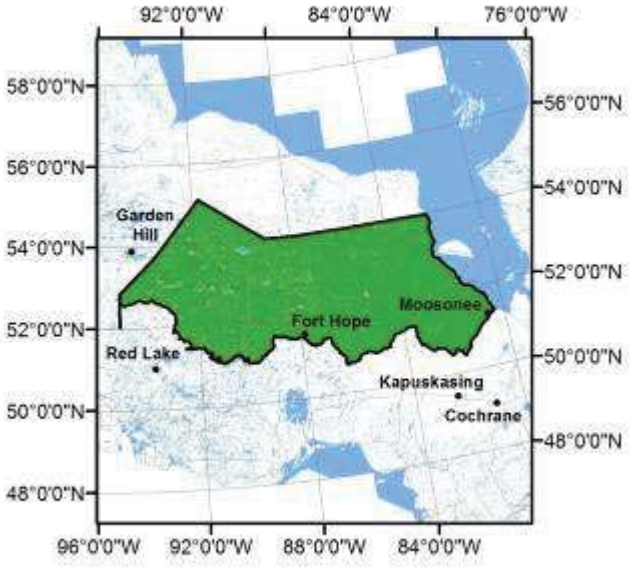


Figure J-84. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
28,265,143	15	1	16	84	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[2]:	Hudson Plain
	Boreal Shield
Ecoregion(s)[2]:	Boreal Shield (West)
	Boreal Shield (West Central)

[1] *The ON9 range was delineated into six new ranges by the province of Ontario in 2013 (https://www.ontario.ca/document/range-management-policy-support-woodland-caribou-conservation-and-recovery).*

[2] *See Appendix H*

CRITICAL HABITAT FACTSHEETS: QUEBEC

Critical Habitat Identification: Val d'Or Range (QC1)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-85. Key map of the general location of the range.

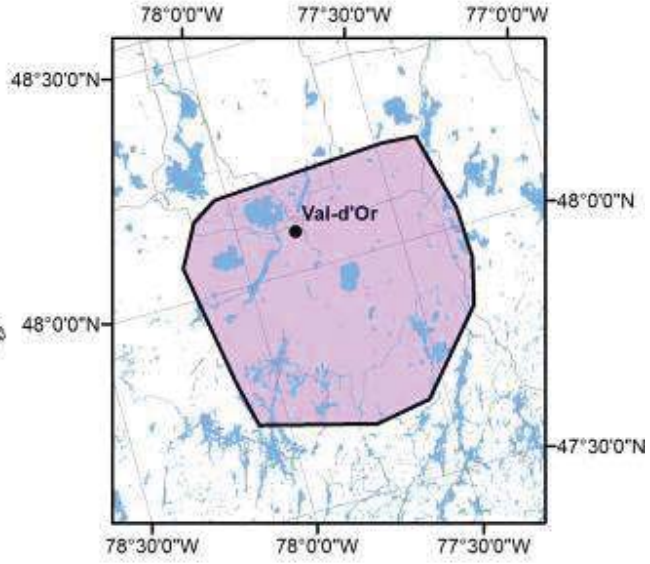


Figure J-86. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
346,861	0.2	65	65	35	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (Central)

[1] *See Appendix H*

Critical Habitat Identification: Charlevoix Range (QC2)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-87. Key map of the general location of the range.

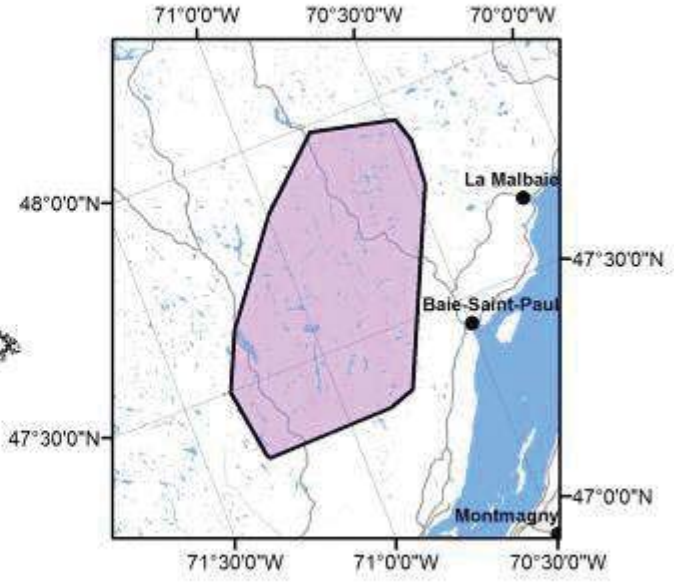


Figure J-88. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
312,803	4	80	82	18	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (Southeast)

[1] *See Appendix H*

Critical Habitat Identification: Pipmuacan Range (QC3)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-89. Key map of the general location of the range.

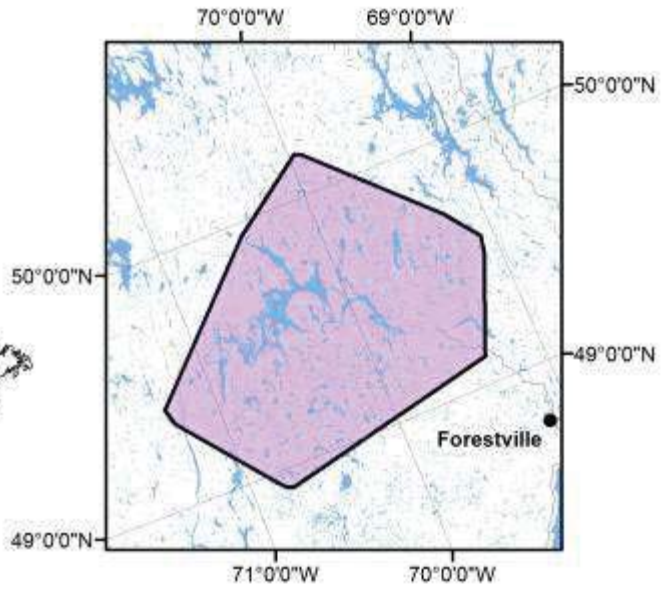


Figure J-90. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
1,376,899	11	60	68	32	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (East)

[1] *See Appendix H*

Critical Habitat Identification: Manouane Range (QC4)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-91. Key map of the general location of the range.

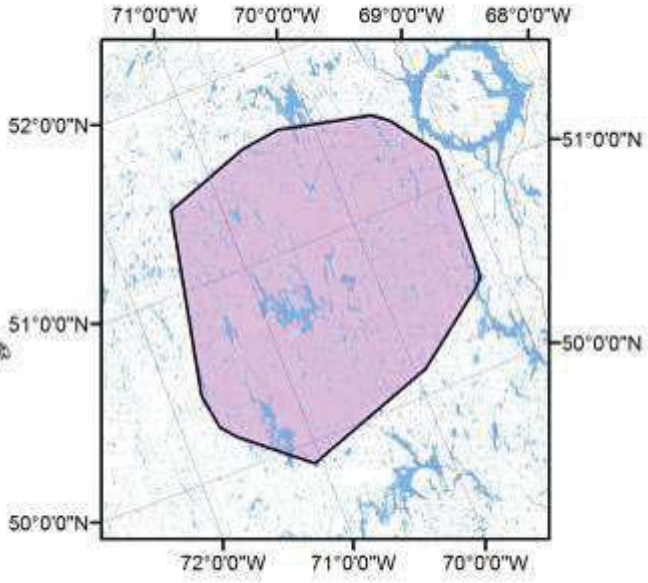


Figure J-92. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
2,716,449	18	26	41	59	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (East)

[1] *See Appendix H*

Critical Habitat Identification: Manicouagan Range (QC5)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-93. Key map of the general location of the range.

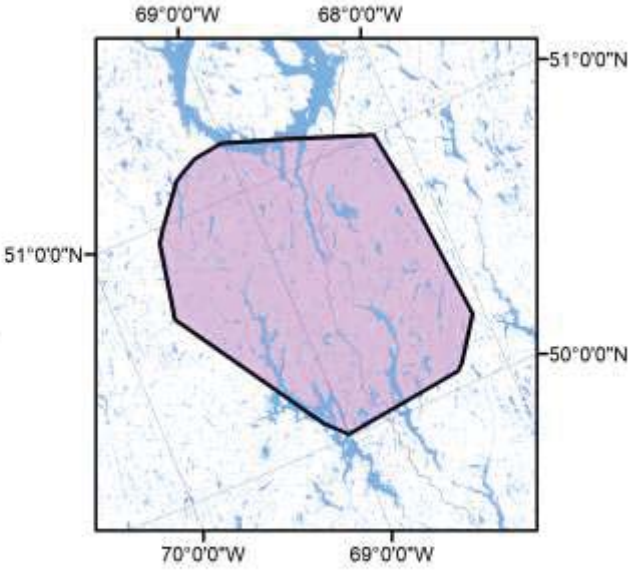


Figure J-94. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
1,134,129	3	36	37	63	Existing habitat that would contribute to at least 65% undisturbed habitat over time.

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (East)

[1] *See Appendix H*

Critical Habitat Identification: Quebec Range (QC6)[1]

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-95. Key map of the general location of the range.



Figure J-96. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
62,156,186	20	13	32	68	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[2]:	Boreal Shield
	Taiga Shield
	Hudson Plain
Ecoregion(s)[2]:	Boreal Shield (Central)
	Boreal Shield (East)
	Boreal Shield (Southeast)

[1] *The range is likely made up of several populations for which the self-sustainability status may vary. New data are currently being collected by the provincial jurisdiction for this range. This may result in an update to the range delineation and/or the identification of new ranges, as well as a revision of their self-sustainability status following integrated risk assessment of new ranges or new range boundaries.*

[2] *See Appendix H*

CRITICAL HABITAT FACTSHEETS: NEWFOUNDLAND AND LABRADOR

Critical Habitat Identification: Lac Joseph Range (NL1)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-97. Key map of the general location of the range.

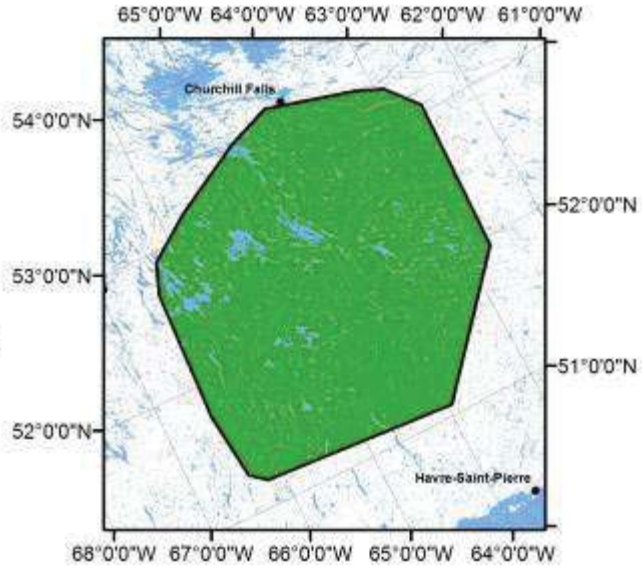


Figure J-98. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
5,802,491	12	2	14	86	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Shield
	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (East)

[1] *See Appendix H*

Critical Habitat Identification: Red Wine Mountain Range (NL2)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-99. Key map of the general location of the range.

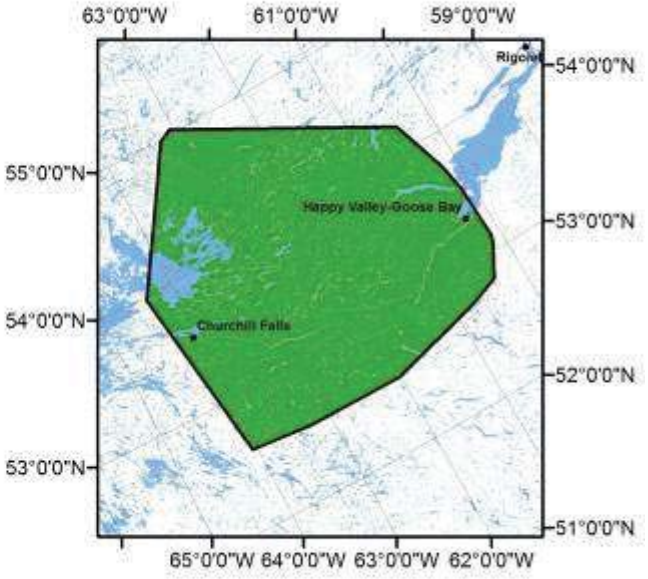


Figure J-100. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
5,838,594	7	3	9	91	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Shield
	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (East)

[1] *See Appendix H*

Critical Habitat Identification: Mealy Mountain Range (NL3)

The identification of critical habitat for boreal caribou is described by three components for each range: i) Location of habitat; ii) Amount of habitat; and iii) Type of habitat.

i) Location: Where critical habitat is found.



Figure J-101. Key map of the general location of the range.

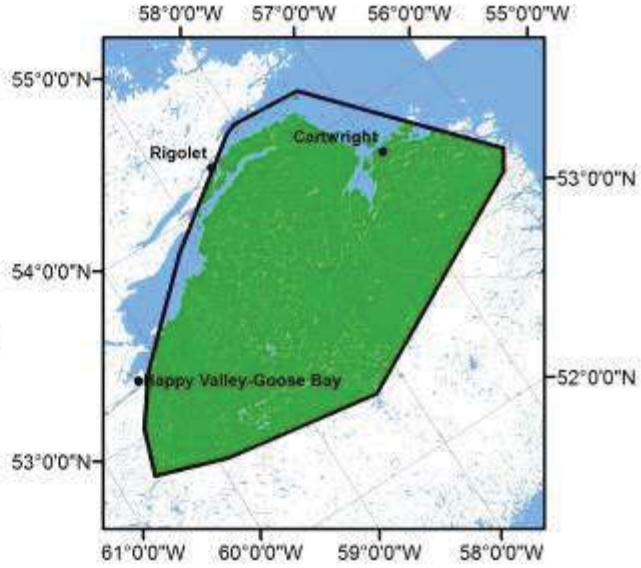


Figure J-102. The geographic boundary within which critical habitat is located.

ii) Amount: Quantity of critical habitat.

Total Range Area (ha)	Disturbed Habitat (%)			Total Undisturbed Habitat (%)	Amount of Critical Habitat
	Fire	Anthropogenic	Total		
3,948,463	1	1	2	98	At least 65% undisturbed habitat

iii) Type: Biophysical attributes of critical habitat.

Ecozone(s)[1]:	Taiga Shield
	Boreal Shield
Ecoregion(s)[1]:	Boreal Shield (East)

[1] *See Appendix H*

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Location, timing and extent of wildfire vary by cause of ignition

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Abstract. The increasing extent of wildfires has prompted investigation into alternative fire management approaches to complement the traditional strategies of fire suppression and fuels manipulation. Wildfire prevention through ignition reduction is an approach with potential for success, but ignitions result from a variety of causes. If some ignition sources result in higher levels of area burned, then ignition prevention programmes could be optimised to target these distributions in space and time. We investigated the most common ignition causes in two southern California sub-regions, where humans are responsible for more than 95% of all fires, and asked whether these causes exhibited distinct spatial or intra-annual temporal patterns, or resulted in different extents of fire in 10–29-year periods, depending on sub-region. Different ignition causes had distinct spatial patterns and those that burned the most area tended to occur in autumn months. Both the number of fires and area burned varied according to cause of ignition, but the cause of the most numerous fires was not always the cause of the greatest area burned. In both sub-regions, power line ignitions were one of the top two causes of area burned: the other major causes were arson in one sub-region and power equipment in the other. Equipment use also caused the largest number of fires in both sub-regions. These results have important implications for understanding why, where and how ignitions are caused, and in turn, how to develop strategies to prioritise and focus fire prevention efforts. Fire extent has increased tremendously in southern California, and because most fires are caused by humans, ignition reduction offers a potentially powerful management strategy, especially if optimised to reflect the distinct spatial and temporal distributions in different ignition causes.

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Introduction

Recent increases in the size and extent of wildfires across the world (Bowman *et al.* 2009) are a major policy and management concern because of their ongoing and potentially escalating effects on ecological integrity (Pausas and Keeley 2009), and human lives and property (Price and Bradstock 2012; Syphard *et al.* 2012). Wildfire policy and management efforts have focussed largely on fire suppression and fuels management (e.g. Butry 2009). However, the growing fire problem has prompted investigation into alternative approaches for reducing fire hazard, such as hardening structures to make them more fire resilient (Gill 2005), land use planning (Syphard *et al.* 2012; 2013) and creating areas of defensible space immediately adjacent to structures in fire-prone areas (Cohen 2000; Winter *et al.* 2009, Syphard *et al.* 2014).

An additional option is to develop wildfire prevention efforts focussed on reducing fire ignitions (Prestemon *et al.* 2010; Gill *et al.* 2013). Simulation models suggest that ignition management, simulated through reduced ignition probability, can be more effective than fuels management in reducing area burned (Cary *et al.* 2009). However, we propose that beyond merely reducing ignitions, there may be value in targeting particular types of ignitions if certain sources play a larger role in area burned. In regions such as southern California and the Mediterranean basin, human-caused ignitions dominate over natural lightning ignitions, accounting for more than 95% of all fires (Syphard *et al.* 2007, 2008; Romero-Calcerrada *et al.* 2008). Human-caused fires derive from a variety of sources and these potentially vary spatially and temporally in ways that could affect the size and destructiveness of wildfires.

Most human-caused fires are unplanned and unintentional; for example, escaped campfires or debris burns, sparks from cars or equipment, children playing with fire or cigarette butts thrown out of car windows. However, arson – or incendiary – fires are intentionally set and represent fundamentally different behaviour. Ignition prevention programmes could take many forms depending on the target source of ignition. For example, some governmental or volunteer organisations devote time and resources to educating the public about the danger of accidental ignitions, law enforcement often targets arsonists and some public parks and forests are closed to recreational activities on days with extreme fire weather.

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Prestemon *et al.* (2010) found that state expenditure on wildfire prevention programmes in Florida yielded net benefits economically and significantly reduced the number of preventable wildfires. However, the authors found spatial variation in the benefits of these programmes, potentially due to geographic differences in the type of prevention activity applied relative to the distribution and proportion of different preventable wildfire causes. It therefore stands to reason that if different causes of ignitions have distinct spatial or temporal distributions, ignition prevention programmes could be optimised to target these distributions in space, time or according to specific cause.

Recent investigations have demonstrated that ignition patterns are non-random and significantly influenced by a range of biophysical and anthropogenic factors (e.g. Cardille *et al.* 2001; Sturtevant and Cleland 2007; Syphard *et al.* 2008; Catry *et al.* 2009; Bar Massada *et al.* 2013; Sadasivuni *et al.* 2013), and that the distribution and drivers of lightning ignitions are quite different from those of anthropogenic ignitions (Reineking *et al.* 2010; Narayanaraj and Wimberly 2011). Other studies have also shown arson fires to be predictable in time and space (Prestemon and Butry 2005; Gonzalez-Olabarria *et al.* 2012; Penman *et al.* 2013). Distinct spatio–temporal signatures of different ignition sources have also been suggested through differences in spatial clustering (Genton *et al.* 2006).

Our objective in this study was to explore further distinctions among ignition causes – that is, beyond arson, accidental and lightning – to identify whether different ignition sources exhibit distinct spatial or intra-annual temporal patterns that result in disproportionate numbers of fires or area burned in two southern California sub-regions. Results demonstrating distinctive characteristics of ignition causes could benefit prevention programmes through the determination of why, where and when most ignitions occur, and which ignition causes are most important to target under varying circumstances.

We asked:

1. Do different ignition causes vary in terms of number of fires, and area and month burned?
2. Are different ignition causes explained by different drivers?
3. Are distinctive spatial patterns exhibited in different ignition causes?

Methods

Sub-regions

The two sub-regions included the Santa Monica Mountains in Ventura and Los Angeles counties and the western portion of San Diego County that falls within the South Coast Ecoregion in southern California, USA (Fig. 1). The San Diego study area did not include the land and ignitions from Military Base Camp Pendleton because of its unique ignition regime that is driven almost entirely by military training activities. Owing to a mediterranean climate, with mild, wet winters and long summer droughts, both areas are extremely fire prone and large, high-intensity wildfires driven by hot, dry Santa Ana winds are characteristic of their natural fire regimes (Keeley 2006). The areas are topographically and biologically diverse, and southern California is home to more threatened species than any other region in the mainland US. Although large areas of wildland vegetation remain in both areas, substantial population growth has resulted in massive expansion of the wildland–urban interface (WUI) (Hammer *et al.* 2007), which in turn has led to a surge in the number and areal extent of human-caused ignitions (Keeley *et al.* 1999). Escalating fire frequency threatens the

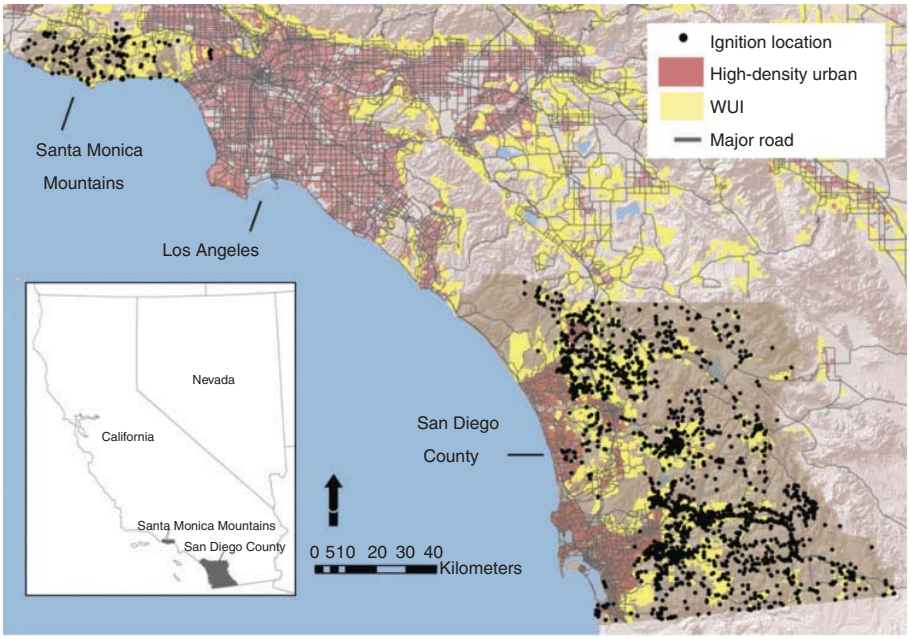


Fig. 1. The Santa Monica Mountains and San Diego County sub-regions in southern California. 'WUI' is the wildland–urban interface.

regions' biodiversity (Keeley *et al.* 2012) and human safety (Keeley *et al.* 2013). Southern California loses an average of 500 homes per year to wildfires (Cal Fire 2000). In both sub-regions, humans are responsible for more than 95% of all ignitions (Syphard *et al.* 2007).

Data

Ignition data

For San Diego County, we acquired all digital ignition data from the California Department of Forestry and Fire Protection (Cal Fire, Carl Palmer, pers. comm.). These data consisted of separate files for different agencies responsible for the fires, and we included those records from agencies that provided the source of ignition. To calculate statistics describing area burned, number of fires and month of ignition by cause, we used data from Cal Fire, the US Fish and Wildlife Service (FWS), and the US Forest Service (USFS) dating from 2000 to 2010, which included 3438 ignitions. Unlike other fire databases, these data had no minimum size limit. For all ignition data, we carefully reviewed the records to remove duplicates that were listed in more than one agency's database.

Owing to the spatial nature of the regression modelling and mapping analysis, we further restricted the San Diego ignition data to recent years when the spatial accuracy was more precise. For spatial analysis of Cal Fire data, we used ignition location data from 2006 to 2010 ($n = 1513$) as these were reported at the highest level of precision (precise to 5 *v.* 2 decimal digits, in earlier years). The precision of the FWS (2000–2010, $n = 372$) and USFS (2000–2010, $n = 535$) data matched the most recent Cal Fire data.

The ignition data for the Santa Monica Mountains included 248 coordinate points from 1982 to 2011 acquired from the National Park Service (NPS) fire records, assembled by Robert S. Taylor (pers. comm.). These data were compiled from the National Fire Plan Operations and Reporting System database, and the Department of Interior Wildland Fire Information Management database. Ignition locations were error checked, validated and corrected using the original paper 1202 forms and ancillary data on fire incidents, including historical orthophotos, satellite imagery and Burned Area Reflectance Classification imagery, as well as first-hand accounts by several long-time NPS personnel. The median estimated accuracy was 30 m, the mode was 10 m and the mean (286 m) was strongly affected by outliers.

Explanatory variable data

In a previous study in the Santa Monica Mountains, we identified several human and biophysical variables that were significant in explaining the spatial distribution of ignitions (Syphard *et al.* 2008). Here we considered the same terrain variables for both sub-regions, including elevation, slope gradient and a transformed slope aspect ('south-westness'),' all derived from 30-m US Geological Survey Digital Elevation Models. Terrain variables may explain ignition patterns through their influence on factors that affect flammability and spread, such as local climate, fuel moisture, vegetation composition and distribution, soil moisture and development, and relative humidity (Whelan 1995). Because human-caused ignitions frequently occur along transportation corridors (Stephens 2005), we also reused the US Topologically Integrated Geographic Encoding and Referencing system TIGER/line files (available at https://www.census.gov/geo/maps-data/data/tiger-line.html, verified 6 November 2014) to create interpolated maps of distance to roads, this time adding the San Diego sub-region.

Variables delineating climate, vegetation and human variables were updated from the Syphard *et al.* (2008) study to ensure data consistency between the two sub-regions, and in the case of human variables, to take advantage of better data availability. Maps of recent historical climate reflecting spatial variability in average conditions (averaged over 1970–1999) included mean January minimum temperature, mean July maximum temperature and mean annual precipitation using 800-m grids from the Parameter-elevation Regressions on Independent Slopes Model (PRISM Climate Group 2004). Broad-scale temperature and precipitation may be important predictors of ignition locations because climate trends are associated with factors such as fuel moisture or composition and productivity, which in turn can affect fuel accumulation or combustion (Whelan 1995). After performing a correlation analysis to check for multicollinearity, we eliminated January minimum temperature and annual precipitation from the analysis because they were correlated ($r > 0.6$) with several other variables. However, mean July maximum temperature was not correlated with the other variables in the analysis.

Because flammability and fire behaviour tend to vary according to vegetation type in southern California (Wells *et al.* 2004), we used the Calveg existing vegetation data (USDA Forest Service 2010), which covered the whole region. We stratified the vegetation classes into five general vegetation types that reflect physiognomic structure and broad differences in fire behaviour, including chaparral shrublands, coastal sage scrub, grass, forest and non-vegetated, which is typically urban and thus includes a mix of cover types, from impervious surface to grass and ornamental landscaping vegetation around homes.

Although fuel age and flammability are unrelated in extreme weather conditions in southern California (Moritz *et al.* 2004), we evaluated fuel age in this study as a potential predictor of ignition locations because our dataset included small fires that burned under a range of weather conditions. This was a variable we did not explore in previous research (Syphard *et al.* 2008). The majority of fires are stand replacing in southern California shrublands, so we calculated the age of the vegetation at every ignition point by subtracting the time of last fire from the year of the ignition event using fire perimeter maps from the California Department of Forestry and Fire Protection (Cal Fire 2013).

Finally, we used updated GIS data of all residential structures in each sub-region (from Syphard *et al.* 2012) to interpolate maps of housing density and distance of ignitions to structures. We used these variables in lieu of data delineating the WUI, which was important in Syphard *et al.* 2008, but correlated with our housing variables here ($r > 0.6$). Because most ignitions in this region are caused by humans, we expected the housing variables to delineate patterns where human activities, and thus fire ignitions, are concentrated.

Analysis

For both sub-regions, we divided the ignition data into groups representing the most common, major causes, which were listed as attributes of the spatial data. The major causes were the same

for both regions, although a substantial number of wildfires were the result of escaped prescribed burns in the Santa Monica Mountains, so we retained this as an additional, separate group in that sub-region. In both regions, ~30% of fire ignition causes were labelled as 'unknown' or 'miscellaneous.' Because these were uninformative relative to our research questions, we excluded them from the analysis.

To evaluate the relative contribution of each ignition cause to the extent of fire in each sub-region, we plotted the proportion of number of fires and the area burned by those fires for all ignition types. We also evaluated the seasonal distribution of area burned by ignition cause by plotting the proportion of each cause's total area burned by the month when the ignitions of those fires occurred.

For both predictive mapping and evaluation of variable importance, we used the MaxEnt model (Phillips *et al.* 2006; Elith *et al.* 2011), which employs a machine learning algorithm to estimate distributions by minimising the relative entropy between probability densities through iterative contrasts among values of explanatory variables at locations where ignitions occurred *v.* locations that are randomly distributed across the sub-region. We chose the MaxEnt modelling approach because it was shown to be more suitable than other statistical methods for ignition modelling (Bar Massada *et al.* 2013); it has been successfully used to project fire risk to houses (Syphard *et al.* 2012, 2013); and it is one of the best-performing species distribution models, especially in cases with presence-only data and small sample sizes (Elith *et al.* 2006, Wisz *et al.* 2008). We developed separate MaxEnt models for all ignition types in both sub-regions.

For all models, we used the default random background sample of 10 000 points. These non-ignition points should not be considered true absence points because it is possible that an ignition could occur in these locations, but simply did not during the time frame of the study. Rather, these background points represent the full range of environmental variation across the sub-region from which we can thus distinguish the environmental conditions that characterise the ignition locations. We used hinge features, and linear and quadratic functions to produce smoother response curves that minimise over fitting of the model (Elith *et al.* 2011). The output of MaxEnt assigns a probability of ignition (from 0–1) to every cell in the map. This probability is based on logistic function of the MaxEnt raw values, which are exponential functions of the explanatory variables. MaxEnt estimates variable importance as a function of information gain resulting from every environmental variable throughout the model iterations. To assess the accuracy of the MaxEnt models, we used a bootstrapping procedure in which we ran the model 10 times, each with a random percentage of the ignition data (sampling with replacement) withheld for testing the model predictions. The results are presented as averages of the 10 replicate simulations.

We did not use fuel age as a predictor in the MaxEnt analysis because the software selects values of background points from static maps. Therefore, to evaluate the contribution of fuel age relative to other variables, and to determine whether relative variable importance was similar between two methodological approaches, we performed a hierarchical partitioning analysis (Chevan and Sutherland 1991) with the hier.part package in R (Walsh and Mac Nally 2008). Hierarchical partitioning evaluates all combinations of explanatory variables in a multiple regression framework and returns the unique, independent percent contribution of each variable to model fit. Because we had a binary dependent variable (ignition *v.* non-ignition), we used the binomial family and maximum likelihood goodness-of-fit measure to develop our models.

To perform the hierarchical partitioning, we generated random background points that were at least 250 m apart to minimise spatial autocorrelation (Dormann *et al.* 2007). We generated 10 000 points in San Diego County and 5089 points in the Santa Monica Mountains, which was the largest number possible while maintaining a 250-m separation distance. For all ignition and background points, we extracted values from our gridded maps of the explanatory variables. To assign a vegetation age to the random background points, we first recorded the proportion of ignitions that occurred in each year in each sub-region. Based on those proportions, we extracted vegetation age data for the background points from maps of time since last fire for every year. Because the hierarchical partitioning algorithm does not treat categorical variables, we converted the categorical vegetation map used for MaxEnt into a discrete binary variable representing grass or no grass. We chose grass as the vegetation type to model because the MaxEnt models showed a disproportionately large number of ignitions that occurred in that vegetation type, particularly in the Santa Monica Mountains.

Because some of the ignition cause groups had fewer than 20 observations, we only performed the hierarchical partitioning analysis for the full set of ignitions in the Santa Monica Mountains. Although MaxEnt has shown excellent predictive power at all sample sizes, even as small as 10 (Wisz *et al.* 2008), we also withdrew several ignition types from the MaxEnt analysis in the Santa Monica Mountains because of low sample size.

Results

There were no substantial differences in the number of fires by cause in the Santa Monica Mountains, although equipment fires were the most numerous (Fig. 2*a*). In contrast, most of the area burned in the Santa Monica Mountains resulted from arson and power line ignitions, with moderate area burned due to campfires and escaped prescribed fires. The most numerous fires occurred primarily in late spring from May through July, but most of the arson, power line and campfire ignitions that burned the majority of area occurred from August through November (Fig. 3*a*).

In San Diego County, equipment-caused fires were by far the most numerous, and these also accounted for most of the area burned, followed closely by the area burned by power line fires (Fig. 2*b*). Ignitions classified as equipment caused frequently resulted from exhaust or sparks from power saws or other equipment with gas or electrical motors, such as lawn mowers, trimmers or tractors. Most of the area burned by equipment use and power lines occurred in October, although a moderate extent of area burned was caused by power lines in July as well (Fig. 3*b*).

The analysis of variable importance in MaxEnt showed that the relative contribution of explanatory variables varied

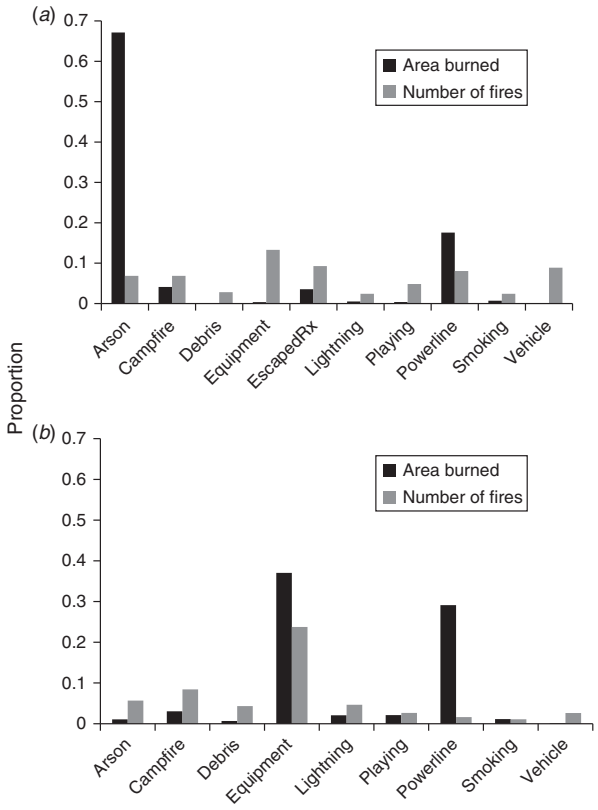


Fig. 2. Proportion of number of fires and area burned by cause of ignition in (*a*) the Santa Monica Mountains and (*b*) San Diego County. 'EscapedRX' means escaped prescribed fire.

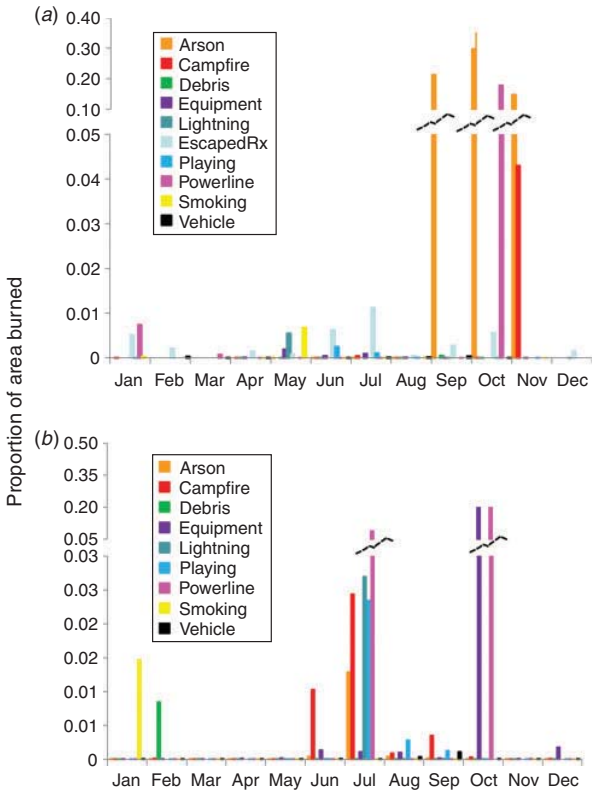


Fig. 3. Proportion of all area burned by ignition cause by month for (*a*) the Santa Monica Mountains and (*b*) San Diego County.

somewhat according to ignition source as well as by sub-region (Table 1). Overall, vegetation type was more important in the Santa Monica Mountains than in San Diego County, with grass being the most common vegetation type for all ignition causes. In San Diego, ignitions occurred most frequently in grass or forest vegetation types. Distance to roads and structure density were more predominant overall in explaining ignitions in San Diego County. In fact, distance to road contributed more than 50% to the model for all ignition sources except for campfire and lightning. In both sub-regions, ignitions were more likely to occur close to roads and structures, and at intermediate structure densities. The mean area under the curve (AUC) of receiver operating characteristic plots for the 10 replicate, bootstrapped models ranged from 0.90 to 0.97 for the Santa Monica Mountains and from 0.81 to 0.96 for San Diego County (Table 1). These AUCs indicated good overall ability of the models to discriminate between ignition and background locations.

The difference in relative contribution of explanatory variables between the sub-regions was not as apparent when all ignition data were modelled together using hierarchical partitioning (Fig. 4), although the hierarchical partitioning analysis of separate ignition cause groups in San Diego County showed similar rankings to the MaxEnt results (not shown). In the Santa Monica Mountains, more ignitions were explained by grass than in San Diego County, although vegetation age was not important in explaining ignition patterns in either sub-region.

Different sources of ignitions also had different spatial patterns, as seen through the predicted ignition probability maps (Figs 5, 6). In the Santa Monica Mountains (Fig. 5), campfires and playing-with-fire ignitions had high prediction probabilities in diffuse patterns throughout the sub-region with slightly higher probabilities along the perimeter. Power line ignitions had a more concentrated distribution along the perimeter of the sub-region and in all three the effect of topography is evident through the lines of high probability that trace the canyons leading into the mountains. The effect of roads on ignition probabilities for arson- and vehicle-caused fires is apparent through the linear features crossing the landscape, and the equipment-caused fires are mostly located near residential areas.

In San Diego County, lightning- and campfire-caused ignitions were predicted at highest probability in distinct patterns in the eastern part of the region, where the higher elevation conifer forests are distributed (Fig. 6). Road influence on the spatial pattern of ignition probabilities is clear in fires caused by arson, equipment use, playing with fire, smoking and vehicles, although arson fires show the highest probabilities in the western, high-density urban areas. The WUI, where housing density is low to intermediate is an apparent influence in most ignition maps as illustrated by comparison of Fig. 1 with Figs 4 and 5.

Table 1. Mean relative variable importance measured by percent contribution and AUC for 10 replicates of MaxEnt models for patterns of different ignition causes in the Santa Monica Mountains and San Diego County

	Distance to road	Distance to structure	Structure density	South-westness	July temperature	Elevation	Slope	Vegetation type	Mean AUC
Santa Monica Mountains									
Arson	37.8	12.9	6.2	6.3	5.5	1.5	14.1	15.6	0.96
Campground	12.4	21.8	10.1	16.4	9.4	8.5	11.4	10.0	0.90
Equipment	13.0	10.1	30.7	9.3	9.2	1.8	6.3	19.7	0.97
Playing	25.7	12.5	11.8	15.3	2.7	10.6	10.9	10.4	0.91
Powerline	20.3	6.3	19.4	7.1	19.8	7.8	4.3	15.0	0.94
Vehicle	47.5	4.4	5.2	12.0	3.4	9.4	5.5	12.5	0.96
San Diego County									
Arson	65.1	5.4	18.3	1.5	3.5	3.0	3.0	0.2	0.87
Campground	5.3	5.7	25.7	2.1	8.9	21.7	11.7	18.9	0.81
Debris	73.3	4.0	16.9	0.8	1.1	0.9	0.2	2.7	0.93
Equipment	72.0	0.5	20.9	0.5	3.8	1.5	0.6	0.3	0.87
Lightning	23.8	3.2	40.1	2.2	8.4	16.4	0.4	5.6	0.77
Playing	78.6	2.9	10.5	1.2	1.5	2.9	1.8	0.6	0.96
Powerline	49.0	4.0	20.0	0.1	1.4	3.3	2.2	1.7	0.96
Smoking	65.5	2.3	17.5	2.6	0.1	8.1	0.7	3.0	0.83
Vehicle	72.0	1.0	17.3	1.7	4.3	1.9	0.5	1.4	0.95

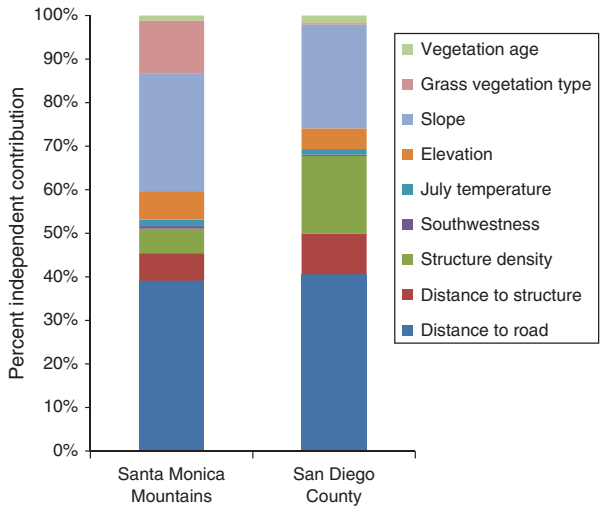


Fig. 4. Percent independent contribution of variables in hierarchical partitioning models explaining patterns of all ignitions in the Santa Monica Mountains and San Diego County.

Discussion

Fire extent and frequency have increased in recent decades in southern California (Keeley *et al.* 1999), and because most fires are caused by humans, ignition reduction offers a potentially powerful management strategy. The present study showed that in southern California, different causes of ignitions had distinctive spatial and temporal patterns, which resulted in varying numbers and extent of fires. This makes clear the point that certain causes of ignition have disproportionately high fire effects. As in previous modelling studies in the southern California region (Syphard *et al.* 2008), ignition locations in this study were generally concentrated in close proximity to human infrastructure, with some significant contributions from climate, terrain and vegetation (Table 1, Fig. 4). Despite these general similarities, however, this study showed that the relative importance in terms of number of ignitions and area burned, as well as factors that explained ignition patterns, varied by ignition cause. These variations in spatial patterns and importance of predictor variables have important implications for understanding why, where and how ignitions are generated in the region and in turn suggest avenues for developing strategies that would focus fire prevention efforts.

For both the Santa Monica Mountains and San Diego County, a major ignition source for area burned is power lines (Fig. 2). Power lines are recognised for causing large and destructive fires, not only in southern California (Keeley *et al.* 2012), but also in Australia (e.g. Cruz *et al.* 2012). One reason this is so important in southern California is that power line fires are concentrated in the autumn months (Fig. 3) and are associated with extreme winds known locally as Santa Ana winds, which contribute to extreme fire behaviour (Mitchell 2013). Santa Ana winds present a major challenge for utilities in the region because high-velocity gusts may cause power lines to fall or arc, conductors to clash or trees to come into contact with the lines. Power line-ignited fires may also become large when they are located in remote areas where access to the fire is difficult.

Aside from minimising vegetation under overhead conductors, options to reduce these ignitions have been controversial. Owing to a rash of lawsuits against utility companies (Keeley *et al.* 2012, box 13.2), some have responded by monitoring weather conditions and selectively turning off the power supply to high-risk areas under high wind conditions. However, this 'solution' is controversial because it carries with it other risks such as encouraging residents to use gas-powered generators, which can cause fires; and if a fire does occur, it disrupts communications and can threaten structure protection for

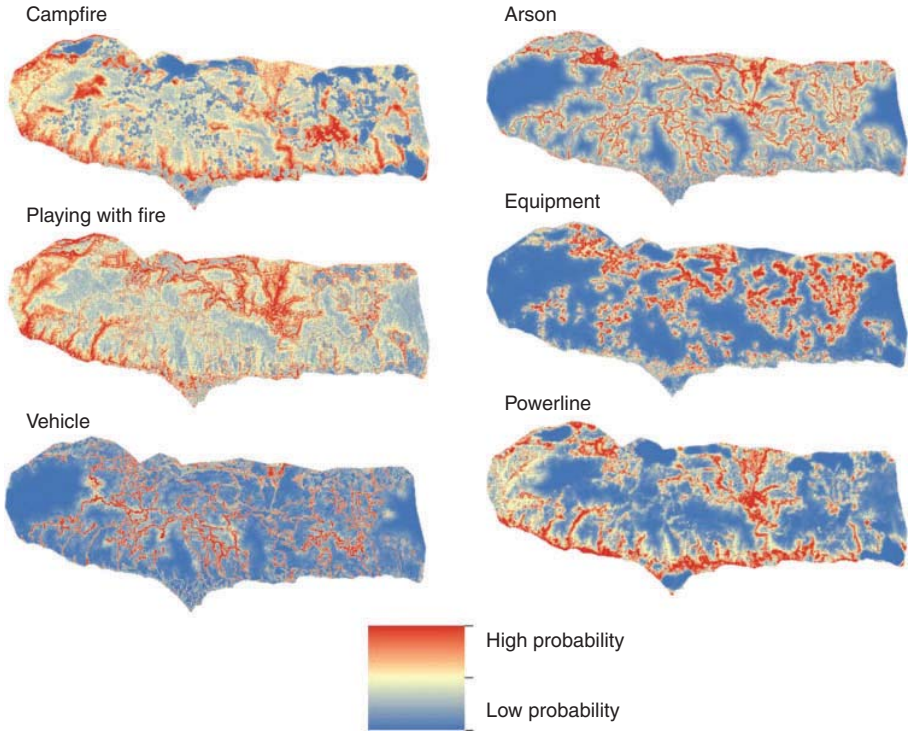


Fig. 5. Predicted probability of ignition (0–1.0) by major cause in the Santa Monica Mountains.

homes dependent on wells for their water source. It has been suggested that underground power lines in high-risk wind corridors could reduce such ignitions (Keeley *et al.* 2009), but this option is generally viewed as too costly by power companies. In Australia, however, underground power lines were recommended after the deadly Victoria fires in 2009, and some state regulations now require them under certain conditions (Victorian Bushfires Royal Commission 2010).

The other very important ignition source for area burned differed between the two regions. In the Santa Monica Mountains, arson fires were a major factor, and such ignitions are fundamentally different from other human ignition causes because they are intentional rather than accidental. Therefore, their location and timing are chosen. Miller (1968) noted a link between Santa Ana winds and crime in southern California, which would be consistent with large arson fires in the autumn months when the extreme fire hazard created by Santa Ana winds is widely noted in the media. Several comprehensive studies of arson ignitions have been conducted (Prestemon and Butry 2005; Thomas *et al.* 2011); but as these studies suggest, much more research needs to be carried out, as the behavioural patterns driving arson ignitions is complex and may be similar to other criminal activities. Further modelling of arson fires could therefore integrate theories from the criminology and social sciences into the development of explanatory variables. In fact, theories on accidents could also be used to create explanatory variables for unintentional human-caused ignitions.

Law enforcement has become quite strict in southern California, as arson is a felony. In fact, the arsonist convicted for starting the 2003 Old Fire in San Bernardino County, CA received the death penalty (http://articles.latimes.com/2013/jan/29/local/la-me-old-fire-sentencing-20130129, verified 13 August 2014). Information on the timing, drivers and spatial pattern of these ignitions, combined with more behavioural analyses, might help police organisations identify how to prevent these fires before they start. However, a potential pitfall of addressing arson fires is that, because arsonists want to cause fires, they might alter their behaviour to adapt to and avoid targeted management or enforcement activities. Nonetheless, research on other crimes suggests that criminal prevention efforts actually help reduce crime in neighbouring areas, rather than to simply move the criminal behaviour to untargeted locations (Weisburd *et al.* 2006).

The other ignition source associated with large area burned was equipment use in San Diego County. Although equipment use was one of the most numerous ignition causes in the Santa Monica Mountains, it did not result in extensive area burned. Across the state of California, equipment use is a common ignition cause and results in more than 1600 fires per year (Cal Fire 2011).

One challenge in trying to manage for equipment fires is that they encompass a wide range of activities that are collectively presented as ‘equipment caused’ in the fire records, making it impossible to pinpoint the type of equipment. Not surprisingly, most equipment-caused ignitions occur close to roads and within the WUI (Figs 5, 6). Because equipment use is such a common ignition source and is a potentially modifiable behaviour, this is one ignition source that should be a target for future

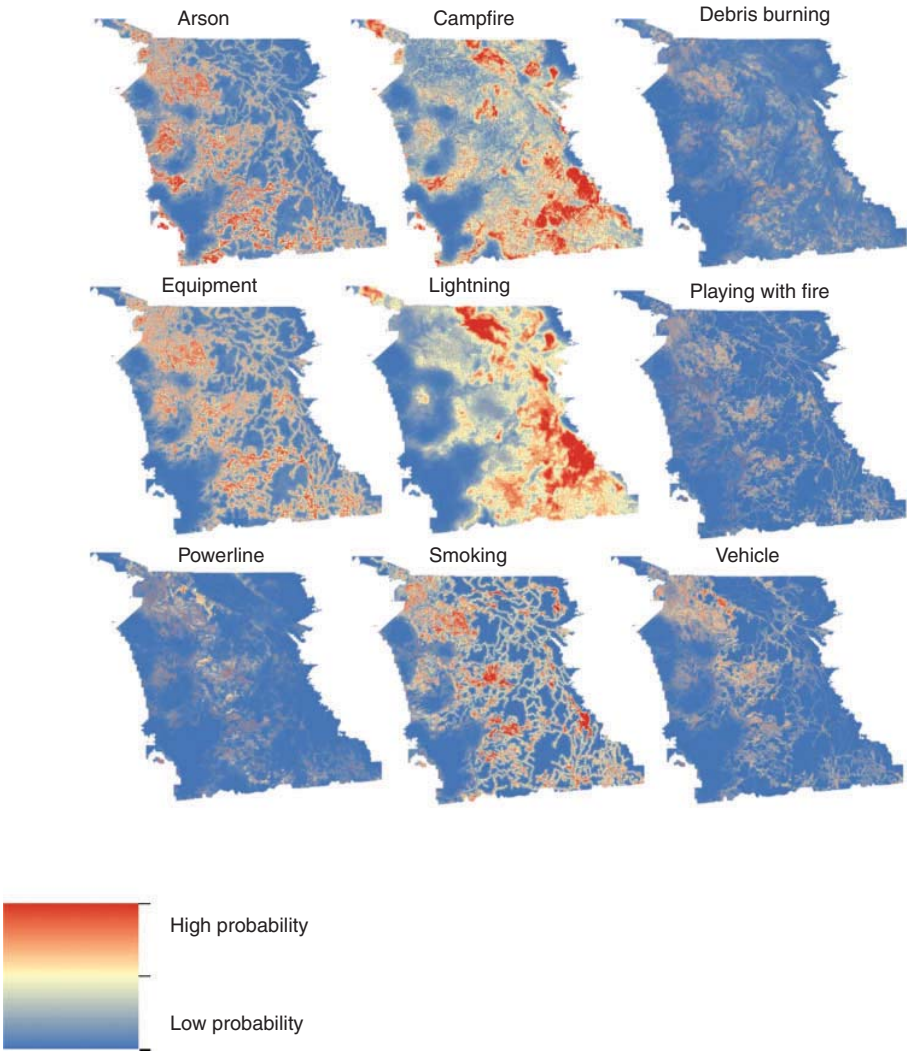


Fig. 6. Predicted probability of ignition (0–1.0) by major cause in San Diego County.

prevention actions. For example, strict ordinances on the use of certain types of equipment in and adjacent to wildland areas during red flag warning days could reduce the incidence of large catastrophic fires in the region. Further investigation into the types of equipment that cause most fires would also be useful in further refining how to best allocate resources for outreach materials.

In addition to the timing of different ignition causes in autumn months, another explanation for differences in number of fires and area burned is that certain ignition causes may exhibit distinct spatial patterns that correspond with locations of higher fire danger. For example, extreme wind patterns in the region follow predictable pathways, and the region's largest fires have historically occurred in those areas (Moritz *et al.* 2010). Therefore, an ignition that occurs along wind corridors during extreme fire weather and is also in a fairly inaccessible region may have a greater chance of developing into a large fire. In some places, these wind corridors are associated with repeated housing losses (Syphard *et al.* 2012).

One limitation in this analysis by ignition cause is that ~30% of ignitions were of unknown or miscellaneous cause in both sub-regions. These ignitions did contribute a substantial extent of fire burned, and it is difficult to develop targeted strategies for preventing these. Nevertheless, the proportion of known ignition causes is much higher in California than in many other regions, and is continuing to improve. Unknown fire causes is a worldwide problem, and many other regions or countries have substantially higher proportions of fires started by unknown causes (United Nations Economic Commission for Europe 2002). This uncertainty explains why some investigators lump human-caused ignitions together for study (e.g. Martínez *et al.* 2009). The importance of documenting fire causes is receiving increased recognition, however, and some studies are beginning to explain the complex social, environmental, economic and

political controls that contribute to human-caused ignitions (Romero-Calcerrada *et al.* 2008; Meddour-Sahar *et al.* 2013).

Regardless of ignition cause, proximity to roads was consistently important in explaining ignition location. This relationship is highly consistent among studies of ignition patterns, including our previous study in the region (e.g. Sturtevant and Cleland 2007; Syphard *et al.* 2008; Narayanaraj and Wimberly 2012). One reason for this consistent relationship is that, in addition to the concentration of human activities that spark ignitions, vegetation may be more flammable along roads (Curt *et al.* 2007; Narayanaraj and Wimberly 2012). More research is needed, however, to understand how and why so many fires start along roads and whether any prevention strategies could be feasibly and effectively implemented. One idea would be to install barriers between roads and the wildland in fire-prone locations. However, this could be more costly than educational campaigns so a cost–benefit analysis would be highly beneficial.

Conclusion

Although it is generally understood that the primary causes and drivers of wildland fire ignitions vary over space and time (Stephens 2005), our results underline the importance of examining local trends in where, why and how ignitions occur. Even within two similar sub-regions in southern California, there were some differences in number and extent of fires by ignition cause, as well as the relative importance of the factors that explained their distribution. For example, the presence of grass explained a larger proportion of ignition distribution in the Santa Monica Mountains, whereas proximity to roads and structure density were more important in San Diego County. In regions where humans cause a substantial number of fire ignitions, it is important to recognise that not all ignitions have the same effect or spatio–temporal signature. Because each ignition cause represents a different type of behaviour, prevention programmes could allocate resources to target behaviours in proportion to their effect in time or space.

Despite local variation, broad-scale similarities within the study regions, such as the importance of power lines, timing of ignition in autumn, and proximity to roads and the WUI also suggest informative general patterns that may be useful when finer scale detail is unavailable. For example, given the overall importance of ignitions occurring close to human infrastructure, planners may want to consider that if housing development and roads continue to expand into the wildland, the distribution of ignitions may therefore also expand. Development of low-density, exurban housing may also lead to more homes being destroyed by fire (Syphard *et al.* 2013). Another consideration is that frequent fires and housing growth may lead to the expansion of highly flammable exotic grasses that can further increase the probability of ignitions (Keeley *et al.* 2012). Longer term management strategies may therefore benefit from future forecasts of ignition patterns relative to projections of housing growth or vegetation change.

Other management responses that could benefit both regions would be restrictions on equipment use and other activities that could start a fire during the Santa Ana wind season and greater patrol for arson during extreme weather conditions. Putting power lines underground and identifying strategies that could effectively reduce roadside ignitions are additional challenges that deserve serious consideration throughout the southern California region.

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References

Bar Massada A, Syphard AD, Stewart SI, Radeloff VC (2013) Wildfire ignition-distribution modelling: a comparative study in the Huron–Manistee National Forest, Michigan, USA. *International Journal of Wildland Fire* **22**, 174–183. doi:10.1071/WF11178

Bowman DMJS, Balch JK, Artaxo P, Bond WJ, Carlson JM, Cochrane MA, D'Antonio CM, DeFries RS, Doyle JC, Harrison SP, Johnston FH, Keeley JE, Krawchuk MA, Kull CA, Marston JB, Moritz MA, Prentice IC, Roos CI, Scott AC, Swetnam TW, van der Werf GR, Pyne SJ (2009) Fire in the earth system. *Science* **324**, 481–484. doi:10.1126/SCIENCE.1163886

Butry D (2009) Fighting fire with fire: estimating the efficacy of wildfire mitigation programs using propensity scores. *Environmental and Ecological Statistics* **16**, 291–319. doi:10.1007/S10651-007-0083-3

Cal Fire (2000) 'Wildland fire hazard assessment: Final report on FEMA 1005–47.' California Division of Forestry and Fire Protection: Sacramento, CA.

Cal Fire (2011) Incident information. Available at http://cdfdata.fire.ca.gov/incidents/incidents_statsevents [Verified 12 May 2014]

Cal Fire (2013) Fire perimeters. Available at http://frap.fire.ca.gov/data/frapgisdata-sw-fireperimeters_download.php [Verified 9 December 2013]

Cardille JA, Ventura SJ, Turner MG (2001) Environmental and social factors influencing wildfires in the Upper Midwest, United States. *Ecological Applications* **11**, 111–127. doi:10.1890/1051-0761(2001)011[0111:EASFIW]2.0.CO;2

Cary GJ, Flannigan MD, Keane RE, Bradstock RA, Davies ID, Lenihan JM, Li C, Logan KA, Parsons RA (2009) Relative importance of fuel management, ignition management and weather for area burned: evidence from five landscape–fire–succession models. *International Journal of Wildland Fire* **18**, 147–156. doi:10.1071/WF07085

Catry FX, Rego FC, Bação F, Moreira F (2009) Modeling and mapping wildfire ignition risk in Portugal. *International Journal of Wildland Fire* **18**, 921–931. doi:10.1071/WF07123

Chevan A, Sutherland M (1991) Hierarchical partitioning. *The American Statistician* **45**, 90–96.

Cohen JD (2000) Home ignitability in the wildland–urban interface. *Journal of Forestry* **98**, 15–21.

Cruz MG, Sullivan AL, Gould JS, Sims NC, Bannister AJ, Hollis JJ, Hurley RJ (2012) Anatomy of a catastrophic wildfire: the Black Saturday Kilmore East fire in Victoria, Australia. *Forest Ecology and Management* **284**, 269–285.

Curt T, Ganteaume A, Alleaume S, Borgniet L, Chandioux O, Jappiot M, Lampin C, Martin W (2007) Vegetation flammability and ignition potential at road–forest interfaces (southern France). In '4th International Wildland Fire Conference 2007', May, Sevilla, Spain (CD-ROM). (Ministerio de Medio Ambiente: Madrid, Spain)

Dormann CF, McPherson JM, Araujo MB, Bivand R, Bolliger J, Carl G, Davies RG, Hirzel A, Jetz W, Kissling WD, Kuhn I, Ohlemuller R, Peres-Neto PR, Reineking B, Schroder B, Schurr FM, Wilson R (2007) Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. *Ecography* **30**, 609–628. doi:10.1111/J.2007.0906-7590.05171.X

Elith J, Graham CH, Anderson RP, Dudik M, Ferrier S, Guisan A, Hijmans RJ, Huettmann F, Leathwick JR, Lehmann A, Li J, Lohmann LG, Loiselle BA, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton JM, Peterson AT, Phillips SJ, Richardson K, Scachetti-Pereira R, Schapire RE, Soberon J, Williams S, Wisz MS, Zimmermann NE (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography* **29**, 129–151. doi:10.1111/J.2006.0906-7590.04596.X

Elith J, Phillips SJ, Hastie T, Dudík M, Chee YE, Yates CJ (2011) A statistical explanation of MaxEnt for ecologists. *Diversity & Distributions* **17**, 43–57. doi:10.1111/J.1472-4642.2010.00725.X

Genton MG, Butry DT, Gumpertz ML, Prestemon JP (2006) Spatio–temporal analysis of wildfire ignitions in the St Johns River Water Management District, Florida. *International Journal of Wildland Fire* **15**, 87–97. doi:10.1071/WF04034

Gill AM (2005) Landscape fires as social disasters: an overview of the bushfire problem. *Environmental Hazards* **6**, 65–80. doi:10.1016/J.HAZARDS.2005.10.005

Gill AM, Stephens SL, Cary GJ (2013) The worldwide 'wildfire' problem. *Ecological Applications* **23**, 438–454. doi:10.1890/10-2213.1

Gonzalez-Olabarria J, Brotons L, Gritten D, Tudela A, Angel Teres J (2012) Identifying location and causality of fire ignition hotspots in a Mediterranean region. *International Journal of Wildland Fire* **21**, 905–914. doi:10.1071/WF11039

Hammer RB, Radeloff VC, Fried JS, Stewart SI (2007) Wildland–urban interface housing growth during the 1990s in California, Oregon, and Washington. *International Journal of Wildland Fire* **16**, 255–265. doi:10.1071/WF05077

Keeley JE (2006) South coast bioregion. In 'Fire California's Ecosystems'. (Eds NG Sugihari, JW van Wagtendonk, KE Shaffer, J Fites-Kaufman, AE Thode) pp. 350–390. (University of California Press: Berkeley, CA)

Keeley JE, Fotheringham CJ, Morais M (1999) Reexamining fire suppression impacts on brushland fire regimes. *Science* **284**, 1829–1832. doi:10.1126/SCIENCE.284.5421.1829

Keeley JE, Safford HD, Fotheringham CJ, Franklin J, Moritz MA (2009) The 2007 southern California wildfires: lessons in complexity. *Journal of Forestry* **107**, 287–296.

Keeley JE, Bond WJ, Bradstock RA, Pausas JG, Rundel PW (2012) 'Fire in Mediterranean Ecosystems Ecology, Evolution and Management.' (Cambridge University Press: Cambridge, UK)

Keeley JE, Syphard AD, Fotheringham CJ (2013) The 2003 and 2007 Wildfires in Southern California. In 'Natural Disasters and Adaptation to Climate Change'. (Eds S Boulter, J Palutikof, DJ Karoly, D Guitart) pp. 42–52. (Cambridge University Press: Oxford, UK)

Martínez J, Vega-Garcia C, Chuvieco E (2009) Human-caused wildfire risk rating for prevention planning in Spain. *Journal of Environmental Management* **90**, 1241–1252. doi:10.1016/J.JENVMAN.2008.07.005

Meddour-Sahar O, Meddour R, Leone V, Lovreglio R, Derridj A (2013) Analysis of forest fires causes and their motivations in northern Algeria: the Delphi method. *Journal of Biogeosciences and Forestry* **6**(4), 247–254. doi:10.3832/IFOR0098-006

Miller WH (1968) Santa Ana winds and crime. *The Professional Geographer* **20**, 23–27. doi:10.1111/J.0033-0124.1968.00023.X

Mitchell JW (2013) Power line failures and catastrophic wildfires under extreme weather conditions. *Engineering Failure Analysis* **35**, 726–735. doi:10.1016/J.ENGFAILANAL.2013.07.006

Moritz MA, Keeley JE, Johnson EA, Schaffner AA (2004) Testing a basic assumption of shrubland fire management: how important is fuel age? *Frontiers in Ecology and the Environment* **2**, 67–72. doi:10.1890/1540-9295(2004)002[0067:TABAOS]2.0.CO;2

Moritz MA, Moody TJ, Krawchuk MA, Hughes M, Hall A (2010) Spatial variation in extreme winds predicts large wildfire locations in chaparral ecosystems. *Geophysical Research Letters* **37**, L04801. doi:10.1890/1540-9295(2004)002[0067:TABAOS]2.0.CO;2

Narayanaraj G, Wimberly MC (2011) Influences of forest roads on the spatial pattern of wildfire boundaries. *International Journal of Wildland Fire* **20**, 792–803. doi:10.1071/WF10032

Narayanaraj G, Wimberly MC (2012) Influences of forest roads on the spatial pattern of human- and lightning-caused wildfire ignitions. *Applied Geography*. **32**(2), 878–888. doi:10.1016/J.APGEOG.2011.09.004

Pausas JG, Keeley JE (2009) A burning story: the role of fire in the history of life. *Bioscience* **59**, 593–601. doi:10.1525/BIO.2009.59.7.10

Penman TD, Bradstock RA, Price O (2013) Modelling the determinants of ignition in the Sydney Basin, Australia: implications for future management. *International Journal of Wildland Fire* **22**, 469–478. doi:10.1071/WF12027

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling* **190**, 231–259. doi:10.1016/J.ECOLMODEL.2005.03.026

Prestemon JP, Butry DT (2005) Time to burn: modeling wildland arson as an autoregressive crime function. *American Journal of Agricultural Economics* **87**, 756–770. doi:10.1111/J.1467-8276.2005.00760.X

Prestemon JP, Butry DT, Abt KL, Sutphen R (2010) Net benefits of wildfire prevention education efforts. *Forest Science* **56**, 181–192.

Price OF, Bradstock RA (2012) The influences of weather, terrain and land management on fire severity in the catastrophic 2009 fires in Victoria, Australia. *Journal of Environmental Management* **113**, 146–157. doi:10.1016/J.JENVMAN.2012.08.041

PRISM Climate Group (2004) PRISM climate data. Available at http://prism.oregonstate.edu [Verified 12 May 2014]

Reineking B, Weibel P, Conedera M, Bugmann H (2010) Environmental determinants of lightning- *v.* human-induced forest fire ignitions differ in a temperate mountain region of Switzerland. *International Journal of Wildland Fire* **19**, 541–557. doi:10.1071/WF08206

Romero-Calcerrada R, Novillo CJ, Millington JDA, Gomez-Jimenez I (2008) GIS analysis of spatial patterns of human-caused wildfire ignition risk in the SW of Madrid (Central Spain). *Landscape Ecology* **23**, 341–354. doi:10.1007/S10980-008-9190-2

Sadasivuni R, Cooke WH, Bhushan S (2013) Wildfire risk prediction in southeastern Mississippi using population interaction. *Ecological Modelling* **251**, 297–306. doi:10.1016/J.ECOLMODEL.2012.12.024

Stephens SL (2005) Forest fire causes and extent on United States forest service lands. *International Journal of Wildland Fire* **14**, 213–222. doi:10.1071/WF04006

Sturtevant BR, Cleland DT (2007) Human and biophysical factors influencing modern fire disturbance in northern Wisconsin. *International Journal of Wildland Fire* **16**, 398–413. doi:10.1071/WF06023

Syphard AD, Radeloff VC, Keeley JE, Hawbaker TJ, Clayton MK, Stewart SI, Hammer RB (2007) Human influence on California fire regimes. *Ecological Applications* **17**, 1388–1402. doi:10.1890/06-1128.1

Syphard AD, Radeloff VC, Keuler NS, Taylor RS, Hawbaker TJ, Stewart SI, Clayton MK (2008) Predicting spatial patterns of fire on a southern California landscape. *International Journal of Wildland Fire* **17**, 602–613. doi:10.1071/WF07087

Syphard AD, Keeley JE, Bar Massada A, Brennan TJ, Radeloff VC (2012) Housing arrangement and location determine the likelihood of housing loss due to wildfire. *PLoS ONE* **7**(3), e33954. doi:10.1371/JOURNAL.PONE.0033954

Syphard AD, Bar Massada A, Butsic V, Keeley JE (2013) Land use planning and wildfire: development policies influence future probability of housing loss. *PLoS ONE* **8**(8), e71708. doi:10.1371/JOURNAL.PONE.0071708

Syphard AD, Brennan TJ, Keeley JE (2014) The role of defensible space for residential structure protection during wildfires. *International Journal of Wildland Fire*, in press. doi:10.1071/WF13158

Thomas DS, Butry DT, Prestemon JP (2011) Enticing arsonists with broken windows and social disorder. *Fire Technology* **47**, 255–273. doi:10.1007/S10694-010-0145-1

United Nations Economic Commission for Europe (2002) Forest fire statistics. UNECE Timber Committee, United Nations, Report ECE/TIM/BULL/2002/4. Available at http://www.unece.org/forests/ff-stats.html [Verified 12 May 2014]

USDA Forest Service (2010) Vegetation classification and mapping. Available at http://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192 [Verified 12 May 2014]

Victorian Bushfires Royal Commission (2010) Fire preparation, response and recovery. Final Report Volume II. (Parliament of Victoria: State of Victoria, Australia).

Walsh C, Mac Nally R (2008). hier.part: Hierarchical Partitioning. R package version 1.0–3. (R Foundation for Statistical Computing: Vienna, Austria)

Weisburd D, Wyckoff LA, Ready J, Eck JE, Hinkle JC, Gajewski F (2006) Does crime just move around the corner? A controlled study of spatial displacement and diffusion of crime control benefits. *Criminology* **44**, 549–592. doi:10.1111/J.1745-9125.2006.00057.X

Wells ML, O'Leary JF, Franklin J, Michaelson J, McKinsey DE (2004) Variations in a regional fire regime related to vegetation type in San Diego County, California (USA). *Landscape Ecology* **19**, 139–152. doi:10.1023/B:LAND.0000021713.81489.A7

Whelan RJ (1995) 'The Ecology of Fire.' (Cambridge University Press: Cambridge, UK)

Winter G, McCaffrey S, Vogt CA (2009) The role of community policies in defensible space compliance. *Forest Policy and Economics* **11**, 570–578. doi:10.1016/J.FORPOL.2009.07.004

Wisz MS, Hijmans RJ, Li J, Peterson AT, Graham CH, Guisan A (2008) Effect of sample size on the performance of species distribution models. *Diversity & Distributions* **14**, 763–773. doi:10.1111/J.1472-4642.2008.00482.X

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ARTICLE

Fringe effects: detecting bull trout (*Salvelinus confluentus*) at distributional boundaries in a montane watershed

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Abstract: Robust assessment and monitoring programs are critical for effective conservation, yet for many taxa we fail to understand how trade-offs in sampling design affect power to detect population trends and describe spatial patterns. We tested an occupancy-based sampling approach to evaluate design considerations for detecting watershed-scale population trends associated with juvenile bull trout (*Salvelinus confluentus*) distributions. Electrofishing surveys were conducted across 275 stream sites from the Prairie Creek watershed, Northwest Territories, Canada. Site-level detectability of juvenile bull trout was not uniform, and imperfect detection affected modelled occupancy probabilities most in fringe habitats near distributional boundaries in steep reaches and large streams. We show that detecting a 30% change in watershed-level occupancy ≥78% of the time, as conservation guidelines suggest, may require three repeat surveys (i.e., temporal replicates) and increased spatial sampling intensity of fringe habitats. Additional sampling effort in fringe sites could be offset by sampling fewer sites in core habitats to optimize designs for detecting demographic shifts in bull trout, while still minimizing risk of nondetection for this cryptic species.

Résumé : Si des programmes d'évaluation et de surveillance robustes sont d'importance capitale pour une conservation efficace, pour de nombreux taxons, l'incidence de compromis dans la conception de l'échantillonnage sur la capacité de déceler des tendances démographiques et de décrire des motifs spatiaux n'est pas bien comprise. Nous avons mis à l'essai une approche d'échantillonnage basée sur l'occupation afin d'évaluer des considérations de conception pour la détection de tendances démographiques à l'échelle du bassin versant associées à la répartition d'ombles à tête plate (*Salvelinus confluentus*) juvéniles. Des relevés à la pêche électrique ont été effectués dans 275 sites dans des cours d'eau du bassin versant de Prairie Creek (Territoires-du-Nord-Ouest, Canada). La détectabilité au niveau du site d'ombles à tête plate juvéniles n'était pas uniforme, et l'incidence d'une détection imparfaite sur les probabilités d'occupation modélisées était la plus grande pour les habitats marginaux près de limites de domaines de répartition dans des tronçons de forte pente et des grands cours d'eau. Nous démontrons que la détection d'un changement de 30 % de l'occupation à l'échelle du bassin versant ≥78 % du temps, comme le suggèrent les directives en matière de conservation, pourrait nécessiter trois relevés répétés (c.-à-d., la répétition d'échantillonnages dans le temps) et une plus grande intensité spatiale de l'échantillonnage des habitats marginaux. Un effort d'échantillonnage accru dans des sites marginaux pourrait être compensé par l'échantillonnage d'un moins grand nombre de sites dans des habitats centraux, afin d'optimiser la conception de l'échantillonnage pour la détection de changements démographiques chez les ombles à tête plate, tout en minimisant le risque de non-détection pour cette espèce cryptique. [Traduit par la Rédaction]

Introduction

The biodiversity of freshwater fishes has declined rapidly across North America in the past 50 years due to habitat perturbation and fragmentation, interactions with non-native species, and overharvest (Dudgeon et al. 2006). Given that threats to biodiversity across rivers are predicted to increase, conservationists must act quickly to prevent further declines in biodiversity (Strayer and Dudgeon 2010; Vörösmarty et al. 2010). However, implementing effective conservation actions to reverse demographic trends requires a precise understanding of the status of populations and effective methods to monitor trends over time (Strayer and Dudgeon 2010).

Historically, assessment methods have focused on abundance estimates using either mark–recapture or census methods at a small number of sites (Thurow et al. 2006; Dunham et al. 2009). However, both are time-consuming, potentially costly, and may not represent population status, or broader scale trends, due to local demographic stochasticity (Maxwell and Jennings 2005), spatial heterogeneity, or nonrepresentative sample allocation (MacKenzie and Nichols 2004; Jones 2011). Consequently, species occurrence data are often collected instead of abundance data, as they can be obtained more rapidly and inexpensively at many sites. Moreover, there is often a positive relationship between occupancy probability and abundance for many taxa (Gaston et al. 2000; Zuckerberg et al. 2009; Linden et al. 2017). Regardless of how well occupancy and abundance metrics are correlated, occupancy has been shown to be a state variable well-suited for monitoring the status of populations across

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broad spatial–temporal scales (Muths et al. 2005; Miller and Grant 2015; MacKenzie et al. 2018).

Although occupancy-based survey designs are commonly used for terrestrial taxa, similar approaches are less often applied to stream fishes (Elith and Leathwick 2009; Comte and Grenouillet 2013; Eby et al. 2014). Occurrence data for fish can be gathered from wadeable streams using various sampling techniques, such as electrofishing, snorkeling, seining, and, more recently, environmental DNA (eDNA) (McKelvey et al. 2016). The detectability of stream fishes, and therefore the ability to determine habitat occupancy status, varies by sampling method (Pregler et al. 2015; Baker et al. 2017), environmental heterogeneity, phenotypic variability among taxa (e.g., behaviour, swimming physiology, and life history), and ontogenetic differences within taxa (Dextrase et al. 2014; Rodtka et al. 2015; Baker et al. 2017). Imperfect detection that results in high rates of "false absences" can confound true absence with nondetection, which can have detrimental effects on initial assessments and monitoring results or on inference from models developed with these data (Tyre et al. 2003). To alleviate this potential sampling bias, an occupancy modelling framework has been developed using detection histories from spatial or temporal replicates (MacKenzie et al. 2002; Bailey et al. 2004; Gu and Swihart 2004).

Occupancy-based assessments typically provide more accurate estimates of species' presence than conventional distributional assessments because the former accounts for imperfect detection by the field methods (MacKenzie et al. 2018). When spatial habitat heterogeneity exists and explains variation in detectability, habitat covariates can be integrated into species distribution models (SDMs) to improve precision of inferences by accounting for false absences (MacKenzie et al. 2002; Kuehne and Olden 2016; Baker et al. 2017). This is a key benefit of occupancy–detection models since detectability is rarely uniform across a species distributional range. In fact, detectability is often highest in the core (centre) of regional distributions and declines towards the edges, due to differences in local abundance related to habitat suitability (Sexton et al. 2009; Peterson 2011; MacKenzie et al. 2018). Although detecting species effectively in fringe habitat may be difficult, it is an integral step for accurately documenting species distributional limits and a key element of effective distributional monitoring (Noon et al. 2012; Comte et al. 2013). Furthermore, when a species declines, sites near distributional boundaries are often lost first (Comte et al. 2013; Eby et al. 2014). However, for many taxa, we fail to understand how trade-offs between additional effort allocated to sampling more sites across larger geographic areas versus temporal replicates at fewer sites will affect the accuracy of distributional assessments, precision of parameter estimates from SDMs, and the power to detect trends in occupancy over time (Noon et al. 2012; Barata et al. 2017). Surprisingly, few studies have used empirical data to evaluate survey effort required to detect changes in fish populations across stream networks (Reid and Haxton 2017) or explore how imperfect detection affects precision and accuracy of habitat–occupancy relationships derived from SDMs (Peterson and Dunham 2003; Comte and Grenouillet 2013; Mollenhauer et al. 2018).

In this study, we used bull trout (*Salvelinus confluentus*) to test the utility of an occupancy-based sampling approach to assess its distribution in a northern montane watershed and evaluate sampling design considerations for detecting spatial patterns and temporal population trends. Bull trout is a cold-water char species found across western North America that has declined in the southern and central parts of its range due to land use, invasive species, and recent climatic trends (USFWS 2008; COSEWIC 2012). Within its range, bull trout occurs at relatively low densities and is patchily distributed among headwater streams within river networks (Rieman and McIntyre 1995; Dunham et al. 2003; Rieman et al. 2007). Effective conservation of bull trout requires assessment and monitoring approaches that are logistically feasible, cost-effective, and capable of detecting spatial and temporal trends. Such data are lacking for populations at the northern range extent (Mochnacz et al. 2013), and although a general protocol to assess bull trout distributions at stream scales is available (Rodtka et al. 2015), evaluating trade-offs between power to detect trends in occupancy and different sampling designs (i.e., number of sites versus number of temporal replicates) has not been attempted. Given that occupancy at larger habitat patch scales using spatial replicates is relatively well understood for bull trout (Peterson and Dunham 2003; Isaak et al. 2015; Rodtka et al. 2015), we focus on site-level occupancy (i.e., sites across streams) estimation and temporal replication within sampling seasons. A better understanding of occupancy dynamics at the site scale may translate to more sensitive monitoring schemes (e.g., Tingley and Beissinger 2009; Eby et al. 2014) and spatial status assessments and SDMs, which often discount detectability (Elith and Leathwick 2009).

Our aim was to design an assessment and monitoring protocol that improves precision and accuracy of initial distributional surveys and is capable of detecting population trends over time. To explore these issues, juvenile bull trout were sampled at sites across the Prairie Creek watershed in the Northwest Territories, Canada, and occupancy and detection modelling was used to (*i*) examine the effect of detectability on the accuracy and precision of site occupancy estimates across environmental gradients; (*ii*) consider the influence of detectability in the use of occupancy models to describe relationships with stream and landscape covariates by comparing results derived from occupancy–detection, constant-detection, and generalized linear models; and (*iii*) examine how detectability influences power to detect temporal trends in occupancy to inform optimal survey design.

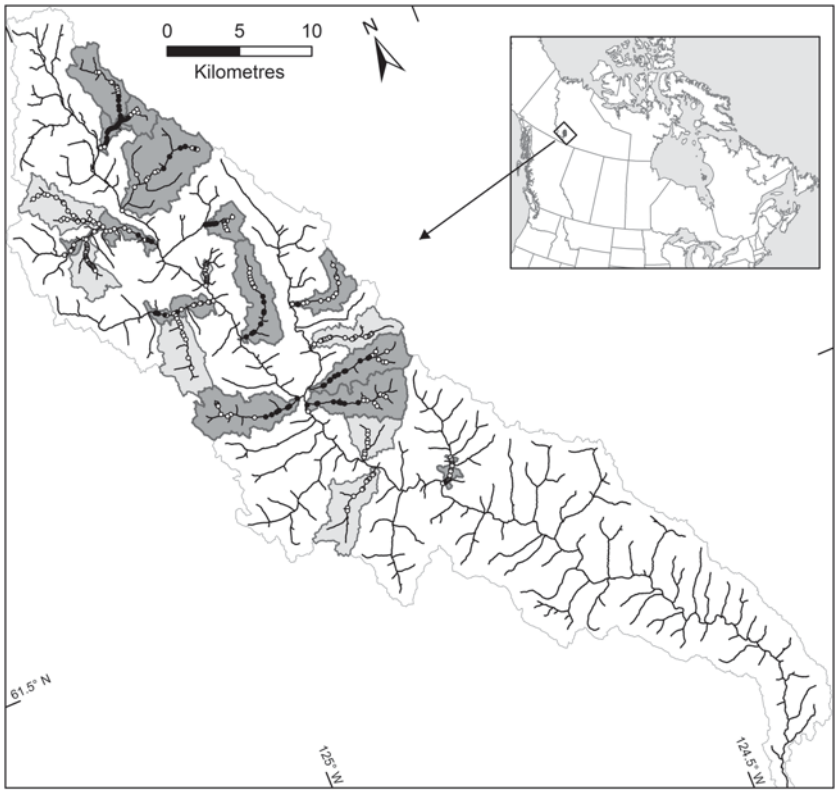
Methods

Study area

Surveys were conducted during the summers of 2014 and 2015 in the Prairie Creek watershed (61°37′N, 124°48′W), which drains ~870 km^2 and is within the South Nahanni River basin, in the Northwest Territories (NWT). Peak precipitation in Prairie Creek occurs from June to August with ~508 mm·year^{-1} of precipitation, of which 300 mm·year^{-1} falls as rain. Flow rates peak in May–June during the spring freshet and are at base flow in July–August (Environment Canada 1991). The climate of the region is characterized by cool summers (mean temperature is 9 °C) and cold winters (mean temperature is −19.5 °C; Halliwell and Catto 2003). The lower half of Prairie Creek bisects dolostone and limestone strata creating high-elevation plateaus and steep canyons (Halliwell and Catto 2003). The lower half of the creek is turbulent and fast-flowing, characterized by deep plunge pools or pools created by stabilized rock fall and swift run and riffle sequences. Flood cycles in this reach have removed much of the finer clasts, leaving cobble and mid- to large-sized boulders. Tributaries to Prairie Creek in the lower half are few, short, and almost entirely ephemeral. The upper half of Prairie Creek changes dramatically to rolling hills dominated by shale, calcareous shale, and minor sandstone (Halliwell and Catto 2003). Stream bed characteristics of the main stem of Prairie Creek also change to deep alluvium of small boulders, cobbles, and pebbles, occasionally punctuated with bedrock outcrops. Large aufeis fields, created by perennial groundwater sources, dominate expansive areas of third-order streams in the upper quarter of the watershed. Mixed geological formations of limestone, dolomite, shale mantled by till, and sandy fluvioglacial drift support groundwater resources across the basin (Halliwell and Catto 2003). Bull trout, slimy sculpin (*Cottus cognatus*), mountain whitefish (*Prosopium williamsoni*), and in the lower reaches, Arctic grayling (*Thymallus arcticus*), are present in Prairie Creek (Babaluk et al. 2015). Bull trout are the most abundant large-bodied fish in Prairie Creek, and all populations are managed under the same regulations across the watershed. Although it is not yet known whether genetically discrete populations occur within individual streams, we expect some stream-level differentiation exists in this watershed

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Fig. 1. Location of the 20 stream patches and 275 sampling sites in the Prairie Creek watershed, Northwest Territories, Canada. White and black circles are unoccupied and occupied sites, respectively. Dark shaded patches are occupied and lighter ones are unoccupied. Sources: 1:50 000 Canadian Digital Elevation Data, Natural Resources Canada; province polygons: Statistics Canada Catalogue No. 92-160-X; state polygons: US Department of Commerce, US Census Bureau, Geography Division, Cartographic Products and Services Branch. This map was created using ArcGIS software by Esri (2019).



given that salmonid fishes commonly exhibit strong homing and local adaptation to natal streams (Fraser et al. 2011). Moreover, individual bull trout populations are often delineated based on the locations where juveniles occur in natal habitat, and these habitats are restricted in ecological scope and geographic distribution (Rieman and McIntyre 1995; Dunham et al. 2002).

Sampling design

The watershed was stratified into patches of potentially suitable habitat for juvenile bull trout based on Strahler stream order (Strahler 1952), stream gradient, and catchment area. We defined habitat patches as all first- to third-order reaches that had <15% gradient and a contributing area > 70 ha. A geographic information system (GIS) was used to generate a stream network and delineate patches using a 1:50 000 Canadian digital elevation model. Our broad definition of suitable patches was based on habitat associations of juvenile bull trout from other areas (Isaak et al. 2009; Al-Chokhachy et al. 2010; Rodtka et al. 2015). Of the 60 suitable patches, 20 were randomly selected and 15 sites (100 m long) within these patches were surveyed. The relative proportions of first- to third-order streams found within patches were representative of those found across the watershed. Within patches, sites were randomly assigned across all streams in a spatially balanced fashion using a generalized random-tessellation stratified design (Fig. 1; Stevens and Olsen 2004). The user specifies a minimal distance for separating sampling sites, and if this condition is violated, the process randomly allocates sites across the sampling frame iteratively until conditions are met. We specified that sites be at least 300 m apart, and most sites in the sampling data frame were, on average, 500 m apart from one another. Each sampling reach was 12–20 mean wetted stream lengths and encompassed at least three pool–riffle–run sequences, representing reach-scale habitat diversity (Simonson et al. 1994). Fewer sites were sampled in some patches (e.g., 12–13) due to logistical constraints (n = 7), barriers (n = 10), or insufficient water (n = 8). However, these nonresponse sites were widely distributed across most patches and often corresponded to sites well beyond upstream distributional boundaries. The generalized random-tessellation stratified process was completed in R (R Core Team 2018), and sites were georeferenced and transposed onto the stream network using a GIS. Fourth-order or higher streams were not sampled because they were too wide and deep to sample effectively with backpack electrofishing gear. Any potential patches with suitable stream lengths < 3000 m were excluded from consideration because local populations of bull trout rarely occur in areas this small (Isaak et al. 2015).

Each summer, an equal number of habitat patches (n = 10) were randomly selected and surveyed to document the occurrence of juvenile bull trout, defined as bull trout with fork lengths < 150 mm (refer to online Supplementary Material, Fig. S1[1]). In total, 275 unique sites were surveyed over 2 years (2014: n = 134; 2015: n = 141) because not all sites could be surveyed in one field season. Sampling occurred between 16 and 26 July, and sites were fished by a two-person crew from downstream to upstream using a single pass with a Smith-Root LR-24 backpack electrofisher (pulsed DC, voltage 400 V, frequency 30 Hz, duty cycle 8). In larger streams, crews moved systematically in a zig-zag direction. All

[1]Supplementary material is available with the article at https://doi.org/10.1139/cjfas-2020-0219.

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fish were collected, identified to species, counted, measured, and returned to the stream. Block nets were not used because sampling during a pilot study showed no appreciable difference in occupancy and relative abundance with or without block nets. This is consistent with what others have found when conducting surveys to determine species occupancy (Samarasin et al. 2017). The electrofishing experience of crews varied, so crews were rotated during stream inventories to alleviate potential biases related to crew experience. The settings on the electrofisher were held relatively constant (i.e., voltage increased or decreased by ≤10 V) across sampling sites. Sampling occurred when streams were at base flow because this is when capture efficiency with electrofishing gear is relatively high (Kuehne and Olden 2016; Baker et al. 2017).

Sites typically had two or three surveys (i.e., temporal replicates) that occurred at 2- to 5-day intervals so that fish distributions could readjust between surveys. A pilot study in 2012 showed that detectability was highest in second-order streams, followed by third- and first-order streams; therefore, first- and second-order streams were surveyed twice and third-order streams were surveyed three times. Detection estimates were derived from the pilot study data and used to determine the number of surveys required to achieve similar false absence rates across stream orders using the RPresence package (https://www.mbr-pwrc.usgs.gov/software/presence.html). Even though most headwater, first-order streams were fishless, we wanted unequivocal evidence that this result was not an artifact of imperfect detection, so we conducted five surveys at a subset of sites (n = 14) across three first-order streams in 2014 and 2015 (Supplementary Table S2[1]). Field sampling was conducted in accordance with Parks Canada Agency research and collection permits NAH-2013-14385 and NAH-2015-19118.

Occupancy–detection modelling

A single-season occupancy–detection model (MacKenzie et al. 2002) was used to estimate site-level occupancy and detectability across the watershed and examine the effects of landscape covariates on these two parameters. To use the full data set (n = 275; Fig. 1) for this analysis, we included year as a covariate (see below) because we did not sample any of these sites in both years. Climatic conditions differed between years with average mean daily July air temperatures of 17.8 °C in 2014 and 16.2 °C in 2015. There are no stream gauges in this watershed, so flows could not be compared, but field crews observed that water levels were similar across years. Detection histories of bull trout at stream sites (e.g., 101: detection, nondetection, detection) were formed from the outcomes of the repeated site surveys within each year. The single-season model has four key assumptions: (1) there are no false detections and failure to detect individuals at a site is a function of the species being truly absent or missed due to imperfect detection; (2) detection of individuals at a sampling unit are independent of detections at all other units; (3) probability of occupancy is equal across all sampling units; and (4) the occupancy status of the species does not change within the sampling period (i.e., closure). To avoid violating the closure assumption, within and across years, we focused on the early juvenile life stage because (*i*) few juveniles move out of natal streams during midsummer (Downs et al. 2006; Hemmingsen et al. 2001); (*ii*) juveniles typically remain in natal streams for 3–4 years (Downs et al. 2006; Homel and Budy 2008); and (*iii*) although annual recruitment of young juveniles (ages 1, 2, 3; <150 mm) varies, complete absence of individuals from all three cohorts at a site across multiple years is rare (Paul et al. 2000; Johnston et al. 2007). Additionally, sites were sampled randomly across both time and space to prevent systematic bias in occupancy, sampling within seasons occurred within a short time period (7–10 days), and sampling year (2014 or 2015) was included as a covariate in models to account for potential interannual variation in occupancy and detection (MacKenzie et al. 2018). In the Prairie Creek watershed, adult bull trout move into first- to third-order habitat patches in the late summer to spawn and then migrate downstream into larger tributaries in the fall. Similar to other areas, juveniles remain in natal streams during early life stages (0 to 3 years) and then join adult populations in downstream areas (N.J. Mochnacz, unpublished data).

Table 1. Covariates describing the 275 stream sampling sites with replicated surveys from the Prairie Creek watershed.

	Mean	Standard deviation	Range
Elevation (m)	1107.0	123.0	795–1399
Stream gradient (%)	4.4	2.5	0.7–13.8
Contributing area (ha)	1219.0	1235.0	73–5060
Mean wetted stream width (m)			
First-order	1.7	0.9	1.0–3.0
Second-order	3.0	0.9	1.0–5.0
Third-order	4.2	1.6	3.0–8.0

Occupancy estimation and detection efficiency may be affected by environmental conditions, so a single-season model was generalized to accommodate landscape covariates to explore those effects. A GIS platform was used to derive elevation (m), gradient (%), and contributing area (ha) covariates for each site that was surveyed (Table 1). These covariates were selected because they have either been shown to influence the distribution of bull trout elsewhere (elevation or contributing area: see Paul and Post 2001; Isaak et al. 2015) or represent surrogates of stream habitat attributes that we predicted may influence juvenile bull trout occurrence or detectability (stream size and velocity: see Rich et al. 2003; Al-Chokhachy et al. 2010). More specifically, we predicted that detectability would decrease as stream size and water velocity increased. Contributing area and stream gradient were selected as covariates for detection because they are indirect measures of stream bankfull width and water velocity, respectively (Gordon et al. 2004; Wilkerson et al. 2014). We predicted that juvenile occupancy would be highest in medium-sized streams, with moderate gradients, and elevation would define upstream distributional limits (Paul and Post 2001; Dunham et al. 2003; Isaak et al. 2015). Correlation analysis was performed on continuous covariates to assess multicollinearity and showed only low to moderate correlation, so all were retained for modelling (elevation – gradient = 0.22; gradient – contributing area = −0.50; contributing area – elevation = −0.45). Prior to analysis, covariates were standardized to a mean of zero and a standard deviation of one. A square-root standardization was used for contributing area to reduce the potential influence of a few relatively large values on the effect size of this covariate (MacKenzie et al. 2018).

We used a three-step modelling process. In the first step, we compared different detection efficiency models to determine the importance of detection covariates (contributing area, stream gradient) while holding the full set of occupancy covariates constant using the global model. A total of 20 candidate models were specified based on the global model:

$$(1) \qquad \text{logit}(p_i) = p(\text{survey} + \text{CA} + \text{CA}^2 + \text{Grad} + \text{Grad}^2 + \text{Year})$$

where p_i is site-level detection, Grad is gradient, CA is contributing area, survey is the temporal replicate at a site, Year is the year that sampling was conducted, and p is detection. Quadratic terms for continuous covariates were included. In step two, we examined relationships between both occupancy and detection and these covariates to better understand systematic trends and the degree to which site-level occupancy estimates might be refined by the incorporation of detection covariates. Results of the detection modelling in step one revealed there was no top model, based on differences in Akaike's information criteria (AIC) values from the top-ranked model and model weights (Table 2).

Table 2. Model ranking and summary statistics for the top 10 single-season detection models fit to the data (n = 275).

Model	Rank	AIC	ΔAIC	AICw	Cumulative w	k	−2log(L)
p(CA + CA^2 + Grad + Year)	1	489.76	0.00	0.52	0.52	13	450.60
p(CA + CA^2 + Grad + Grad^2 + Year)	2	490.80	1.04	0.31	0.83	14	453.16
p(CA + CA^2 + Year)	3	492.62	2.86	0.13	0.96	12	449.28
p(Survey + CA + CA^2 + Grad + Year)	4	497.02	7.26	0.01	0.97	17	458.10
p(Survey + CA + CA^2 + Grad + Grad^2 + Year)	5	498.04	8.28	0.01	0.98	18	455.05
p(Grad + Year)	6	498.88	9.12	0.01	0.99	11	457.13
p(Survey + CA + CA^2 + Year)	7	499.12	9.35	0.00	0.99	16	460.23
p(Grad + Grad^2 + Year)	8	499.68	9.92	0.00	0.99	12	458.25
p(CA + Grad + Year)	9	500.74	10.98	0.00	0.99	12	449.18
p(Grad + Grad^2 + Year)	10	501.64	11.88	0.00	1.00	13	447.98

Note: AIC is Akaike's information criterion; ΔAIC is the change in AIC values between the lowest AIC (i.e., highest ranking model) and the given model; AICw is AIC weight; cumulative w is the cumulative AIC weight; k is the number of parameters; and −2log(L) is the model multinomial log-likelihood value multiplied by negative two. Abbreviations: Elev, elevation (m); CA, contributing area (ha); Grad, gradient (%); squared transformations of continuous covariates (CA^2, Grad^2) were included to assess quadratic effects; p, detection; Survey, survey-specific detection (i.e., detection varies across surveys). A total of 20 models were fit to these data. The full set of covariates (Elev + Elev^2 + CA + CA^2 + Grad + Grad^2 + Year) was held constant for the occupancy component of all candidate models.

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Therefore, different combinations of occupancy covariates were specified against detection covariate combinations from the top three detection models (ΔAIC < 3.0, cumulative weight = 0.96; Table 2) for the full occupancy candidate model set. A constant-detection model was included, as this model holds detection constant across surveys and sites and assumes that it is not associated with any of the covariates examined. A total of 104 candidate models were specified based on the global model:

$$(2)\quad \text{logit}(\Psi_i) = \Psi(\text{Elev} + \text{Elev}^2 + \text{CA} + \text{CA}^2 + \text{Grad} + \text{Grad}^2 + \text{Year}), p(\text{CA} + \text{CA}^2 + \text{Grad} + \text{Grad}^2 + \text{Year})$$

where Ψ_i is site-level occupancy, Elev is stream elevation (m), and Ψ is occupancy. In step three, a generalized linear model was fit to the same data set using only data from the first survey to simulate a study design without temporal replicates. Only a global modal was defined for this step:

$$(3)\quad \text{logit}(\Psi_i) = (\text{Elev} + \text{Elev}^2 + \text{CA} + \text{CA}^2 + \text{Grad} + \text{Grad}^2 + \text{Year})$$

where Ψ_i is site-level occupancy.

For the detection and occupancy models (steps 1 and 2), a global model was initially specified and subsequent combinations of covariates were fit to the data with no interaction terms. For all models, covariate effects were represented by the GIS attributes described previously, and both linear and quadratic terms were assessed for each covariate based on knowledge of occupancy–habitat relationships from other studies (Paul and Post 2001; Al-Chokhachy et al. 2010; Isaak et al. 2015). The logit-link function was used to model response variables as a function of covariates in all models.

Maximum likelihood methods were used to estimate detection and occupancy parameters and occupancy models–outputs were run using the programs RPresence and PRESENCE, version 11.6 (Hines 2006). For each candidate model set, AIC was used for model selection (Burnham and Anderson 2002), and 95% confidence intervals (CIs) were calculated using the Wald method on the logit scale, then limits were transformed to the probability scale. Where multiple models had support on the basis of AIC (i.e., ΔAIC < 3.0), model averaging was used to combine the model-specific estimates to account for model selection uncertainty (Burnham and Anderson 2002; MacKenzie et al. 2018). Model averaging of occupancy and detection probability estimates was performed using the subset of models that accounted for at least 96% of the total AIC model weight. Model-averaged estimates were used to make overall inferences from occupancy models. Odds ratios were used to examine the effects of sampling year on both detection and occupancy parameters. Model fit for occupancy–detection models was assessed using Pearson's χ^2 goodness-of-fit and variance inflation factor ($\hat{c}$) (MacKenzie and Bailey 2004). Graphical diagnostics were performed with Dunn–Smyth residuals (Warton et al. 2017). Since the variation inflation factor from our global occupancy–detection model was less than one ($\hat{c}$ = 0.04), no adjustment of standard errors was necessary.

To examine the influence of detectability on these models, we used occupancy–detection, constant-detection, and generalized linear models with the same set of global occupancy variables to predict occurrence probabilities at three spatial scales: sampling sites (n = 275), points at 1 km intervals across the watershed, and all stream segments. These outputs were then used to plot distribution maps of stream segment probabilities and corresponding standard errors and absolute differences in point probabilities derived from the occupancy–detection and generalized linear models. Within-sample predictive performance was assessed for all three models using the area under the curve of the receiver operator characteristic plot, sensitivity, specificity, and actual classification accuracy. The data set was split into training and testing data sets that comprised 80% and 20% of the original data set, respectively, and repeated (n = 5) fivefold cross-validation was completed.

Optimal survey design and trend detection

Power analyses were used to explore the effectiveness of detecting temporal trends in watershed-level occupancy across different occupancy and detection scenarios using results from the single-season model. We specified our effect size (R) as the proportional difference between occupancy from time 1 to time 2. The effect size was then used to calculate Ψ_1, Ψ_2 as the underlying occupancy probabilities for the two samples, where $\Psi_2 = \Psi_1(1 - R)$ (Guillera-Arroita and Lahoz-Monfort 2012). Our effect size varied across a range of values (0.20 to 0.50) to encompass ecological thresholds relevant to conservation and management. Endangered status designations are often assessed as a 30% reduction in a relevant population metric (e.g., area of occupancy) across generational time frames (Dudgeon et al. 2006; COSEWIC 2012; Lemieux Lefebvre et al. 2018). Therefore, an absolute decline equal to or greater than 0.3 (30% reduction) should motivate management action.

Since we did not expect that occupancy and detectability would be homogeneous across our data frame, we used results from the single-season occupancy model to define areas where occupancy and detection differed. We identified an upper transition value

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corresponding to high (≥0.70) detection and occupancy probabilities using response curves for contributing area and gradient, respectively. Sites above this limit (>0.70) were defined as core habitat and those that fell below were fringe habitat. This transition value was selected because when detection and occupancy are at or above 0.70, species can be detected efficiently, and presence–absence data provide unbiased occupancy estimates (Mackenzie et al. 2018). Because single-season models with covariates provide site-specific parameter estimates, we calculated mean occupancy and detection probability for sites within core and fringe habitats (as defined above), using model-averaged site-level estimates from the full model. Mean estimates from these two areas were then used in simulations to examine how trade-offs in survey design affected power to detect changes in occupancy using tools described in Guillera-Arroita and Lahoz-Monfort (2012). The type I error rate (α; probability of incorrectly rejecting null hypothesis of no change in occupancy) was set at 0.1, as this best reflected priorities for monitoring at-risk populations (Isaak et al. 2009; COSEWIC 2012; Rodtka et al. 2015).

We first examined the number of temporal surveys (k) required to determine whether the species was present at an occupied site for a given proportion. The probability of detecting the species at least once from k surveys at a site when present is

$$p^* = 1 - (1-p)^k \quad (4)$$

where p is the detection probability for a single survey. Using this expression, the number of surveys required to achieve p^* of 0.80, 0.90, and 0.95 was derived as

$$k = \frac{\log(1-p^*)}{\log(1-p)} \quad (5)$$

We then examined how the number of surveys (k) affected power (G) to detect an absolute change in occupancy between 0.20 and 0.50 using

$$G = 1 - \beta = \left\{1 - \Phi\left[\frac{z_\alpha/2\sqrt{\sigma_1^2+\sigma_2^2} - (\Psi_1 - \Psi_2)}{\sqrt{\sigma_1^2+\sigma_2^2}}\right]\right\} + \Phi\left[\frac{-z_\alpha/2\sqrt{\sigma_1^2+\sigma_2^2} - (\Psi_1 - \Psi_2)}{\sqrt{\sigma_1^2+\sigma_2^2}}\right] \quad (6)$$

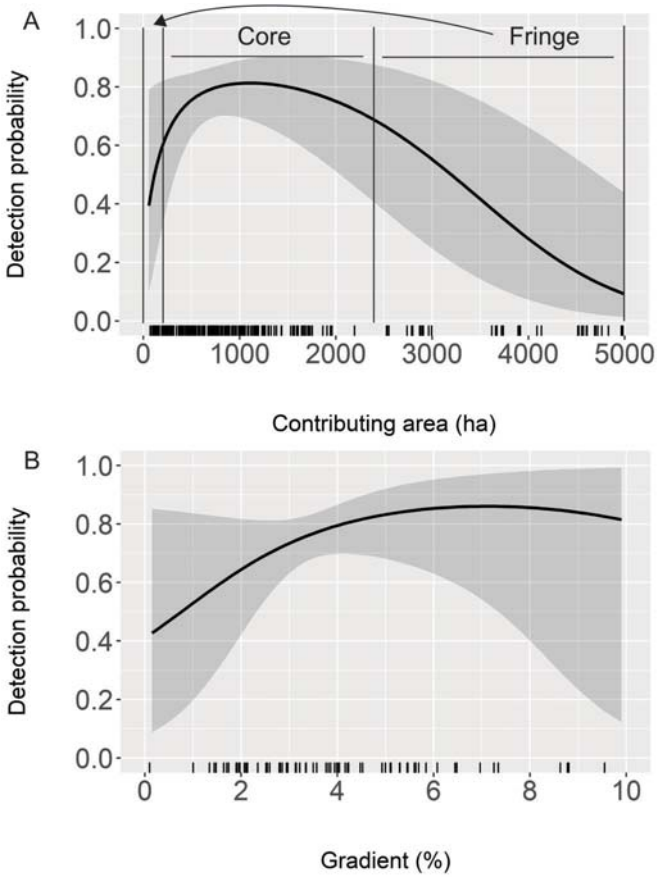
where β is the probability of a type II error, $\Phi(x)$ is the cumulative distribution function for the standard normal distribution, σ_i^2 is the asymptotic variance of the occupancy estimator, $z_\alpha/2$ is the upper 100 α 2-percentage point for the standard normal distribution, and Ψ_1 and Ψ_2 are the underlying occupancy probabilities for the two samples (Guillera-Arroita and Lahoz-Monfort 2012). For these analyses, the sample size (i.e., density of sampling sites) and initial occupancy and detectability estimates were set at values corresponding to core and fringe sites (as described above).

In the final analysis, we used simulations to assess how sample size (spatial replicates) influenced the power to detect changes in occupancy (0.20 to 0.50) and included our current sampling design based on fringe (n = 80) and core (n = 195) habitats. Two-tailed power curves were generated using the closed-form equation above (eq. 6) while keeping occupancy, detectability, and number of surveys (temporal replicates) constant (Guillera-Arroita and Lahoz-Monfort 2012).

Results

Juvenile bull trout were captured from 13 of the 20 stream patches that were surveyed in Prairie Creek between 2014 and 2015 and from 75 of the 275 sites (Fig. 1). Of the 13 patches that were occupied, there were eight where site occupancy was ≥50%.

Fig. 2. Relationship between site-level detection probability and contributing area (A) and gradient (B) using model-averaged detection estimates derived from the top five ranked single-season occupancy–detection models shown in Table 3. Detection probability was predicted for each covariate while holding the other covariates on detection constant. The areas between grey vertical lines correspond to core and fringe habitats, where detection probability is either above or below 0.70. Vertical tick marks along the x axis are sites where samples were taken to build these models.



The relative density per 100 m site ranged between 0 and 30 fish, and mean (±SD) catch was 1.28 (±2.30) fish per site.

Detectability

In the single-season detection candidate model set (n = 20), there was little support for the constant-detection model (ΔAIC = 16.9, weight = 0.0002), as detection probability differed across sites but not surveys (Table 2). Although there was no single top detection model, contributing area was in all three of the top models and gradient was in two, which suggests that both covariates had an influence on detectability. The detectability response curves show that contributing area had a greater effect on site-level detection probability than gradient (Fig. 2). Detection probability was between 0.38 and 0.70 in sites across small streams (<250 ha), high (≥0.70) in medium-sized streams (500–2500 ha), and low (≤0.30) in larger streams with contributing areas >4000 ha. Detection probability was between 0.41 and 0.75 in sites across low-gradient streams (<3.0%) and ≥0.80 across mid- to high-gradient (>4.0%) streams (Fig. 2). In core habitat, fish could be detected >80% of the time at sites with two or fewer surveys, whereas in fringe habitat three or more surveys were required (Supplementary Table S1[1]). Five surveys were completed at 14 sites to examine

Table 3. Model ranking and summary statistics for the top 10 single-season occupancy–detection models fit to the data (n = 275).

Model	Rank	AIC	ΔAIC	AICw	Cumulative w	k	−2log(L)
Ψ(Elev + Elev^2 + CA + Grad + Grad^2 + Year), p(CA + CA^2 + Grad + Year)	1	488.05	0.00	0.38	0.38	12	464.05
Ψ(Elev + Elev^2 + CA + Grad + Grad^2 + Year), p(CA + CA^2 + Grad + Grad^2 + Year)	2	489.05	1.00	0.23	0.61	13	463.05
Ψ(Elev + Elev^2 + CA + CA^2 + Grad + Grad^2 + Year), p(CA + CA^2 + Grad + Year)	3	489.76	1.71	0.16	0.77	13	463.76
Ψ(Elev + Elev^2 + CA + CA^2 + Grad + Grad^2 + Year), p(CA + CA^2 + Grad + Grad^2 + Year)	4	490.80	2.74	0.10	0.87	14	462.80
Ψ(Elev + Elev^2 + CA + Grad + Grad^2 + Year), p(CA + CA^2 + Year)	5	490.97	2.92	0.09	0.96	11	468.97
Ψ(Elev + Elev^2 + CA + CA^2+ Grad + Grad^2 + Year), p(CA + CA^2 + Year)	6	492.62	4.56	0.04	1.00	12	468.62
Ψ(Elev + Elev^2 + CA + Grad + Year), p(CA + CA^2 + Grad + Grad^2 + Year)	7	499.24	11.19	0.00	1.00	12	475.24
Ψ(Elev + Elev^2 + CA + Grad + Year), p(CA + CA^2 + Grad + Year)	8	502.20	14.14	0.00	1.00	11	480.20
Ψ(Elev + Elev^2 + CA + CA^2 + Grad + Grad^2 + Year), p(.)	9	506.62	18.56	0.00	1.00	9	488.62
Ψ(Elev + CA + CA^2 + Grad + Grad^2 + Year), p(CA + CA^2 + Grad + Year)	10	507.63	19.58	0.00	1.00	12	483.63

Note: AIC is Akaike's information criterion; ΔAIC is the change in AIC values between the lowest AIC (i.e., highest ranking model) and the given model; AICw is AIC weight; cumulative w is the cumulative AIC weight; k is the number of parameters; and −2log(L) is the model multinomial log-likelihood value multiplied by negative two. Abbreviations: Elev, elevation (m); CA, contributing area (ha); Grad, gradient (%); p, detection; Ψ, occupancy; squared transformations of continuous covariates (Elev^2, CA^2, Grad^2) were included to assess quadratic effects; (.), where parameters are constant. A total of 104 models were fit to these data.

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presence–absence near hypothesized upstream distributional boundaries, and juvenile bull trout were never detected at 12 of the 14 sites surveyed (Supplementary Table S2[1]). Detection probabilities across all sites differed between years, as the log odds ratio showed that the chance of juvenile bull trout being detected at a site was 1.9 times lower in 2014 than in 2015 (95% CI = 0.84–4.4). Despite the difference, parameter estimates showed that detectability was relatively high in both years (p-2014 = 0.69, 95% CI = 0.50–0.81; p-2015 = 0.76, 95% CI = 0.51–0.89).

Occupancy

Naïve site-level occupancy, which assumes perfect detection (p = 1), was 0.27 and was 25% lower than the modelled site-level occupancy (±SE) of 0.36 ± 0.03 derived from the single-season model. Of the 104 candidate models specified, there was clearly no preferred model based on AIC values and model weights. Despite model selection uncertainty, elevation, gradient, and their quadratic terms were included in the occupancy component of the top five models (ΔAIC < 2.9, cumulative weight = 0.96). Quadratic terms for contributing area were included in two of the top five models for occupancy (Table 3). Modelled occupancy estimates differed little between years, as the odds ratio showed that the chance of juvenile bull trout occupying a site was 0.10 (95% CI = 0.05, 0.25) times greater in 2015 than in 2014. Model-averaged occupancy estimates from the top five single-season models showed that occupancy probability was highest across sites ranging in elevation from 1000 to 1275 m and gradients between 3% and 7%. Site occupancy estimates were lowest in small streams (<250 ha) but high across intermediate to large-sized streams (Fig. 3*a*). Few differences were observed between the top occupancy–detection model and the constant-detection model, but the constant-detection model did have larger confidence intervals for modelled estimates at higher elevations and in sites with contributing areas greater than 4000 ha (Fig. 3). Conversely, site occupancy estimates derived from the generalized linear model showed different relationships with elevation and contributing area than both the occupancy–detection and constant-detection models (Fig. 3; Table 4). Differences in the magnitude and precision of coefficients were most notable between the generalized linear model and occupancy–detection model (Table 4). Distribution maps of occupancy probabilities derived from the occupancy–detection model and the generalized linear model showed that the largest differences in point predictions (occupancy–detection probability – generalized linear model probability) occurred near upstream and downstream distributional limits, and in most instances the occupancy model probabilities were larger than the generalized linear model (Fig. 4*c*). In several stream segments, the standard error of occupancy estimates from the occupancy–detection model were higher than the ones generated using the generalized linear model (Fig. 4*b*); however, detectability was low in most of these segments. Goodness-of-fit and residual diagnostics suggested that the top five occupancy–detection models ($\hat{c}$ = 0.04) fit our data set well. The AIC ranking of candidate models showed that there was much better support for the occupancy–detection model than the constant-detection model (Table 3). Performance metrics revealed that classification accuracy was similar across models, and the confusion matrix showed the occupancy–detection model had slightly higher sensitivity and specificity than the other models (Table 4).

Optimal survey design and trend detection

The data was subset into core and fringe habitats using the modelled occupancy–detection covariate response relationships for contributing area and gradient, bracketed by occupancy–detection probabilities that were >0.70 or <0.70. Core habitat was defined as sites with contributing area >250 and <2450 ha and gradient >2.6% and <7.6% (n = 195), whereas fringe habitat were sites with contributing area <251 and >2451 ha and gradient <2.5% and >7.7% (n = 80; Figs. 2, 3*a*). Results of power curves generated using mean occupancy and detection estimates from core (Ψ = 0.40, p = 0.78; n = 195) and fringe habitats (Ψ = 0.29, p = 0.48; n = 80) are shown in Fig. 5. In core habitat, two surveys were sufficient to detect 30%–50% changes in occupancy ≥78% of the time, and the increase in power by using more than two surveys was minimal (Fig. 5*a*). Conversely, in fringe habitat the power to detect similar changes in occupancy was much lower overall, increased with three or more surveys, and plateaued at five surveys regardless of effect size (Fig. 5*b*).

Results of two-tailed power curves generated using mean occupancy and detection estimates from core (Ψ = 0.40, p = 0.78; n = 195) and fringe sites (Ψ = 0.29, p = 0.48; n = 80) are shown in Fig. 6. Simulations show that in core habitat using the sample size from this study (n = 195), a 30% change in occupancy can be detected ≥78% of the time (Fig. 6*a*). Conversely, in fringe habitat that had fewer sampling sites (this study, n = 80), a 30% change in occupancy can be detected 29% of the time, but if sample size is quadrupled (n = 320) then power to detect a similar change increases to 70% (Fig. 6*b*). The last simulation shows that as sampling density (i.e., sampling sites, n) in fringe habitat increases so does the power to detect a change in occupancy. Detecting changes in occupancy with equal probability in fringe sites as core sites requires three temporal surveys at each site and a fivefold increase in the sampling density (n = 400) across this area (Fig. 6*c*).

Discussion

Site-level detectability of juvenile bull trout is not uniform across environmental gradients in the Prairie Creek watershed and is lowest in fringe habitats near distributional boundaries. Consequently, failing to account for imperfect detection in these habitats makes it difficult to accurately delineate distributional

Table 4. Comparison of single-season occupancy–detection model with constant-detection and generalized linear models.

Model	Predictor	*b*	SE	AIC	ACC	AUC	SENS	SPEC
Occupancy–detection								
Ψ(Elev + Elev^2 + CA + CA^2 + Grad + Grad^2 + Year), *p* (CA + CA^2 + Grad + Year)	Intercept	2.49	0.47	488.05	0.77	0.85	0.84	0.75
	Elev	0.41	0.32					
	Elev^2	−0.92	0.24					
	CA	1.59	0.36					
	CA^2	−0.08	0.15					
	Grad	1.09	0.48					
	Grad^2	−1.75	0.56					
	Year	−2.14	0.40					
Constant-detection model								
Ψ(Elev + Elev^2 + CA + CA^2 + Grad + Grad^2 + Year), *p*(.)	Intercept	2.23	0.44	506.62	0.75	0.85	0.83	0.72
	Elev	0.52	0.30					
	Elev^2	−0.65	0.21					
	CA	1.49	0.35					
	CA^2	−0.39	0.09					
	Grad	1.32	0.47					
	Grad^2	−1.50	0.47					
	Year	−1.62	0.36					
GLM								
(Elev + Elev^2 + CA + CA^2 + Grad + Grad^2 + Year)	Intercept	1.56	0.39		0.74	0.84	0.78	0.70
	Elev	0.57	0.29					
	Elev^2	−0.44	0.21					
	CA	1.30	0.34					
	CA^2	−0.49	0.12					
	Grad	1.42	0.44					
	Grad^2	−1.45	0.46					
	Year	−1.31	0.34					

Note: Abbreviations: ACC, actual internal classification accuracy of fivefold (leave-one-out) cross-validation; AUC, area under of the curve of the receive operator characteristic plot; *b*, beta parameter value; AIC, Akaike's information criterion; SE, standard error; Elev, elevation (m); CA, contributing area (ha); Grad, gradient (%); *p*, detection; Ψ, occupancy; SENS (sensitivity) and SPEC (specifitivity), respectively, from the confusion matrix; squared transformations of continuous covariates (Elev^2, CA^2, Grad^2) were included to assess quadratic effects; (.), a model where detection is constant across all sites and surveys. The constant-detection model coefficients for occupancy were adjusted based on a constant-detection coefficient across sites and surveys. Only coefficients for covariates of occupancy are shown for the occupancy–detection model and the constant-detection model after adjustment of detection. Coefficients for all models are expressed on the logit scale.

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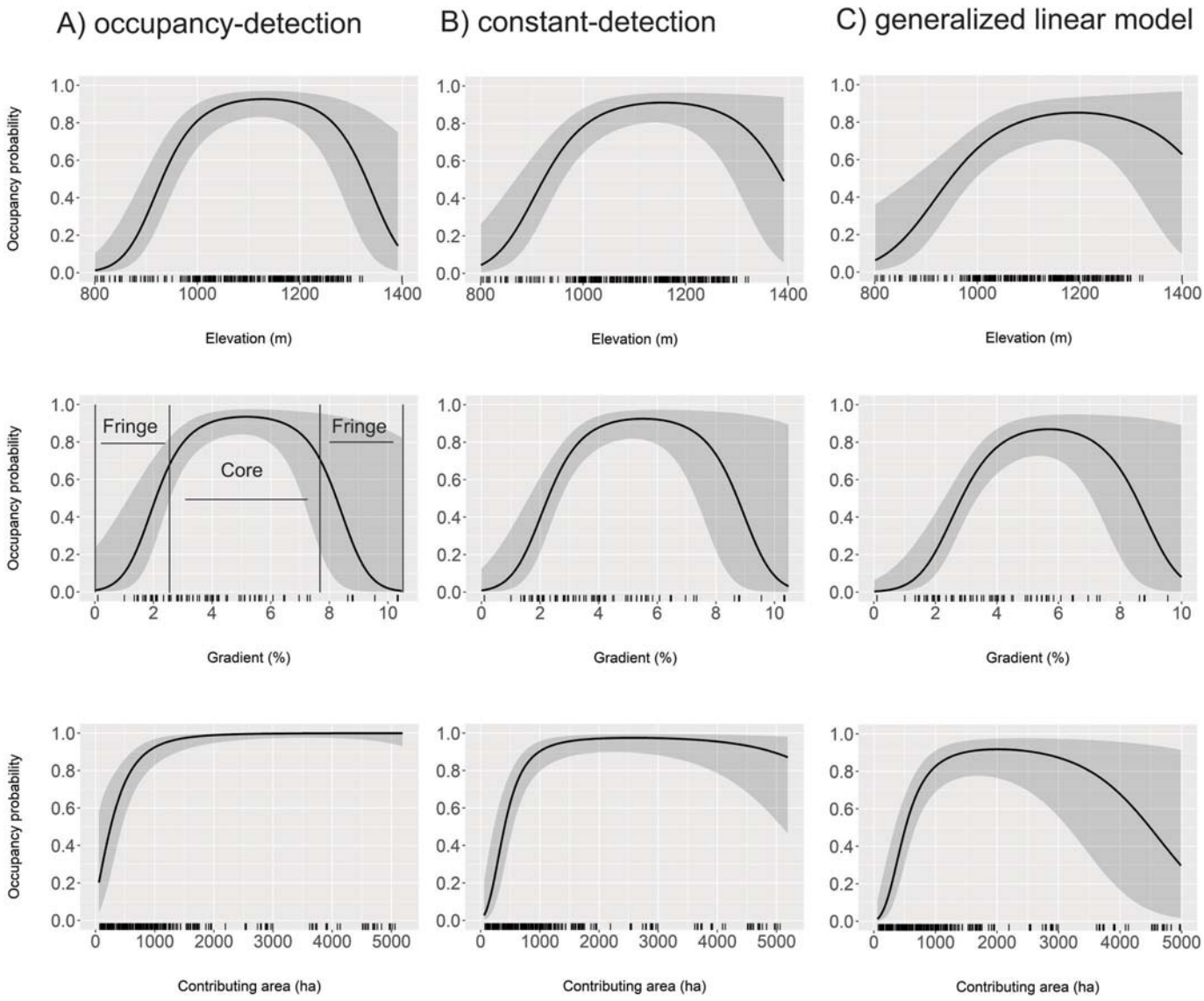
limits and affects model inferences. For example, modelled occupancy estimates derived from a generalized linear model in downstream sites were much lower than estimates from the occupancy–detection model. This reflects the inability of the generalized linear model to impose an upward adjustment of occupancy estimates at sites where there is imperfect detection, and similar effects of detectability on occupancy estimates have been reported in other stream fishes (Comte and Grenouillet 2013; Baker et al. 2017; Dextrase et al. 2014). Ignoring the effect of detectability on site-level surveys could negatively affect trend detection because it is impossible to disentangle the reason for observed distributional changes (i.e., site extirpation or false absence). This presents a conservation risk, because as shown by others (Eby et al. 2014; Lemoine et al. 2020), downstream distributional boundaries are most likely to be abandoned by bull trout as they move upstream from marginal habitats to presumably better habitat at higher elevations. However, in the Prairie Creek watershed, one can mitigate the risk of failing to detect juvenile bull trout in downstream fringe habitats by implementing three temporal replicates and imposing a fivefold increase in the density of spatial replicates. Implementing these changes in study design improves accuracy of assessments by allowing one to relax assumptions of constant detection. Further, we show how a modified watershed-scale sampling approach, tailored to both core and fringe habitats, can detect 30% changes in juvenile occupancy >78% of the time. This approach capitalizes on detectability results by allocating more sampling effort near distributional boundaries and less effort (fewer sampling sites and temporal replicates) in core habitat where occupancy and detectability are high. In fact, our results suggest that in core habitat, a single survey may be as effective as two for detecting juveniles because occupancy and detection are high in these areas. Although this could be a more cost-effective sampling strategy, the risk (i.e., increasing the probability of false absence) should be balanced against conservation objectives (e.g., single distributional assessments versus monitoring watershed-level population trends).

Detectability

We found a 25% difference between our naïve and modelled site occupancy (0.27 versus 0.36, respectively), which is higher than what Rodtka et al. (2015) report for bull trout, and suggests detectability has a greater influence on the accuracy of distributional assessments and occupancy estimates in Praire Creek. Although the difference we report (9%) is well below the threshold shown by Tyre et al. (2003) to significantly degrade estimation of model parameters, we highlight important nuances of how ignoring detectability affects parameters in our model. As expected, the occupancy–detection model ranked much higher than the constant-detection model, reafirming that detectability of juvenile bull trout is not uniform across Prairie Creek and is similar to what has been reported for other stream fishes (Dextrase et al. 2014; Kuehne and Olden 2016; Mollenhauer et al. 2018). However, extending what others have done, we refine our detectability analyses to describe the spatial heterogeneity pattern of imperfect detection across Prairie Creek. Specifically, detectability was lowest near downstream–upstream distributional boundaries and high (≥0.70) everywhere else. Consequently, distributional assessments that fail to account for imperfect detection in Prairie Creek yield the least accurate results (i.e., highest occurrence of imperfect detection) in streams near distributional boundaries and, as our modelling results show, lead to a negative bias of occupancy estimates in

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Fig. 3. Relationship between occupancy and covariates using estimates from occupancy–detection (A), constant-detection (B), and generalized linear (C) models. Estimates are the black lines and 95% confidence intervals are shown by the dark shaded areas. Model-averaged estimates of the occupancy–detection model were derived from the top five models shown in Table 3. Occupancy probability was predicted for each covariate after accounting for detection probability and holding all other covariates constant. The areas between grey vertical lines correspond to core and fringe habitats, where occupancy probability estimates are either above or below 0.70. Vertical tick marks along the *x* axis are sites where samples were taken to build these models.



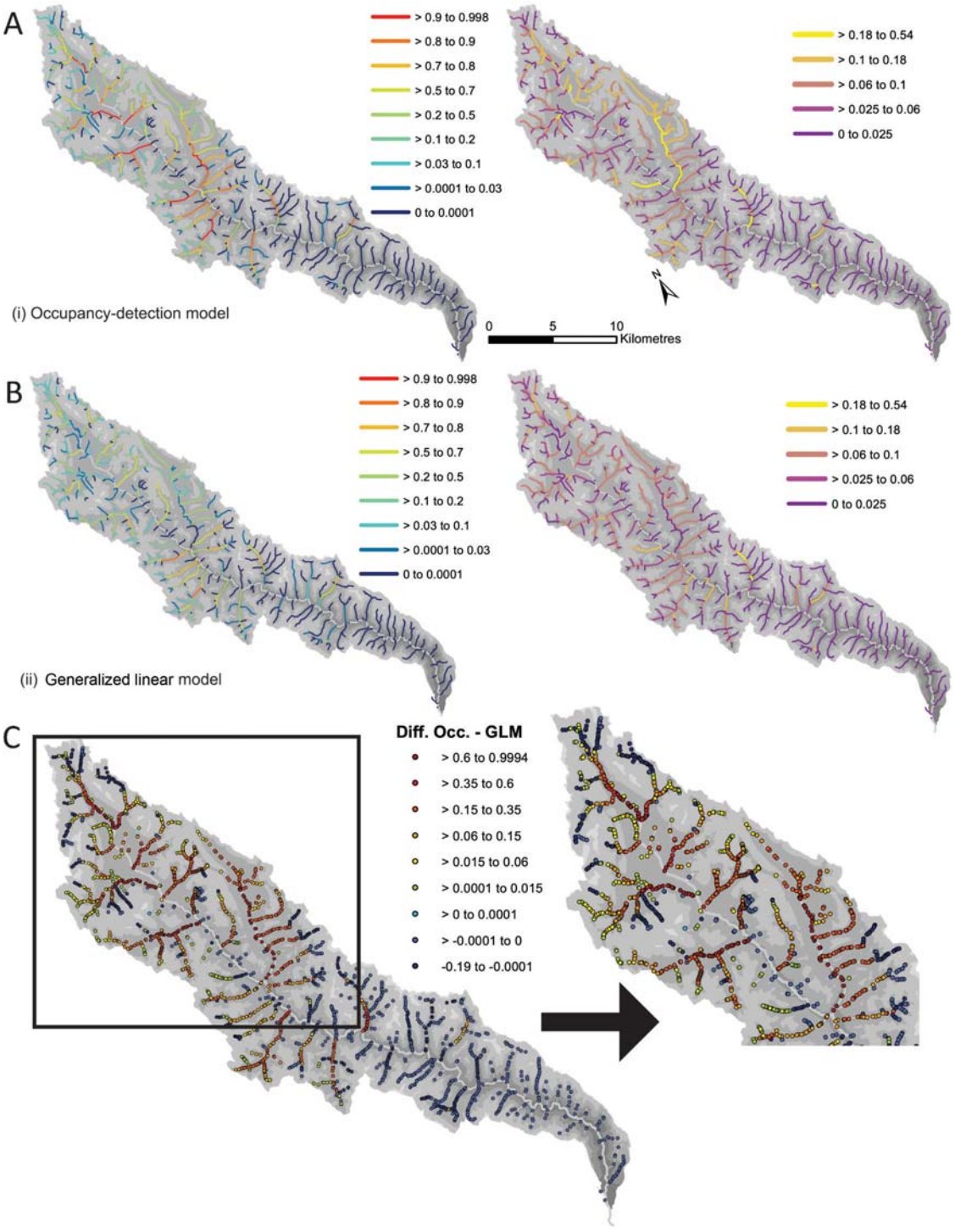
these fringe habitats. This bias was primarily driven by large differences in occupancy-contributing area coefficients between the occupancy–detection and generalized linear model. Similar effects of detectability on occupancy estimates have been shown for other stream fishes (Comte and Grenouillet 2013; Dextrase et al. 2014) and across other taxa (e.g., small mammals, Gu and Swihart 2004; pronghorn antelope (*Antilocapra americana*), MacKenzie et al. 2018), but these studies do not explicitly describe the spatial dimensions of imperfect detection patterns.

Within fringe habitats, detection of juvenile bull trout was lowest in the most downstream extent of second- and third-order streams and emphasizes the importance of using temporal replicates in larger streams. Similar detectability patterns with discharge have been reported for other stream fish (McManamay et al. 2014; Mollenhauer et al. 2018) and support our results, given that contributing area is related to discharge (Gordon et al. 2004). The detection probability confidence intervals at the upper boundary of the stream gradient sampling dimension (8%–10%) were large and is a result of low occupancy, low detection, and small sample size near upstream distributional boundaries. Consequently, none of the models did particularly well predicting occupancy in these areas. Although high gradient sites are difficult to sample, they warrant additional sampling effort for accurate distributional assessments because, as seen elsewhere, high-gradient or high-elevation stream habitat may become important cold-water refugia for northern bull populations as climate warms (Isaak et al. 2016; Lemoine et al. 2020).

Watershed-level occupancy

Juvenile bull trout are patchily distributed across sites in the Prairie Creek watershed, and although only 40% of the patches surveyed appear to represent strongholds for core populations, site occupancy within these patches is relatively high (0.50). This distributional pattern is similar to what others have observed in

Fig. 4. Juvenile bull trout distribution maps for Prairie Creek derived from (A) the occupancy–detection model (*i*) and generalized linear model (*ii*). Distribution is expressed as the probability of juvenile bull trout being present in a 1 km stream segment. Corresponding standard error estimates for each model are shown in panels to the right of A and B. Absolute differences between point probability estimates derived from the occupancy–detection model and the generalized linear model (occupancy–detection – generalized linear model (GLM)) are shown in panel C.



montane watersheds further south (Rodtka et al. 2015; Isaak et al. 2015). However, we have further refined our understanding of site occupancy estimates to include estimates for fringe habitats. Given that this bull trout population occurs in a minimally perturbed watershed, our juvenile occupancy estimates represent those from an otherwise healthy population and could serve as a benchmark for monitoring the status of this population. Also, our detectability and occupancy estimates suggest juveniles exhibit two distributional patterns at downstream and upstream boundaries. First, in upstream areas our modelled occupancy and detection probabilities and detection data suggest a relatively abrupt transition from high to low occupancy. This is similar to what others have seen

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Fig. 5. Power to detect absolute changes in occupancy based on simulations using mean occupancy (Ψ) and detection (p) estimates for varying levels of survey effort (k) and different effect sizes (0.2–0.5). Two scenarios are presented using mean model-averaged occupancy and detection estimates derived from the top five occupancy–detection models corresponding to core (A) and fringe (B) habitats. The following were held constant for each scenario (A: Ψ = 0.40, p = 0.78, n = 195; B: Ψ = 0.29, p = 0.48, n = 80). Power was assessed at α = 0.10.

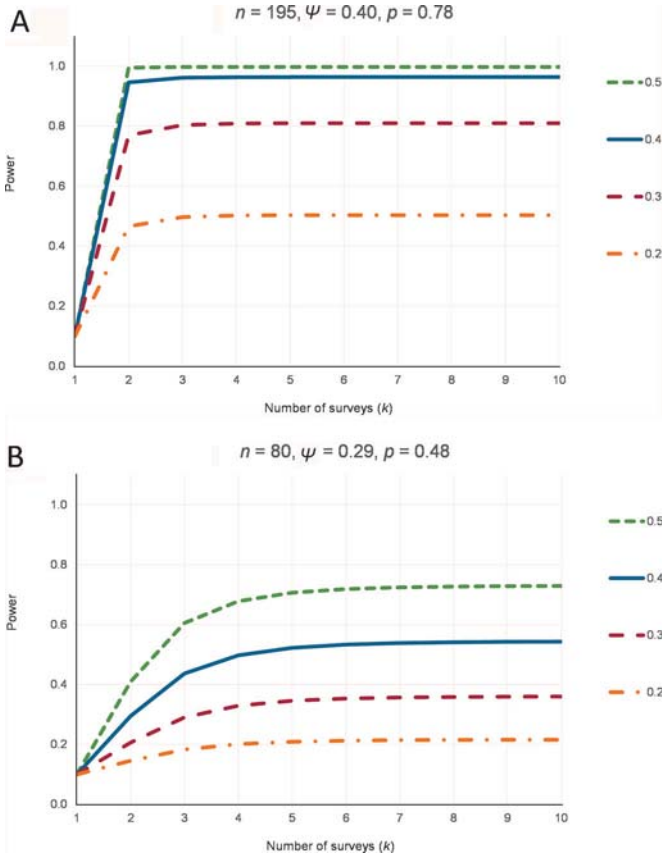
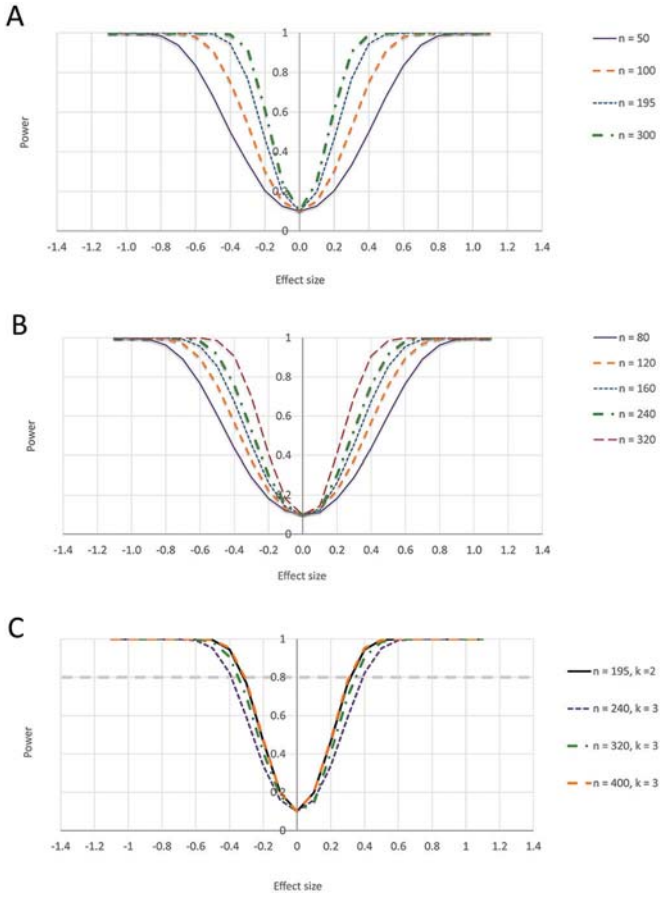


Fig. 6. Power to detect absolute changes in occupancy (effect size) for core (A), fringe (B), and both core and fringe sites (C) based on number of sampling sites (n). The third simulation provides potential outcomes of a hybrid sampling approach where we compared power to detect changes in occupancy for core sites using the sampling design from this study (n = 195, k = 2) and different sampling densities for fringe sites (n = 240, 320, 400) while holding temporal replicates constant (k = 3). The following parameters were held constant for each scenario (A: Ψ = 0.40, p = 0.78, n = 195, k = 2; B: Ψ = 0.29, p = 0.48, n = 80, k = 3) and power was calculated at α = 0.10. The hatched grey line depicts an 80% power level.



related to upstream boundaries associated with elevation (Paul and Post 2001; Rieman et al. 2007). Conversely, the transition from high to low occupancy in downstream areas appears to encompass a much broader spatial dimension. The broader downstream transitional zone from high to low occupancy is a result of low detectability and occupancy, which reflects differences in abiotic (e.g., stream size) and, presumably, biotic characteristics between downstream and upstream areas. Although we did not explicitly address abundance in this study, variability in abundance is also a potential mechanism driving the patchy occupancy and heterogeneous detectability across the watershed (Al-Chokhachy et al. 2009). We highlight that contributing area is an important abiotic factor to consider, but the influence of other abiotic (e.g., stream temperature, groundwater) and biotic parameters (e.g., food availability, abundance) on detectability and occupancy of juvenile bull trout requires further investigation.

Optimal survey design and trend detection

Understanding where best to allocate resources is a critical element of successful monitoring programs, but for many taxa we fail to understand how trade-offs in sampling design affect power to detect population trends. Here, we capitalize on our understanding of the spatial heterogeneity in detectability of juvenile bull trout across the Prairie Creek watershed to develop a more in-depth understanding of how trends in occupancy can be assessed over time. Similar to other studies, our results show that changes in occupancy can be detected more precisely, and with less effort, in areas where occupancy and detection are higher (Steenweg et al. 2016; Barata et al. 2017). In core areas, as few as two surveys were sufficient for detecting changes with reasonable precision (≥78%), but similar effort did not provide equal precision in fringe sites. Power to detect changes in fringe sites increased with additional surveys (i.e., temporal replicates), but plateaued at five, suggesting that conducting additional surveys would provide little benefit. Rodtka et al. (2015) report a similar range of site-level detection (20%–80%) for juvenile bull trout using five spatial replicates, and Lemoine et al. (2020) document changes in site-level occupancy using two or more spatial replicates. We are aware of one other study on riverine fish that reports sampling requirements to detect changes in occupancy (Reid and Haxton 2017), but this study was also different than ours, as it examined how the amount of time spent electrofishing influenced detectability and power to detect changes in occupancy. Although results from Reid and Haxton (2017) are not directly

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comparable with ours, they also illustrate that when detection is low the only way to increase power is by allocating more sampling effort in these areas. In addition, even though the Lemoine et al. (2020) study design is not directly comparable with ours, their ability to detect changes in occupancy in fringe habitats using similar effort as we propose (two to five replicates) provides some confidence that our sampling design would also be effective.

In fringe habitat we show that one can realize improvements in power to detect trends in watershed-scale occupancy by not only increasing the number of surveys (temporal replicates) but also the density of sampling sites (i.e., spatial replicates). In similar studies, investigators have done simulations to generate power curves using mean occupancy and detection probability estimates derived from their entire sampling frame (Steenweg et al. 2016; Barata et al. 2017). This approach is reasonable if estimates are uniform across sites, but this is not the case in Prairie Creek. Therefore, detecting changes in juvenile occupancy across the watershed with similar precision requires different sampling strategies for fringe and core habitats. Trade-offs in sampling effort versus trend detection could be achieved by adjusting sampling design to increase effort (i.e., number of surveys and sampling density) in fringe areas and reduce sampling effort in core areas where occupancy and detectability are higher. We show that detecting 30%–50% changes in watershed-level occupancy can be achieved with reasonable confidence (≥0.78%) by surveying 195 sites twice in core habitat and 400 sites three times in fringe habitat. This is similar to other studies that demonstrate in areas where occupancy and detectability levels are low, the ability to detect changes in occupancy in subsequent time periods can be improved by increasing the number of surveys, number of sampling sites, or a combination of both (Steenweg et al. 2016; Barata et al. 2017; Reid and Haxton 2017). Similarly, Al-Chokhachy et al. (2009) show that improving trend detection in abundance for bull trout requires substantial sampling effort, which is further compounded in areas where the species is rare and abundance is low. Our simulations offer insight on how monitoring programs can be designed to reliably detect changes in occupancy of juvenile bull trout in Prairie Creek, and although sampling requirements are high in fringe areas, they do not require the same level of temporal commitment (i.e., multiple years over long periods) as programs focused on abundance (Al-Chokhachy et al. 2009; Maxwell and Jennings 2005).

Effectively monitoring demographic trends in bull trout populations has proven to be a challenging endeavor that requires substantial effort to detect moderate changes in abundance (Al-Chokhachy et al. 2009). Results from our study suggest that monitoring trends in juvenile occupancy could be a more effective alternative to abundance, as presence–absence data are less expensive to collect and precision is high (>80%) for detecting moderate (≥30%) trends in core areas. Additionally, Isaak and Thurow (2006) show that in a Chinook salmon (*Oncorhynchus tshawytscha*) population core areas of high abundance are more resilient and usually decreases manifest at slower rates than populations in fringe areas. This suggests that observing declines in site occupancy in fringe areas could act as an early warning sign of impending declines in abundance across core sites. However, detecting trends in occupancy in fringe areas requires substantially more effort than in core areas, but sites near the edge of distributional boundaries is where extirpation is most likely for declining populations (Lemoine et al. 2020). This creates an interesting paradox for those wishing to monitor the occupancy status of bull trout populations. In the Prairie Creek watershed, results suggest that trade-offs could be made by allocating less sampling effort in core habitat and more in fringe habitat. For example, since detectability is so high in core sites, one could consider doing only a single survey at these sites. If only one survey was conducted in core sites, sampling effort initially planned for the second replicate at these sites (n = 195) could be reallocated to additional spatial sampling (n), temporal replicates, or a combination of both in fringe habitat. Although this could be a more cost-effective sampling strategy, this approach could increase the probability of false absence in core sites if the population has experienced declines in abundance. Consequently, these type of sampling design trade-offs require careful consideration of conservation and management objectives.

The trade-off between adding more sampling sites to fringe habitat versus additional temporal replicates warrants further consideration. For many, the proposed increase in sampling effort to effectively detect trends in fringe habitat may be cost-prohibitive with the design we suggest. Therefore, spatial sampling replicates and appropriate modelling that accounts for nonindependence among adjacent sampling sites could provide a more efficient sampling alternative (Rodtka et al. 2015; Baker et al. 2017). However, an explicit comparison of the effectiveness of spatial versus temporal replicates for detecting juvenile salmonids across similar stream networks has not been done and would benefit those seeking alternative designs (but see Charbonnel et al. 2014; Baker et al. 2017). Also, sampling more sites fewer times would be less invasive, especially if backpack electrofishing is the capture method, but this could be alleviated by employing less invasive techniques, such as snorkel surveys or environmental DNA (eDNA; Thurow et al. 2006; McKelvey et al. 2016). eDNA offers a promising solution for sampling fringe habitat because samples can be collected with less effort than electrofishing or snorkeling but still provides reliable results (McKelvey et al. 2016). Hybrid sampling approaches could be designed that primarily use eDNA and strategically employ electrofishing to confirm life stage across a subset of sites. Others have successfully used eDNA to document bull trout distribution (Wilcox et al. 2018), and this method warrants further consideration and testing in northern stream systems.

For initial assessments where detectability is unknown, power curves could serve as a guideline to identify how many temporal surveys and sampling sites are needed to minimize false absences. This will increase the chance of detecting juveniles, when present, but also provide greater assurance of "true absence". Once detectability estimates are known for a watershed, users can balance trade-offs in sampling efficiency versus power to detect changes in occupancy by adjusting the number of temporal surveys and sampling sites to achieve desired power for assessing populations trends. The latter will be especially important in situations where monitoring population trends is a key conservation objective. Overall, designing and implementing standardized sampling protocols will be critical for effectively monitoring sentinel species, like bull trout, and detecting effects of climate change on northern freshwater ecosystems (Heino et al. 2020). Furthermore, documenting range contraction, expansion, or shifts from climate change in stream fishes requires effective monitoring at distributional boundaries (i.e., fringe habitat) within watersheds, rather than core areas where populations are most abundant (Gibson-Reinemer et al. 2017).

Ecological relationships

Occupancy–landscape covariate relationships derived from the single-season occupancy model offer two additional benefits beyond informing development of more effective sampling programs. First, site-level occupancy predictions could be validated in similar watersheds as a further test of model performance and to assess transferability of these relationships to other regions — an important step often skipped in the iterative modelling process (Araújo and Peterson 2012; MacKenzie et al. 2018). Second, these occupancy–covariate relationships provide ecological insight into habitat associations of juvenile bull trout from a northern watershed. The stream elevation where we started to see juvenile occupancy decline (~1350 m) is lower than what others have reported in Alberta and Idaho (Paul and Post 2001; Dunham et al. 2003) and probably reflects differences in local climatic conditions from latitudinal variation. Although elevation, contributing area, and gradient are in all the top-ranked models, gradient had the

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greatest influence on juvenile occupancy. The presence of juveniles at sites across a narrow range of stream gradients may be a function of physiological limitations associated with swimming capability and habitat suitability. This seems plausible given that juveniles often seek low-velocity refugia in streams with moderate gradient and larger substrate (Al-Chokhachy et al. 2010), exhibit high fidelity to natal spawning–emergence sites (Homel and Budy 2008), and may seek refuge from predators in these types of habitat (Banish et al. 2008; Al-Chokhachy et al. 2010).

Conclusion

We show that presence–absence data collected during distributional assessments for juvenile bull trout in the Prairie Creek watershed are very reliable in core areas where occupancy and detectability is high. Despite this, our findings illustrate why it is important to recognize that detectability of juveniles is context-dependent and how it can affect the accuracy of distributional assessments. The influence of detectability on survey accuracy has two potential conservation consequences. First, not accounting for imperfect detection during initial and follow-on assessments could result in failure to detect a change in occupancy. Failing to detect a declining trend in an imperilled population could prevent management intervention (e.g., fishing restriction) and ultimately hinder recovery efforts. Second, because stream habitat protection is usually based on habitat quality, modelled occupancy probabilities can help guide this classification (see Isaak et al. 2015). If models that ignore detectability are used to assign occupancy probabilities to fringe habitats, these habitats may be misclassified as low-quality habitat or may be grossly underestimated and fail to receive suitable protection. A better understanding of where and when to implement temporal replication and increase sampling density will help biologists design more sensitive site-scale monitoring schemes (e.g., Tingley and Beissinger 2009; Eby et al. 2014) and improve chances of detecting changes in bull trout occupancy across montane watersheds. Given that few local streams support juvenile bull trout populations in Prairie Creek, effective monitoring should be a critical element of the overall conservation plan for this population.

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References

Al-Chokhachy, R., Budy, P., and Conner, M. 2009. Detecting declines in the abundance of a bull trout (*Salvelinus confluentus*) population: understanding the accuracy, precision, and costs of our efforts. Can. J. Fish. Aquat. Sci. **66**(4): 649–658. doi:10.1139/F09-026.

Al-Chokhachy, R., Roper, B.B., Bowerman, T., and Budy, P. 2010. A review of bull trout habitat associations and exploratory analyses of patterns across the interior Columbia River basin. N. Am. J. Fish. Manage. **30**(2): 464–480. Available from ISI:000277947800012. doi:10.1577/M09-034.1.

Araújo, M.B., and Peterson, A.T. 2012. Uses and misuses of bioclimatic envelope modeling. Ecology, **93**(7): 1527–1539. doi:10.1890/11-1930.1. PMID:22919900.

Babaluk, J., Sawatzky, C., Watkinson, D.A., Tate, D., Mochnacz, N., and Reist, J. 2015. Distributions of fish species within the South Nahanni River watershed, Northwest Territories. *In* Canadian Manuscript Report of Fisheries and Aquatic Sciences 3064. Fisheries and Oceans Canada, Ottawa, Ont.

Bailey, L.L., Simons, T.R., and Pollock, K.H. 2004. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. Ecol. Appl. **14**(3): 692–702. doi:10.1890/03-5012.

Baker, L.F., Artym, K.J., and Swanson, H.K. 2017. Optimal sampling methods for modelling the occupancy of Arctic grayling (*Thymallus arcticus*) in the Canadian Barrenlands. Can. J. Fish. Aquat. Sci. **74**(10): 1564–1574. doi:10.1139/cjfas-2016-0429.

Banish, N.P., Peterson, J.T., and Thurow, R.F. 2008. Physical, biotic, and sampling influences on diel habitat use by stream-dwelling bull trout. N. Am. J. Fish. Manage. **28**(1): 176–187. Available from ISI:000254032500015. doi:10.1577/M06-273.1.

Barata, I.M., Griffiths, R.A., and Ridout, M.S. 2017. The power of monitoring: optimizing survey designs to detect occupancy changes in a rare amphibian population. Sci. Rep. **7**(1): 16491. doi:10.1038/s41598-017-16534-8. PMID:29184083.

Burnham, K.P., and Anderson, D.R. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer-Verlag, New York.

Charbonnel, A., D'Amico, F., Besnard, A., Blanc, F., Buisson, L., Némoz, M., and Laffaille, P. 2014. Spatial replicates as an alternative to temporal replicates for occupancy modelling when surveys are based on linear features of the landscape. J. Appl. Ecol. **51**(5): 1425–1433. doi:10.1111/1365-2664.12301.

Comte, L., Buisson, L., Daufresne, M., and Grenouillet, G. 2013. Climate-induced changes in the distribution of freshwater fish: observed and predicted trends. Freshw. Biol. **58**(4): 625–639. doi:10.1111/fwb.12081.

Comte, L., and Grenouillet, G. 2013. Species distribution modelling and imperfect detection: comparing occupancy versus consensus methods. Divers. Distrib. **19**(8): 996–1007. doi:10.1111/ddi.12078.

COSEWIC. 2012. COSEWIC assessment and status report on the Bull Trout Salvelinus confluentus in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Ont.

Dextrase, A.J., Mandrak, N.E., and Schaefer, J.A. 2014. Modelling occupancy of an imperilled stream fish at multiple scales while accounting for imperfect detection: implications for conservation. Freshw. Biol. **59**(9): 1799–1815. doi:10.1111/fwb.12384.

Downs, C.C., Horan, D., Morgan-Harris, E., and Jakubowski, R. 2006. Spawning demographics and juvenile dispersal of an adfluvial bull trout population in Trestle Creek, Idaho. N. Am. J. Fish. Manage. **26**: 190–200. doi:10.1577/M04-180.1.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., et al. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol. Rev. **81**(2): 163–182. doi:10.1017/S1464793105006950. PMID:16336747.

Dunham, J., Bruce, R., and Gwynne, C. 2003. Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. N. Am. J. Fish. Manage. **23**(3): 894–904. doi:10.1577/M02-028.

Dunham, J.B., Rieman, B.E., and Peterson, J.T. 2002. Patch-based models to predict species occurrence: lessons from salmonid fishes in streams. *In* Predicting species occurrences: issues of scale and accuracy. Island Press, Covelo, Calif. pp. 327–334.

Dunham, J.B., Rosenberger, A.E., Thurow, R.F., Dolloff, C.A., and Howell, P.J. 2009. Coldwater fish in wadeable streams. *In* Standard methods for sampling North American freshwater fishes. *Edited by* S.A. Bonar, W.A. Hubert, and D.W. Willis. American Fisheries Society, Bethesda, Md. pp. 119–138.

Eby, L.A., Helmy, O., Holsinger, L.M., and Young, M.K. 2014. Evidence of climate-induced range contractions in bull trout *Salvelinus confluentus* in a Rocky Mountain watershed, U.S.A. PLoS ONE, **9**(6): e98812. doi:10.1371/journal.pone.0098812. PMID:24897341.

Elith, J., and Leathwick, J.R. 2009. Species distribution models: ecological explanation and prediction across space and time. Annu. Rev. Ecol. Evol. Syst. **40**(1): 677–697. doi:10.1146/annurev.ecolsys.110308.120159.

Environment Canada. 1991. Protecting the waters of the Nahanni National Park Reserve, Northwest Territories. Contract report TR91-I/NAH. Environment Canada, Yellowknife, N.W.T.

Esri. 2019. Prairie Creek watershed: Prairie Creek geometry: 1:50 000 Canadian Digital Elevation Data, Natural Resources Canada; Province Polygons: Provinces/Territories: Boundary Files, 2016 Census. Statistics Canada Catalogue no. 92-160-X; State polygons: U.S. Department of Commerce, U.S. Census Bureau, Geography Division, Cartographic Products and Services Branch. Using: ArcGIS. Version 10.1. Redlands, Calif.

Fraser, D., Weir, L., Bernatchez, L., Hansen, M., and Taylor, E. 2011. Extent and scale of local adaptation in salmonid fishes: review and meta-analysis. Heredity, **106**(3): 404–420. doi:10.1038/hdy.2010.167. PMID:21224881.

Gaston, K.J., Blackburn, T.M., Greenwood, J.J., Gregory, R.D., Quinn, R.M., and Lawton, J.H. 2000. Abundance–occupancy relationships. J. Appl. Ecol. **37**(S1): 39–59. doi:10.1046/j.1365-2664.2000.00485.x.

Gibson-Reinemer, D.K., Rahel, F.J., Albeke, S.E., and Fitzpatrick, R.M. 2017. Natural and anthropogenic barriers to climate tracking in river fishes along a mountain–plains transition zone. Divers. Distrib. **23**(7): 761–770. doi:10.1111/ddi.12576.

Gordon, N.D., McMahon, T.A., and Finlayson, B.L. 2004. Stream hydrology: an introduction for ecologists. John Wiley and Sons, New York.

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Gu, W., and Swihart, R.K. 2004. Absent or undetected? Effects of non-detection of species occurrence on wildlife–habitat models. Biol. Conserv. **116**(2): 195–203. doi:10.1016/S0006-3207(03)00190-3.

Guillera-Arroita, G., and Lahoz-Monfort, J.J. 2012. Designing studies to detect differences in species occupancy: power analysis under imperfect detection. Methods Ecol. Evol. **3**(5): 860–869. doi:10.1111/j.2041-210X.2012.00225.x.

Halliwell, D.R., and Catto, S. 2003. How and why is aquatic quality changing at Nahanni National Park Reserve, NWT, Canada? Environ. Monit. Assess. **88**: 243–281. doi:10.1023/A:1025577325352. PMID:14570418.

Heino, J., Culp, J.M., Erkinaro, J., Goedkoop, W., Lento, J., Rühland, K.M., and Smol, J.P. 2020. Abruptly and irreversibly changing Arctic freshwaters urgently require standardized monitoring. J. Appl. Ecol. **57**: 1192–1198. doi:10.1111/1365-2664.13645.

Hemmingsen, A.R., Gunckel, S., Sankovich, P., and Howell, P. 2001. Bull trout life history, genetics, habitat needs, and limiting factors in central and northeast Oregon. 1997 Annual Report, Proj. No. 95-54. Prepared for US Dept. Energy, Bonneville Power Administration, Environment, Fish and Wildlife, Portland, Ore.

Hines, J.E., 2006. PRESENCE-Software to estimate patch occupancy and related parameters. USGS-PWRC. [Online.] Available from http://www.mbr-pwrc.usgs.gov/software/presence.html [accessed August 2019].

Homel, K., and Budy, P. 2008. Temporal and spatial variability in the migration patterns of juvenile and subadult bull trout in northeastern Oregon. Trans. Am. Fish. Soc. **137**(3): 869–880. Available from ISI:000256288000020. doi:10.1577/T07-019.1.

Isaak, D., Rieman, B.E., and Horan, D. 2009. A watershed-scale monitoring protocol for bull trout. General Technical Report RMRS-GTR-224, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colo.

Isaak, D.J., and Thurow, R.F. 2006. Network-scale spatial and temporal variation in Chinook salmon (*Oncorhynchus tshawytscha*) redd distributions: patterns inferred from spatially continuous replicate surveys. Can. J. Fish. Aquat. Sci. **63**(2): 285–296. doi:10.1139/f05-214.

Isaak, D.J., Young, M.K., Nagel, D.E., Horan, D.L., and Groce, M.C. 2015. The cold-water climate shield: delineating refugia for preserving salmonid fishes through the 21st century. Global Change Biol. **21**: 2540–2553. doi:10.1111/gcb.12879. PMID:25728937.

Isaak, D.J., Young, M.K., Luce, C.H., Hostetler, S.W., Wenger, S.J., Peterson, E.E., et al. 2016. Slow climate velocities of mountain streams portend their role as refugia for cold-water biodiversity. Proc. Natl. Acad. Sci. U.S.A. **113**(16): 4374–4379. doi:10.1073/pnas.1522429113. PMID:27044091.

Johnston, F.D., Post, J.R., Mushens, C.J., Stelfox, J.D., Paul, A.J., and Lajeunesse, B. 2007. The demography of recovery of an overexploited bull trout, *Salvelinus confluentus*, population. Can. J. Fish. Aquat. Sci. **64**: 113–126. doi:10.1139/f06-172.

Jones, J.P. 2011. Monitoring species abundance and distribution at the landscape scale. J. Appl. Ecol. **48**(1): 9–13. doi:10.1111/j.1365-2664.2010.01917.x.

Kuehne, L.M., and Olden, J.D. 2016. Environmental drivers of occupancy and detection of Olympic Mudminnow. Trans. Am. Fish. Soc. **145**(1): 17–26. doi:10.1080/00028487.2015.1091383.

Lemieux Lefebvre, S., Landry-Cuerrier, M., and Humphries, M.M. 2018. Identifying the critical habitat of Canadian vertebrate species at risk. Can. J. Zool. **96**(4): 297–304. doi:10.1139/cjz-2016-0304.

LeMoine, M.T., Eby, L.A., Clancy, C.G., Nyce, L.G., Jakober, M., and Isaak, D.J. 2020. Landscape resistance mediates native fish species distribution shifts and vulnerability to climate change in riverscapes. Global Change Biol. **26**: 5492–5508. doi:10.1111/gcb.15281. PMID:32677074.

Linden, D.W., Fuller, A.K., Royle, J.A., and Hare, M.P. 2017. Examining the occupancy–density relationship for a low-density carnivore. J. Appl. Ecol. **54**(6): 2043–2052. doi:10.1111/1365-2664.12883.

MacKenzie, D.I., and Bailey, L.L. 2004. Assessing the fit of site-occupancy models. J. Agric. Biol. Environ. Stat. **9**(3): 300–318. doi:10.1198/108571104X3361.

MacKenzie, D.I., and Nichols, J.D. 2004. Occupancy as a surrogate for abundance estimation. Anim. Biodivers. Conserv. **27**(1): 461–467.

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Andrew Royle, J., and Langtimm, C.A. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology, **83**(8): 2248–2255. doi:10.1890/0012-9658(2002)083[2248:ESORWD]2.0.CO;2

MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L., and Hines, J.E. 2018. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Elsevier, San Diego, Calif.

Maxwell, D., and Jennings, S. 2005. Power of monitoring programmes to detect decline and recovery of rare and vulnerable fish. J. Appl. Ecol. **42**(1): 25–37. doi:10.1111/j.1365-2664.2005.01000.x.

McKelvey, K., Young, M., Knotek, W., Carim, K., Wilcox, T., Padgett-Stewart, T., and Schwartz, M. 2016. Sampling large geographic areas for rare species using environmental DNA: a study of bull trout *Salvelinus confluentus* occupancy in western Montana. J. Fish Biol. **88**: 1215–1222. doi:10.1111/jfb.12863. PMID:26762274.

McManamay, R., Orth, D., and Jager, H. 2014. Accounting for variation in species detection in fish community monitoring. Fish. Manage. Ecol. **21**(2): 96–112. doi:10.1111/fme.12056.

Miller, D.A., and Grant, E.H.C. 2015. Estimating occupancy dynamics for large-scale monitoring networks: amphibian breeding occupancy across protected areas in the northeast United States. Ecol. Evol. **5**(21): 4735–4746. doi:10.1002/ece3.1679. PMID:26640655.

Mochnacz, N.J., Bajno, R., Reist, J.D., Low, G., and Babaluk, J.A. 2013. Distribution and biology of Bull Trout (*Salvelinus confluentus*) in the Mackenzie Valley, Northwest Territories, with notes on sympatry with Dolly Varden (*Salvelinus malma*). Arctic, **66**(1): 79–93. doi:10.14430/arctic4268.

Mollenhauer, R., Mouser, J.B., and Brewer, S.K. 2018. Sampling the stream landscape: improving the applicability of an ecoregion-level capture probability model for stream fishes. Can. J. Fish. Aquat. Sci. **75**(10): 1614–1625. doi:10.1139/cjfas-2016-0422.

Muths, E., Jung, R.E., Bailey, L.L., Adams, M.J., Corn, P.S., Dodd, C.K., et al. 2005. Amphibian Research and Monitoring Initiative (ARMI): a successful start to a national program in the United States. Appl. Herpetol. **2**(4): 355–371. doi:10.1163/157075405774483139.

Noon, B.R., Bailey, L.L., Sisk, T.D., and McKelvey, K.S. 2012. Efficient species-level monitoring at the landscape scale. Conserv. Biol. **26**(3): 432–441. doi:10.1111/j.1523-1739.2012.01855.x. PMID:22594594.

Paul, A.J., and Post, J.R. 2001. Spatial distribution of native and nonnative salmonids in streams of the eastern slopes of the Canadian Rocky Mountains. Trans. Am. Fish. Soc. **130**: 417–430. doi:10.1577/1548-8659(2001)130<0417:SDONAN>2.0.CO;2.

Paul, A.J., Post, J.R., Sterling, G.L., and Hunt, C. 2000. Density-dependent intercohort interactions and recruitment dynamics: models and a bull trout (*Salvelinus confluentus*) time series. Can. J. Fish. Aquat. Sci. **57**(6): 1220–1231. doi:10.1139/f00-048.

Peterson, A.T. 2011. Ecological niches and geographic distributions. No. 49. Princeton University Press, Princeton, N.J.

Peterson, J.T., and Dunham, J. 2003. Combining inferences from models of capture efficiency, detectability, and suitable habitat to classify landscapes for conservation of threatened bull trout. Conserv. Biol. **17**(4): 1070–1077. doi:10.1046/j.1523-1739.2003.01579.x.

Pregler, K.C., Vokoun, J.C., Jensen, T., and Hagstrom, N. 2015. Using multimethod occupancy estimation models to quantify gear differences in detection probabilities: is backpack electrofishing missing occurrences for a species of concern? Trans. Am. Fish. Soc. **144**(1): 89–95. doi:10.1080/00028487.2014.968291.

R Core Team. 2018. R: a language and environment for statistical computing. [Online.] R Foundation for Statistical Computing, Vienna, Austria. Available from https://www.r-project.org/ [accessed August 2018].

Reid, S., and Haxton, T. 2017. Backpack electrofishing effort and imperfect detection: Influence on riverine fish inventories and monitoring. J. Appl. Ichthyol. **33**: 1083–1091. doi:10.1111/jai.13463.

Rich, C.F., Jr., McMahon, T.E., Rieman, B.E., and Thompson, W.L. 2003. Local-habitat, watershed, and biotic features associated with bull trout occurrence in Montana streams. Trans. Am. Fish. Soc. **132**: 1053–1064. doi:10.1577/T02-109.

Rieman, B.E., and McIntyre, J.D. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Trans. Am. Fish. Soc. **124**(3): 285–296. Available from ISI:A1995QW86900001. doi:10.1577/1548-8659(1995)124<0285:OOBTIN>2.3.CO;2.

Rieman, B.E., Isaak, D., Adams, S., Horan, D., Nagel, D., Luce, C., and Myers, D. 2007. Anticipated climate warming effects on bull trout habitats and populations across the interior Columbia River basin. Trans. Am. Fish. Soc. **136**(6): 1552–1565. Available from ISI:000252371400009. doi:10.1577/T07-028.1.

Rodtka, M.C., Judd, C.S., Aku, P.K.M., and Fitzsimmons, K.M. 2015. Estimating occupancy and detection probability of juvenile bull trout using backpack electrofishing gear in a west-central Alberta watershed. Can. J. Fish. Aquat. Sci. **72**(5): 742–749. doi:10.1139/cjfas-2014-0175.

Samarasin, P., Reid, S.M., and Mandrak, N.E. 2017. Optimal sampling effort required to characterize wetland fish communities. Can. J. Fish. Aquat. Sci. **74**(8): 1251–1259. doi:10.1139/cjfas-2016-0424.

Sexton, J.P., McIntyre, P.J., Angert, A.L., and Rice, K.J. 2009. Evolution and ecology of species range limits. Annu. Rev. Ecol. Evol. Syst. **40**: 415–436. doi:10.1146/annurev.ecolsys.110308.120317.

Simonson, T.D., Lyons, J., and Kanehl, P. 1994. Quantifying fish habitat in streams: transects spacing, sample size, and a proposed framework. N. Am. J. Fish. Manage. **14**: 607–615. doi:10.1577/1548-8675(1994)014<0607:QFHIST>2.3.CO;2.

Steenweg, R., Whittington, J., Hebblewhite, M., Forshner, A., Johnston, B., Petersen, D., et al. 2016. Camera-based occupancy monitoring at large scales: Power to detect trends in grizzly bears across the Canadian Rockies. Biol. Conserv. **201**: 192–200. doi:10.1016/j.biocon.2016.06.020.

Stevens, D.L., Jr., and Olsen, A.R. 2004. Spatially balanced sampling of natural resources. J. Am. Stat. Assoc. **99**(465): 262–278. doi:10.1198/016214504000000250.

Strahler, A.N. 1952. Hypsometric (area-altitude) analysis of erosional topography. Geol. Soc. Am. Bull. **63**(11): 1117–1142. doi:10.1130/0016-7606(1952)63[1117:HAAOET]2.0.CO;2

Strayer, D.L., and Dudgeon, D. 2010. Freshwater biodiversity conservation: recent progress and future challenges. J. N. Am. Benthol. Soc. **29**(1): 344–358. doi:10.1899/08-171.1.

Thurow, R.F., Peterson, J.T., and Guzevich, J.W. 2006. Utility and validation of day and night snorkel counts for estimating bull trout abundance in first- to third-order streams. N. Am. J. Fish. Manage. **26**: 217–232. doi:10.1577/M05-054.1.

Tingley, M.W., and Beissinger, S.R. 2009. Detecting range shifts from historical species occurrences: new perspectives on old data. Trends Ecol. Evol. **24**(11): 625–633. doi:10.1016/j.tree.2009.05.009. PMID:19683829.

Tyre, A.J., Tenhumberg, B., Field, S.A., Niejalke, D., Parris, K., and Possingham, H.P. 2003. Improving precision and reducing bias in biological surveys: estimating false-negative error rates. Ecol. Appl. **13**(6): 1790–1801. doi:10.1890/02-5078.

USFWS. 2008. Bull trout (Salvelinus confluentus) 5-year review: summary and evaluation. US Fish and Wildlife Service, Portland, Ore.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., et al. 2010. Global threats to human water security and river biodiversity. Nature, **467**: 555–561. doi:10.1038/nature09440. PMID:20882010.

Warton, D.I., Stoklosa, J., Guillera-Arroita, G., MacKenzie, D.I., and Welsh, A.H. 2017. Graphical diagnostics for occupancy models with imperfect detection. Methods Ecol. Evol. **8**(4): 408–419. doi:10.1111/2041-210X.12761.

Wilcox, T.M., Young, M.K., McKelvey, K.S., Isaak, D.J., Horan, D.L., and Schwartz, M.K. 2018. Fine-scale environmental DNA sampling reveals climate-mediated interactions between native and invasive trout species. Ecosphere, **9**(11): e02500. doi:10.1002/ecs2.2500.

Wilkerson, G., Kandel, D.R., Perg, L.A., Dietrich, W.E., Wilcock, P.R., and Whiles, M.R. 2014. Continental-scale relationship between bankfull width and drainage area for single-thread alluvial channels. Water Resour. Res. **50**(2): 919–936. doi:10.1002/2013WR013916.

Zuckerberg, B., Porter, W.F., and Corwin, K. 2009. The consistency and stability of abundance–occupancy relationships in large-scale population dynamics. J. Anim. Ecol. **78**(1): 172–181. doi:10.1111/j.1365-2656.2008.01463.x. PMID:18717742.

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(ECCC)

From: Dufour,Jean-Francois (ECCC)
Sent: Sunday, March 13, 2022 9:48 PM
To: 'Kelly Bourassa'
Cc: James Hodson; Hamsha Pathmanathan; 'Bonhomme, Erica'; 'Routhier, Daniel'; Patricia Coyne; MVH; Hache,Samuel (ECCC)
Subject: RE: MVH proposed 2022 bird study scope

Categories: Red category

Hi Kelly,

Thanks for sharing the MVH 2022 Bird Study Scope and Approach document. ECCC-CWS's thoughts remain the same as during the meeting, i.e. we have differing views on the adequacy of the proposed approach to assess the effects of the project on migratory birds and avian SAR. Therefore, we are unable to fully support the proposed scope of work. ECCC-CWS provides the following comments.

Predictive Modeling and Use of BAM models

The use of predictive modeling (i.e. species distribution models) to produce distribution and density maps is ECCC-CWS's preferred approach to assessing project impacts on migratory bird populations by comparing the bird densities and distribution at different scales to identify whether any species may be disproportionately exposed to potential project effects. As mentioned during the meeting, this approach is the standard in forthcoming national ECCC-CWS guidance and was provided for the last 2 major linear projects in the NWT (i.e. CanZinc and TASR). This approach adds more confidence to the impact assessment by allowing to identify the significance of the effect on the population and quantifying the certainty of the effect.

Under the "traditional" approach, effects assessments are limited to how the project contributes to the loss of suitable habitat, and these habitat changes are used to infer population consequences. Exclusive use of habitat-based analyses are less favored because (i) habitat is assumed to be a useful measure of population status, (ii) habitat needs of the target species are assumed to be known, and (iii) specific project effects on the target species are not as well quantified (e.g., the shape, magnitude, and direction of species' response).

ECCC-CWS recommends that all standardized point count data (ARU and traditional human point count surveys) in Level IV ecoregions intersecting the project as well as additional data collected in 2022 be used to develop species distribution or occupancy models.

The approach proposed for MVH is to use existing BAM models to compare bird densities and distribution at different scales. ECCC-CWS encourages the use of the BAM density and distribution models to support impact assessments as it can be an important source of information. However, ECCC-CWS's concern is that the BAM models are the only data source being proposed for the spatial analyses. BAM uses all available data at the BCR level to develop these models and it is unclear how distant and much larger datasets within the BCR (e.g. Alberta and Saskatchewan datasets) are influencing/biasing the estimated densities and distribution of birds near the project. ECCC-CWS, therefore, disagrees that the BAM models are "adequately robust to support the objectives of the DAR" without further analyses to confirm this.

Guidance on number of sample sites per land cover class

ECCC-CWS would also like to caution you of the reliance on our 2018 guidance as it relates to minimum sample sizes. This guidance was developed before lessons learned from the Prairie Creek and TASR bird analyses. It has become evident that a minimum of 10 samples per land cover will not be sufficient to develop adequate precision for most species density and distribution estimates. A power analysis using the existing data is recommended to determine adequate sample sizes for predictive modeling.

Standardize point count data to account for imperfect detection

The proposed methods (in the Data Processing and Analyses section) for summarizing existing and new bird point count data are insufficient. Raw data will not account for imperfect detection. For most forest birds, statistical offsets are available to "standardize" raw counts for imperfect detection, i.e. time of day, dates, and habitat types (Solymos 2016). These are important to provide more nuance and adequate density estimates to test for potential project effects.

ECCC-CWS recommends the use of statistical offsets to convert count data into density estimates, and that it be reported as a mean or median density for each stratum with associated 95% confidence intervals. Reporting species as densities (versus relative abundance) provides (i) a relevant and readily communicated metric, (ii) a standardized metric to compare across regions and studies, and (iii) allows evaluation against conservation or management targets. Occupancy-based modeling may be appropriate in other cases.

Sólymos, P. (2016). QPAD version 3 documentation. Technical Report. Boreal Avian Modelling Project, Edmonton, Alberta, Canada. http://www.borealbirds.ca/files/QPAD_v3_report_1.pdf.

Use of recognizers

ECCC-CWS supports the use of automated recognizers to increase the detection rates and validate the presence of SAR species.

Data Sharing

ECCC-CWS encourages proponents to upload all acoustic data and associated habitat photos to Wildtrax (http://wildtrax.ca), a platform designed for that purpose by the Alberta Biodiversity Monitoring Institute in collaboration with ECCC-CWS and Birds Canada. Recordings can be viewed as spectrograms, and the user can tag individual acoustic cues for confirmation by experts. Note that data uploaded to Wildtrax can be flagged as private until ready for public release.

Thank you for the opportunity to provide comments. Should you have any questions or would like any clarification on these comments, please let us know.

Regards,
JF

Jean-Francois Dufour

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From: Kelly Bourassa <Kelly_Bourassa@gov.nt.ca>
Sent: March 7, 2022 1:26 PM
To: Hache,Samuel (ECCC) <Samuel.Hache@ec.gc.ca>; Dufour,Jean-Francois (ECCC) <Jean-Francois.Dufour@ec.gc.ca>
Cc: James Hodson <James_Hodson@gov.nt.ca>; Hamsha Pathmanathan <Hamsha_Pathmanathan@gov.nt.ca>; 'Bonhomme, Erica' <Erica.Bonhomme@stantec.com>; 'Routhier, Daniel' <Daniel.Routhier@stantec.com>; Patricia Coyne <Patricia_Coyne@gov.nt.ca>; MVH <MVH@gov.nt.ca>
Subject: RE: MVH proposed 2022 bird study scope

Hi Sam and JF.

I am just checking in to see if you have had a chance to review the proposed study scope and what your thoughts might be on it?

Cheers,

Kelly

From: Kelly Bourassa
Sent: February 28, 2022 4:41 PM
To: 'samuel.hache@ec.gc.ca' <samuel.hache@ec.gc.ca>; 'jean-francois.dufour@ec.gc.ca' <jean-francois.dufour@ec.gc.ca>
Cc: James Hodson <James_Hodson@gov.nt.ca>; Hamsha Pathmanathan <Hamsha_Pathmanathan@gov.nt.ca>; 'Bonhomme, Erica' <Erica.Bonhomme@stantec.com>; Routhier, Daniel <Daniel.Routhier@stantec.com>; Patricia Coyne <Patricia_Coyne@gov.nt.ca>; MVH <MVH@gov.nt.ca>
Subject: MVH proposed 2022 bird study scope

Hi Sam and JF.

Thanks again for taking the time on Feb 8, to discuss our planned approach to data collection and analysis for the Bird and Bird Habitat section of the Developer's Assessment Report for the Mackenzie Valley Highway project.

To follow up from the meeting I have attached our proposed study scope for this summer.

If you would like to discuss further, please do not hesitate to reach out.

Cheers,

Kelly

Mársı | Kinanāskomitin | Thank you | Merci | Hąį' | Quana | Qujannamiik | Quyanainni | Máhsı | Máhsı | Mahsì

Kelly Bourassa
Senior Environmental Analyst
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May 31, 2024

Superintendent Dyson Smith
Acting Commanding Officer, RCMP "G" Division
BAG SERVICE 5000
YELLOWKNIFE NT X1A 2R3
dyson.smith@rcmp-grc.gc.ca

Dear Superintendent Smith:

Policing Priorities 2024-2027

I am pleased to share the 2024-2027 policing priorities pursuant to Article 6 of the Territorial Police Services Agreement.

Policing priorities have previously been developed annually through a review of Community policing reports, input received from Indigenous governments, community leaders, partners, and service providers. While policing priorities continue to be informed by engagement with partners and stakeholders, they will now be established for a three-year period to better support community policing needs. This approach will provide the RCMP with the added opportunity to develop well considered plans over an extended period of time, enable consistent reporting, and the chance to demonstrate and evaluate results.

With the inclusion of policing priority performance measures for the first time last year, the 2024-2027 priorities build on this with the continued identification of activities and measures connected to each priority. The policing priorities will continue to be reported on annually to demonstrate progress and communicate this to the public.

Policing priorities remain aligned and are mindful of the Truth and Reconciliation Commission Calls to Action, the Inquiry into Missing and Murdered Indigenous Women and Girls Calls for Justice, and the United Nations Declaration on the Rights of Indigenous Peoples.

Priority #1: Target enforcement responses to reduce illegal drugs and alcohol.

The transport and sale of illegal drugs and alcohol in NWT communities remains a significant concern. Police-reported violent crime, including homicides and gun violence, have increased in recent years.

…/2

Criminal organizations continue to take advantage of vulnerable residents and communities are expressing rising concerns about safety, identifying increases in drug use and drug dealing, violence, and other crimes. Of particular concern is the impact on Indigenous youth, and particularly young men, who are often targeted.

While work across sectors is needed to target the effects of illicit drugs and alcohol, continued focus on enforcement is necessary. Ongoing and expanded efforts by the RCMP to decrease the transport and sale of illegal drugs and alcohol will help to reduce both the prevalence of violent crime and further victimization of NWT residents.

Priority #2: Continue to build strong relationships with Indigenous communities and residents.

Approximately 50% of the NWT population is Indigenous. Residential schools are part of our recent history and are a cause of intergenerational trauma in NWT communities. This priority encourages a continued openness and understanding that traumatic experiences can be carried forward from one generation to the next and acknowledges that trauma is often associated with, or the cause of, addiction, mental health, and homelessness. This can often lead to unintended interactions with the RCMP.

Consistent dialogue through the setting of and participation in policing priorities between RCMP, Community Justice Committees and Indigenous leaders will help to develop collaborative relationships, community-based solutions and increased trust in police.

Priority #3: Provide policing services that reflect recognition and efforts to reduce harm to Indigenous women, girls, families, and children.

Rates of family violence in the NWT are very high. We know that family, partner, and sexualized violence is underreported relative to other criminal activity. Indigenous women are also more likely to have substance use disorders, experience trauma, and to be victims of a crime than non-Indigenous women, increasing their interactions with police.

Continued work with partners and stakeholders, including non-governmental organizations, and Indigenous community-based victim services are essential. The provision of policing services that are guided by “G” Division’s Sexual Assault Investigations Review Committee, best practices in trauma informed policing and investigations, cultural competency and consultation with external stakeholders, partners and experts, can support direction for RCMP policy, training and public engagement.

…/3

RCMP play a critical role in connecting Indigenous women, girls, families, and children to culturally appropriate local programs and services, including safe places to stay, family violence shelters, victim services programs, emergency protection orders, and the free legal advice and representation program. Investigators, supervisors, and detachment commanders are encouraged to strengthen relationships with victim services partners and hold regular meetings to share information, identify concerns, and work collaboratively to support victims. Programs like victim services may also be called on by the RCMP in some communities to provide additional trauma support when there are complex social issues involved.

Priority #4: Increase community knowledge and understanding of RCMP roles and responsibilities.

The RCMP has made great improvements to increase their media engagement over the last year. However, NWT residents are still limited in the public information available to them about policing and criminal activities in their communities. Increasing awareness and public information about what RCMP officers do, policing services, and new or emerging trends in criminal activity, will allow communities to become more aware of the important role RCMP play in supporting community safety and their efforts to reduce crime. Increasing public information supports proactive problem solving, empowers communities to make more informed decisions and creates appreciation for the efforts of the RCMP to combat crime in their communities.

A summary of the activities and associated performance measures under each priority is included (Appendix A) and will help to monitor and measure the RCMP's work towards achieving these priorities.

I would like to extend my utmost appreciation to you and the hard working members and staff within "G" Division for your dedication, commitment, and efforts to support public safety in the NWT.



R.J. Simpson
Minister, Justice

Attachment

c. Charlene Doolittle
Deputy Minister, Justice

Mandi Bolstad
Assistant Deputy Minister - Solicitor General, Justice

Appendix A

2024-2027 Northwest Territories Policing Priority Activities and Performance Measures

<table>
<tr><th colspan="2">Priority #1: Target enforcement responses to reduce illegal drugs and alcohol.</th></tr>
<tr><th>Activities</th><th>Performance measures</th></tr>
<tr><td>a) Law enforcement efforts to target and disrupt organized crime, illicit drugs, and alcohol.</td><td>• Number of drug and organized crime investigations undertaken.
• Number and type of weapon seized and if linked to organized crime by community.
• Number type and amount of drug seizures by community.
• Number of people charged with drug trafficking by community.
• Number of residents charged with bootlegging.
• Number of calls related to bootlegging and drug trafficking by community.</td></tr>
<tr><td>b) Work collaboratively to support social programs with partners to recognize and work with at-risk people, including youth, who may be vulnerable to the influence of the drug trade and other serious crime.</td><td>• Report on activities undertaken with:
o Community Justice Committees
o Victim Services programs
o Community Safety Officers
o Shelters and other housing related social programs</td></tr>
<tr><th colspan="2">Anticipated Outcomes</th></tr>
<tr><td colspan="2">NWT residents have up to date information and confidence that the RCMP are responding to drug and alcohol occurrences.</td></tr>
<tr><th colspan="2">Priority #2: Continue to build strong relationships with Indigenous communities and residents.</th></tr>
<tr><th>Activities</th><th>Performance measures</th></tr>
<tr><td>a) RCMP attend and participate in regular meetings to discuss, set and report on policing services, priorities, and orientation of new police officers with key stakeholders.</td><td>• Number of policing priority setting meetings with stakeholders, including:
o Community Justice Committees
o Municipal and Indigenous governments and organizations
• Number of communities with letters of collaboration and policing priorities in place</td></tr>
<tr><td>b) Community critical incidence response information sessions focused on safety protocols in communities without detachments.</td><td>• Number of information sharing meetings in communities without detachments.
• Number of pro-active patrols and meetings with leadership in communities without detachments.</td></tr>
</table>

Anticipated outcomes	
Community leaders and members are sharing community-based cultural knowledge and participate in crime prevention and community safety activities with RCMP. RCMP visibility is increased.	
Priority #3: Provide policing services that reflect recognition and efforts to reduce harm to Indigenous women, girls, families, and children.	
Activities	**Performance measures**
a) RCMP will strengthen relationships with victim services partners, victim support advocates and hold regular meetings to share information, identify concerns and work collaboratively to support victims.	• Number of Victim Services Workers accompanying RCMP to calls to support victims. • Number of RCMP referrals to safety programming, including Victims Services, Shelters, Emergency Protection Order, and Independent Legal Advice and Representation Programs. • RCMP bi-annual reporting on policing data for NWT family, intimate partner, and sexualized violence. • Victim public awareness products to encourage reporting to police, explain what victims may expect when reporting a sexual assault.
b) RCMP members receive cultural awareness and safety training and apply cultural awareness and cultural safety to their service delivery.	• Number and type of "G" division members trained in cultural safety, awareness cultural competency training for RCMP employees and trauma informed practices.
c) RCMP conduct Sexual Assault and Intimate Partner Violence Investigative Review Committees.	• The RCMP develop a sexual assault training curriculum that addresses existing legislation and consent law; trauma-informed investigative tools; gender-based violence; reinforces victim rights and support services; bolsters oversight and review and is inclusive of vulnerable populations reflective of the diverse cultures and communities the RCMP serves. • RCMP Detachments have established protocols for providing safe, secure and private environments for victims to report sexual assault. • Number of reviews completed by the Sexual Assault and Intimate Partner Violence Investigative Review Committees.

	• Number of RCMP members trained in courses to increase knowledge and awareness about family, intimate partner, and sexualized violence such as: Common Sexual Assault Investigational Gaps; Consent and Sexual Assault Myths; Uniform Crime Reporting (UCR) Scoring; Trauma Informed Approach Course.
Anticipated outcomes	
RCMP are providing policing services that are responsive, culturally safe, and sensitive to the needs of Indigenous women, girls, families, and children. Stakeholders and residents express confidence in the RCMP in dealing with the needs of Indigenous women, girls, families, and children experiencing family, intimate partner, and sexualized violence in the NWT.	
Priority #4: Increase community knowledge and understanding of RCMP roles and responsibilities.	
Activities	**Performance measures**
a) Increase knowledge about RCMP programs and services through online tools, in person activities, social media, radio and other forms of communication mechanisms, and ensure RCMP members are visible and approachable to the public.	• Number of online, in person, social media, radio, and other communication on RCMP programs and services about policing in the NWT. • Number of community events and activities where RCMP participate and/or share information.
b) RCMP work with the Department of Justice to ensure there is up to date and publicly available policing services information to ensure the public are aware of emerging trends.	• Number of public reporting of RCMP policing information.
c) Ensure RCMP members are visible and approachable to the public.	• Number of community patrols, community meetings, events and/or activities.
Anticipated outcomes	
NWT residents have awareness of the RCMP's role and their programs and services. RCMP presence is visible to community members.	

August 14, 2024

JoAnne Deneron
Chair
Mackenzie Valley Environmental Impact Review Board
Yellowknife, NT

Via: Online Review System

Government of Canada's Information Requests for the proposed Mackenzie Valley Highway Project (EA1213-02)

Dear Ms. Deneron,

To support the Review Board's environmental assessment process, and in accordance with the Review Board's Rules of Procedure, the Government of Canada is submitting information requests (attached) for the Government of the Northwest Territories (GNWT) Department of Infrastructure's (INF) proposed Mackenzie Valley Highway (MVH) Project.

As provided in the Online Review System's information request (first round) public review, it is understood that this information request process allows for detailed questioning to help parties better understand the MVH Project, its potential impacts on the environment and people, and how to mitigate those impacts. In response, the Northern Projects Management Office (NPMO) is submitting the attached information requests on behalf of Heath Canada (HC), Natural Resources Canada (NRCan), Fisheries and Oceans Canada (DFO), and Environment and Climate Change Canada (ECCC). Transport Canada and Crown-Indigenous Relations and Northern Affairs Canada have reviewed materials available on the Review Board's public registry but do not have any information requests at this time.

It is understood that there will continue to be opportunities to provide comments and recommendations on the proposed MVH Project as the environmental assessment continues. The Government of Canada appreciates the opportunity to submit these information requests.

If you have any questions related to this correspondence, please contact Shannon Allerston at Shannon.allerston@cannor.gc.ca or 867-445-7230.

Sincerely,

Adrian Paradis
Projects Director
Northern Projects Management Office
Canadian Northern Economic Development Agency

Fish life history and habitat use in the Northwest Territories: bull trout (*Salvelinus confluentus*)

D.B. Stewart, N.J. Mochnacz, C.D. Sawatzky,
T.J. Carmichael, and J.D. Reist

Central and Arctic Region
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Winnipeg, MB R3T 2N6

2007

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2801



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2007

FISH LIFE HISTORY AND HABITAT USE IN THE NORTHWEST TERRITORIES: BULL TROUT (*Salvelinus confluentus*)

by

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ABSTRACT

Stewart, D.B., Mochnacz, N.J., Sawatzky, C.D., Carmichael, T.J., and Reist, J.D. 2007. Fish life history and habitat use in the Northwest Territories: bull trout (*Salvelinus confluentus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2801: vi + 46 p.

Bull trout occur in the Mackenzie River Valley south of Great Bear Lake, and possibly also in some rivers north of this area. The species requires cold, clean water and populations can be resident or migratory. The latter can follow fluvial, adfluvial or anadromous life histories. Differences in habitat use by these populations and in the seasonal requirements of eggs, fry, juveniles, and adults are summarized. Spawning occurs in shallow, fast-flowing tributary streams with stable channels and gravel to boulder substrates, often in areas fed by groundwater that maintains suitable incubation and rearing conditions through the winter. To support the assessment, avoidance and mitigation of environmental impacts in the Mackenzie Valley, the potential impacts of development activities and climate change on survival of the species are reviewed. The species' narrow habitat requirements for spawning and rearing make populations vulnerable to extirpation by habitat fragmentation and disruption. As slow-maturing but voracious predators, bull trout are also vulnerable to overharvesting and other stressors that target the older segment of the population. They do not compete well with other trout species at temperatures above 12°C, and are vulnerable to the introduction of other trout species.

Key words: distribution; life history; habitat requirements; seasonal movements; reproduction; spawning; rearing; life cycle; Mackenzie watershed; hydrological integrity; fresh water; Salmonidae.

RÉSUMÉ

Stewart, D.B., Mochnacz, N.J., Sawatzky, C.D., Carmichael, T.J., and Reist, J.D. 2007. Fish life history and habitat use in the Northwest Territories: bull trout (*Salvelinus confluentus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2801: vi + 46 p.

L'omble à tête plate se trouve dans les eaux de la vallée du Mackenzie au sud du Grand lac de l'Ours et habite probablement certaines rivières au nord de cette région. L'espèce requiert des eaux froides et propres. Les populations peuvent être sédentaires ou migratrices. Les populations migratrices peuvent être de nature fluviale, adfluviale ou anadrome. Nous résumons ici les différences dans l'utilisation des habitats par ces populations et les différences dans les besoins saisonniers des œufs, des alevins, des juvéniles et des adultes. La fraie se produit dans les tributaires peu profonds et à fort courant comportant des chenaux stables et des substrats graveleux à rocheux, souvent aux endroits alimentés par des eaux souterraines qui assurent des conditions favorables à l'incubation et à l'alevinage tout au long de l'hiver. Nous examinons les incidences éventuelles des activités humaines et du changement climatique sur la survie de l'espèce en appui de l'évaluation, de l'évitement ou de l'atténuation des incidences environnementales dans la vallée du Mackenzie. Les exigences strictes en matière d'habitat de fraie et d'alevinage rendent ces populations vulnérables à la disparition en raison de la fragmentation et de la perturbation des habitats. Bien qu'il vieillisse lentement et qu'il soit un prédateur vorace, l'omble à tête plate est également vulnérable à la surpêche et à d'autres agents stressants qui touchent la strate la plus âgée de la population. Il ne rivalise pas bien avec les autres espèces d'omble à des températures supérieures à 12°C et il est vulnérable à l'introduction d'autres espèces d'omble.

Mots clés : répartition; cycle vital; exigences en matière d'habitat; déplacements saisonniers; reproduction; fraie; alevinage; bassin versant du Mackenzie; intégrité hydrologique; eau douce; Salmonidés.

1.0 INTRODUCTION

Renewed interest in natural gas pipeline development along the Mackenzie Valley has raised the prospect that fish species in the watershed may be impacted by changes to their habitat. The proposed pipeline would extend from near the Beaufort Sea coast to markets in the south (http://www.mackenziegasproject.com/). Fishes in the Mackenzie River depend upon the integrity of their aquatic habitats, so it is important to summarize knowledge that can be used to assess potential impacts of this development proposal and others, and to facilitate efforts to avoid and mitigate these impacts.

This report reviews knowledge of the bull trout, *Salvelinus confluentus* (Suckley, 1859), an attractive but sensitive sportfish. It includes information on the species' distribution, habitat use during the various stages of its life history, and about threats posed to the species and its habitat by development activities. Knowledge gaps are also identified. This information was compiled to assist developers, habitat managers, and researchers. Similar reports have been prepared for other fishes that inhabit the Mackenzie River watershed.

The distribution and life history of bull trout in the Northwest Territories (NT) are poorly known, so the discussion that follows is based largely on populations from other regions.

1.1 Taxonomic units

Prior to 1991, bull trout in the Mackenzie Valley were identified as Dolly Varden (*Salvelinus malma*). This has led to confusion of the species' life histories, and the need to reassess literature from studies conducted in the 1970s and 1980s (e.g., Stein *et al*. 1973; McCart *et al*. 1974; Porter *et al*. 1974; Sigma Resource Consultants Ltd. 1976; Wickstrom 1977, 1979; Chang-Kue and Cameron 1980; Wickstrom and Lutz 1981; McCart 1982). Fish from the Great Bear River and further upstream in the Mackenzie River watershed that were originally identified as Arctic charr (*S. alpinus*) or Dolly Varden are now believed to be bull trout (Reist *et al*. 2002).

Genetic variability within bull trout populations is low, but genetic differences among populations are often marked (McPhail and Baxter 1996). This, along with striking inter-population differences in nuptial colouration and sexual dimorphism, suggest the existence of distinct stocks. However, separate taxonomic units have not been identified. Phylogenetic work suggests that periodic contraction and local extinction followed by expansion and colonization from local refugia have been important across the species' range (Haas and McPhail 2001).

1.2 Distribution

Bull trout are endemic to western North America (Haas and McPhail 1991). Their current distribution extends from the southern Yukon and southwestern Northwest Territories south to northern California and Nevada, and from the Pacific coast east to western Alberta (AB) (Haas and McPhail 2001; Mochnacz 2002). The range of bull trout has declined in recent years due to population extinctions, particularly in the southern portion of their range (Goetz 1989; Brown 1992; McPhail and Baxter 1996; Baxter *et al*. 1999). Even in pristine habitats, bull trout have a patchy distribution (Rieman and McIntyre 1993). Within the Mackenzie River system, the bull trout has been found in the Hyland Highland, Sibbeston Lake Plain, Nahanni Plateau, Hay River Lowland, Peel River Plateau, Franklin Mountains, Mackenzie River Plain, and Norman Range ecoregions, where it is widely but sparsely distributed (Figure 1) (Marshall and Schut 1999; Sawatzky *et al*. 2007)

Bull trout often occur with mountain whitefish (*Prosopium williamsoni*) and upstream of barriers, an indication of early colonization (Meehan and Bjornn 1991). Like cutthroat trout (*Oncorhynchus clarki*), they tend to occur in stream reaches at higher elevations than brook trout (*S. fontinalis*) or rainbow trout (*O. mykiss*) (Paul and Post 2001). Ripley *et al*. (2005) found that the vast majority of bull trout in the Kakwa River basin of Alberta were present in third- and fourth-order streams located at elevations of 950 to 1,600 m above sea level. These reaches may provide refugia, wherein bull trout can prevent colonization by introduced species and are isolated from harvesting pressures (Paul and Post 2001). In Washington and Oregon the species' distribution follows a pattern of decreasing elevation with increasing latitude and longitude (Goetz 1994).

Bull trout distributions can be difficult to delineate, as the species is often found in low conductivity water in areas with cover and current. Electrofishing during the day may tend to underestimate juvenile bull trout populations, which may be more efficiently sampled or observed by divers at night, using nets or flashlights respectively (Bonneau 1994; Bonneau *et al*. 1995; Goetz 1994, 1997a). Snorkelling surveys in streams tend to generate higher bull trout counts at night than during the day, and these counts can be biased toward fish longer than 100 mm (Zurstadt 2000).

2.0 LIFE HISTORY TYPES

Bull trout exhibit both non-migratory and migratory life history types in response to the local environmental conditions (Table 1; Goetz 1989; Brenkman *et al*. 2001; Bahr and Shrimpton 2004; Mogen and Kaeding 2005). The non-migratory populations are stream residents that inhabit spawning tributaries year-round. The migratory populations

also spawn and rear in tributary streams but, as older fish, winter in larger rivers (**fluvial**[1]) or in lakes (**adfluvial**), and sometimes feed at sea (**anadromous**). Most migrations take place from June through October, when fish move to and from the spawning tributaries.

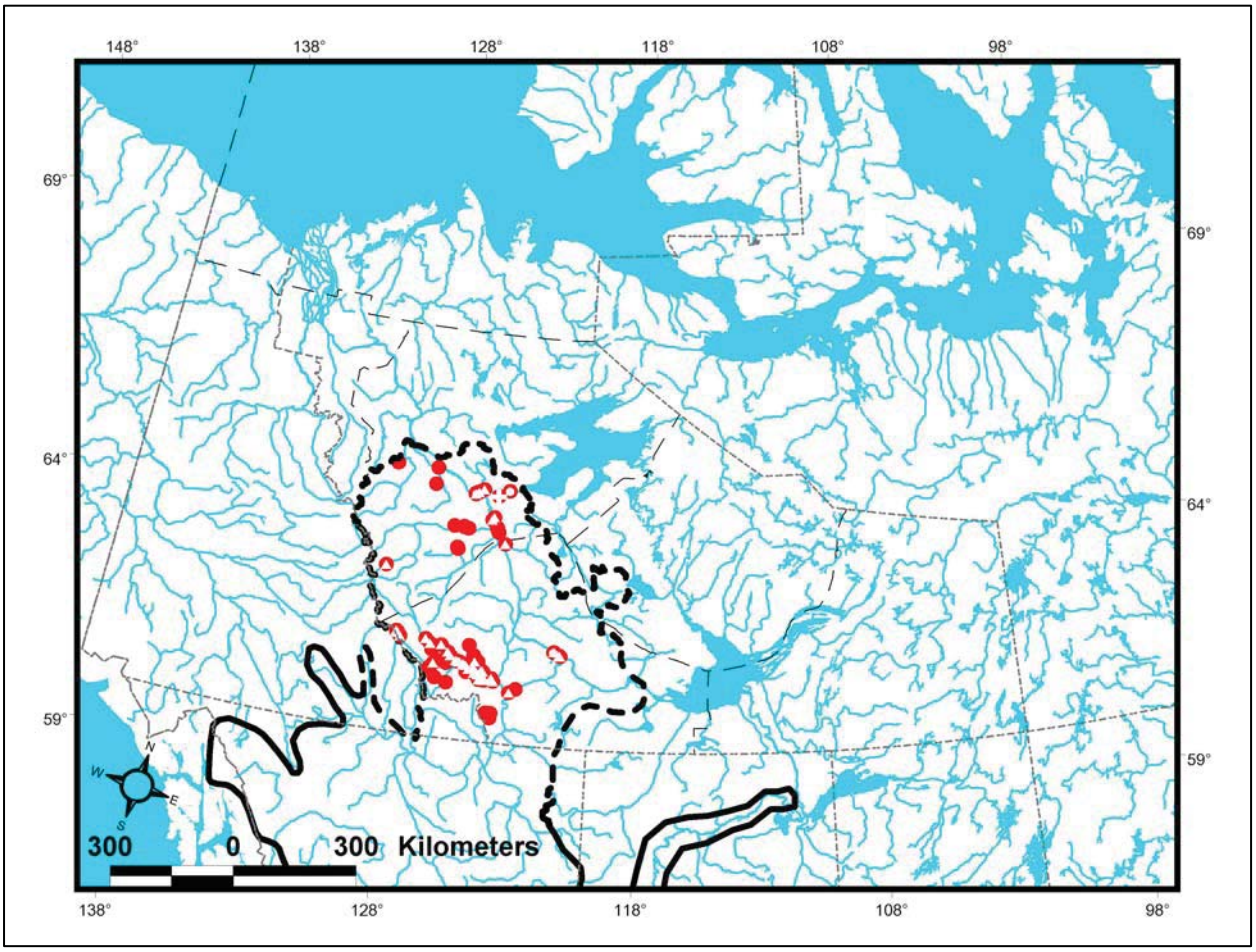


Figure 1. Bull trout distribution in the Northwest Territories (from Sawatzky *et al*. 2007). Solid red dots indicate recent specimens with confirmed identity; dots with symbols are older records that are now considered to be bull trout but cannot be verified. Those containing a white triangle were initially identified as Dolly Varden, a white "+" as Arctic charr, and a white dot as *Salvelinus* species complex.

Stream resident, fluvial, and adfluvial populations of bull trout have been reported from the Northwest Territories, but the life histories of these populations are not well known (Mochnacz 2002). Fish from stream resident populations are typically shorter and smaller bodied than those from fluvial and adfluvial populations (Rieman and McIntyre 1993; McPhail and Baxter 1996), and may mature earlier and at a smaller size than migratory forms (Cannings and Ptolemy 1998; Mochnacz 2002). Stream resident adults range from 150 to 300 mm in length, while migratory fish commonly exceed 600 mm

[1] Terms in bold type are defined in the Glossary.

Table 1. Habitat use by bull trout populations with different life history types.

HABITAT	POPULATION			
	STREAM-RESIDENT	FLUVIAL	ADFLUVIAL	ANADROMOUS
Small high-gradient tributary streams	• Year-round use by all life history stages for all activities.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.
Rivers		• Migration corridors and feeding and overwintering habitat for juveniles and adults.	• Migration corridors and feeding habitat for juveniles and adults. • Overwintering habitat for some juveniles.	• Migration corridors and feeding and overwintering habitat for juveniles and adults.
Lakes		• Migration corridors for some adults.	• Feeding and overwintering habitat for juveniles and adults.	• Migration corridors and feeding and overwintering habitat for juveniles and adults.
Brackish or marine coastal waters				• Migration corridors and feeding habitat for juveniles and adults.

(Rieman and McIntyre 1993). Adfluvial bull trout can grow to at least 1,025 mm and 14.5 kg (Goetz 1989).

Life history and habitat parameters are defined in Appendix 1. Stream and lake habitat requirements are summarized in Appendices 2 and 3, respectively.

2.1 Stream Resident

In the Northwest Territories, fish caught in summer at the Kotaneelee River system, Funeral Creek, the South Nahanni River (Mochnacz 2002), Little Smith Creek, a tributary of the Blackwater River (McCart *et al*. 1974), and Prairie Creek (Beak Consultants Ltd. 1981) may be stream resident (Figure 1).

Stream resident fish remain in the spawning tributary streams year-round, and often spawn and overwinter within a 2 km reach of river (Jakober *et al*. 1998; Chandler *et al*. 2001). In the West Castle River of southwestern Alberta, juvenile and adult bull trout overwinter in small, shallow (maximum depth 0.4 to 1.5 m) pools that are isolated from one another, have little cover, and receive flow from groundwater springs (Boag and Hvenegaard 1997). In the Bitterroot River drainage of Montana fish will move 1 to 2 km downstream in early October from spawning sites to overwintering sites; some move over 1 km further downstream later in the winter at temperatures of 1°C or lower (Jakober 1995; Jakober *et al*. 1998). The first movements coincide with decreasing water temperature, and may reflect a change in concealment behaviour; the second, about 6 weeks later, coincides with formation of anchor ice and exclusion of fish from habitat with preferred cover. Beaver ponds provide important overwintering habitat for some stream resident bull trout.

Reaches influenced by groundwater provide resident bull trout with cold-water refugia in summer, and warm-water refugia in winter (Baxter and Hauer 2000). These areas have relatively stable thermal regimes, with less winter ice cover and no anchor ice formation. Groundwater upwellings also prevent frazil ice formation (Bonneau and Scarnecchia 1998). While **redds** are associated with areas of groundwater upwelling, within these areas they can also be associated with localized downwelling (Baxter and Hauer 2000). Stream resident fish remain active on or above the substrate throughout the winter at night, even during extreme temperatures and ice conditions (Jakober 1995; Jakober *et al*. 2000). During the day, small (<200 mm) fish stay concealed in the interstices of large substrates and in accumulations of large woody debris.

2.2 Fluvial

Fluvial bull trout populations inhabit the Keele, Flat and South Nahanni rivers of the Northwest Territories (Figure 1; Mochnacz 2002). Like the stream resident populations,

the fluvial populations spawn in high-gradient smaller rivers and tributary streams (Bahr and Shrimpton 2004). These streams also provide rearing habitat for periods of months or years. Older juveniles eventually move downstream into larger rivers where they feed, mature and overwinter. Adults remain in these rivers unless they are returning to the tributaries to spawn, or to escape overly warm water. Spawning in the mainstems of these larger rivers has not been documented.

Unlike stream-resident populations, adult bull trout from fluvial populations undertake extensive seasonal movements, typically upstream into tributary streams in May-August, and downstream to overwintering areas by late September or early October (Pattenden *et al*. 1991; McLeod and Clayton 1993, 1997; Fernet and O'Neil 1997; Swanberg 1997a; Burrows *et al*. 2001; Hemmingsen *et al*. 2001; Bahr and Shrimpton 2004; Pillipow and Williamson 2004). Upstream pre-spawning migrations are typically slower than the downstream post-spawning movements, when fish can move 30 km in a 6 to 7 h period (Pillipow and Williamson 2004). Downstream movements to spawning tributaries have been observed in the McLeod River of Alberta (Carson 2001). Migrations of up to 500 km demonstrate the large spatial scale and diversity of habitats required to sustain fluvial bull trout populations (Swanberg 1997a), and the importance of high-quality stream spawning habitat (Pillipow and Williamson 2004) and of stream connectivity (USFWS 2000; Muhlfeld and Marotz 2005).

Migration timing varies among systems. Fish that undertake longer migrations and gain more elevation, that enter systems where there is a greater seasonal decline in flow following the spring freshet (Thiesfeld *et al*. 1996), or that find themselves in unfavourable temperature conditions (Swanberg 1997a) may migrate earlier in the season. The temperature at which peak migrations are observed varies among rivers. McPhail and Murray (1979) found migrations to peak at 10 to 12°C. Fish migrating at the lower temperatures are typically preparing to spawn shortly.

In contrast, the annual migrations in the Blackfoot River of Montana are cued by an increase in the maximum daily water temperature and a decrease in discharge from peak runoff (Swanberg 1997a). In this southern system, the mean temperature at which fish began their migrations was 17.7°C. Larger fish began moving upstream at cooler temperatures and earlier in the season than smaller fish. The migrations were nocturnal and generally rapid (4.4 $\pm$ 2.2 km/d; see also McPhail and Murray 1979). Spawners ascended tributaries in late June to early July, 67 $\pm$ 10 d before spawning (Swanberg 1997a). Non-spawning fish entered the lower portions of these tributaries after the spawning fish, and remained there 28 $\pm$ 18 d before returning downriver in late August. The primary purpose of these migrations by non-spawners may be to avoid unfavourable temperature conditions, since prey densities were lower in the tributaries than in the Blackfoot River. Some bull trout, probably immature, did not migrate but they

did use confluences with cold tributaries when temperature conditions became unfavourable.

Exclusive of spawning, adult bull trout in some fluvial populations appear to occupy small discrete home ranges with great fidelity (Carson 2001; Hvenegaard and Thera 2001). In some systems the fish show strong fidelity to the same spawning tributaries and overwintering areas (Bahr and Shrimpton 2004), but in others they shift spawning sites over time (McPhail and Murray 1979; Pratt 1992). In the Blackfoot River of Montana, most (86%) migrants returned downriver to within 20 km of sites occupied in the spring, and winter movements were very local, never exceeding 300 m (Swanberg 1997a). Likewise, only localized movements were detected among fish overwintering under the ice in the mainstem of the Athabasca River in Alberta (McLeod and Clayton 1997).

Bull trout in the Morice River system of British Columbia (BC) appear to use Morice Lake primarily as a corridor for moving between river systems; larger fish sometimes spend part of the winter in the lake but would still be classified as fluvial (Bahr and Shrimpton 2004).

2.3 Adfluvial

Drum Lake, Northwest Territories, supports an adfluvial bull trout population (Figure 1; Mochnacz 2002). Adfluvial bull trout follow a similar life-history pattern to that of the fluvial populations, spawning in high gradient small rivers and tributary streams (Fraley and Shepard 1989; Ratliff *et al*. 1996; Olmsted *et al*. 2001). Lake spawning has not been documented. Juveniles begin rearing in the spawning streams and eventually move downstream into large rivers or lakes to feed, mature, and overwinter. Larger adults are more likely to feed and winter in lakes (Connor *et al*. 1997). They remain in the lakes unless they are returning to the tributaries to spawn, or to escape overly warm water.

In Chester Morse Lake, Washington, adult bull trout were found in every habitat zone (Connor *et al*. 1997). They occurred in the highest densities in the deepest areas of the lake (**profundal**, 42 m), but were also locally abundant along the shore of the lake (littoral). Relatively few fish were observed in the pelagic regions of the lake. Peak activity was observed during the night and few fish were active during daylight or full moon, when they rested on the bottom.

The availability of suitable stream spawning habitat affects the distance and duration of spawning migrations by adfluvial populations. Some fish from Flathead Lake, Montana, for example, migrate 250 km upstream in the Flathead River to spawn in headwater streams (Fraley and Shepard 1989). They move upstream from May through July and spawn from late August through early October before returning downstream to

overwinter. In contrast, fish in high, isolated, oligotrophic lakes, such as Pinto and Harrison lakes in Alberta, spawn a short distance upstream in the lake inlet, or downstream in the outlet (Herman 1997; Wilhelm *et al*. 1999). The spawning migrations of populations in these two lakes last only a few weeks and, because stream rearing habitat is close and limited, juveniles tend to enter the lakes at a younger age than those with access to more suitable river habitat (Hanzel 1985; Ratliff *et al*. 1996; Wilhelm *et al*. 1999; Brenkman *et al*. 2001).

2.4 Anadromous

In general, bull trout do not appear to undertake extensive ocean migrations, although some regularly enter the sea and even move between drainages (Haas and McPhail 1991, 2001). Anadromous bull trout have not been reported from the Northwest Territories. However, they have been reported from the Hoh River (Brenkman *et al*. 2007) and Puget Sound (Mongillo 1993) areas of Washington State and the lower reaches of the Fraser and Skeena rivers in British Columbia, and may be present in other coastal rivers such as the Nass (Haas and McPhail 1991, 2001). Fish from the Hoh River migrated to sea for the first time at age 3 to 6, and the smallest juvenile migrant observed was 243 mm TL (Brenkman *et al*. 2007). Adults moved at least 47 km along the coast from their river of origin (Brenkman and Corbett 2005).

3.0 LIFE HISTORY STAGES AND HABITAT USE

Bull trout have very specific habitat requirements, that are often summed by the “Four C’s” -- cold, clean, complex, and connected (USFWS 2000). Habitat selection by different age classes appears to be heavily influenced by intraspecific competition and avoidance of predation by younger animals (Goetz 1997b). Stream habitat use by bull trout has been studied in detail, but the specifics of habitat use and requirements in rivers, lakes, and coastal waters are poorly known. Key transitions in the bull trout life history are illustrated schematically in Figure 2 and discussed below.

These fish require a narrow range of cold temperature conditions to reproduce and survive (Table 2). In general, they are observed more frequently and appear more likely to occur at summer means of about 6 to 9°C, or with summer maxima less than about 13 to 14°C (Rieman and Chandler 1999; Gamett 2002). The upper optimal temperature threshold for bull trout has been estimated at a maximum daily maximum temperature (MDMT) of 12°C, which translates to a maximum weekly maximum temperature (MWMT) of 11°C (McCullough and Spalding 2002). Temperatures greater than 16°C are generally unsuitable for long-term survival of bull trout (McMahon *et al*. 2001).

Bull trout do, however, exhibit a high degree of behavioural thermoregulation and are able to forage for periods of time in areas where temperatures are higher than their preferred (USFWS 2000). While age 0, juvenile, and adult bull trout in Idaho streams will enter water that exceeds 20.0°C for several hours on hot, summer days, the average daily temperatures recorded at their distribution limits were between 2.0 and 12.0°C (Adams 1994). As water temperatures exceed a single daily maximum of 20°C, it becomes increasingly unlikely that juvenile bull trout will be found using a given habitat (Dunham and Chandler 2001).

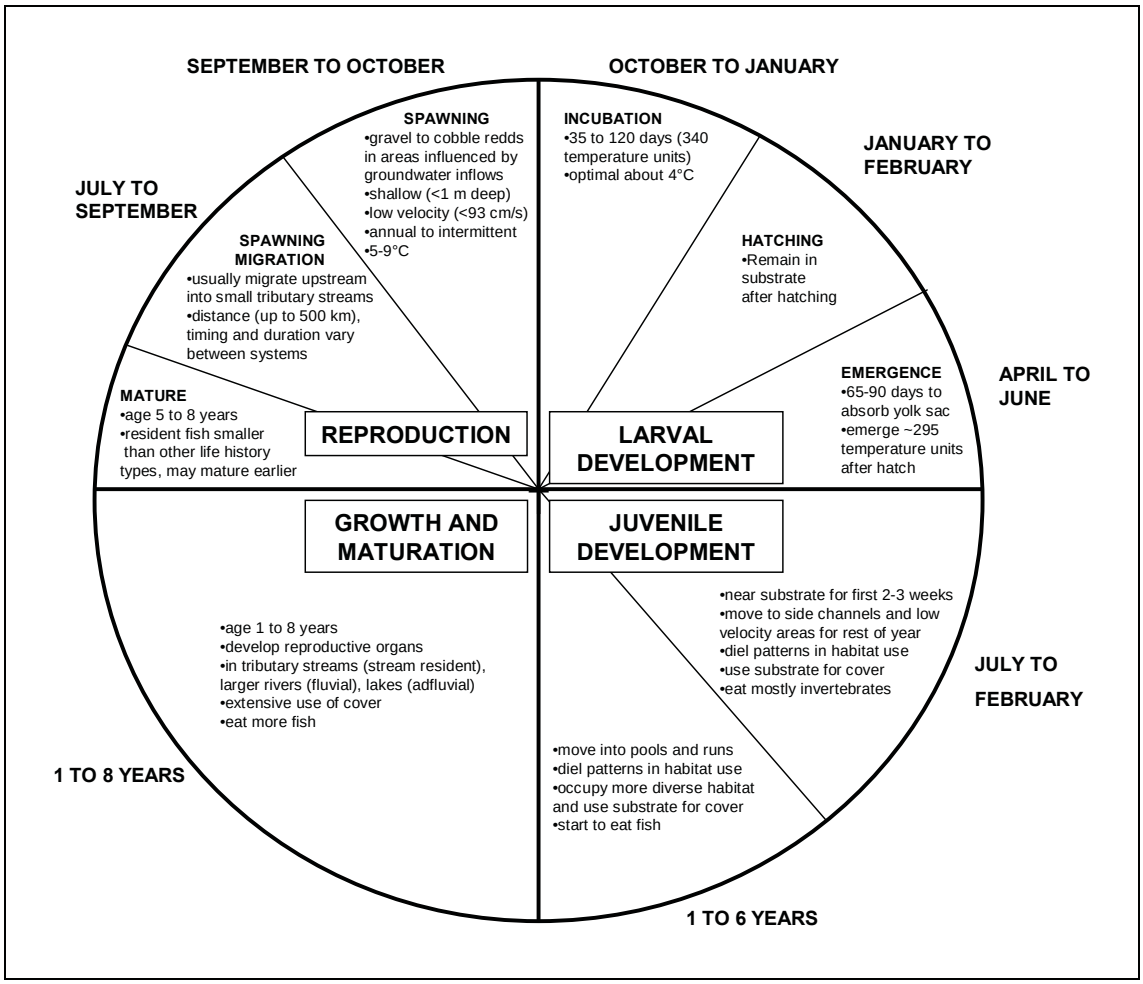


Figure 2. Generic life cycle of bull trout (modified from Mochnacz 2001).

General characteristics of stream habitats where bull trout have been captured in the summer in the Northwest Territories include: average water velocities in the range of 18 to 68 cm/s (range 0.0 – 172 cm/s), depths of 19 to 149 cm (range 3 – 282 cm), average temperature 3.6 to 12.7°C, average wetted width 1.70 to 16.4 m, with cobble as the dominant substrate and boulders as the dominant cover (Table 2) (Mochnacz *et al*. 2004).

Table 2. Observed stream habitat use by bull trout (data from Northwest Territories populations in bold type; numbers in brackets refer to sources cited below). Abbreviations are defined in Section 8.0 and habitat parameters are defined in Appendix 1.

HABITAT FEATURES		LIFE STAGE			
		Spawn/egg	**Young-of-the-year (YOY)**	**Juvenile**	**Adult**
Habitat type		Interstices of bottom substrate in small tributary streams. Redds often associated with groundwater discharges (4, 6,10, 16, 19)	Shallow shoreline pools and riffles in side channels of high gradient streams; interstices of bottom substrate; diel changes in microhabitat preferences (5b); will winter in the interstitial, sub-surface flow under a dry channel bed (8)	**High gradient habitats at or near the bottom, often in** shallow pools and riffles; interstices of bottom substrate; **pocket pools created by large cobble and boulders (1a,b);** sometimes winter in isolated pools maintained by groundwater inflows (7)	**High-gradient mountain streams (1c)**; pools, riffles, runs; sometimes winter in isolated pools maintained by groundwater inflows (7)
Stream gradient		High (4), Low, Meandering (12)	**High (1a)**	**High (1a,b)**	**High (1c)** 1.0 - 15.6% (21)
Depth range (m)		0.454 ± 0.022 (4a) 0.07 - 0.93 (4b)	**0.222 - 0.468 means (1a)** **0.07 - 0.90 overall range (1a)**	**0.222 - 0.468 means (1a,b)** **0.07 - 1.30 overall range (1a,b)**	**0.191 - 1.49 means (1c)** **0.03 - 2.82 overall range (1c)**
Substrate		Gravel (4a), sand to cobble (4b), sometimes with an appreciable amount of silt (8)	**Cobble (1a)** and boulder (5a)	**Cobble and boulder (1a,b)**	**Gravel, rubble, cobble (23) and boulder (1c)**
Cover		Overhead cover is not a prerequisite for spawning (7), will construct redds within 2.5 m of the banks (8)	**Boulder (1a)**	**Boulder (1a,b)**	**Undercut banks, deep pools, boulders (1c)**
Velocity range (cm/s)		58 ± 2 (4a) 2 - 93 (4b)	**22 - 30 means (1a)** **10 - 133 overall range (1a)** Microhabitat values may be lower	**22 - 55 means (1a,b)** **0 - 146 overall range (1a,b)** Microhabitat values may be lower, 0 - 10 (11,13)	**18 - 68 means (1c)** **0 - 172 overall range (1c)**
Turbidity (NTU)	Range	0.1 - 1.0 (14)			
	Limits				
Oxygen (mg/L)	Range	Intergravel: 8 - 12, mean 9 (16) Instream: 10 - 11.5, mean 10 (16)			**11 (23)**
	Limits				
Temperature (°C)	Range	Spawning: 5 - 9 (9,24) Incubation: 1.2 - 5.4 (9,18)	**Summer: 4.1 - 4.6 (1a)** Rearing: 2 - 12 (20)	**Summer: 4.1 - 12.7 (1a,b)**	**Summer: 1.5 (23), 3.6 - 7.9 (1c)**
	Limits		UUILT 20.9 (60 d) (3) UUILT 23.5 (7 d) (3)	UUILT slightly lower than for young-of-the-year (3)	MDMT 12°C (2), MWMT 11°C (2)

Prey items	Primary		Aquatic insects (17)	**Aquatic and terrestrial insects /larvae (1a)**	**Fish (Arctic grayling, bull trout, longnose sucker, slimy sculpin) (1c)**
	Secondary			**Fish (1a)**	**Aquatic and terrestrial insects /larvae (1c)**
Period		Spawning: 1 August - 31 September (15, 24) Incubation: 113 d (340 temperature units) (9) Fry emergence: 223 d (635 temperature units) (9)		**Female: 6 - 7 y (age range 1 - 8) (1c)** **Male: 6 - 8 y (age range 1 - 7) (1c)**	**Female: 8 - 9 y (age range 7 - 16) (1c)** **Male: 8 - 10 y (age range 9 - 18) (1c)**
Size/age range (Note: fish are considered to be age 0 until December 31 of the year they are hatched)		Egg diameter: 5.0 - 6.2 mm (15,18), 3.9 - 4.8 mm (16) Redds: 1m long by 0.5 m wide (16, 18)		**Female: 35-289 mm, 1 - 235 g, age 1 - 8 (1c)** **Male: 75-323 mm, 1.8 - 387 g, age 1 - 7 (1c)**	**Female: Maximum: 661 mm, 3379 g, age 16 (1c)** **Male: Maximum: 642 mm, 3144 g, age 18 (1c)** Stream resident: 140 - 410 mm FL; Fluvial: 410 - 730 mm FL; Adfluvial: 508 - 824 mm FL (22).

1 = Mochnacz *et al*. 2004 – a) Funeral Creek, NT - 61°36'N 124°44'W; b) unnamed creek, Keele River - 64°14'N, 125°59'W; c) NT.
2 = McCullough and Spalding 2002 – laboratory study.
3 = Selong *et al*. 2001 – laboratory study.
4 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, BC, b) various systems throughout the range from 49-56°N.
5 = Baxter and McPhail 1997 – a) Chowade River, Peace R. drainage, BC, b) laboratory study.
6 = Boag and Hvenegaard 1997 – West Castle River, AB.
7 = Shepard 1985 – Flathead River, Montana.
8 = Oliver 1985 – Wigwam River, BC.
9 = Fraley and Shepard 1989 – Flathead River, Montana.
10 = Baxter and Hauer 2000 – Swan River, Montana.
11 = Earle and McKenzie 2001 – Beaverdam Creek, Alberta.
12 = Pillipow and Williamson 2004 – Goat River, Fraser River drainage, BC.
13 = Sexauer and James 1997 – Yakima and Wenatchee river drainages, Washington.
14 = Craig 1997 – Yakima River basin, Washington.
15 = Goetz 1989 – review.
16 = Fairless *et al*. 1994 – Clearwater River, AB.
17 = Shepard *et al*. 1984 – Flathead River, Montana.
18 = McPhail and Murray 1979 – Mackenzie Creek, BC.
19 = Cope *et al*. 2002 – Wigwam River, BC.
20 = Adams 1994 – Weiser River drainage, Idaho.
21 = Rich 1996 – streams in western Montana.
22 = Mochnacz 2002 – review.
23 = Beak Consultants Limited 1981 – Prairie Creek, NT.
24 = Herman 1997 – Pinto Lake, AB.

3.1 Eggs (Spawning and incubation habitat)

Bull trout spawn more than once, but not necessarily every year following maturity **(iteroparous**) (Fraley and Shepard 1989; Cannings and Ptolemy 1998; Bahr and Shrimpton 2004) (Table 3). Alternate year spawning is common and probably an adaptation to marginal productivity throughout the year (Clayton 2001; Hvenegaard and Thera 2001; Mochnacz 2002). Resting females and males have been found in the Northwest Territories from all life history types, and spawning there may occur at 2 to 3 year intervals (Mochnacz 2002). If a smaller proportion of the mature population spawns each year, northern populations may be slower to recover from adverse impacts.

Temperatures ≤ 9°C may trigger spawning (McPhail and Murray 1979; Weaver and White 1985; Fraley and Shepard 1989; Ratliff *et al*. 1996), while those ≤ 5°C cause it to be suspended (Allan 1987 cited in McPhail and Baxter 1996). Spawning activity in the Pine Creek watershed of Oregon was initiated in mid-September at mean daily stream temperatures between 9.3 and 11.5°C, which declined rapidly to between 4.9 and 6.9°C near the completion of spawning activity in early October (Chandler *et al*. 2001). Kitano *et al*. (1994) observed spawning in the upper Flathead River of Montana in mid-September at water temperatures of 5.3 to 8.9°C. Bull trout in the Chowade River of northeastern British Columbia (Baxter and McPhail 1999) and Castle River system in Alberta (Fernet and O'Neil 1997) also spawn in mid-September through early October.

The female chooses the spawning site and constructs the redd, while the male defends the area and remains nearby for an average of two weeks after spawning (Fraley and Shepard 1989). In some systems, higher densities of redds have been observed in areas with > 54% overhead cover (Craig 1997). Fertilized eggs are fanned by the female and then covered with gravel (James and Sexauer (1997). The demersal, non-adhesive eggs incubate under the gravel throughout the winter and the **fry** emerge in early to late spring (Baxter and McPhail 1999). Detailed descriptions of spawning behaviour and spawning site activities are provided by James and Sexauer (1997), Kitano *et al*. (1994), and McPhail and Murray (1979).

The fecundity of bull trout populations varies widely, with larger fish having greater fecundity. In the Flathead River system of Montana, fecundity averaged 5,482 eggs per female for a sample of 32 adults averaging 645 mm TL (Fraley and Shepard 1989), while bull trout in the Arrow Lakes of British Columbia were smaller and contained fewer than 2000 eggs (McPhail and Murray 1979). A 6.7 kg female in the Flathead River system contained 12,000 eggs (Fraley and Shepard 1989); while fish in Sun Creek, Oregon, can mature at 152 mm and carry as few as 74 eggs (Goetz 1994). Eggs typically range in diameter from 5.0 to 6.2 mm (Goetz 1989), but eggs ranging from 3.9 to 4.8 mm have been found in redds in the upper Clearwater River of Alberta (Fairless *et*

al. 1994). The bottom area disturbed by redd construction varies from 0.50 to 3.72 m² (Goetz 1989).

Table 3. Habitat and life history parameters related to bull trout reproduction, with data from the NT in bold type. Numbers in brackets refer to data sources listed below.

PARAMETER	STREAM (data source)
Reproductive strategy:	Iteroparous
Age at maturity:	Female: **age 7 - 8 (1c ,** 8**),** 6 - 7 (9) Male: **age 8 - 9 (1c),** 7 - 8 (9)
Fecundity (eggs/female):	Mean 5482 (mean TL 645 mm) (5); Range <2000 (6) to 12000 (5)
Spawning:	May not occur annually following maturity (5; 10)
Habitat type	Redds often associated with groundwater upwellings (2a, 3); Stream gradient 1.5% (5)
Builds nest	Yes. Gravel redd (2a)
Temperature (°C)	5 - 9°C (5a, 6, 8)
Depth (m)	0.454 $\pm$ 0.022 (4a) 0.07 - 0.93 (4b)
Substrate	Gravel (2a), sand to cobble (2b, 5), sometimes with an appreciable amount of silt – 22 - 30% (3, 7)
Current velocity (cm/s)	2 - 93 (2b)
Maximum age: (Note: fish are considered to be age 0 until December 31 of the year they are hatched)	Female: **age 16** (1b) Male: **age 18** (1b)
Age at senescence:	Unknown.

1 = Mochnacz *et al*. 2004 – a) Funeral Creek, NT, b) Drum Lake outlet, NU, c) NT.
2 = Baxter and McPhail 1999 – a) Chowade River, Peace River drainage, BC; b) systems through range from 49-56°N.
3 = Oliver 1985 – Wigwam River, BC.
4 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, BC; b) various systems throughout the range from 49-56°N.
5 = Fraley and Shepard 1989 – Flathead River, Montana.
6 = McPhail and Murray 1979 – Mackenzie Creek, BC.
7 = Ratliff *et al*. 1996 – Metolius River basin, Oregon.
8 = Herman 1997 – Pinto Lake, AB.
9 = Mushens and Post 2000 – Kananaskis Lake, AB.
10 = Bustard and Schell 2002 – Morice River, BC.

Water velocities at redd sites range from 2 to 92 cm/s, and depths from 0.07 to 0.93 m (Fernet and Bjornson 1997; James and Sexauer 1997; Baxter and McPhail 1999). In the Cedar River watershed of Washington State, the majority of bull trout redds were found in water depths ranging from 12 to 49 cm (mean 25 cm) and water velocities (mean column) ranging from 12 to 61 cm/s (mean 38 cm/s) (Reiser *et al*. 1997). Redd surveys were conducted during the day, but no spawning activity was observed, suggesting that spawning may take place primarily at night.

Water in the interstitial spaces of the gravel (8-12 mg/L) and above the redds (10-11.5 mg/L) is well oxygenated (Weaver and White 1985; Fairless *et al*. 1994).

Intergravel flow may be an important factor in spawning area selection by bull trout (Weaver and White 1985). In Washington's Yakima River basin, conductivity ranged from 193 to 222 mV, pH 7.5 to 7.8, and turbidity 0.1 to 1.0 NTU in most watersheds that contained redds (Craig 1997). An exception was the South Fork Tieton River, which receives turbid glacial runoff (3.3 NTU) during the summer, when eggs and larvae are not affected by siltation.

Bull trout redds in the shallow, high-gradient Chowade River of British Columbia were often associated with groundwater discharges that provided warmer, more stable temperatures for incubating eggs -- particularly during the coldest part of the winter (Baxter and McPhail 1999). These warmer temperatures provided a stable rearing environment and protection from freezing, and they reduced incubation time leading to an earlier date of emergence than for eggs reared at a lower temperature. The survival rate from eggs to **alevins** was significantly higher (88.6 vs. 76.1%) and less variable in areas selected by female bull trout, than in non-selected areas. There was no difference in alevin survival rates at different depths (10, 20, 30 cm).

The association of redds with groundwater discharge suggests that optimal habitats for bull trout reproduction may be limited, and that site selection by females may increase reproductive success (Baxter and McPhail 1999). The close association with groundwater inflows is a common feature of bull trout spawning habitat (Shephard 1985; Fraley and Shepard 1989; Fairless *et al*. 1994; Ratliff *et al*. 1996; Thiesfeld *et al*. 1996; Boag and Hvenegaard 1997; Craig 1997, 2001; James and Sexauer 1997; Bonneau and Scarnecchia 1998; Baxter and Hauer 2000; Gamett 2002). In the Swan River of Montana, zones of upwellings occurred consistently in bounded alluvial valley segments (Baxter and Hauer 2000). Spawning there was associated with low gradient reaches that had upwellings and stable, well sorted gravel and cobble. Floodplains in these segments allow overbank flow, which moderates sediment scour associated with flooding. In southwestern Alberta bull trout spawning is typically associated with bedrock that may intercept subsurface flow and direct it toward the surface (D. Evans, DFO Calgary, pers. comm.). These areas also provide suitable pool cover habitat and appropriately sorted substrates.

Bull trout eggs from an interior population showed an increase in survival as the temperature decreased from 10°C and a slight decrease in survival if the temperature dropped below 4°C (McPhail and Murray 1979). Lower temperatures slowed embryonic development, but led to the production of larger fry. Incubation time is temperature dependant (Weaver and White 1985), and can take from 35 to 120 days (McPhail and Murray 1979). In Coal Creek, a tributary of the Flathead River, Montana, bull trout eggs required 113 days (340 **temperature units**) to 50 percent hatch; the fry emerged from the gravel 233 days (635 temperature units) after egg deposition. Intergravel

temperatures during the incubation period (October-March) ranged from 1.2 to 5.4°C, and survival to emergence averaged 53 percent.

Chronic exposure to oxygen concentrations ranging from 3 to 13.5 mg/L did not cause significant mortality or increase physical deformities in developing bull trout eggs, but low oxygen levels did retard embryonic development (Giles and Van der Zweep 1996).

Bull trout in the Flathead River, Montana, rework the substrate but do not alter its composition when constructing redds (Shephard and Graham 1982). The average percentages of fine substrates (sand, clay/silt; <2 mm sieved) ranged from 8 to 20%; gravel (2 to <6.5 mm) ranged from 16 to 19%; and larger substrates (e.g., rubble and cobble, ≥6.5 mm) ranged from 62 to 76%. Higher levels of fine substrates may impact egg survival. Redds in Smith-Dorrien Creek, Alberta, were composed largely of gravel to cobble sized substrate (Fernet and Bjornson 1997).

Hatching success is inversely related to the percent of fine material (<6.35 mm) in gravels (Weaver and White 1985; Weaver and Fraley 1991). In experimental studies, survival to emergence ranged from 49 to 69% in substrates that contained 10% fines to 0 to 4% in substrates that contained 50% fines. Kitano *et al*. (1994) observed that redds on the upper Flathead River of Montana were constructed at the downstream ends of pools, where fine gravels were prevalent. Levels of fine sediment in spawning areas of Oregon's Metolius River tributaries, which have high densities of juvenile bull trout, ranged from 22 to 30% (Ratliff *et al*. 1996). Entombment by sediment and crushing by gravel movement may be significant sources of egg mortality (Weaver and White 1985).

3.2 Alevins and fry (Rearing habitat)

Yolk absorption after hatching takes 65 to 90 days (Shepard *et al*. 1984), and fry do not attain neutral buoyancy for another three weeks (McPhail and Murray 1979). Negative buoyancy makes feeding after emergence awkward, but enables them to maintain their position in the stream. After emergence in late spring, young-of-the-year are typically found in shallow, low velocity areas near the edges of small tributary streams with an abundance of cover (McPhail and Murray 1979; Fraley and Shepard 1989; Baxter 1997a,b; Cope *et al*. 2002), although some out migration to lakes occurs shortly after fry emergence in some systems (Reiser *et al*. 1997). In the Northwest Territories, young-of-the-year are about 35 to 38 mm fork length and weigh less than 1 g in mid-September (Mochnacz *et al*. 2004).

Fry show diel movement patterns, with peak numbers out of cover from late morning to early evening, and all individuals under cover about two hours before dusk (Goetz 1997a). In the upper Chowade River of British Columbia, during summer days,

fry (33-62 mm FL; 3.94-14.04 g) used slightly shallower, slower areas of side channels than juveniles (71-112 mm FL; 0.2.8-2.3 g) (Baxter 1997b). They used depths between 2 and 50 cm, but preferred depths between 10 and 30 cm. They used focal points with bottom velocities between 0 and 25 cm/s, but strongly preferred areas with bottom velocities between 5 and 18 cm/s. Fry used primarily instream overhead cover in the form of boulder, cobble and small wood. However, when habitat availability is considered, fry preferred cover in the form of small rootwads, followed by boulder, small wood, and cobble. They were found primarily over substrates consisting of silt, pebble, and cobble, but preferred areas with boulder and cobble substrate.

In Idaho streams, during summer nights, age 0 bull trout (<75 mm TL) were found primarily (88%) in the channel margins of runs and riffles, while the older juveniles (≥ age 1; 75-270 mm TL) were found primarily (92%) in the main channels, where they selected deeper, slower pool areas (Saffel and Scarnecchia 1995). The density of juvenile bull trout in reaches increased with the number of pocket pools. Reaches with high densities (3.9 to 11.2 fish/100 m^2) of bull trout had maximum summer temperatures ranging from 7.8 to 13.9°C. During summer nights, fry (<66 mm TL) in the South Fork Clearwater River basin of Idaho were associated with shallow stream margins over coarse substrates (Spangler and Scarnecchia 2001). They moved to significantly deeper (mean 0.19 m), lower velocity water and closer to cover in the fall, but maintained their association with coarse substrates.

Young-of-the-year bull trout in the West Castle River drainage of Alberta overwinter in interstitial, sub-surface flow under a dry channel bed, within and upstream of the spawning area (Boag and Hvenegaard 1997).

3.3 Juveniles (Rearing habitat)

Juvenile bull trout rear in second and third order streams, and move to rivers primarily during ages 3 to 4 (14-36 cm TL) (Fraley and Shepard 1989), although in Alberta they may remain in rearing areas for up to 6 years (Allan 1980). Sexual maturation typically occurs during ages 5 to 7 at total lengths of 30 to 50 cm (Fraley and Shepard 1989; Pratt 1992). Juveniles become less associated with the streambed as they grow larger than 100 mm TL, but remain near cover (Fraley and Shepard 1989).

During summer days, juveniles (71-112 mm FL; 0.2.8-2.3 g) in the upper Chowade River of British Columbia used slightly deeper, faster areas of side channels than the fry (33-62 mm FL; 3.94-14.04 g) (Baxter 1997b). Both groups used depths between 2 and 50 cm, but the larger fish preferred slightly deeper areas (30-40 cm), used a slightly broader range of bottom velocities (0 to 40 cm/s), and preferred slightly faster water (28 cm/s). During summer nights, juvenile bull trout (66-130 mm TL) in the South Fork Clearwater River basin of Idaho occupied significantly deeper water on average (0.30 m)

than the fry (0.05 m) (Spangler and Scarnecchia 2001). In the fall, like the fry, they too moved to deeper, lower velocity water and closer to cover.

In both summer and winter juvenile bull trout (70-170 mm TL) in Idaho's Trestle Creek selected pools over riffles and used a wide range of depths at night but were absent from shallow water (<15 cm) during the day (Bonneau and Scarnecchia 1998). They occupied higher velocity water on average during summer days (21 cm/s) than nights (7 cm/s) and during summer days than winter days (0 cm/s -- assuming water velocities were at or near zero below the substrate). During summer days they were, on average, 7 cm above the substrate, while on winter days they were found within or resting upon the cobble substrate. They were more closely associated with cover during the day, and made greatest use of cover during winter days (Bonneau and Scarnecchia 1998). However, even at night juveniles usually stay within 72 cm of cover (Sexauer 1994; Sexauer and James 1997).

Cover use appears to be dictated by latitude and elevation, since the diversity of cover types (e.g., woody debris) tends to decrease with increasing latitude and/or elevation (Mochnacz *et al*. 2004). In summer, in Funeral Creek, Northwest Territories (61°36'N, 124°48'W), juvenile bull trout were found most frequently in high velocity habitats, at or near the bottom, in pocket pools created by large cobble and boulders (Mochnacz *et al*. 2004). Unembedded cobbles and boulders are particularly important cover for juvenile bull trout, followed by overhanging vegetation (Sexauer 1994; Baxter 1997b; Sexauer and James 1997; Bonneau and Scarnecchia 1998; Earle and McKenzie 2001). However, where rootwads are available they may be preferred over other forms of cover (Baxter 1997b). The water velocity in microhabitats selected by juvenile bull trout is significantly lower than that across stream transects, indicating that the fish are selecting low velocity habitats (Sexauer 1994; Sexauer and James 1997; Earle and McKenzie 2001).

Further south, in Oregon, juvenile rearing habitat is characterized by high levels of shade, undercut banks, the presence of large woody debris, gravel in riffles, low levels of fine sediment in riffles, and little bank erosion (Dambacher and Jones 1997). The presence of pools was not an important descriptor of juvenile bull trout presence, since the typical rearing streams have gradients of 5.0%, and are dominated by riffles and rapids.

With the onset of winter, at water temperatures of 1.1 to 1.3°C, juvenile bull trout remain concealed beneath "home stones" during the day and emerge at night to feed and rest on the bottom, primarily in pool and run habitats (Thurow 1997; Jakober *et al*. 2000). Once ice cover forms, use of submerged cover declines (Jakober 1995; Jakober *et al*. 1998). They avoid areas where frazil or bottom ice forms and will move downstream or into adjacent riffles and runs in mid-winter to avoid these unfavourable

ice conditions (Jakober 1995; Jakober *et al*. 1998; D. Evans, DFO Calgary, pers. comm.).

In laboratory studies, juvenile age 1 bull trout (62.4 mm mean FL; 2.23 g mean round weight), showed diel microhabitat preferences (Baxter and McPhail 1997). Substrate preference during the day was primarily cobble and boulder, and at night primarily silts and gravel. Significantly shallower water and lower water velocity were associated with the habitats preferred during the day, than those at night. A similar pattern has been observed in the wild (Goetz 1997a).

The preference of juvenile bull trout for coarser substrate than is used by spawning adults (Goetz 1994), means that it is important to ensure that adequate amounts of large substrates are maintained in bull trout streams to provide rearing habitat (Baxter and McPhail 1997). The high fidelity of juvenile bull trout to cover during the day makes it difficult to accurately assess their populations and habitat use using daytime observations (Jakober *et al*. 2000).

Given a natural thermal gradient (8-15°C) juvenile bull trout chose the coldest water available (Bonneau and Scarnecchia 1996). In the Flathead River system they were seldom observed in streams with summer water temperatures over 15°C (Fraley and Shepard 1989). They were present in many reaches that were not used by adults, and apparently swam upstream to these sections to grow.

Age 0 bull trout began to show evidence of heat shock response at 14°C (Weber *et al*. 2001). In laboratory studies, food consumption by age 0 bull trout declined significantly at temperatures over 16°C, and fish held at temperatures ≥22°C did not feed (Selong *et al*. 2001). Age 0 and 1 bull trout did survive temperatures up to 20°C for up to 60 d, but survival decreased rapidly with exposure to even small increases in temperature above this level. None of the fish held at 22°C survived a 60 day trial. In Idaho streams, bull trout have been observed in temperatures of 20.5°C (Adams and Bjornn 1997).

Radiotelemetry studies found that some subadult bull trout (247-399 mm TL) in Montana's upper Flathead River are migratory, while others are not (32 cf. 35 fish; Muhlfield and Marotz 2005). Most migrating subadults made rapid or incremental downstream movements (mean distance 33 km; range 6-129 km) within the river system or to Flathead Lake during high spring flows and as temperatures declined in the fall and winter. During the day, subadults used complex habitats throughout the upper river system, including deep runs that contained unembedded boulder and cobble substrates, pools with large woody debris, and deep lake-influenced areas of the lower river system.

Juvenile bull trout are benthic foragers that roam slack water areas and pick prey items off the bottom during both day and night (Nakano *et al*. 1992; Bonneau and Scarnecchia 1998; Stewart *et al*. 2007). They use different foraging strategies and occupy different microhabitats than sympatric cutthroat trout (Nakano *et al*. 1992). In summer, juvenile bull trout in the Mackenzie River watershed eat aquatic and terrestrial insects (e.g., grasshopper) and insect larvae (Mochnacz *et al*. 2004). In August, baetid mayflies are an important dietary item for juvenile bull trout in the upper Flathead River of Montana (Nakano *et al*. 1992).

3.4 Adults

In summer, adult bull trout in the Mackenzie River drainage are typically captured in deep pools of small, high gradient mountain streams with cobble to boulder-type substrates (Mochnacz *et al*. 2004). During the day they are often associated with some type of large cover, such as undercut banks, deep pools, or boulders.

The maximum size of adult bull trout, and their weight at length relationship, varies among systems (Pillipow and Williamson 2004). Precocious males, aged 3 and averaging 215 mm in length, have been observed actively spawning with larger females (500 to 600 mm) (Shepard and Graham 1983a cited in Goetz 1989). Small “sneaker” males (mean 412 mm TL) have also been observed avoiding larger dominant males (mean 735 mm TL) to spawn with larger females (mean 651 mm TL) (Baxter 1997a), as have small resident males with fluvial females (Brown 1994).

Within its range the occurrence of bull trout is strongly correlated with maximum daily water temperatures <14 to 16°C (Dunham *et al*. 2003). Temperature may affect the ability of bull trout to compete with other species. In sympatry, bull trout were numerically dominant to rainbow trout at temperatures <13°C and vice versa (Haas 2001). In warmer water, bull trout are in **allopatry**, rather than **sympatry**, with westslope cutthroat trout, suggesting that the distribution of bull trout with respect to temperature may be partially dependant on the presence or absence of cutthroat trout (Pratt 1984). Shephard *et al*. (1984) suggested that increasing temperatures might shift species distribution in the Flathead River, Montana to favour cutthroat trout over bull trout.

Brook trout seem to be segregated from bull trout by temperature (Parkinson and Haas 1996). In the North Thompson River of British Columbia, bull trout are absent from warmer streams and brook trout from colder streams, with an overlap in temperature range of <2°C. In the laboratory, bull trout growth was 25% higher in allopatry than when they were held in sympatry with brook trout, while the presence of bull trout had a significant positive effect on brook trout, especially at temperatures >12°C (McMahon *et al*. 1999). In the laboratory, brook trout had a 2.5-times greater growth rate advantage over bull trout when together at 17°C (McMahon *et al*. 2001). Bull

trout may inhabit warmer waters in the absence of other *Salvelinus* species (Adams 1994).

Adult bull trout eat a wide variety of invertebrates and fishes (Boag 1987; Connor *et al*. 1997; Wilhelm *et al*. 1999; Mochnacz *et al*. 2004; Stewart *et al*. 2007). In the Mackenzie River watershed they eat aquatic and terrestrial insects (e.g., grasshoppers, ants, wasps) and insect larvae; fish (e.g., slimy sculpin *Cottus cognatus*, longnose sucker *Catostomus catostomus*, Arctic grayling *Thymallus arcticus*, and bull trout); and small worms (Mochnacz *et al*. 2004). In the upper reaches of the Muskeg River system of Alberta they eat primarily insects, while in the lower reaches they also feed on rainbow trout (Boag 1987). After ice-out in July, both small ($\leq$250 mm FL) and large ($\geq$250 mm FL) bull trout in a small alpine lake fed on seasonally abundant prey species, in particular chironomid pupae, *Daphnia pulex* var. and the amphipod *Gammarus lacustris*, which are cropped after they reproduce (Wilhelm *et al*. 1999). Mink (*Mustela vison*), bears (*Ursus* spp.), osprey (*Pandion haliaetus*), and river otter (*Lontra canadensis*) prey on adult bull trout (Stelfox 1997; Jakober *et al*. 1998; Chandler *et al*. 2001).

4.0 HABITAT IMPACTS ON FISH BIOLOGY

Bull trout populations in tributary streams of the Mackenzie River drainage appear to be small, but are wide ranging and use a variety of habitat types over a large geographical area (Mochnacz *et al*. 2004). Many of these streams likely provide critical spawning and rearing habitat for bull trout and other species, so care must be taken to ensure that industrial development does not disrupt these habitats, especially at times critical to the species' life history. Understanding of local bull trout ecology and microhabitat use is necessary to prevent or mitigate adverse effects from development (Earle and McKenzie 2001).

Habitat degradation and fragmentation are leading causes of the decline and extirpation of migratory bull trout populations throughout their range (Fraley and Shephard 1989; Goetz 1994; Rieman and McIntyre 1995; Rieman *et al*. 1997; Baxter *et al*. 1999; Ripley *et al*. 2005) (Table 4). Harvesting pressure and species introductions are also important factors affecting the survival of bull trout populations. The bull trout's specific requirements for spawning and rearing habitat, and the general sensitivity of each life stage, make it an excellent indicator of environmental disturbance (Fraley and Shepard 1989; Mochnacz 2002). Shepard and Graham (1983b) provide a detailed description of the program and techniques used to monitor bull trout populations in the Upper Flathead River of Montana.

Table 4. Some activities with the potential to affect key aspects of bull trout habitat and their potential effects on the species.

Activity	Potential impact		
	Habitat	Species	Directly affected life stage(s)
• water removal • drainage alterations • seismic testing	• reduced groundwater flow • altered baseflow and ice and temperature regimes	• degradation, reduction or loss of spawning habitat • increased winter mortality of eggs, larvae, fry, juveniles, and resident adults	• all
• construction of roadways, pads, and structures • stream crossings	• streambed alteration by removal or disturbance of sand, gravel, and cobble substrates • sediment mobilization • streambed destabilization • bank alteration	• egg, **larval**, fry and juvenile mortality from physical damage, exposure, loss of cover, sediment mobilization • degradation, reduction or loss of spawning habitat	• all
• logging • clearing for right-of-ways, camps, etc. • stream crossings	• inland clearing • loss of riparian and instream cover (i.e. shoreline, large woody debris) • altered hydrological regime with more abrupt runoff • warming, increased sediment inputs	• degradation of spawning and rearing habitat • higher mortality rates for all life stages	• all
• culvert installation for stream crossings • dam construction • in-stream construction	• flow impoundment • changes in seasonal flow regimes, water depth, water velocity • habitat fragmentation • alteration of bedload movement and bottom substrate composition	• interruption of spawning migrations • restricted access to coldwater summer refugia in headwater tributaries • inundation or dewatering of spawning areas • population extirpation • creation of new overwintering areas • alteration of bottom substrate suitability for spawning, rearing, and invertebrate production	• all life stages with greatest effects on adult spawners
• road and right-of way construction • population growth	• improved access to bull trout habitat	• increasing harvest pressure on adults and possibly large immature fish • visual and physical disturbance of fish and fish eggs • increased potential for species introductions • population reduction or extirpation	• adults and large juveniles by harvesting • all life stages by introductions
• contaminants releases	• chemical pollution	• reduction in fish quality • increased mortality	• all
• climate change	• changes in the temperature and hydrological regimes • warming	• decrease in suitable habitat at lower elevations and latitudes • increase in suitable habitat at higher elevations and latitudes • increasing competition and predation by warmer water species • changes in the frequency of extreme weather events that lead to flooding or drying and alter recruitment	• all

4.1 Habitat degradation

The reliance of bull trout on groundwater inflows to provide suitable stream spawning habitats and maintain shallow isolated pools for overwintering, makes them very vulnerable to activities that disturb or reduce these inflows (Boag and Hvenegaard 1997; Craig 2001). High road densities may degrade bull trout habitat by reducing **baseflow** discharges (Craig 2001) and increasing sediment inputs (Rieman and McIntyre 1993; Ripley *et al*. 2005). Blasting and water withdrawals are examples of other activities that might affect inflows from these aquifers; global or local climate change might also alter baseflow. Logging may increase warm surface runoff, moderating the cooling influence of groundwater-dominated stream flow (Ripley *et al*. 2005). It may also result in nutrient pulses that alter food web structure.

Logging, right-of-way construction for roads, transmission lines and pipelines, often remove riparian vegetation, reducing instream woody debris that provides important bull trout habitat and increasing overland runoff and sedimentation (McPhail and Baxter 1996; Knotek *et al*. 1997; de Graff 1999; USFWS 2001; Post and Johnston 2002; Ripley *et al*. 2005). Mathematical projections suggest that forest harvesting over the next 20 years might result in the local extirpation of bull trout from 24 to 43% of stream reaches that currently support them in the Kakwa River basin of Alberta (Ripley *et al*. 2005). Attempts have been made to restore reaches of tributaries in the upper Flathead River basin that have been adversely affected by high sediment inputs (Knotek *et al*. 1997). Sediment can also be introduced by small-scale suction dredging for gold (USFWS 2001). Washington State has imposed timing restrictions on this form of mining to decrease its impact on bull trout eggs and fry.

Unrestricted grazing by livestock can harm bull trout by mobilizing sediment, damaging riparian vegetation and trampling redds, but is readily mitigated by fencing (USFWS 2001).

Land management activities that reduce pool habitat, instream cover, and streambed stability may be especially detrimental to juvenile bull trout in winter (Bonneau and Scarnecchia 1998). The presence of stable, unembedded cobbles is important to juvenile bull trout, particularly as overwintering habitat. Sediment inputs that embed these cobbles may limit the carrying capacity of stream habitats for juvenile salmonids. In contrast, destabilization of cobble habitats may also result in low survival rates of eggs and fry, washouts of fish from sections of streams (Pearsons *et al*. 1992), and direct crushing of fish (Erman *et al*. 1988).

In the Swan River of Montana, changes in bull trout redds were positively correlated with the extent of alluvial valley segments bounded by knickpoints (abrupt

changes in the longitudinal profile of the stream valley as a result of bedrock structure) and negatively correlated with the density of logging roads in spawning tributary catchments (Baxter *et al*. 1999). The alluvial valley segments may contain significant areas of groundwater discharge (Baxter and Hauer 2000), while the logging roads and logging may cause changes in the morphology and stream-channel features that provide habitat for aquatic biota and facilitate access by harvesters (Baxter *et al*. 1999). Logging the riparian zone of bull trout streams can alter the delivery, storage, and transport of large woody debris, and thereby alter natural stream morphology and habitat features (Cross and Everest 1995; Hauer *et al*. 1999). Upland logging can alter water flow regimes and sediment delivery, and may have cumulative effects on the balance of large woody debris in the streams. However, further work is needed to clarify the underlying mechanisms by which forest harvesting and road networks adversely affect the occurrence and abundance of bull trout (Ripley *et al*. 2005).

The relocation of spawners from areas affected by development does not appear to compensate for habitat losses. Development of a tailings dam for the Kerness Mine, in the Thutade watershed of northwestern British Columbia, removed 4.1 km of stream habitat used by bull trout in S. Kerness Creek (Paul and Bustard 2004). The total number of spawners in the creek decreased significantly following mine construction, as did the density of juveniles in the remaining 2 km section. While some spawners may have relocated to nearby tributaries the densities of age 0 and 1 bull trout in these tributaries did not increase. This suggests that relocation of spawners may not compensate for habitat losses, and that habitat quantity must be maintained. The effectiveness of mitigation measures to address the habitat losses, including removal of migration barriers and the construction of artificial spawning beds below the tailings dam, are being tested.

4.2 Habitat fragmentation

Complex river habitats with abundant cover, and natural connections of suitable spawning and rearing habitat, must be maintained over a large scale to conserve bull trout populations (Muhlfeld and Marotz 2005). Late-summer dewatering of stream habitats fragments populations, and can cause significant mortality among spawning bull trout in shallow tributaries (Wissmar and Craig 1997).

Barriers such as hydroelectric dams and beaver dams can fragment bull trout habitat and prevent fish from accessing optimal spawning habitat (Goetz 1994; Baxter and McPhail 1996; Fernet and O'Neil 1997; Swanberg 1997b; USFWS 2001; Post and Johnston 2002). Programs to transport adult bull trout upstream of hydroelectric dams can mitigate this damage, particularly in areas with small populations (Swanberg 1997b). BC Hydro has used discharge tunnels successfully to provide bull trout with upstream passage through the Duncan Dam (Olmsted *et al*. 2001). Entrainment of bull

trout in irrigation channels caused significant (15%) mortality among bull trout spawning in the Belly River of Alberta and Montana until screening was installed at the canal headgate (Clayton 2001). In Oregon, the construction of water storage structures led to the extirpation of eight populations above these dams within 15 years (Goetz 1994).

Improperly designed, installed, or maintained culverts and weirs can also create smaller, often seasonal, physical barriers to bull trout movements (Goetz 1994). In some instances, impoundments can provide overwintering habitat and, in the case of the Williston Reservoir on the Peace River, may have led to the development of an adfluvial population (Bruce and Starr 1985; McPhail and Baxter 1996).

4.3 Species introductions

The introduction of lake trout (*Salvelinus namaycush*), brook trout (*Salvelinus fontinalis*), or their hybrids (splake) can displace bull trout, and may prevent them from becoming established in certain low-elevation lakes (Donald and Alger 1993; Donald and Stelfox 1997). In Bow Lake, Alberta, for example, the introduction of lake trout in 1964 decimated the bull trout population by 1992. Competitive interactions with brook trout may be an important factor in the mechanism responsible for the regulation of bull trout densities in tributary streams, at least on a local scale (Nakano *et al*. 1998). Stocking bull trout streams with hatchery reared steelhead trout (*O. mykiss*) and chinook salmon (*O. tshawytscha*) may slow bull trout growth (Underwood *et al*. 1995). Removal or suppression of introduced species to promote bull trout recovery is difficult (Montana Bull Trout Scientific Group 1995).

Bull trout will hybridize with Dolly Varden (Haas and McPhail 1991; Baxter *et al*. 1997; Hagen and Taylor 2001) and brook trout (Markle 1992; Adams 1994; Kitano *et al*. 1994; Saffel and Scarnecchia 1995). However, hybrids do not appear to be common in the wild (Baxter *et al*. 1997; Leary and Allendorf 1997). Sympatric populations of Dolly Varden and bull trout maintain their genetic integrity in spite of gene flow (Baxter *et al*. 1997; Hagen and Taylor 2001).

4.4 Improved access

Bull trout are sensitive to exploitation because their populations are small and individuals are slow-growing, late to mature, and spawn in non-consecutive years (Carl *et al*. 1989; Clayton 2001; Bustard and Schell 2002; Post and Johnston 2002). They are voracious **piscivores** and highly susceptible to exploitation by angling before they reach maturity (Goetz 1989; Brown 1992; Stelfox and Egan 1995; McPhail and Baxter 1996; Mushens and Post 2000; Olmsted *et al*. 2001). Because of their migratory habit and range, bull trout populations can be very vulnerable to activities that interrupt migration routes, and to angling pressure along the migration route (McLeod and Clayton 1997;

Stelfox 1997; Pillipow and Williamson 2004). However, overharvested populations can recover quickly when sport angling is reduced or eliminated (Stelfox 1997). Adfluvial populations in lakes that do not have restricted access, and that have been stocked with other *Salvelinus* species are particularly vulnerable to extirpation (Donald and Stelfox 1997).

Unfortunately, opportunities for population enhancement are limited, and the major hope for restoring bull trout numbers lies with regulation (e.g., closures, gear restrictions, minimum size limits, harvest limits) (McPhail and Baxter 1996). In the Northwest Territories sport harvesters are allowed to catch 2 bull trout per day, and can only have 3 in their possession at any one time (G. Low, DFO Hay River, pers. comm. 2005).

4.5 Climate change

Elevated temperature is considered a major factor in the decline of southern bull trout populations (Rieman *et al*. 1997), some of which already migrate into headwater streams early in the season to avoid unfavourably warm temperatures (Swanberg 1997a). Climatic warming could change the availability of suitable thermal habitat to bull trout. In the south this might significantly restrict the species' range over its current distribution (Rieman and McIntyre 1993). In the north, it might facilitate northward colonization by bull trout and subsequent sympatry and hybridization with Dolly Varden (Reist 1994; Mochnacz 2002). In both areas, it could increase competition or predation by other species that colonize cold bull trout habitat as it warms. Whether bull trout distributions would expand to the north and to higher elevations in the event of significant warming is unknown.

Winter flooding caused by heavy precipitation or glacial floods can damage bull trout habitat and extirpate populations (Goetz 1994). Under normal circumstances populations should recover over time, but those that are already depleted or limited by migratory barriers or other factors may not recover.

5.0 SUMMARY

Bull trout require cold, clean water. They have complex life histories and, in some cases, very large home ranges. Their populations can be resident or migratory, and the latter can follow fluvial, adfluvial or anadromous life histories. Spawning occurs in shallow, fast-flowing tributary streams, often in areas fed by groundwater that maintains suitable incubation and rearing conditions through the winter. Spawning streams have stable channels with suitable substrate (gravel-boulder) for redd construction and rearing, and abundant cover. The migratory populations require uninterrupted migratory corridors that connect suitable spawning and overwintering habitats that may be

hundreds of kilometers apart. The species' relatively specific habitat requirements, particularly for spawning and rearing, make populations vulnerable to extirpation by habitat fragmentation and disruption. As slow-maturing but voracious predators bull trout are also vulnerable to overharvesting. They do not compete well with other trout species at temperatures above 12°C, and are vulnerable to the introduction of other trout species.

Based on the limited data available, habitats used by bull trout for spawning and rearing in the Northwest Territories appear to be similar to those used elsewhere. However, they may make less use of large woody debris for cover, as it is less abundant in the region.

Efforts to understand and conserve key processes likely to influence the persistence of populations may be more likely to conserve bull trout populations than efforts to design minimal habitat reserves (Rieman and Dunham 2000). Land management for bull trout protection should be site-specific (Watson and Hillman 1997), due to the species' patchy seasonal habitat use, extensive migratory movements, and narrow spawning and rearing requirements.

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7.0 REFERENCES

Adams, S.B. 1994. Bull trout distribution and habitat use in the Weiser River drainage, Idaho. M. Sc. Thesis, University of Idaho. x + 84 pp.

Adams, S.B., and Bjornn, T.C. 1997. Bull trout distributions related to temperature regimes in four central Idaho streams, p. 371-380. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Allan, J.H. 1980. Life history notes on the Dolly Varden char (*Salvelinus malma*) in the upper Clearwater River, Alberta. Alberta Energy and Natural Resources, Fish and Wildlife Division, Red Deer, AB. iv + 59 p.

Allan, J.H. 1987. Fisheries investigations in Line Creek - 1987. Prepared for Line Creek Resources Ltd., Sparwood, BC. 67 p.

Bahr, M.A., and Shrimpton, J.M. 2004. Spatial and quantitative patterns of movement in large bull trout (*Salvelinus confluentus*) from a watershed in north-western British Columbia, Canada, are due to habitat selection and not differences in life history. Ecol. Freshw. Fish **13**: 294-304.

Baxter, C.V., and Hauer, F.R. 2000. Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (*Salvelinus confluentus*). Can. J. Fish. Aquat. Sci. **57**: 1470-1481.

Baxter, C.V., Frissell, C.A., and Hauer, F.R. 1999. Geomorphology, logging roads, and the distribution of bull trout spawning in a forested river basin: implications for management and conservation. Trans. Am. Fish. Soc. **128**: 854-867.

Baxter, J.S. 1997a. Aspects of the reproductive ecology of bull trout (*Salvelinus confluentus*) in the Chowade River, British Columbia. M.Sc. Thesis, University of British Columbia, Vancouver, BC. xii + 97 p.

Baxter, J.S. 1997b. Summer daytime microhabitat use and preference of bull trout fry and juveniles in the Chowade River, British Columbia. University of British Columbia, Department of Zoology, Fisheries Management Report No. 107: ii + 36 p.

Baxter, J.S., and McPhail, J.D. 1996. Bull trout spawning and rearing habitat requirements: summary of the literature. University of British Columbia, Department of Zoology, Fisheries Technical Circular No. **98**: 1-27.

Baxter, J.S., and McPhail, J.D. 1997. Diel microhabitat preferences of juvenile bull trout in an artificial stream channel. N. Am. J. Fish. Manage. **17**: 975-980.

Baxter, J.S., and McPhail, J.D. 1999. The influence of redd site selection, groundwater upwelling, and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. Can. J. Zool. **77**: 1233-1239.

Baxter, J.S., Taylor, E.B.D.R.H., Hagen, J., and McPhail, J.D. 1997. Evidence for natural hybridization between Dolly Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*) in a northcentral British Columbia watershed. Can. J. Fish. Aquat. Sci. **54**: 421-429.

Beak Consultants Limited. 1981. Prairie Creek Project - fall fisheries study, 1981. Report prepared by Beak Consultants Limited, Vancouver, B.C. for Cadillac Explorations Ltd., Calgary, Alberta. iii + 10 p. + Tables, Figures, and Appendix.

Boag, T.D. 1987. Food habits of bull char, *Salvelinus confluentus*, and rainbow trout, *Salmo gairdneri*, coexisting in a foothills stream in northern Alberta. Can. Field-Nat. **101**: 56-62.

Boag, T.D., and Hvenegaard, P.J. 1997. Spawning movements and habitat selection of bull trout in a small Alberta foothills stream, p. 317-323. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.). Friends of the Bull Trout Conference Proceedings, Calgary, AB.

Bonneau, J.L. 1994. Seasonal habitat use and changes in distribution of juvenile bull trout and cutthroat trout in small, high gradient streams. M.Sc. Thesis, University of Idaho. ix + 92 p.

Bonneau, J.L., and Scarnecchia, D.L. 1996. Distribution of juvenile bull trout in a thermal gradient of a plunge pool in Granite Creek, Idaho. Trans. Am. Fish. Soc. **125**: 628-630.

Bonneau, J.L., and Scarnecchia, D.L. 1998. Seasonal and diel changes in habitat use by juvenile bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarki*) in a mountain stream. Can. J. Zool. **76**: 783-790.

Bonneau, J.L., Thurow, R.F., and Scarnecchia, D.L. 1995. Capture, marking, and enumeration of juvenile bull trout and cutthroat trout in small, low-conductivity streams. N. Am. J. Fish. Manage. **15**: 563-568.

Brenkman, S.J., and Corbett, S.C. 2005. Extent of anadromy in bull trout and implications for conservation of a threatened species. N. Am. J. Fish. Manage. **25**: 1073-1081.

Brenkman, S.J., Larson, G.L., and Gresswell, R.E. 2001. Spawning migration of lacustrine-adfluvial bull trout in a natural area. Trans. Am. Fish. Soc. **130**: 981-987.

Brenkman, S.J., Corbett, S.C., and Volk, E.C. 2007. Use of otolith chemistry and radiotelemetry to determine age-specific migratory patterns of anadromous bull trout in the Hoh River, Washington. Trans. Am. Fish. Soc. **136**: 1-11.

Brown, L.G. 1992. Draft management guide for the bull trout *Salvelinus confluentus* (Suckley) on the Wenatchee National Forest. Prepared for Wenatchee National Forest, Wenatchee, Washington. viii + 104 p.

Brown, L.G. 1994. On the zoogeography and life history of Washington's native char - Dolly Varden: *Salvelinus malma* (Walbaum), bull trout: *Salvelinus confluentus* (Suckley). Washington Department of Fish and Wildlife Report **94-04**: ii + 41 p.

Bruce, P.G., and Starr, P.J. 1985. Fisheries resources and fisheries potential of Williston Reservoir and its tributary streams. Vol. II, Fisheries resources and fisheries potential of the Williston Reservoir and its tributary streams - a preliminary overview. British Columbia Ministry of the Environment, Fish. Tech. Circ. No. **69**: v + 101 p. + appendices.

Burrows, J., Euchner, T., and Baccante, N. 2001. Bull trout movement patterns: Halfway River and Peace River progress, p. 153-157. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Bustard, D., and Schell, C. 2002. Conserving Morice Watershed fish populations and their habitat, Stage II Biophysical profile, Section 3.8 Bull Trout, p. 97-110. Prepared by David Bustard and Associates Ltd. for Community Futures Development Corporation of Nadina, Nadina, BC.

Cannings, S.G., and Ptolemy, J. 1998. Bull trout, p. 18-26. In S.G. Cannings and J. Ptolemy (ed.) Rare freshwater fish of British Columbia. BC Environment.

Carl, L.M., Kraft, M., and Rhude, L. 1989. Growth and taxonomy of bull charr, *Salvelinus confluentus*, in Pinto Lake, Alberta. Environ. Biol. Fishes **26**: 239-246.

Carson, R.J. 2001. Bull trout spawning movements and homing behaviour back to pre-spawning locations in the McLeod River, Alberta, p. 137-140. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Chandler, J.A., Fedora, M.A., and Walters, T.A. 2001. Pre- and post-spawn movements and spawning observations of resident bull trout in the Pine Creek watershed, eastern Oregon, p. 167-172. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Chang-Kue, K.T.J., and Cameron, R.T. 1980. A survey of the fish resources of the Great Bear River, Northwest Territories, 1974. Can. Fish. Mar. Serv. Manuscr. Rep. **1510**: vi + 59 p.

Clayton, T.B. 2001. Movements and status of bull trout (*Salvelinus confluentus*) in the Belly River, Alberta and Montana, p. 141-145. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Connor, E., Reiser, D., Binkley, K., Paige, D., and Lynch, K. 1997. Abundance and distribution of an unexploited bull trout population in the Cedar River watershed, Washington, p. 403-411. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Cope, R., Morris, M., and Bisset, J. 2002. Wigwam River juvenile bull trout and fish habitat monitoring program, annual report 2001. Bonneville Power Administration, Portland, Oregon. v + 119 p. [Project No. 2000-00400. BPA Report DOE/BP-00005672-1].

Craig, S.D. 1997. Habitat conditions affecting bull trout, *Salvelinus confluentus*, spawning areas within the Yakima River basin, Washington. M.Sc. Thesis, Central Washington University. x + 74 p.

Craig, S.D. 2001. Bull trout, baseflows and water temperatures: quantifying minimum surface water discharges in small groundwater influenced catchments, p. 129-135. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Cross, D., and Everest, L. 1995. Fish habitat attributes of reference and managed watersheds with special reference to the location of bull charr (*Salvelinus confluentus*) spawning sites in the upper Spokane River ecosystem, northern Idaho. USDA Forest Service, Fish Habitat Relationships Technical Bulletin **17**: ii + 6 p.

Dambacher, J.M., and Jones, K.K. 1997. Stream habitat of juvenile bull trout populations in Oregon and benchmarks for habitat quality, p. 353-360. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

de Graff, N. 1999. Compiled fisheries information for the La Biche River, Yukon. Unpublished report prepared by Can-nic-a-Nick Environmental for Canadian Wildilfe Service. 12 p.

Donald, D.B., and Alger, D.J. 1993. Geographic distribution, species displacement, and niche overlap for lake trout and bull trout in mountain lakes. Can. J. Zool. **71**: 238-247.

Donald, D.B., and Stelfox, J.D. 1997. Effects of fisheries enhancement and access on adfluvial bull trout populations in mountain lakes of southern Alberta, p. 227-234. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Dunham, J.B., and Chandler, G.L. 2001. Models to predict suitable habitat for juvenile bull trout in Washington State. Final Report. U.S. Forest Service, Boise, Idaho. 75 p.

Dunham, J., Rieman, B., and Chandler, G. 2003. Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. N. Am. J. Fish. Manage. **23**: 894-904.

Earle, J.E., and McKenzie, J.S. 2001. Habitat use by juvenile bull trout in mountain streams in the Copton Creek drainage, Alberta and its relation to mining activity, p. 121-128. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Erman, D.C., Andrews, E.D., and Yoder-Williams, M. 1988. Effects of winter floods on fishes in the Sierra Nevada. Can.J. Fish. Aquat. Sci. **45**: 2195-2200.

Fairless, D.M., Herman, S.J., and Rhem, P.J. 1994. Characteristics of bull trout (*Salvelinus confluentus*) spawning sites in five tributaries of the upper Clearwater River, Alberta. Alberta Environmental Protection, Fish and Wildlife Services, Rocky Mountain House, AB. vii + 49 p.

Fernet, D.A., and Bjornson, C.P. 1997. A delphi analysis of bull trout habitat preference criteria with comparison to information collected from Smith-Dorrien Creek, Alberta, p. 435-442. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Fernet, D.A., and O'Neil, J. 1997. Use of radio telemetry to document seasonal movements and spawning locations for bull trout in relation to a newly created reservoir, p. 427-434. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Ford, B.S., Higgins, P.S., Lewis, A.F., Cooper, K.L., Watson, T.A., Gee, C.M., Ennis, G.L., and Sweeting, R.L. 1995. Literature reviews of the life history, habitat requirements and mitigation / compensation strategies for thirteen sport fish species in the Peace, Liard, and Columbia river drainages of British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. **2321**: xxiv + 342 p.

Fraley, J.J., and Shepard, B.B. 1989. Life history, ecology and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and River system, Montana. Northwest Sci. **63**: 133-143.

Gamett, B.L. 2002. The relationship between water temperature and bull trout distribution and abundance. M.Sc. Thesis, Utah State University, Logan, Utah. xi + 83 p.

Giles, M.A., and Van der Zweep, M. 1996. Dissolved oxygen requirements for fish of the Peace, Athabasca and Slave River basins: a laboratory study of bull trout (*Salvelinus confluentus*) and mountain whitefish (*Prosopium williamsoni*). Northern River Basins Study Project Report **120**: ix + 153 p.

Goetz, F. 1989. Biology of the bull trout *Salvelinus confluentus* a literature review. USDA Forest Service, Wilamette National Forest, Eugene, Oregon. iii + 53 p.

Goetz, F.A. 1994. Distribution and juvenile ecology of bull trout (*Salvelinus confluentus*) in the Cascade Mountains. M.Sc. Thesis, Oregon State University, Corvallis, Oregon. xv + 173 p.

Goetz, F.A. 1997a. Diel behavior of juvenile bull trout and its influence on selection of appropriate sampling techniques, p. 387-402. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Goetz, F.A. 1997b. Habitat use of juvenile bull trout in Cascade Mountain streams of Oregon and Washington, p. 339-351. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Haas, G. 2001. The mediated associations and preferences of native bull trout and rainbow trout with respect to maximum water temperatures, its measurement standards, and habitat, p. 53-55. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, AB.

Haas, G.R., and McPhail, J.D. 1991. Systematics and distributions of Dolly Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*) in North America. Can. J. Fish. Aquat. Sci. **48**: 2191-2211.

Haas, G.R., and McPhail, J.D. 2001. The post-Wisconsinan glacial biogeography of bull trout (*Salvelinus confluentus*): a multivariate morphometric approach for conservation biology and management. Can. J. Fish. Aquat. Sci. **58**: 2189-2203.

Hagen, J., and Taylor, E.B. 2001. Resource partitioning as a factor limiting gene flow in hybridizing populations of Dolly Varden char (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*). Can. J. Fish. Aquat. Sci. **58**: 2037-2047.

Hanzel, L. 1985. Past and present status of bull trout in Flathead Lake, p. 19-24. In D.D. Macdonald (ed.) Proceedings of the Flathead River basin bull trout biology and population dynamics modelling information exchange. Fisheries Branch, B.C. Ministry of the Environment, Cranbrook, BC.

Hauer, F.R., Poole, G.C., Gangemi, J.T., and Baxter, C.V. 1999. Large woody debris in bull trout (*Salvelinus confluentus*) spawning streams of logged and wilderness watersheds in northwest Montana. Can. J. Fish. Aquat. Sci. **56**: 915-924.

Hemmingsen, A.R., Bellerud, B.L., Buchanan, D.V. , Gunckel, S.L., Shappart, J.K., and Howell, P.J. 2001. Bull trout life history, genetics, habitat needs, and limiting factors in central and northeast Oregon. 1997 Annual Report. Prepared for U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon. 37 p. [Project Number 95-54, Contract Number 94B134342].

Herman, S.J. 1997. The unique bull trout spawning population of Pinto Lake, Alberta, p. 217-226. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Hvenegaard, P.J., and Thera, T.M. 2001. Monitoring the bull trout (*Salvelinus confluentus*) spawning run in Lynx Creek, a tributary to the Kakwa River, west central Alberta, p. 147-151. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, AB.

Jakober, M.J. 1995. Autumn and winter movement and habitat use of resident bull trout and westslope cutthroat trout in Montana. M.Sc. Thesis, University of Montana, Bozeman, Montana. xii + 110 p.

Jakober, M.J., McMahon, T.E., Thurow, R.F., and Clancy, C.G. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Trans. Am. Fish. Soc. **127**: 223-235.

Jakober, M.J., McMahon, T.E., and Thurow, R.F. 2000. Diel habitat partitioning by bull charr and cutthroat trout during fall and winter in Rocky Mountain streams. Environ. Biol. Fishes **59**: 79-89.

James, P.W., and Sexauer, H.M. 1997. Spawning behaviour, spawning habitat and alternative mating strategies in an adfluvial population of bull trout, p. 325-329. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Kitano, S., Maekawa, K., Nakano, S., and Fausch, K.D. 1994. Spawning behavior of bull trout in the upper Flathead drainage, Montana, with special reference to hybridization with brook trout. Trans. Am. Fish. Soc. **123**: 988-992.

Knotek, W.L., Deleray, M., and Marotz, B. 1997. Hungry Horse Dam Fisheries Mitigation Program: fish passage and habitat improvement in the upper Flathead River basin. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. vii + 60 p. + apps. [DOE/BP-60559-4].

Leary, R.F., and Allendorf, F.W. 1997. Genetic confirmation of sympatric bull trout and Dolly Varden in western Washington. Trans. Am. Fish. Soc. **126**: 715-720.

Markle, D.F. 1992. Evidence of bull trout x brook trout hybrids in Oregon, p. 58-67. In P.J. Howell and D.V. Buchanan (ed.) Proceedings of the Gearhart Mountain bull trout workshop. Oregon Chapter of the American Fisheries Society, Corvallis, Oregon.

Marshall, I.B. and Schut, P.H. 1999. A national ecological framework for Canada. Ecosystems Science Directorate, Environment Canada and Research Branch, Agriculture and Agri-Food Canada, Ottawa, ON. [http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html, Accessed 28 May 2007].

McCart, D. 1982. An assessment of the fisheries resources of the Great Bear and Mackenzie Rivers in the vicinity of proposed IPL Pipeline crossings. Aquatic Environments Limited for Inter Provincial Pipelines Ltd, Calgary, AB. 33 p. + tables, figures.

McCart, P.J., Griffiths, W., Gossen, C., Bain, H., and Tripp, D. 1974. Catalogue of lakes and streams in Canada along routes of the proposed Arctic gas pipeline from the Alaskan/Canadian border to the 60th parallel. Canadian/Alaskan Arctic Gas Study Limited Biological Report Series **16**: 251 p. + 11 maps.

McCullough, D.A., and Spalding, S. 2002. Multiple lines of evidence for determining upper optimal temperature thresholds for bull trout. Columbia River Inter-Tribal Fish Commission (CRITFC) Techncial Report **02-4**: 25 p.

McLeod, C., and Clayton, T. 1993. Fish radio telemetry demonstration project, upper Athabasca River, May to August, 1992. Northern River Basins Study Project Report **11**: 41 p.

McLeod, C.L., and Clayton, T.B. 1997. Use of radio telemetry to monitor movements and locate critical habitats for fluvial bull trout in the Athabasca River, Alberta, p. 413-419. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the Bull Trout Conference Proceedings. Trout Unlimited Canada, Calgary, Alberta.

McMahon, T., Zale, A., Selong, J., and Barrows, R. 1999. Growth and survival temperature criteria for bull trout. Annual Report 1999 (year two). Prepared for the National Council for Air and Stream Improvement.

McMahon, T., Zale, A., Selong, J., and Barrows, R. 2001. Growth and survival temperature criteria for bull trout. Annual Report 2000 (year three). Prepared for the National Council for Air and Stream Improvement. 31 p.

McPhail, J.D., and Baxter, J.S. 1996. A review of bull trout (*Salvelinus confluentus*) life-history and habitat use in relation to compensation and improvement opportunities. University of British Columbia, Department of Zoology, Fisheries Management Report **104**: 1-35.

McPhail, J.D., and Murray, C.B. 1979. The early life history and ecology of Dolly Varden (*Salvelinus malma*) in the upper Arrow Lakes. Department of Zoology and Institute of Animal Resources, University of British Columbia, Vancouver, BC. 113 p.

Meehan, W.R., and Bjornn, T.C. 1991. Salmonid distributions and life histories, p. 47-82. In W.R. Meehan (ed.) Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Mochnacz, N. 2001. Life history stages of bull trout, *Salvelinus confluentus*, a literature review. Prepared for Canada Department of Fisheries and Oceans, Winnipeg, MB. 23 p.

Mochnacz, N.J. 2002. Bull trout distribution, life history, and habitat requirements in the southern and central Mackenzie River Valley, Northwest Territories. A report prepared for the Habitat Stewardship Program for Species at Risk, Government of Canada [Edmonton, AB]. ii + 52 p.

Mochnacz, N.J., Reist, J.D., Cott, P., Low, G., and Wastle, R. 2004. Biological and habitat data for bull trout (*Salvelinus confluentus*) and associated species from stream surveys conducted in the southern and central Mackenzie River Valley, Northwest Territories, 2000 to 2001. Can. Data. Rep. Fish. Aquat. Sci. **1131**: iv + 38 p.

Mogen, J.T. and Kaeding, L.R. 2005. Identification and characterization of migratory and nonmigratory bull trout populations in the St. Mary River drainage, Montana. Trans. Am. Fish. Soc. **134**: 841-852.

Mongillo, P.E. 1993. The distribution and status of bull trout/Dolly Varden in Washington State, June 1992. Washington Department of Wildlife, Fisheries Management Division Report No. **93-22**: iii + 45 p.

Montana Bull Trout Scientific Group. 1995. The role of removal and suppression of non-native fish in bull trout recovery. Prepared for the Montana Bull Trout Restoration Team. ii + 41 p.

Muhlfeld, C.C., and Marotz, B. 2005. Seasonal movement and habitat use by subadult bull trout in the upper Flathead River system, Montana. N. Am. J. Fish. Manage. **25**: 797-810.

Mushens, C.J., and Post, J.R. 2000. Population dynamics of the lower Kananaskis Lake bull trout: 1999 progress report. Prepared by University of Calgary, Department of Biological Sciences, Calgary, AB, for Alberta Conservation Association and TransAlta Utilities. xii + 65 p. + tables, figures.

Nakano, S., Fausch, K.D., Furukawa-Tanaka, T., Maekawa, K., and Kawanabe, H. 1992. Resource utilization by bull char and cutthroat trout in a mountain stream in Montana, U.S.A. Jpn. J. Ichthyol. **39**: 211-217.

Nakano, S., Kitano, S., Nakai, K., and Fausch, K.D. 1998. Competitive interactions for foraging microhabitat among introduced brook charr, *Salvelinus fontinalis*, and native bull charr, *S. confluentus*, and westslope cutthroat trout, *Oncorhynchus clarki lewisi*, in a Montana stream. Environ. Biol. Fishes **52**: 345-355.

Oliver, G. 1985. Habitat requirements of Dolly Varden char in the Wigwam River drainage, p. 36. In D.D. Macdonald (ed.) Proceedings of the Flathead River basin bull trout biology and population dynamics modelling information exchange. Fisheries Branch, B.C. Ministry of the Environment, Cranbrook, BC.

Olmsted, W.R., den Biesen, D., and Birch, G.J. 2001. Migration timing and abundance trends in an adfluvial bull trout population in Kootenay Lake, British Columbia, p. 159-166. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Parkinson, E.A., and Haas, G.R. 1996. The role of macrohabitat and temperature in defining the range of bull trout. Province of British Columbia, Fisheries Project Report **RD51**: 15 p.

Pattenden, R., McLeod, C., and Ash, G. 1991. Peace River Site C hydroelectric development. Fish movements and population status. Prepared by R.L.&L. Environmental Services Ltd., Edmonton, for B.C. Hydro, Environmental Resources Division, Vancouver, BC.

Paul, A.J., and Bustard, D. 2004. Study designs for environmental impact assessment: an example using the bull trout (*Salvelinus confluentus*) and the South Kerness Mine Project, p. 17-18. In G.J. Scrimgeour, G. Eisler, B. McCulloch, U. Silins, and M. Monita (ed.) Forest Land-Fish Conference II - Ecosystem Stewardship through Collaboration. Proc. Forest-Land-Fish Conf. II, April 26-28, 2004, Edmonton, AB.

Paul, A.J., and Post, J.R. 2001. Spatial distribution of native and nonnative salmonids in streams of the eastern slopes of the Canadian Rocky Mountains. Trans. Am. Fish. Soc. **130**: 417-430.

Pearsons, T.N., Li, H.W., and Lamberti, G.A. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. Trans. Am. Fish. Soc. **121**: 427-436.

Pillipow, R., and Williamson, C. 2004. Goat River bull trout (*Salvelinus confluentus*) biotelemetry and spawning assessments 2002-03. BC J. Ecosyst. Manage. **4**: 1-9.

Porter, T.R., Rosenberg, D.M., and McGowan, D.K. 1974. Winter studies of the effects of a highway crossing on the fish and benthos of the Martin River, N.W.T. Can. Fish. Mar. Serv. Tech. Rep. Ser. CEN-T **74-3**: vii + 50 p.

Post, J.R., and Johnston, F.D. 2002. Status of the bull trout (*Salvelinus confluentus*) in Alberta. Alberta Wildlife Status Report No. **39**: viii + 40 p.

Pratt, K.L. 1984. Habitat use and species interactions of juvenile cutthroat (*Salmo clarki lewisi*) and bulltrout (*Salvelinus confluentus*) in the upper Flathead River Basin. M.Sc. Thesis, University of Idaho, Moscow, ID. xi + 95 p.

Pratt, K.L. 1992. A review of bull trout life history, p. 1-4. In P.J. Howell and D.V. Buchanan (ed.) Proceedings of the Gearhart Mountain bull trout workshop. Oregon Chapter of the American Fisheries Society, Corvallis, Oregon.

Ratliff, D.E., Thiesfeld, S.L., Weber, W.G., Stuart, A.M., Riehle, M.D., and Buchanan, D.V. 1996. Distribution, life history, abundance, harvest, habitat, and limiting factors of bull trout in the Metolius River and Lake Billy Chinook, Oregon, 1983-1994. Oregon Department of Fish and Wildlife, Fish Division, Information Reports **96-7**: ii + 44 p.

Reiser, D.W., Connor, E., Binkley, K., Lynch, K., and Paige, D. 1997. Evaluation of spawning habitat used by bull trout in the Cedar River watershed, Washington, p. 331-338. In W.C. Mackay, M.K. Brewin, M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Reist, J.D. 1994. An overview of the possible effects of climate change on northern freshwater and anadromous fishes, p. 377-385. In S.J. Cohen (ed.) Mackenzie Basin Impact Study (MBIS) Interim Report 2. Environment Canada, Downsview, ON.

Reist, J.D., Low, G., Johnson, J.D., and McDowell, D. 2002. Range extension of bull trout, *Salvelinus confluentus*, to the central Northwest Territories, with notes on identification and distribution of Dolly Varden, *Salvelinus malma,* in the western Canadian Arctic. Arctic **55** : 70-76.

Rich, C.F. 1996. Influence of abiotic and biotic factors on occurrence of resident bull trout in fragmented habitats, western Montana. M.Sc. Thesis, Montana State University, Bozeman, Montana. viii + 53 p.

Rieman, B.E., and Chandler, G.L. 1999. Empirical evaluation of temperature effects on bull trout distribution in the northwest. Prepared by U.S. Forest Service, Boise, Idaho for U.S. Environmental Protection Agency, Boise, Idaho. 31 p. [Contract No. 12957242-01-0].

Rieman, B.E., and Dunham, J.B. 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. Ecol. Freshw. Fish **9**: 51-64.

Rieman, B.E., and McIntyre, J.D. 1993. Demographic and habitat requirements for conservation of bull trout. U.S. Department of Agriculture, Forest Service, Intermountain Research Station (Ogden, UT), General Technical Report **INT-302**: i + 38 p.

Rieman, B.E., and McIntyre, J.D. 1995. Occurrence of bull trout in naturally fragmented habitat patches in varied sizes. Trans. Am. Fish. Soc. **124**: 285-296.

Rieman, B.E., Lee, D.C., Chandler, G., and Myers, D. 1997. Does wildfire threaten extinction for salmonids? Responses of redband trout and bull trout following recent large fires on the Boise National Forest, p. 47-47. In J. Greenlee (ed.) Proceedings - Fire effects on rare and endangered species and habitats conference. International Association of Wildlands Fire, Fairfield, Washington.

Ripley, T., Scrimgeour, G., and Boyce, M.S. 2005. Bull trout (*Salvelinus confluentus*) occurrence and abundance influenced by cumulative industrial developments in a Canadian boreal forest watershed. Can. J. Fish. Aquat. Sci. **62**: 2431-2442.

Roberge, M., Hume, J.M.B., Minns, C.T., and Slaney, T. 2002. Life history characteristics of freshwater fishes occurring in British Columbia and the Yukon, with major emphasis on stream habitat characteristics. Can. Manuscr. Rep. Fish. Aquat. Sci. **2611**: xiv + 248 p.

Saffel, P.D., and Scarnecchia, D.L. 1995. Habitat use by juvenile bull trout in belt-series geology watersheds of northern Idaho. Northwest Sci. **69** : 304-317.

Sawatzky, C.D., Michalak, D., Reist, J.D., Carmichael, T.J., Mandrak, N.E., and Heuring, L.G. 2007. Distributions of freshwater and anadromous fishes from the mainland Northwest Territories, Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. **2793**: xiv + 239 p.

Selong, J.H., McMahon, T.E., Zale, A.V., and Barrows, F.T. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Trans. Am. Fish. Soc. **130**: 1026-1037.

Sexauer, H.M. 1994. Life history aspects of bull trout, *Salvelinus confluentus*, in the eastern Cascades, Washington. M.Sc. Thesis, Central Washington University, Ellensburg, WA. ix + 85 p.

Sexauer, H.M., and James, P.W. 1997. Microhabitat use by juvenile bull trout in four streams located in the eastern Cascades, Washington, p. 361-370. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Shepard, B. 1985. Habitat variables related to bull trout spawning site selection and thermal preference exhibited in a thermal gradient, p. 18. In D.D. Macdonald (ed.) Proceedings of the Flathead River Basin bull trout biology and population dynamics modelling information exchange. Fisheries Branch, B.C. Ministry of the Environment, Cranbrook, BC.

Shepard, B.B., and Graham, P.J. 1982. Monitoring spawning bed material used by bull trout on the Glacier View District Flathead National Forest. Completion Report. Montana Department of Fish, Wildlife and Parks, Region 1, Kalispell, Montana. v + 37 p. + apps.

Shepard, B.B., and Graham, P.J. 1983a. Flathead River fisheries study. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Shepard, B.B., and Graham, P.J. 1983b. Fish resource monitoring program for the upper Flathead Basin. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana. 61 p.

Shepard, B.B., Leathe, S.A., Weaver, T.M., and Enk, M.D. 1984. Monitoring levels of fine sediment within tributaries to Flathead Lake, and impacts of fine sediment on bull trout recruitment, p. 146-156. In F. Richardson and R. H. Hamre (ed.) Wild Trout III: Proceedings of the Symposium, September 24-25, Yellowstone National Park.

Sigma Resource Consultants Ltd. 1976. Study of aquatic biology and water quality of Flat River, NWT. Prepared for Canada Tungsten Mining Corporation Ltd., variously paginated.

Spangler, R.E., and Scarnecchia, D.L. 2001. Summer and fall microhabitat utilization of juvenile bull trout and cutthroat trout in a wilderness stream, Idaho. Hydrobiologia **452**: 145-154.

Stein, J.N., Jessop, C.S., Porter, T.R., and Chang-Kue, K.T.J. 1973. Fish Resources of the Mackenzie River Valley, Interim Report II. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development Rep. **2**: xvii + 260 p.

Stelfox, J.D. 1997. Seasonal movements, growth, survival and population status of the adfluvial bull trout population in Lower Kananaskis Lake, Alberta, p. 309-316. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Stelfox, J.D., and Egan, K.L. 1995. Bull trout investigations in the Smith-Dorrien Creek/Lower Kananaskis Lake system. Report prepared by Fisheries Management Division, Alberta Environmental Protection, and by Golder Associates Limited, Calgary, AB. xi + 148 p.

Stewart, D.B., Mochnacz, N.J., Sawatzky, C.D., Carmichael, T.J., and Reist, J.D. 2007. Fish diets and food webs in the Northwest Territories: bull trout (*Salvelinus confluentus*). Can. Manuscr. Rep. Fish. Aquat. Sci. **2800**: vi + 18 p.

Swanberg, T.R. 1997a. Movements of and habitat use by fluvial bull trout in the Blackfoot River, Montana. Trans. Am. Fish. Soc. **126**: 735-746.

Swanberg, T.R. 1997b. Movements of bull trout (*Salvelinus confluentus*) in the Clark Fork River system after transport upstream of Milltown Dam. Northwest Sci. **71**: 313-317.

Thiesfeld, S.L., Stuart, A.M., Ratliff, D.E., and Lampman, B.D. 1996. Migration patterns of adult bull trout in the Metolius River and Lake Billy Chinook, Oregon. Oregon Department of Fish and Wildlife, Fish Division, Information Reports No. **96-1**: i + 18 p.

Thurow, R.F. 1997. Habitat utilization and diel behavior of juvenile bull trout (*Salvelinus confluentus*) at the onset of winter. Ecol. Freshw. Fish **6**: 1-7.

Underwood, K.D., Martin, S.W., Schuck, M.L., and Scholz, A.T. 1995. Investigations of bull trout (*Salvelinus confluentus*), steelhead trout (*Oncorhynchus mykiss*), and spring chinook salmon (*O. tshawytscha*) interactions in southeast Washington Streams, 1992 Final Report. Prepared by Department of Biology, Eastern Washington University and Washington Department of Wildlife for U.S. Department of Energy, Bonneville Power Administration, Portland, OR. viii + 173 p.

USFWS (U.S. Fish and Wildlife Service). 2000. Bull trout occurrence and habitat selection. A White Paper addressing bull trout distribution and habitat requirements as related to potentially occupied habitats. U.S. Fish and Wildlife Service, Western Washington Office. 3 p.

USFWS (U.S. Fish and Wildlife Service). 2001. US Fish and Wildlife Service bull trout workshop: Yakima Basin case history for bull trout (*Salvelinus confluentus*). USFWS, Columbia River Fisheries Program Office, Vancouver, Washington. 32 p.

Watson, G., and Hillman, T.W. 1997. Factors affecting the distribution and abundance of bull trout: an investigation at hierchical scales. N. Am. J. Fish. Manage. **17**: 237-252.

Weaver, T., and Fraley, J. 1991. Fisheries habitat and fish populations. Flathead Basin Forest Practices, Water Quality and Fisheries Cooperative Program. Flathead Basin Commission, Kalispell, Montana. viii + 47 p.

Weaver, T.M., and White, R.G. 1985. Coal Creek fisheries monitoring study number III. Quarterly progress report to the United States Department of Agriculture, Forest Service, Montana State Cooperative Fisheries Research Unit, Bozeman, Montana. 94 p.

Weber, L.A., Hickey, E., Hargis, M., and Costa, D. 2001. Heat shock protein induction temperature as a predictor of the thermal injury in bull trout, *Salvelinus confluentus*. Prepared by Biology Department and Center for Conservation Genetics, University of Nevada, Reno, for the National Council of the Paper Industry for Air and Stream Improvement. 25 MS p.

Wickstrom, R.D. 1977. Limnological survey of Nahanni National Park, 1975-1976 progress report. Unpublished report prepared for Parks Canada by the Canadian Wildlife Service, Winnipeg. MB. vii + 42 p.

Wickstrom, R.D. 1979. Limnological survey of Nahanni National Park, N.W.T., 1978 progress report. unpublished report prepared for Parks Canada by the Canadian Wildlife Service, Winnipeg. MB. viii + 23 p.

Wickstrom, R.D., and Lutz, A. 1981. Tungsten and copper analysis of fish and sediments from the lower Flat River, Nahanni National Park, N.W.T. Unpublished report prepared for Parks Canada by the Canadian Wildlife Service, Winnipeg. MB. vi + 34 p.

Wilhelm, F.M., Parker, B.R., Schindler, D.W., and Donald, D.B. 1999. Seasonal food habits of bull trout from a small alpine lake in the Canadian Rocky Mountains. Trans. Am. Fish. Soc. **128**: 1176-1192.

Wissmar, R.C., and Craig, S. 1997. Bull trout spawning activity, Gold Creek, Washington. Fisheries Research Institute University of Washington **FRI-UW-9701**: v + 15 p.

Zurstadt, C.F. 2000. Relationships between relative abundance of resident bull trout (*Salvelinus confluentus*) and habitat characteristics in central Idaho mountain streams. M.Sc. Thesis, Oregon State University. ix + 65 p.

8.0 ABBREVIATIONS

FL = fork length—distance from the tip of the fish's snout to the notch in its tail.

MDMT = Maximum daily maximum temperature is the warmest daily maximum temperature recorded during a given year or survey period.

MWMT = Maximum weekly maximum temperature is the mean of daily maximum temperatures measured over the warmest consecutive seven-day period (typically during a given year).

NTU = Nephelometric turbidity units or NTU are a measure of light scattered by suspended particles in water. High NTU measurements indicate low water clarity (i.e. high turbidity).

SL = standard length—distance from the tip of the snout to the base of the caudal fin rays.

TL = total length—distance from the tip of the fish's snout to the tip of its tail.

UUILT = ultimate upper incipient lethal temperature.

YOY = young-of-the-year.

9.0 GLOSSARY

Adfluvial fish populations move between lake and river or stream environments.

Alevins are newly hatched, incompletely developed fishes (usually salmonids) still in the nest or inactive on the bottom and living off stored yolk.

Allopatric species occur in geographical isolation from one another.

Anadromous fish populations move downstream into marine waters to feed, and return upstream into fresh water to spawn and/or overwinter.

Baseflow is stream flow derived from groundwater.

Fluvial fish populations remain in rivers and streams throughout their lives.

Fry are young fish, newly hatched, after yolk has been used up and active feeding has commenced.

Iteroparous fish spawn more than once in their lives.

Piscivores eat fish.

Profundal species occupy deep water habits near the lake bottom, below the effective depth of light penetration.

Larval fishes (plural larvae) are young fish, newly hatched, before the yolk has been used up (see also **Alevins**).

Redds are gravel nests constructed by salmonid fishes.

Sympatric species occur in the same or overlapping areas.

Temperature units are Centigrade degree days above 0°C.

Appendix 1. Life history and habitat parameters

The emphasis of this work is on observations from within the Mackenzie Valley region. Terms such as “dominant”, “preferred” and “optimum”, which have been used in other summaries (e.g., Ford *et al*. 1995; Roberge *et al*. 2002), are avoided unless they are supported by directed research studies. This is because sampling observations may not accurately reflect a species’ preferences unless the spatial and temporal biases related to sampling design and gear are carefully controlled. The following sections define what is meant by the various life history and habitat use parameters used in the text and tables and in the appendices that follow. Some parameters described here may not be used in this report because this description applies to all of the habitat use reports in the series.

TABLES 2 and 3

Habitat use and requirements

These tables summarize habitat associations during the life history stages of the species. Separate tables may be included for stream, river, and lake environments. Observations from areas within the Mackenzie River watershed are in bold type. The following parameters are included, with the units of measurement typically used:

- **Habitat type** – habitat type most commonly associated with observations of the life history stage (e.g., streams–pools, runs, riffles; lakes–littoral, pelagic, benthic);
- **Stream gradient** – percent (%) slope;
- **Depth range (m)** – range of depths from which the species has been reported;
- **Substrate** – substrate type(s) most commonly associated with observations of the species;
- **Cover** – cover type(s) most commonly associated with observations of the species:
- **Habit** – typical distribution within the habitat type (e.g., surface, midwater, benthic, above or below thermocline, inshore or offshore);
- **Velocity range** – water velocities (cm/s) wherein the species is most commonly observed;
- **Turbidity (NTU):**
    - **range** – turbidity range wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Oxygen (mg/L):**
    - **range** – dissolved oxygen levels wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Temperature (°C):**
    - **range** – water temperatures wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Prey:**
    - **Primary** – taxa or taxon typically comprising the majority (by weight/volume/food value) of the food found in the stomachs of fishes sampled, or that were seen to be eaten during *in situ* behavioural studies;
    - **Secondary** – taxa or taxon comprising the minority (by weight/volume/food value) of food found in the stomach of fish sampled, or that were seen to be eaten during *in situ* behavioural studies. [Note: Differences in prey selection (i.e. primary/secondary) may reflect changes in the seasonal availability rather than the relative importance of food items.];
- **Duration** – number of seasons, months, or years in which each specific life stage exists or occurs;
- **Size/Age range** – average and/or maximum size range (mm) of the life history stage; or maximum size range (mm); FL = fork length, SL = standard length, TL = total length. A fish is age 0 until December 31 of the year it was hatched unless otherwise indicated.

Reproduction

This table summarizes habitat and life history parameters related to the species' reproduction. Observations from areas outside the Mackenzie River watershed are italicized. The following parameters are included:

- **Reproductive strategy** – *oviparous* species produce eggs that hatch outside the body of the mother; *iteroparous* species produce their young in annual or seasonal batches (most fishes); *semeloparous* species (e.g., salmon) produce all of their offspring at one time and then usually die; *annual* spawners reproduce each year following maturity until they die or reach reproductive senescence; under marginal conditions a portion of the reproductive population may rest for a year or more between spawning events (*% resting*);
- **Age at maturity** – range of ages at which males (M) and females (F) become sexually mature, with any estimate of the most common age at maturity provided in brackets;
- **Fecundity** – range in the number of eggs produced by females;
- **Spawning habitat** – habitat types wherein spawning has been observed, ripe and running fish have been caught, ripe and spent fish have been caught together, or eggs or sac larvae have been found. The presence of mobile young-of-the-year was used to identify nursery areas, and sometimes "suspected" spawning areas;
- **Spawning habit** – some species *build a nest* by altering the bottom substrates to meet their requirements before spawning; others *use existing nests* constructed by other species; *broadcast spawners* spread their eggs over suitable areas of unaltered bottom substrates; some species *care for the eggs* or *care for the young*;
- **Spawning temperature** – temperature range at which spawning has been observed;
- **Spawning depth** – depth range at which spawning has been observed;
- **Spawning substrate** – substrate type(s) observed at spawning locations;
- **Spawning current velocity** – current velocity observed at spawning locations;
- **Maximum age** – life expectancy of the species;
- **Reproductive senescence** – age at which the species stops reproducing.

APPENDICES 2 and 3

The seasonal habitat requirements for each life history stage are presented below in separate appendices for stream and lake environments. Within these appendices, observations from the Mackenzie River watershed are in bold type.

Life history stage

Observations on habitat use are summarized by life history stage. Four stages are recognized:

- **Spawning/eggs** – includes habitats on the spawning grounds where adults spawn and eggs mature and hatch;
- **Young-of-the-year (YOY)** – larvae and fry less than age 1 (age 0 until December 31 of the year they are hatched);
- **Juveniles** – sexually immature fish older than age 1;
- **Adults** – include fish that have attained sexual maturity.

Seasons

Habitat use was divided into four seasons, which correspond to the environmental conditions rather than to the calendar seasons. Calendar months are also provided if possible, but the correspondence between environmental variables and calendar months varies from south to north and from year to year. In the north of the Mackenzie watershed (Inuvik; S. Stephenson, DFO, pers. comm.), the seasons used are:

- **Spring (Sp)** – the period of ice breakup and spring runoff, typically late April to mid June;
- **Summer (Su)** – the period of open water, typically mid-June to late September;

- **Fall (Fa)** – the period of ice formation, typically late September to late November;
- **Winte**r **(Wi)** – the period of ice cover, typically late November to late April.

In the south (Hay River; G. Low, DFO, pers. comm.) they are:

- **Spring (Sp)** – the period of ice breakup and spring runoff, mid-April to early June;
- **Summer (Su)** – the period of open water, typically early June to late-September;
- **Fall (Fa)** – the period of ice formation, typically late-September to mid-November;
- **Winte**r **(Wi)** – the period of ice cover, typically mid-November to mid-April.

These date ranges are averages, since the timing of breakup varies from river to river and lake to lake depending upon factors such as stream gradient, exposure to sunlight, and lake size.

Water depth

Five water depth categories area used for stream environments: 0–0.2, >0.2–0.6, >0.6–1, >1–2, and >2 m. Depth represents the distance from the surface of the water downwards. The depth association of a fish found in the upper metre of the water column, for example, would be reported as 0–0.2, >0.2–0.6 and >0.6–1.0. Depth is reported as stated in the reference, but if "shallow" water was the only descriptor, a depth of 0–20 cm was used to represent "shallow" water. A broader range of depths is used to describe lake environments: 0–1, >1–2, >2–5, >5–10, and >10 m.

Substrate type

Substrate type was reported as stated in the reference. However, if particle size was provided, substrate type was classified as follows:

- **bedrock** = uniform continuous substrate;
- **boulder** = >25 cm;
- **cobble** = 17–<25 cm;
- **rubble** = 6.4–<17 cm;
- **gravel** = 0.2–<6.4 cm;
- **sand** = <0.2 cm;
- **silt/clay** = finer than sand with fine organic content;
- **muck (detritus)** = mud with coarse organic content;
- **hard-pan clay** = clay; and
- **pelagic** = open water.

Cover type

Cover features that may provide protection, or a refuge, from predators, competitors, and adverse environmental conditions include:

- **None** – no cover;
- **Submergent vegetation** – aquatic plants that grow entirely below the surface and are attached to the bottom by roots or rhizomes;
- **Emergent vegetation** – aquatic plants with foliage that is partly or entirely borne above the water surface (e.g., cattail *Typha* spp.) or float on the surface of the water (e.g., milfoil);
- **Algae** – aquatic algae present on the bottom or within the water column;
- **Wood** – large (LWD) or smaller woody debris (SWD) on the bottom or within the water;
- ***In situ*** – submerged cavities and/or crevices, undercut banks;
- **Substrate** – interstitial spaces between any size of substrate (boulder-sand);
- **Overhead** – cover originating outside the riparian zone that overhangs the stream and/or banks, which includes overhanging banks or riparian vegetation, woody debris outside the channel, or anything above the surface that provides shade.

Habitat

In flowing water, habitat refers to the type of channel unit, and typical water velocity within the unit that the species inhabits, including:

- **Pool** – velocity range <0.25 $m \cdot s^{-1}$;
- **Run** – velocity range 0.25–0.50 $m \cdot s^{-1}$;
- **Riffle** – velocity range 0.50–1.00 $m \cdot s^{-1}$;
- **Rapid** – velocity range >1.00 $m \cdot s^{-1}$;
- **River margin** – habitat along the banks of the mainstem channel, often low velocity;
- **Off-channel** – any habitat that is outside the mainstem flow including side channels, backwaters, and off channel habitats, often low or no velocity.

Water velocity differences are not used to differentiate lake habitats; rather they are differentiated on the basis of their proximity to flowing water or shorelines, as follows:

- **Lake inlet** – near or within stream or river plumes entering the lake;
- **Lake outlet** – near or within the channel that drains the lake;
- **Inshore** – typically associated with littoral habitat along the edges, rather than the middle of the lake;
- **Offshore** – typically associated with the middle, rather than the edges of the lake. Where possible their typical position in the water column is described (e.g., surface, midwater, benthic, above or below thermocline).

Appendix 2. Stream habitat requirements for bull trout. Data from the Northwest Territories are in bold type.

Stream habitat features:	**LIFE STAGES** [Season of use (reference)]				**LEGEND/COMMENTS/REFERENCES**
	Spawn/egg	**YOY**	**Juvenile**	**Adult**	**Season of use:**
Depth (m)					Sp = spring
0-0.2	Fa, Wi (2a,b)	**Su** (**1**,6), Fa (6)	**Su** (**1**,6), Fa (6)	**Su (1)**	Su = summer
>0.2-0.6	Fa, Wi (2a,b)	**Su (1)**, Fa (6)	**Su** (**1**,6), Fa (6), Wi (5)	**Su (1)**, Wi (5)	Fa = fall
>0.6-1	Fa, Wi (2a,b)	**Su (1)**	**Su** (**1**,6), Fa (6), Wi (5)	**Su (1)**, Wi (5)	Wi = winter
>1-2			**Su (1)**, Fa (6), Wi (5)	**Su (1)**, Wi (5)	
>2				**Su (1)**	
Substrate					
Bedrock					
Boulder		Wi (5*)	**Su** (**1**,8)	**Su (3)**, Wi (5)	*In areas without surface flow, YOY may winter in the interstices of the substrate where there is sub-surface flow (5)
Cobble	Fa, Wi (2b)	**Su (1)**, Wi (5*)	**Su** (**1**,8)	**Su (3)**, Wi (5)	
Rubble	Fa, Wi (2b)		Su (8)	**Su (3)**	
Gravel	Fa, Wi (2a,b, 4, 5)		Su (8)	**Su (3)**	
Sand	Fa, Wi (2b)		Su (8)		
Silt/Clay	Fa, Wi (4)				Some spawning sites have appreciable amounts of silt (4)
Muck (Detritus)					
Hard-pan clay					
Pelagic					
Cover					Use of submerged cover decreases after formation of surface ice (7)
None					
Submergents					
Emergents					
Algae					
Wood			Su (8)		
In situ					
Substrate		**Su (1)**	**Su** (**1**,8)	**Su (1)**	Boulder, cobble
Undercut bank/overhang	Fa, Wi (4)			**Su (1)**	Shallow redds excavated within 2.5 m of the banks of the Wigwam R. (4)
Overhead					
Other				**Su (1)**	Depth, turbulence
Velocity/Habitat					
Pool	Fa, Wi (2b)	**Su (1)**	**Su** (**1**,8)	**Su (1)**	
Run	Fa, Wi (2a,b)	**Su (1)**	**Su** (**1**,8)	**Su (1)**	
Riffle	Fa, Wi (2b)		**Su** (**1**,8)	**Su (1)**	
Rapid					
River Margin					
Off-channel					

1 = Mochnacz *et al*. 2004 – Northwest Territories.

2 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, British Columbia, b) various systems throughout the range 49-56°N.
3 = Beak Consultants Inc. 1981 – Prairie Creek, Northwest Territories.
4 = Oliver 1985 – Wigwam River, British Columbia.
5 = Boag and Hvenegaard 1997 – West Castle River, a tributary of the Oldman River, Alberta.
6 = Spangler and Scarnecchia 2001 – South fork Clearwater River, Idaho.
7 = Jakober *et al*. 1998 – Bitterroot River drainage, Montana.
8 = Sexauer 1994, Sexauer and James 1997 – Yakima and Wenatchee river drainages, Washington.

Appendix 3. Lake habitat requirements for bull trout.

Lake habitat features:	LIFE STAGE [Season of use (reference number)]				LEGEND/COMMENTS/REFERENCES
	Spawn/egg	**YOY**	**Juvenile**	**Adult**	**LEGEND**
Depth (m)					**Season of use:**
0-1				All (1)	Sp = spring
>1-2				All (1)	Su = summer
>2-5				All (1)	Fa = fall
>5-10				All (1)	Wi = winter
>10				All (1)	All = year-round
Substrate					
Bedrock					
Boulder					
Cobble					
Rubble					
Gravel					
Sand					
Silt/Clay					
Muck (Detritus)					
Hard-pan clay					
Pelagic					
Cover					
None					
Submergents					
Emergents					
Algae					
Wood					
In situ					
Substrate					
Undercut bank/overhang					
Overhead					
Other					
Habitat					
Lake inlet					
Lake outlet					
Inshore (littoral)				All (1,2)	
Offshore-surface					
Offshore-midwater					
Offshore-benthic				All (1,2)	

1 = Connor *et al*. 1997 – Chester Morse Lake, Washington.

2 = Hanzel 1985 – Flathead Lake, Montana.

Fish life history and habitat use in the Northwest Territories: bull trout (*Salvelinus confluentus*)

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2007

FISH LIFE HISTORY AND HABITAT USE IN THE NORTHWEST TERRITORIES: BULL TROUT (*Salvelinus confluentus*)

by

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ABSTRACT

Stewart, D.B., Mochnacz, N.J., Sawatzky, C.D., Carmichael, T.J., and Reist, J.D. 2007. Fish life history and habitat use in the Northwest Territories: bull trout (*Salvelinus confluentus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2801: vi + 46 p.

Bull trout occur in the Mackenzie River Valley south of Great Bear Lake, and possibly also in some rivers north of this area. The species requires cold, clean water and populations can be resident or migratory. The latter can follow fluvial, adfluvial or anadromous life histories. Differences in habitat use by these populations and in the seasonal requirements of eggs, fry, juveniles, and adults are summarized. Spawning occurs in shallow, fast-flowing tributary streams with stable channels and gravel to boulder substrates, often in areas fed by groundwater that maintains suitable incubation and rearing conditions through the winter. To support the assessment, avoidance and mitigation of environmental impacts in the Mackenzie Valley, the potential impacts of development activities and climate change on survival of the species are reviewed. The species' narrow habitat requirements for spawning and rearing make populations vulnerable to extirpation by habitat fragmentation and disruption. As slow-maturing but voracious predators, bull trout are also vulnerable to overharvesting and other stressors that target the older segment of the population. They do not compete well with other trout species at temperatures above 12°C, and are vulnerable to the introduction of other trout species.

Key words: distribution; life history; habitat requirements; seasonal movements; reproduction; spawning; rearing; life cycle; Mackenzie watershed; hydrological integrity; fresh water; Salmonidae.

RÉSUMÉ

Stewart, D.B., Mochnacz, N.J., Sawatzky, C.D., Carmichael, T.J., and Reist, J.D. 2007. Fish life history and habitat use in the Northwest Territories: bull trout (*Salvelinus confluentus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 2801: vi + 46 p.

L'omble à tête plate se trouve dans les eaux de la vallée du Mackenzie au sud du Grand lac de l'Ours et habite probablement certaines rivières au nord de cette région. L'espèce requiert des eaux froides et propres. Les populations peuvent être sédentaires ou migratrices. Les populations migratrices peuvent être de nature fluviale, adfluviale ou anadrome. Nous résumons ici les différences dans l'utilisation des habitats par ces populations et les différences dans les besoins saisonniers des œufs, des alevins, des juvéniles et des adultes. La fraie se produit dans les tributaires peu profonds et à fort courant comportant des chenaux stables et des substrats graveleux à rocheux, souvent aux endroits alimentés par des eaux souterraines qui assurent des conditions favorables à l'incubation et à l'alevinage tout au long de l'hiver. Nous examinons les incidences éventuelles des activités humaines et du changement climatique sur la survie de l'espèce en appui de l'évaluation, de l'évitement ou de l'atténuation des incidences environnementales dans la vallée du Mackenzie. Les exigences strictes en matière d'habitat de fraie et d'alevinage rendent ces populations vulnérables à la disparition en raison de la fragmentation et de la perturbation des habitats. Bien qu'il vieillisse lentement et qu'il soit un prédateur vorace, l'omble à tête plate est également vulnérable à la surpêche et à d'autres agents stressants qui touchent la strate la plus âgée de la population. Il ne rivalise pas bien avec les autres espèces d'omble à des températures supérieures à 12°C et il est vulnérable à l'introduction d'autres espèces d'omble.

Mots clés : répartition; cycle vital; exigences en matière d'habitat; déplacements saisonniers; reproduction; fraie; alevinage; bassin versant du Mackenzie; intégrité hydrologique; eau douce; Salmonidés.

1.0 INTRODUCTION

Renewed interest in natural gas pipeline development along the Mackenzie Valley has raised the prospect that fish species in the watershed may be impacted by changes to their habitat. The proposed pipeline would extend from near the Beaufort Sea coast to markets in the south (http://www.mackenziegasproject.com/). Fishes in the Mackenzie River depend upon the integrity of their aquatic habitats, so it is important to summarize knowledge that can be used to assess potential impacts of this development proposal and others, and to facilitate efforts to avoid and mitigate these impacts.

This report reviews knowledge of the bull trout, *Salvelinus confluentus* (Suckley, 1859), an attractive but sensitive sportfish. It includes information on the species' distribution, habitat use during the various stages of its life history, and about threats posed to the species and its habitat by development activities. Knowledge gaps are also identified. This information was compiled to assist developers, habitat managers, and researchers. Similar reports have been prepared for other fishes that inhabit the Mackenzie River watershed.

The distribution and life history of bull trout in the Northwest Territories (NT) are poorly known, so the discussion that follows is based largely on populations from other regions.

1.1 Taxonomic units

Prior to 1991, bull trout in the Mackenzie Valley were identified as Dolly Varden (*Salvelinus malma*). This has led to confusion of the species' life histories, and the need to reassess literature from studies conducted in the 1970s and 1980s (e.g., Stein *et al*. 1973; McCart *et al*. 1974; Porter *et al*. 1974; Sigma Resource Consultants Ltd. 1976; Wickstrom 1977, 1979; Chang-Kue and Cameron 1980; Wickstrom and Lutz 1981; McCart 1982). Fish from the Great Bear River and further upstream in the Mackenzie River watershed that were originally identified as Arctic charr (*S. alpinus*) or Dolly Varden are now believed to be bull trout (Reist *et al*. 2002).

Genetic variability within bull trout populations is low, but genetic differences among populations are often marked (McPhail and Baxter 1996). This, along with striking inter-population differences in nuptial colouration and sexual dimorphism, suggest the existence of distinct stocks. However, separate taxonomic units have not been identified. Phylogenetic work suggests that periodic contraction and local extinction followed by expansion and colonization from local refugia have been important across the species' range (Haas and McPhail 2001).

1.2 Distribution

Bull trout are endemic to western North America (Haas and McPhail 1991). Their current distribution extends from the southern Yukon and southwestern Northwest Territories south to northern California and Nevada, and from the Pacific coast east to western Alberta (AB) (Haas and McPhail 2001; Mochnacz 2002). The range of bull trout has declined in recent years due to population extinctions, particularly in the southern portion of their range (Goetz 1989; Brown 1992; McPhail and Baxter 1996; Baxter *et al*. 1999). Even in pristine habitats, bull trout have a patchy distribution (Rieman and McIntyre 1993). Within the Mackenzie River system, the bull trout has been found in the Hyland Highland, Sibbeston Lake Plain, Nahanni Plateau, Hay River Lowland, Peel River Plateau, Franklin Mountains, Mackenzie River Plain, and Norman Range ecoregions, where it is widely but sparsely distributed (Figure 1) (Marshall and Schut 1999; Sawatzky *et al*. 2007)

Bull trout often occur with mountain whitefish (*Prosopium williamsoni*) and upstream of barriers, an indication of early colonization (Meehan and Bjornn 1991). Like cutthroat trout (*Oncorhynchus clarki*), they tend to occur in stream reaches at higher elevations than brook trout (*S. fontinalis*) or rainbow trout (*O. mykiss*) (Paul and Post 2001). Ripley *et al*. (2005) found that the vast majority of bull trout in the Kakwa River basin of Alberta were present in third- and fourth-order streams located at elevations of 950 to 1,600 m above sea level. These reaches may provide refugia, wherein bull trout can prevent colonization by introduced species and are isolated from harvesting pressures (Paul and Post 2001). In Washington and Oregon the species' distribution follows a pattern of decreasing elevation with increasing latitude and longitude (Goetz 1994).

Bull trout distributions can be difficult to delineate, as the species is often found in low conductivity water in areas with cover and current. Electrofishing during the day may tend to underestimate juvenile bull trout populations, which may be more efficiently sampled or observed by divers at night, using nets or flashlights respectively (Bonneau 1994; Bonneau *et al*. 1995; Goetz 1994, 1997a). Snorkelling surveys in streams tend to generate higher bull trout counts at night than during the day, and these counts can be biased toward fish longer than 100 mm (Zurstadt 2000).

2.0 LIFE HISTORY TYPES

Bull trout exhibit both non-migratory and migratory life history types in response to the local environmental conditions (Table 1; Goetz 1989; Brenkman *et al*. 2001; Bahr and Shrimpton 2004; Mogen and Kaeding 2005). The non-migratory populations are stream residents that inhabit spawning tributaries year-round. The migratory populations

also spawn and rear in tributary streams but, as older fish, winter in larger rivers (**fluvial**[1]) or in lakes (**adfluvial**), and sometimes feed at sea (**anadromous**). Most migrations take place from June through October, when fish move to and from the spawning tributaries.

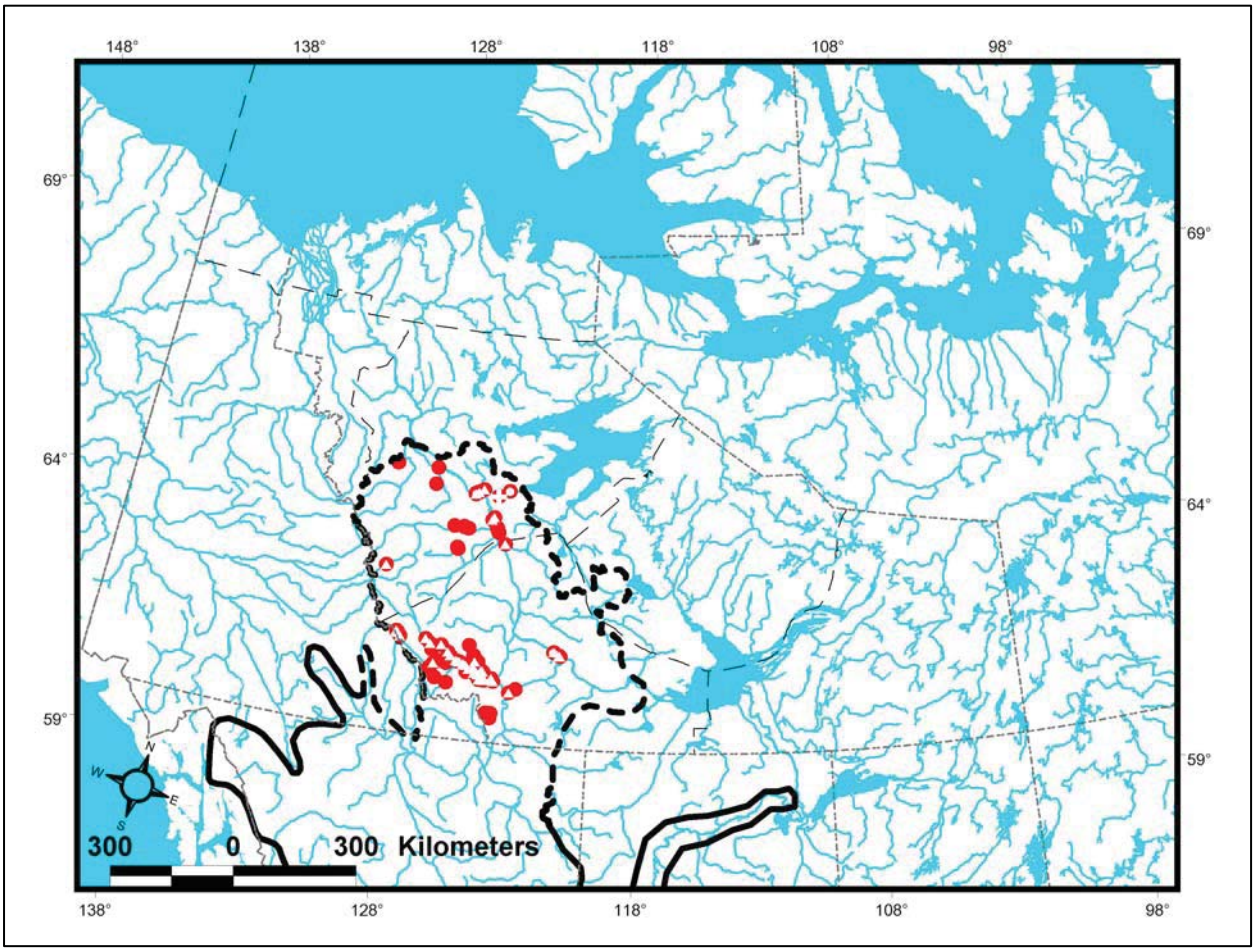


Figure 1. Bull trout distribution in the Northwest Territories (from Sawatzky *et al*. 2007). Solid red dots indicate recent specimens with confirmed identity; dots with symbols are older records that are now considered to be bull trout but cannot be verified. Those containing a white triangle were initially identified as Dolly Varden, a white "+" as Arctic charr, and a white dot as *Salvelinus* species complex.

Stream resident, fluvial, and adfluvial populations of bull trout have been reported from the Northwest Territories, but the life histories of these populations are not well known (Mochnacz 2002). Fish from stream resident populations are typically shorter and smaller bodied than those from fluvial and adfluvial populations (Rieman and McIntyre 1993; McPhail and Baxter 1996), and may mature earlier and at a smaller size than migratory forms (Cannings and Ptolemy 1998; Mochnacz 2002). Stream resident adults range from 150 to 300 mm in length, while migratory fish commonly exceed 600 mm

[1] Terms in bold type are defined in the Glossary.

Table 1. Habitat use by bull trout populations with different life history types.

HABITAT	POPULATION			
	STREAM-RESIDENT	FLUVIAL	ADFLUVIAL	ANADROMOUS
Small high-gradient tributary streams	• Year-round use by all life history stages for all activities.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.	• Spawning and rearing habitat. • Feeding habitat for all life stages. • Overwintering habitat for eggs, larvae, fry, and juveniles. • Migratory corridors for juveniles and adults.
Rivers		• Migration corridors and feeding and overwintering habitat for juveniles and adults.	• Migration corridors and feeding habitat for juveniles and adults. • Overwintering habitat for some juveniles.	• Migration corridors and feeding and overwintering habitat for juveniles and adults.
Lakes		• Migration corridors for some adults.	• Feeding and overwintering habitat for juveniles and adults.	• Migration corridors and feeding and overwintering habitat for juveniles and adults.
Brackish or marine coastal waters				• Migration corridors and feeding habitat for juveniles and adults.

(Rieman and McIntyre 1993). Adfluvial bull trout can grow to at least 1,025 mm and 14.5 kg (Goetz 1989).

Life history and habitat parameters are defined in Appendix 1. Stream and lake habitat requirements are summarized in Appendices 2 and 3, respectively.

2.1 Stream Resident

In the Northwest Territories, fish caught in summer at the Kotaneelee River system, Funeral Creek, the South Nahanni River (Mochnacz 2002), Little Smith Creek, a tributary of the Blackwater River (McCart *et al*. 1974), and Prairie Creek (Beak Consultants Ltd. 1981) may be stream resident (Figure 1).

Stream resident fish remain in the spawning tributary streams year-round, and often spawn and overwinter within a 2 km reach of river (Jakober *et al*. 1998; Chandler *et al*. 2001). In the West Castle River of southwestern Alberta, juvenile and adult bull trout overwinter in small, shallow (maximum depth 0.4 to 1.5 m) pools that are isolated from one another, have little cover, and receive flow from groundwater springs (Boag and Hvenegaard 1997). In the Bitterroot River drainage of Montana fish will move 1 to 2 km downstream in early October from spawning sites to overwintering sites; some move over 1 km further downstream later in the winter at temperatures of 1°C or lower (Jakober 1995; Jakober *et al*. 1998). The first movements coincide with decreasing water temperature, and may reflect a change in concealment behaviour; the second, about 6 weeks later, coincides with formation of anchor ice and exclusion of fish from habitat with preferred cover. Beaver ponds provide important overwintering habitat for some stream resident bull trout.

Reaches influenced by groundwater provide resident bull trout with cold-water refugia in summer, and warm-water refugia in winter (Baxter and Hauer 2000). These areas have relatively stable thermal regimes, with less winter ice cover and no anchor ice formation. Groundwater upwellings also prevent frazil ice formation (Bonneau and Scarnecchia 1998). While **redds** are associated with areas of groundwater upwelling, within these areas they can also be associated with localized downwelling (Baxter and Hauer 2000). Stream resident fish remain active on or above the substrate throughout the winter at night, even during extreme temperatures and ice conditions (Jakober 1995; Jakober *et al*. 2000). During the day, small (<200 mm) fish stay concealed in the interstices of large substrates and in accumulations of large woody debris.

2.2 Fluvial

Fluvial bull trout populations inhabit the Keele, Flat and South Nahanni rivers of the Northwest Territories (Figure 1; Mochnacz 2002). Like the stream resident populations,

the fluvial populations spawn in high-gradient smaller rivers and tributary streams (Bahr and Shrimpton 2004). These streams also provide rearing habitat for periods of months or years. Older juveniles eventually move downstream into larger rivers where they feed, mature and overwinter. Adults remain in these rivers unless they are returning to the tributaries to spawn, or to escape overly warm water. Spawning in the mainstems of these larger rivers has not been documented.

Unlike stream-resident populations, adult bull trout from fluvial populations undertake extensive seasonal movements, typically upstream into tributary streams in May-August, and downstream to overwintering areas by late September or early October (Pattenden *et al*. 1991; McLeod and Clayton 1993, 1997; Fernet and O'Neil 1997; Swanberg 1997a; Burrows *et al*. 2001; Hemmingsen *et al*. 2001; Bahr and Shrimpton 2004; Pillipow and Williamson 2004). Upstream pre-spawning migrations are typically slower than the downstream post-spawning movements, when fish can move 30 km in a 6 to 7 h period (Pillipow and Williamson 2004). Downstream movements to spawning tributaries have been observed in the McLeod River of Alberta (Carson 2001). Migrations of up to 500 km demonstrate the large spatial scale and diversity of habitats required to sustain fluvial bull trout populations (Swanberg 1997a), and the importance of high-quality stream spawning habitat (Pillipow and Williamson 2004) and of stream connectivity (USFWS 2000; Muhlfeld and Marotz 2005).

Migration timing varies among systems. Fish that undertake longer migrations and gain more elevation, that enter systems where there is a greater seasonal decline in flow following the spring freshet (Thiesfeld *et al*. 1996), or that find themselves in unfavourable temperature conditions (Swanberg 1997a) may migrate earlier in the season. The temperature at which peak migrations are observed varies among rivers. McPhail and Murray (1979) found migrations to peak at 10 to 12°C. Fish migrating at the lower temperatures are typically preparing to spawn shortly.

In contrast, the annual migrations in the Blackfoot River of Montana are cued by an increase in the maximum daily water temperature and a decrease in discharge from peak runoff (Swanberg 1997a). In this southern system, the mean temperature at which fish began their migrations was 17.7°C. Larger fish began moving upstream at cooler temperatures and earlier in the season than smaller fish. The migrations were nocturnal and generally rapid (4.4 $\pm$ 2.2 km/d; see also McPhail and Murray 1979). Spawners ascended tributaries in late June to early July, 67 $\pm$ 10 d before spawning (Swanberg 1997a). Non-spawning fish entered the lower portions of these tributaries after the spawning fish, and remained there 28 $\pm$ 18 d before returning downriver in late August. The primary purpose of these migrations by non-spawners may be to avoid unfavourable temperature conditions, since prey densities were lower in the tributaries than in the Blackfoot River. Some bull trout, probably immature, did not migrate but they

did use confluences with cold tributaries when temperature conditions became unfavourable.

Exclusive of spawning, adult bull trout in some fluvial populations appear to occupy small discrete home ranges with great fidelity (Carson 2001; Hvenegaard and Thera 2001). In some systems the fish show strong fidelity to the same spawning tributaries and overwintering areas (Bahr and Shrimpton 2004), but in others they shift spawning sites over time (McPhail and Murray 1979; Pratt 1992). In the Blackfoot River of Montana, most (86%) migrants returned downriver to within 20 km of sites occupied in the spring, and winter movements were very local, never exceeding 300 m (Swanberg 1997a). Likewise, only localized movements were detected among fish overwintering under the ice in the mainstem of the Athabasca River in Alberta (McLeod and Clayton 1997).

Bull trout in the Morice River system of British Columbia (BC) appear to use Morice Lake primarily as a corridor for moving between river systems; larger fish sometimes spend part of the winter in the lake but would still be classified as fluvial (Bahr and Shrimpton 2004).

2.3 Adfluvial

Drum Lake, Northwest Territories, supports an adfluvial bull trout population (Figure 1; Mochnacz 2002). Adfluvial bull trout follow a similar life-history pattern to that of the fluvial populations, spawning in high gradient small rivers and tributary streams (Fraley and Shepard 1989; Ratliff *et al*. 1996; Olmsted *et al*. 2001). Lake spawning has not been documented. Juveniles begin rearing in the spawning streams and eventually move downstream into large rivers or lakes to feed, mature, and overwinter. Larger adults are more likely to feed and winter in lakes (Connor *et al*. 1997). They remain in the lakes unless they are returning to the tributaries to spawn, or to escape overly warm water.

In Chester Morse Lake, Washington, adult bull trout were found in every habitat zone (Connor *et al*. 1997). They occurred in the highest densities in the deepest areas of the lake (**profundal**, 42 m), but were also locally abundant along the shore of the lake (littoral). Relatively few fish were observed in the pelagic regions of the lake. Peak activity was observed during the night and few fish were active during daylight or full moon, when they rested on the bottom.

The availability of suitable stream spawning habitat affects the distance and duration of spawning migrations by adfluvial populations. Some fish from Flathead Lake, Montana, for example, migrate 250 km upstream in the Flathead River to spawn in headwater streams (Fraley and Shepard 1989). They move upstream from May through July and spawn from late August through early October before returning downstream to

overwinter. In contrast, fish in high, isolated, oligotrophic lakes, such as Pinto and Harrison lakes in Alberta, spawn a short distance upstream in the lake inlet, or downstream in the outlet (Herman 1997; Wilhelm *et al*. 1999). The spawning migrations of populations in these two lakes last only a few weeks and, because stream rearing habitat is close and limited, juveniles tend to enter the lakes at a younger age than those with access to more suitable river habitat (Hanzel 1985; Ratliff *et al*. 1996; Wilhelm *et al*. 1999; Brenkman *et al*. 2001).

2.4 Anadromous

In general, bull trout do not appear to undertake extensive ocean migrations, although some regularly enter the sea and even move between drainages (Haas and McPhail 1991, 2001). Anadromous bull trout have not been reported from the Northwest Territories. However, they have been reported from the Hoh River (Brenkman *et al*. 2007) and Puget Sound (Mongillo 1993) areas of Washington State and the lower reaches of the Fraser and Skeena rivers in British Columbia, and may be present in other coastal rivers such as the Nass (Haas and McPhail 1991, 2001). Fish from the Hoh River migrated to sea for the first time at age 3 to 6, and the smallest juvenile migrant observed was 243 mm TL (Brenkman *et al*. 2007). Adults moved at least 47 km along the coast from their river of origin (Brenkman and Corbett 2005).

3.0 LIFE HISTORY STAGES AND HABITAT USE

Bull trout have very specific habitat requirements, that are often summed by the “Four C’s” -- cold, clean, complex, and connected (USFWS 2000). Habitat selection by different age classes appears to be heavily influenced by intraspecific competition and avoidance of predation by younger animals (Goetz 1997b). Stream habitat use by bull trout has been studied in detail, but the specifics of habitat use and requirements in rivers, lakes, and coastal waters are poorly known. Key transitions in the bull trout life history are illustrated schematically in Figure 2 and discussed below.

These fish require a narrow range of cold temperature conditions to reproduce and survive (Table 2). In general, they are observed more frequently and appear more likely to occur at summer means of about 6 to 9°C, or with summer maxima less than about 13 to 14°C (Rieman and Chandler 1999; Gamett 2002). The upper optimal temperature threshold for bull trout has been estimated at a maximum daily maximum temperature (MDMT) of 12°C, which translates to a maximum weekly maximum temperature (MWMT) of 11°C (McCullough and Spalding 2002). Temperatures greater than 16°C are generally unsuitable for long-term survival of bull trout (McMahon *et al*. 2001).

Bull trout do, however, exhibit a high degree of behavioural thermoregulation and are able to forage for periods of time in areas where temperatures are higher than their preferred (USFWS 2000). While age 0, juvenile, and adult bull trout in Idaho streams will enter water that exceeds 20.0°C for several hours on hot, summer days, the average daily temperatures recorded at their distribution limits were between 2.0 and 12.0°C (Adams 1994). As water temperatures exceed a single daily maximum of 20°C, it becomes increasingly unlikely that juvenile bull trout will be found using a given habitat (Dunham and Chandler 2001).

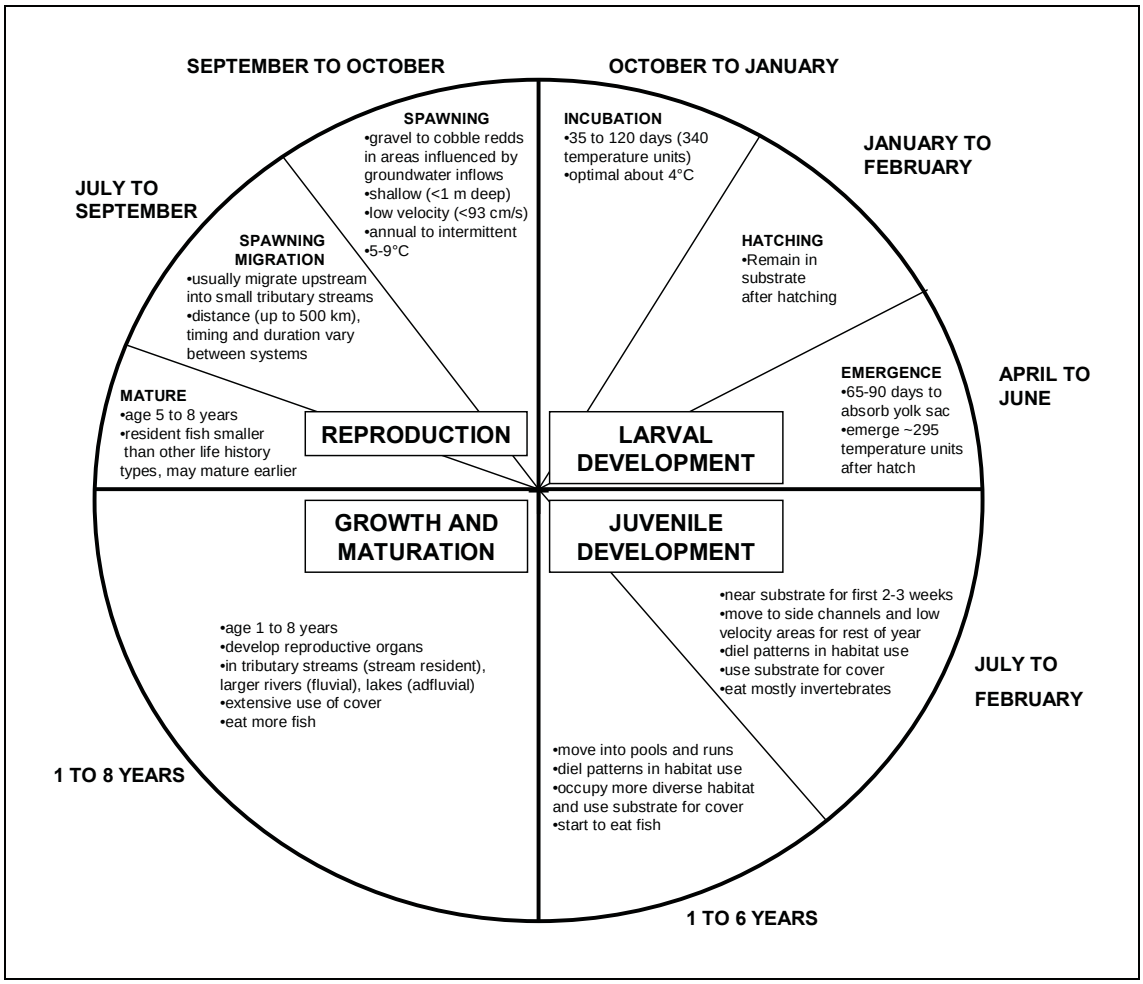


Figure 2. Generic life cycle of bull trout (modified from Mochnacz 2001).

General characteristics of stream habitats where bull trout have been captured in the summer in the Northwest Territories include: average water velocities in the range of 18 to 68 cm/s (range 0.0 – 172 cm/s), depths of 19 to 149 cm (range 3 – 282 cm), average temperature 3.6 to 12.7°C, average wetted width 1.70 to 16.4 m, with cobble as the dominant substrate and boulders as the dominant cover (Table 2) (Mochnacz *et al*. 2004).

Table 2. Observed stream habitat use by bull trout (data from Northwest Territories populations in bold type; numbers in brackets refer to sources cited below). Abbreviations are defined in Section 8.0 and habitat parameters are defined in Appendix 1.

HABITAT FEATURES		LIFE STAGE			
		Spawn/egg	**Young-of-the-year (YOY)**	**Juvenile**	**Adult**
Habitat type		Interstices of bottom substrate in small tributary streams. Redds often associated with groundwater discharges (4, 6,10, 16, 19)	Shallow shoreline pools and riffles in side channels of high gradient streams; interstices of bottom substrate; diel changes in microhabitat preferences (5b); will winter in the interstitial, sub-surface flow under a dry channel bed (8)	**High gradient habitats at or near the bottom, often in** shallow pools and riffles; interstices of bottom substrate; **pocket pools created by large cobble and boulders (1a,b);** sometimes winter in isolated pools maintained by groundwater inflows (7)	**High-gradient mountain streams (1c)**; pools, riffles, runs; sometimes winter in isolated pools maintained by groundwater inflows (7)
Stream gradient		High (4), Low, Meandering (12)	**High (1a)**	**High (1a,b)**	**High (1c)** 1.0 - 15.6% (21)
Depth range (m)		0.454 ± 0.022 (4a) 0.07 - 0.93 (4b)	**0.222 - 0.468 means (1a)** **0.07 - 0.90 overall range (1a)**	**0.222 - 0.468 means (1a,b)** **0.07 - 1.30 overall range (1a,b)**	**0.191 - 1.49 means (1c)** **0.03 - 2.82 overall range (1c)**
Substrate		Gravel (4a), sand to cobble (4b), sometimes with an appreciable amount of silt (8)	**Cobble (1a)** and boulder (5a)	**Cobble and boulder (1a,b)**	**Gravel, rubble, cobble (23) and boulder (1c)**
Cover		Overhead cover is not a prerequisite for spawning (7), will construct redds within 2.5 m of the banks (8)	**Boulder (1a)**	**Boulder (1a,b)**	**Undercut banks, deep pools, boulders (1c)**
Velocity range (cm/s)		58 ± 2 (4a) 2 - 93 (4b)	**22 - 30 means (1a)** **10 - 133 overall range (1a)** Microhabitat values may be lower	**22 - 55 means (1a,b)** **0 - 146 overall range (1a,b)** Microhabitat values may be lower, 0 - 10 (11,13)	**18 - 68 means (1c)** **0 - 172 overall range (1c)**
Turbidity (NTU)	Range	0.1 - 1.0 (14)			
	Limits				
Oxygen (mg/L)	Range	Intergravel: 8 - 12, mean 9 (16) Instream: 10 - 11.5, mean 10 (16)			**11 (23)**
	Limits				
Temperature (°C)	Range	Spawning: 5 - 9 (9,24) Incubation: 1.2 - 5.4 (9,18)	**Summer: 4.1 - 4.6 (1a)** Rearing: 2 - 12 (20)	**Summer: 4.1 - 12.7 (1a,b)**	**Summer: 1.5 (23), 3.6 - 7.9 (1c)**
	Limits		UUILT 20.9 (60 d) (3) UUILT 23.5 (7 d) (3)	UUILT slightly lower than for young-of-the-year (3)	MDMT 12°C (2), MWMT 11°C (2)

Prey items	Primary		Aquatic insects (17)	**Aquatic and terrestrial insects /larvae (1a)**	**Fish (Arctic grayling, bull trout, longnose sucker, slimy sculpin) (1c)**
	Secondary			**Fish (1a)**	**Aquatic and terrestrial insects /larvae (1c)**
Period		Spawning: 1 August - 31 September (15, 24) Incubation: 113 d (340 temperature units) (9) Fry emergence: 223 d (635 temperature units) (9)		**Female: 6 - 7 y (age range 1 - 8) (1c)** **Male: 6 - 8 y (age range 1 - 7) (1c)**	**Female: 8 - 9 y (age range 7 - 16) (1c)** **Male: 8 - 10 y (age range 9 - 18) (1c)**
Size/age range (Note: fish are considered to be age 0 until December 31 of the year they are hatched)		Egg diameter: 5.0 - 6.2 mm (15,18), 3.9 - 4.8 mm (16) Redds: 1m long by 0.5 m wide (16, 18)		**Female: 35-289 mm, 1 - 235 g, age 1 - 8 (1c)** **Male: 75-323 mm, 1.8 - 387 g, age 1 - 7 (1c)**	**Female: Maximum: 661 mm, 3379 g, age 16 (1c)** **Male: Maximum: 642 mm, 3144 g, age 18 (1c)** Stream resident: 140 - 410 mm FL; Fluvial: 410 - 730 mm FL; Adfluvial: 508 - 824 mm FL (22).

1 = Mochnacz *et al*. 2004 – a) Funeral Creek, NT - 61°36'N 124°44'W; b) unnamed creek, Keele River - 64°14'N, 125°59'W; c) NT.
2 = McCullough and Spalding 2002 – laboratory study.
3 = Selong *et al*. 2001 – laboratory study.
4 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, BC, b) various systems throughout the range from 49-56°N.
5 = Baxter and McPhail 1997 – a) Chowade River, Peace R. drainage, BC, b) laboratory study.
6 = Boag and Hvenegaard 1997 – West Castle River, AB.
7 = Shepard 1985 – Flathead River, Montana.
8 = Oliver 1985 – Wigwam River, BC.
9 = Fraley and Shepard 1989 – Flathead River, Montana.
10 = Baxter and Hauer 2000 – Swan River, Montana.
11 = Earle and McKenzie 2001 – Beaverdam Creek, Alberta.
12 = Pillipow and Williamson 2004 – Goat River, Fraser River drainage, BC.
13 = Sexauer and James 1997 – Yakima and Wenatchee river drainages, Washington.
14 = Craig 1997 – Yakima River basin, Washington.
15 = Goetz 1989 – review.
16 = Fairless *et al*. 1994 – Clearwater River, AB.
17 = Shepard *et al*. 1984 – Flathead River, Montana.
18 = McPhail and Murray 1979 – Mackenzie Creek, BC.
19 = Cope *et al*. 2002 – Wigwam River, BC.
20 = Adams 1994 – Weiser River drainage, Idaho.
21 = Rich 1996 – streams in western Montana.
22 = Mochnacz 2002 – review.
23 = Beak Consultants Limited 1981 – Prairie Creek, NT.
24 = Herman 1997 – Pinto Lake, AB.

3.1 Eggs (Spawning and incubation habitat)

Bull trout spawn more than once, but not necessarily every year following maturity **(iteroparous**) (Fraley and Shepard 1989; Cannings and Ptolemy 1998; Bahr and Shrimpton 2004) (Table 3). Alternate year spawning is common and probably an adaptation to marginal productivity throughout the year (Clayton 2001; Hvenegaard and Thera 2001; Mochnacz 2002). Resting females and males have been found in the Northwest Territories from all life history types, and spawning there may occur at 2 to 3 year intervals (Mochnacz 2002). If a smaller proportion of the mature population spawns each year, northern populations may be slower to recover from adverse impacts.

Temperatures ≤ 9°C may trigger spawning (McPhail and Murray 1979; Weaver and White 1985; Fraley and Shepard 1989; Ratliff *et al*. 1996), while those ≤ 5°C cause it to be suspended (Allan 1987 cited in McPhail and Baxter 1996). Spawning activity in the Pine Creek watershed of Oregon was initiated in mid-September at mean daily stream temperatures between 9.3 and 11.5°C, which declined rapidly to between 4.9 and 6.9°C near the completion of spawning activity in early October (Chandler *et al*. 2001). Kitano *et al*. (1994) observed spawning in the upper Flathead River of Montana in mid-September at water temperatures of 5.3 to 8.9°C. Bull trout in the Chowade River of northeastern British Columbia (Baxter and McPhail 1999) and Castle River system in Alberta (Fernet and O'Neil 1997) also spawn in mid-September through early October.

The female chooses the spawning site and constructs the redd, while the male defends the area and remains nearby for an average of two weeks after spawning (Fraley and Shepard 1989). In some systems, higher densities of redds have been observed in areas with > 54% overhead cover (Craig 1997). Fertilized eggs are fanned by the female and then covered with gravel (James and Sexauer (1997). The demersal, non-adhesive eggs incubate under the gravel throughout the winter and the **fry** emerge in early to late spring (Baxter and McPhail 1999). Detailed descriptions of spawning behaviour and spawning site activities are provided by James and Sexauer (1997), Kitano *et al*. (1994), and McPhail and Murray (1979).

The fecundity of bull trout populations varies widely, with larger fish having greater fecundity. In the Flathead River system of Montana, fecundity averaged 5,482 eggs per female for a sample of 32 adults averaging 645 mm TL (Fraley and Shepard 1989), while bull trout in the Arrow Lakes of British Columbia were smaller and contained fewer than 2000 eggs (McPhail and Murray 1979). A 6.7 kg female in the Flathead River system contained 12,000 eggs (Fraley and Shepard 1989); while fish in Sun Creek, Oregon, can mature at 152 mm and carry as few as 74 eggs (Goetz 1994). Eggs typically range in diameter from 5.0 to 6.2 mm (Goetz 1989), but eggs ranging from 3.9 to 4.8 mm have been found in redds in the upper Clearwater River of Alberta (Fairless *et*

al. 1994). The bottom area disturbed by redd construction varies from 0.50 to 3.72 m² (Goetz 1989).

Table 3. Habitat and life history parameters related to bull trout reproduction, with data from the NT in bold type. Numbers in brackets refer to data sources listed below.

PARAMETER	STREAM (data source)
Reproductive strategy:	Iteroparous
Age at maturity:	Female: **age 7 - 8 (1c ,** 8**),** 6 - 7 (9) Male: **age 8 - 9 (1c),** 7 - 8 (9)
Fecundity (eggs/female):	Mean 5482 (mean TL 645 mm) (5); Range <2000 (6) to 12000 (5)
Spawning:	May not occur annually following maturity (5; 10)
Habitat type	Redds often associated with groundwater upwellings (2a, 3); Stream gradient 1.5% (5)
Builds nest	Yes. Gravel redd (2a)
Temperature (°C)	5 - 9°C (5a, 6, 8)
Depth (m)	0.454 $\pm$ 0.022 (4a) 0.07 - 0.93 (4b)
Substrate	Gravel (2a), sand to cobble (2b, 5), sometimes with an appreciable amount of silt – 22 - 30% (3, 7)
Current velocity (cm/s)	2 - 93 (2b)
Maximum age: (Note: fish are considered to be age 0 until December 31 of the year they are hatched)	Female: **age 16** (1b) Male: **age 18** (1b)
Age at senescence:	Unknown.

1 = Mochnacz *et al*. 2004 – a) Funeral Creek, NT, b) Drum Lake outlet, NU, c) NT.
2 = Baxter and McPhail 1999 – a) Chowade River, Peace River drainage, BC; b) systems through range from 49-56°N.
3 = Oliver 1985 – Wigwam River, BC.
4 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, BC; b) various systems throughout the range from 49-56°N.
5 = Fraley and Shepard 1989 – Flathead River, Montana.
6 = McPhail and Murray 1979 – Mackenzie Creek, BC.
7 = Ratliff *et al*. 1996 – Metolius River basin, Oregon.
8 = Herman 1997 – Pinto Lake, AB.
9 = Mushens and Post 2000 – Kananaskis Lake, AB.
10 = Bustard and Schell 2002 – Morice River, BC.

Water velocities at redd sites range from 2 to 92 cm/s, and depths from 0.07 to 0.93 m (Fernet and Bjornson 1997; James and Sexauer 1997; Baxter and McPhail 1999). In the Cedar River watershed of Washington State, the majority of bull trout redds were found in water depths ranging from 12 to 49 cm (mean 25 cm) and water velocities (mean column) ranging from 12 to 61 cm/s (mean 38 cm/s) (Reiser *et al*. 1997). Redd surveys were conducted during the day, but no spawning activity was observed, suggesting that spawning may take place primarily at night.

Water in the interstitial spaces of the gravel (8-12 mg/L) and above the redds (10-11.5 mg/L) is well oxygenated (Weaver and White 1985; Fairless *et al*. 1994).

Intergravel flow may be an important factor in spawning area selection by bull trout (Weaver and White 1985). In Washington's Yakima River basin, conductivity ranged from 193 to 222 mV, pH 7.5 to 7.8, and turbidity 0.1 to 1.0 NTU in most watersheds that contained redds (Craig 1997). An exception was the South Fork Tieton River, which receives turbid glacial runoff (3.3 NTU) during the summer, when eggs and larvae are not affected by siltation.

Bull trout redds in the shallow, high-gradient Chowade River of British Columbia were often associated with groundwater discharges that provided warmer, more stable temperatures for incubating eggs -- particularly during the coldest part of the winter (Baxter and McPhail 1999). These warmer temperatures provided a stable rearing environment and protection from freezing, and they reduced incubation time leading to an earlier date of emergence than for eggs reared at a lower temperature. The survival rate from eggs to **alevins** was significantly higher (88.6 vs. 76.1%) and less variable in areas selected by female bull trout, than in non-selected areas. There was no difference in alevin survival rates at different depths (10, 20, 30 cm).

The association of redds with groundwater discharge suggests that optimal habitats for bull trout reproduction may be limited, and that site selection by females may increase reproductive success (Baxter and McPhail 1999). The close association with groundwater inflows is a common feature of bull trout spawning habitat (Shephard 1985; Fraley and Shepard 1989; Fairless *et al*. 1994; Ratliff *et al*. 1996; Thiesfeld *et al*. 1996; Boag and Hvenegaard 1997; Craig 1997, 2001; James and Sexauer 1997; Bonneau and Scarnecchia 1998; Baxter and Hauer 2000; Gamett 2002). In the Swan River of Montana, zones of upwellings occurred consistently in bounded alluvial valley segments (Baxter and Hauer 2000). Spawning there was associated with low gradient reaches that had upwellings and stable, well sorted gravel and cobble. Floodplains in these segments allow overbank flow, which moderates sediment scour associated with flooding. In southwestern Alberta bull trout spawning is typically associated with bedrock that may intercept subsurface flow and direct it toward the surface (D. Evans, DFO Calgary, pers. comm.). These areas also provide suitable pool cover habitat and appropriately sorted substrates.

Bull trout eggs from an interior population showed an increase in survival as the temperature decreased from 10°C and a slight decrease in survival if the temperature dropped below 4°C (McPhail and Murray 1979). Lower temperatures slowed embryonic development, but led to the production of larger fry. Incubation time is temperature dependant (Weaver and White 1985), and can take from 35 to 120 days (McPhail and Murray 1979). In Coal Creek, a tributary of the Flathead River, Montana, bull trout eggs required 113 days (340 **temperature units**) to 50 percent hatch; the fry emerged from the gravel 233 days (635 temperature units) after egg deposition. Intergravel

temperatures during the incubation period (October-March) ranged from 1.2 to 5.4°C, and survival to emergence averaged 53 percent.

Chronic exposure to oxygen concentrations ranging from 3 to 13.5 mg/L did not cause significant mortality or increase physical deformities in developing bull trout eggs, but low oxygen levels did retard embryonic development (Giles and Van der Zweep 1996).

Bull trout in the Flathead River, Montana, rework the substrate but do not alter its composition when constructing redds (Shephard and Graham 1982). The average percentages of fine substrates (sand, clay/silt; <2 mm sieved) ranged from 8 to 20%; gravel (2 to <6.5 mm) ranged from 16 to 19%; and larger substrates (e.g., rubble and cobble, ≥6.5 mm) ranged from 62 to 76%. Higher levels of fine substrates may impact egg survival. Redds in Smith-Dorrien Creek, Alberta, were composed largely of gravel to cobble sized substrate (Fernet and Bjornson 1997).

Hatching success is inversely related to the percent of fine material (<6.35 mm) in gravels (Weaver and White 1985; Weaver and Fraley 1991). In experimental studies, survival to emergence ranged from 49 to 69% in substrates that contained 10% fines to 0 to 4% in substrates that contained 50% fines. Kitano *et al*. (1994) observed that redds on the upper Flathead River of Montana were constructed at the downstream ends of pools, where fine gravels were prevalent. Levels of fine sediment in spawning areas of Oregon's Metolius River tributaries, which have high densities of juvenile bull trout, ranged from 22 to 30% (Ratliff *et al*. 1996). Entombment by sediment and crushing by gravel movement may be significant sources of egg mortality (Weaver and White 1985).

3.2 Alevins and fry (Rearing habitat)

Yolk absorption after hatching takes 65 to 90 days (Shepard *et al*. 1984), and fry do not attain neutral buoyancy for another three weeks (McPhail and Murray 1979). Negative buoyancy makes feeding after emergence awkward, but enables them to maintain their position in the stream. After emergence in late spring, young-of-the-year are typically found in shallow, low velocity areas near the edges of small tributary streams with an abundance of cover (McPhail and Murray 1979; Fraley and Shepard 1989; Baxter 1997a,b; Cope *et al*. 2002), although some out migration to lakes occurs shortly after fry emergence in some systems (Reiser *et al*. 1997). In the Northwest Territories, young-of-the-year are about 35 to 38 mm fork length and weigh less than 1 g in mid-September (Mochnacz *et al*. 2004).

Fry show diel movement patterns, with peak numbers out of cover from late morning to early evening, and all individuals under cover about two hours before dusk (Goetz 1997a). In the upper Chowade River of British Columbia, during summer days,

fry (33-62 mm FL; 3.94-14.04 g) used slightly shallower, slower areas of side channels than juveniles (71-112 mm FL; 0.2.8-2.3 g) (Baxter 1997b). They used depths between 2 and 50 cm, but preferred depths between 10 and 30 cm. They used focal points with bottom velocities between 0 and 25 cm/s, but strongly preferred areas with bottom velocities between 5 and 18 cm/s. Fry used primarily instream overhead cover in the form of boulder, cobble and small wood. However, when habitat availability is considered, fry preferred cover in the form of small rootwads, followed by boulder, small wood, and cobble. They were found primarily over substrates consisting of silt, pebble, and cobble, but preferred areas with boulder and cobble substrate.

In Idaho streams, during summer nights, age 0 bull trout (<75 mm TL) were found primarily (88%) in the channel margins of runs and riffles, while the older juveniles (≥ age 1; 75-270 mm TL) were found primarily (92%) in the main channels, where they selected deeper, slower pool areas (Saffel and Scarnecchia 1995). The density of juvenile bull trout in reaches increased with the number of pocket pools. Reaches with high densities (3.9 to 11.2 fish/100 m^2) of bull trout had maximum summer temperatures ranging from 7.8 to 13.9°C. During summer nights, fry (<66 mm TL) in the South Fork Clearwater River basin of Idaho were associated with shallow stream margins over coarse substrates (Spangler and Scarnecchia 2001). They moved to significantly deeper (mean 0.19 m), lower velocity water and closer to cover in the fall, but maintained their association with coarse substrates.

Young-of-the-year bull trout in the West Castle River drainage of Alberta overwinter in interstitial, sub-surface flow under a dry channel bed, within and upstream of the spawning area (Boag and Hvenegaard 1997).

3.3 Juveniles (Rearing habitat)

Juvenile bull trout rear in second and third order streams, and move to rivers primarily during ages 3 to 4 (14-36 cm TL) (Fraley and Shepard 1989), although in Alberta they may remain in rearing areas for up to 6 years (Allan 1980). Sexual maturation typically occurs during ages 5 to 7 at total lengths of 30 to 50 cm (Fraley and Shepard 1989; Pratt 1992). Juveniles become less associated with the streambed as they grow larger than 100 mm TL, but remain near cover (Fraley and Shepard 1989).

During summer days, juveniles (71-112 mm FL; 0.2.8-2.3 g) in the upper Chowade River of British Columbia used slightly deeper, faster areas of side channels than the fry (33-62 mm FL; 3.94-14.04 g) (Baxter 1997b). Both groups used depths between 2 and 50 cm, but the larger fish preferred slightly deeper areas (30-40 cm), used a slightly broader range of bottom velocities (0 to 40 cm/s), and preferred slightly faster water (28 cm/s). During summer nights, juvenile bull trout (66-130 mm TL) in the South Fork Clearwater River basin of Idaho occupied significantly deeper water on average (0.30 m)

than the fry (0.05 m) (Spangler and Scarnecchia 2001). In the fall, like the fry, they too moved to deeper, lower velocity water and closer to cover.

In both summer and winter juvenile bull trout (70-170 mm TL) in Idaho's Trestle Creek selected pools over riffles and used a wide range of depths at night but were absent from shallow water (<15 cm) during the day (Bonneau and Scarnecchia 1998). They occupied higher velocity water on average during summer days (21 cm/s) than nights (7 cm/s) and during summer days than winter days (0 cm/s -- assuming water velocities were at or near zero below the substrate). During summer days they were, on average, 7 cm above the substrate, while on winter days they were found within or resting upon the cobble substrate. They were more closely associated with cover during the day, and made greatest use of cover during winter days (Bonneau and Scarnecchia 1998). However, even at night juveniles usually stay within 72 cm of cover (Sexauer 1994; Sexauer and James 1997).

Cover use appears to be dictated by latitude and elevation, since the diversity of cover types (e.g., woody debris) tends to decrease with increasing latitude and/or elevation (Mochnacz *et al*. 2004). In summer, in Funeral Creek, Northwest Territories (61°36'N, 124°48'W), juvenile bull trout were found most frequently in high velocity habitats, at or near the bottom, in pocket pools created by large cobble and boulders (Mochnacz *et al*. 2004). Unembedded cobbles and boulders are particularly important cover for juvenile bull trout, followed by overhanging vegetation (Sexauer 1994; Baxter 1997b; Sexauer and James 1997; Bonneau and Scarnecchia 1998; Earle and McKenzie 2001). However, where rootwads are available they may be preferred over other forms of cover (Baxter 1997b). The water velocity in microhabitats selected by juvenile bull trout is significantly lower than that across stream transects, indicating that the fish are selecting low velocity habitats (Sexauer 1994; Sexauer and James 1997; Earle and McKenzie 2001).

Further south, in Oregon, juvenile rearing habitat is characterized by high levels of shade, undercut banks, the presence of large woody debris, gravel in riffles, low levels of fine sediment in riffles, and little bank erosion (Dambacher and Jones 1997). The presence of pools was not an important descriptor of juvenile bull trout presence, since the typical rearing streams have gradients of 5.0%, and are dominated by riffles and rapids.

With the onset of winter, at water temperatures of 1.1 to 1.3°C, juvenile bull trout remain concealed beneath "home stones" during the day and emerge at night to feed and rest on the bottom, primarily in pool and run habitats (Thurow 1997; Jakober *et al*. 2000). Once ice cover forms, use of submerged cover declines (Jakober 1995; Jakober *et al*. 1998). They avoid areas where frazil or bottom ice forms and will move downstream or into adjacent riffles and runs in mid-winter to avoid these unfavourable

ice conditions (Jakober 1995; Jakober *et al*. 1998; D. Evans, DFO Calgary, pers. comm.).

In laboratory studies, juvenile age 1 bull trout (62.4 mm mean FL; 2.23 g mean round weight), showed diel microhabitat preferences (Baxter and McPhail 1997). Substrate preference during the day was primarily cobble and boulder, and at night primarily silts and gravel. Significantly shallower water and lower water velocity were associated with the habitats preferred during the day, than those at night. A similar pattern has been observed in the wild (Goetz 1997a).

The preference of juvenile bull trout for coarser substrate than is used by spawning adults (Goetz 1994), means that it is important to ensure that adequate amounts of large substrates are maintained in bull trout streams to provide rearing habitat (Baxter and McPhail 1997). The high fidelity of juvenile bull trout to cover during the day makes it difficult to accurately assess their populations and habitat use using daytime observations (Jakober *et al*. 2000).

Given a natural thermal gradient (8-15°C) juvenile bull trout chose the coldest water available (Bonneau and Scarnecchia 1996). In the Flathead River system they were seldom observed in streams with summer water temperatures over 15°C (Fraley and Shepard 1989). They were present in many reaches that were not used by adults, and apparently swam upstream to these sections to grow.

Age 0 bull trout began to show evidence of heat shock response at 14°C (Weber *et al*. 2001). In laboratory studies, food consumption by age 0 bull trout declined significantly at temperatures over 16°C, and fish held at temperatures ≥22°C did not feed (Selong *et al*. 2001). Age 0 and 1 bull trout did survive temperatures up to 20°C for up to 60 d, but survival decreased rapidly with exposure to even small increases in temperature above this level. None of the fish held at 22°C survived a 60 day trial. In Idaho streams, bull trout have been observed in temperatures of 20.5°C (Adams and Bjornn 1997).

Radiotelemetry studies found that some subadult bull trout (247-399 mm TL) in Montana's upper Flathead River are migratory, while others are not (32 cf. 35 fish; Muhlfield and Marotz 2005). Most migrating subadults made rapid or incremental downstream movements (mean distance 33 km; range 6-129 km) within the river system or to Flathead Lake during high spring flows and as temperatures declined in the fall and winter. During the day, subadults used complex habitats throughout the upper river system, including deep runs that contained unembedded boulder and cobble substrates, pools with large woody debris, and deep lake-influenced areas of the lower river system.

Juvenile bull trout are benthic foragers that roam slack water areas and pick prey items off the bottom during both day and night (Nakano *et al*. 1992; Bonneau and Scarnecchia 1998; Stewart *et al*. 2007). They use different foraging strategies and occupy different microhabitats than sympatric cutthroat trout (Nakano *et al*. 1992). In summer, juvenile bull trout in the Mackenzie River watershed eat aquatic and terrestrial insects (e.g., grasshopper) and insect larvae (Mochnacz *et al*. 2004). In August, baetid mayflies are an important dietary item for juvenile bull trout in the upper Flathead River of Montana (Nakano *et al*. 1992).

3.4 Adults

In summer, adult bull trout in the Mackenzie River drainage are typically captured in deep pools of small, high gradient mountain streams with cobble to boulder-type substrates (Mochnacz *et al*. 2004). During the day they are often associated with some type of large cover, such as undercut banks, deep pools, or boulders.

The maximum size of adult bull trout, and their weight at length relationship, varies among systems (Pillipow and Williamson 2004). Precocious males, aged 3 and averaging 215 mm in length, have been observed actively spawning with larger females (500 to 600 mm) (Shepard and Graham 1983a cited in Goetz 1989). Small “sneaker” males (mean 412 mm TL) have also been observed avoiding larger dominant males (mean 735 mm TL) to spawn with larger females (mean 651 mm TL) (Baxter 1997a), as have small resident males with fluvial females (Brown 1994).

Within its range the occurrence of bull trout is strongly correlated with maximum daily water temperatures <14 to 16°C (Dunham *et al*. 2003). Temperature may affect the ability of bull trout to compete with other species. In sympatry, bull trout were numerically dominant to rainbow trout at temperatures <13°C and vice versa (Haas 2001). In warmer water, bull trout are in **allopatry**, rather than **sympatry**, with westslope cutthroat trout, suggesting that the distribution of bull trout with respect to temperature may be partially dependant on the presence or absence of cutthroat trout (Pratt 1984). Shephard *et al*. (1984) suggested that increasing temperatures might shift species distribution in the Flathead River, Montana to favour cutthroat trout over bull trout.

Brook trout seem to be segregated from bull trout by temperature (Parkinson and Haas 1996). In the North Thompson River of British Columbia, bull trout are absent from warmer streams and brook trout from colder streams, with an overlap in temperature range of <2°C. In the laboratory, bull trout growth was 25% higher in allopatry than when they were held in sympatry with brook trout, while the presence of bull trout had a significant positive effect on brook trout, especially at temperatures >12°C (McMahon *et al*. 1999). In the laboratory, brook trout had a 2.5-times greater growth rate advantage over bull trout when together at 17°C (McMahon *et al*. 2001). Bull

trout may inhabit warmer waters in the absence of other *Salvelinus* species (Adams 1994).

Adult bull trout eat a wide variety of invertebrates and fishes (Boag 1987; Connor *et al*. 1997; Wilhelm *et al*. 1999; Mochnacz *et al*. 2004; Stewart *et al*. 2007). In the Mackenzie River watershed they eat aquatic and terrestrial insects (e.g., grasshoppers, ants, wasps) and insect larvae; fish (e.g., slimy sculpin *Cottus cognatus*, longnose sucker *Catostomus catostomus*, Arctic grayling *Thymallus arcticus*, and bull trout); and small worms (Mochnacz *et al*. 2004). In the upper reaches of the Muskeg River system of Alberta they eat primarily insects, while in the lower reaches they also feed on rainbow trout (Boag 1987). After ice-out in July, both small ($\leq$250 mm FL) and large ($\geq$250 mm FL) bull trout in a small alpine lake fed on seasonally abundant prey species, in particular chironomid pupae, *Daphnia pulex* var. and the amphipod *Gammarus lacustris*, which are cropped after they reproduce (Wilhelm *et al*. 1999). Mink (*Mustela vison*), bears (*Ursus* spp.), osprey (*Pandion haliaetus*), and river otter (*Lontra canadensis*) prey on adult bull trout (Stelfox 1997; Jakober *et al*. 1998; Chandler *et al*. 2001).

4.0 HABITAT IMPACTS ON FISH BIOLOGY

Bull trout populations in tributary streams of the Mackenzie River drainage appear to be small, but are wide ranging and use a variety of habitat types over a large geographical area (Mochnacz *et al*. 2004). Many of these streams likely provide critical spawning and rearing habitat for bull trout and other species, so care must be taken to ensure that industrial development does not disrupt these habitats, especially at times critical to the species' life history. Understanding of local bull trout ecology and microhabitat use is necessary to prevent or mitigate adverse effects from development (Earle and McKenzie 2001).

Habitat degradation and fragmentation are leading causes of the decline and extirpation of migratory bull trout populations throughout their range (Fraley and Shephard 1989; Goetz 1994; Rieman and McIntyre 1995; Rieman *et al*. 1997; Baxter *et al*. 1999; Ripley *et al*. 2005) (Table 4). Harvesting pressure and species introductions are also important factors affecting the survival of bull trout populations. The bull trout's specific requirements for spawning and rearing habitat, and the general sensitivity of each life stage, make it an excellent indicator of environmental disturbance (Fraley and Shepard 1989; Mochnacz 2002). Shepard and Graham (1983b) provide a detailed description of the program and techniques used to monitor bull trout populations in the Upper Flathead River of Montana.

Table 4. Some activities with the potential to affect key aspects of bull trout habitat and their potential effects on the species.

Activity	Potential impact		
	Habitat	Species	Directly affected life stage(s)
• water removal • drainage alterations • seismic testing	• reduced groundwater flow • altered baseflow and ice and temperature regimes	• degradation, reduction or loss of spawning habitat • increased winter mortality of eggs, larvae, fry, juveniles, and resident adults	• all
• construction of roadways, pads, and structures • stream crossings	• streambed alteration by removal or disturbance of sand, gravel, and cobble substrates • sediment mobilization • streambed destabilization • bank alteration	• egg, **larval**, fry and juvenile mortality from physical damage, exposure, loss of cover, sediment mobilization • degradation, reduction or loss of spawning habitat	• all
• logging • clearing for right-of-ways, camps, etc. • stream crossings	• inland clearing • loss of riparian and instream cover (i.e. shoreline, large woody debris) • altered hydrological regime with more abrupt runoff • warming, increased sediment inputs	• degradation of spawning and rearing habitat • higher mortality rates for all life stages	• all
• culvert installation for stream crossings • dam construction • in-stream construction	• flow impoundment • changes in seasonal flow regimes, water depth, water velocity • habitat fragmentation • alteration of bedload movement and bottom substrate composition	• interruption of spawning migrations • restricted access to coldwater summer refugia in headwater tributaries • inundation or dewatering of spawning areas • population extirpation • creation of new overwintering areas • alteration of bottom substrate suitability for spawning, rearing, and invertebrate production	• all life stages with greatest effects on adult spawners
• road and right-of way construction • population growth	• improved access to bull trout habitat	• increasing harvest pressure on adults and possibly large immature fish • visual and physical disturbance of fish and fish eggs • increased potential for species introductions • population reduction or extirpation	• adults and large juveniles by harvesting • all life stages by introductions
• contaminants releases	• chemical pollution	• reduction in fish quality • increased mortality	• all
• climate change	• changes in the temperature and hydrological regimes • warming	• decrease in suitable habitat at lower elevations and latitudes • increase in suitable habitat at higher elevations and latitudes • increasing competition and predation by warmer water species • changes in the frequency of extreme weather events that lead to flooding or drying and alter recruitment	• all

4.1 Habitat degradation

The reliance of bull trout on groundwater inflows to provide suitable stream spawning habitats and maintain shallow isolated pools for overwintering, makes them very vulnerable to activities that disturb or reduce these inflows (Boag and Hvenegaard 1997; Craig 2001). High road densities may degrade bull trout habitat by reducing **baseflow** discharges (Craig 2001) and increasing sediment inputs (Rieman and McIntyre 1993; Ripley *et al*. 2005). Blasting and water withdrawals are examples of other activities that might affect inflows from these aquifers; global or local climate change might also alter baseflow. Logging may increase warm surface runoff, moderating the cooling influence of groundwater-dominated stream flow (Ripley *et al*. 2005). It may also result in nutrient pulses that alter food web structure.

Logging, right-of-way construction for roads, transmission lines and pipelines, often remove riparian vegetation, reducing instream woody debris that provides important bull trout habitat and increasing overland runoff and sedimentation (McPhail and Baxter 1996; Knotek *et al*. 1997; de Graff 1999; USFWS 2001; Post and Johnston 2002; Ripley *et al*. 2005). Mathematical projections suggest that forest harvesting over the next 20 years might result in the local extirpation of bull trout from 24 to 43% of stream reaches that currently support them in the Kakwa River basin of Alberta (Ripley *et al*. 2005). Attempts have been made to restore reaches of tributaries in the upper Flathead River basin that have been adversely affected by high sediment inputs (Knotek *et al*. 1997). Sediment can also be introduced by small-scale suction dredging for gold (USFWS 2001). Washington State has imposed timing restrictions on this form of mining to decrease its impact on bull trout eggs and fry.

Unrestricted grazing by livestock can harm bull trout by mobilizing sediment, damaging riparian vegetation and trampling redds, but is readily mitigated by fencing (USFWS 2001).

Land management activities that reduce pool habitat, instream cover, and streambed stability may be especially detrimental to juvenile bull trout in winter (Bonneau and Scarnecchia 1998). The presence of stable, unembedded cobbles is important to juvenile bull trout, particularly as overwintering habitat. Sediment inputs that embed these cobbles may limit the carrying capacity of stream habitats for juvenile salmonids. In contrast, destabilization of cobble habitats may also result in low survival rates of eggs and fry, washouts of fish from sections of streams (Pearsons *et al*. 1992), and direct crushing of fish (Erman *et al*. 1988).

In the Swan River of Montana, changes in bull trout redds were positively correlated with the extent of alluvial valley segments bounded by knickpoints (abrupt

changes in the longitudinal profile of the stream valley as a result of bedrock structure) and negatively correlated with the density of logging roads in spawning tributary catchments (Baxter *et al*. 1999). The alluvial valley segments may contain significant areas of groundwater discharge (Baxter and Hauer 2000), while the logging roads and logging may cause changes in the morphology and stream-channel features that provide habitat for aquatic biota and facilitate access by harvesters (Baxter *et al*. 1999). Logging the riparian zone of bull trout streams can alter the delivery, storage, and transport of large woody debris, and thereby alter natural stream morphology and habitat features (Cross and Everest 1995; Hauer *et al*. 1999). Upland logging can alter water flow regimes and sediment delivery, and may have cumulative effects on the balance of large woody debris in the streams. However, further work is needed to clarify the underlying mechanisms by which forest harvesting and road networks adversely affect the occurrence and abundance of bull trout (Ripley *et al*. 2005).

The relocation of spawners from areas affected by development does not appear to compensate for habitat losses. Development of a tailings dam for the Kerness Mine, in the Thutade watershed of northwestern British Columbia, removed 4.1 km of stream habitat used by bull trout in S. Kerness Creek (Paul and Bustard 2004). The total number of spawners in the creek decreased significantly following mine construction, as did the density of juveniles in the remaining 2 km section. While some spawners may have relocated to nearby tributaries the densities of age 0 and 1 bull trout in these tributaries did not increase. This suggests that relocation of spawners may not compensate for habitat losses, and that habitat quantity must be maintained. The effectiveness of mitigation measures to address the habitat losses, including removal of migration barriers and the construction of artificial spawning beds below the tailings dam, are being tested.

4.2 Habitat fragmentation

Complex river habitats with abundant cover, and natural connections of suitable spawning and rearing habitat, must be maintained over a large scale to conserve bull trout populations (Muhlfeld and Marotz 2005). Late-summer dewatering of stream habitats fragments populations, and can cause significant mortality among spawning bull trout in shallow tributaries (Wissmar and Craig 1997).

Barriers such as hydroelectric dams and beaver dams can fragment bull trout habitat and prevent fish from accessing optimal spawning habitat (Goetz 1994; Baxter and McPhail 1996; Fernet and O'Neil 1997; Swanberg 1997b; USFWS 2001; Post and Johnston 2002). Programs to transport adult bull trout upstream of hydroelectric dams can mitigate this damage, particularly in areas with small populations (Swanberg 1997b). BC Hydro has used discharge tunnels successfully to provide bull trout with upstream passage through the Duncan Dam (Olmsted *et al*. 2001). Entrainment of bull

trout in irrigation channels caused significant (15%) mortality among bull trout spawning in the Belly River of Alberta and Montana until screening was installed at the canal headgate (Clayton 2001). In Oregon, the construction of water storage structures led to the extirpation of eight populations above these dams within 15 years (Goetz 1994).

Improperly designed, installed, or maintained culverts and weirs can also create smaller, often seasonal, physical barriers to bull trout movements (Goetz 1994). In some instances, impoundments can provide overwintering habitat and, in the case of the Williston Reservoir on the Peace River, may have led to the development of an adfluvial population (Bruce and Starr 1985; McPhail and Baxter 1996).

4.3 Species introductions

The introduction of lake trout (*Salvelinus namaycush*), brook trout (*Salvelinus fontinalis*), or their hybrids (splake) can displace bull trout, and may prevent them from becoming established in certain low-elevation lakes (Donald and Alger 1993; Donald and Stelfox 1997). In Bow Lake, Alberta, for example, the introduction of lake trout in 1964 decimated the bull trout population by 1992. Competitive interactions with brook trout may be an important factor in the mechanism responsible for the regulation of bull trout densities in tributary streams, at least on a local scale (Nakano *et al*. 1998). Stocking bull trout streams with hatchery reared steelhead trout (*O. mykiss*) and chinook salmon (*O. tshawytscha*) may slow bull trout growth (Underwood *et al*. 1995). Removal or suppression of introduced species to promote bull trout recovery is difficult (Montana Bull Trout Scientific Group 1995).

Bull trout will hybridize with Dolly Varden (Haas and McPhail 1991; Baxter *et al*. 1997; Hagen and Taylor 2001) and brook trout (Markle 1992; Adams 1994; Kitano *et al*. 1994; Saffel and Scarnecchia 1995). However, hybrids do not appear to be common in the wild (Baxter *et al*. 1997; Leary and Allendorf 1997). Sympatric populations of Dolly Varden and bull trout maintain their genetic integrity in spite of gene flow (Baxter *et al*. 1997; Hagen and Taylor 2001).

4.4 Improved access

Bull trout are sensitive to exploitation because their populations are small and individuals are slow-growing, late to mature, and spawn in non-consecutive years (Carl *et al*. 1989; Clayton 2001; Bustard and Schell 2002; Post and Johnston 2002). They are voracious **piscivores** and highly susceptible to exploitation by angling before they reach maturity (Goetz 1989; Brown 1992; Stelfox and Egan 1995; McPhail and Baxter 1996; Mushens and Post 2000; Olmsted *et al*. 2001). Because of their migratory habit and range, bull trout populations can be very vulnerable to activities that interrupt migration routes, and to angling pressure along the migration route (McLeod and Clayton 1997;

Stelfox 1997; Pillipow and Williamson 2004). However, overharvested populations can recover quickly when sport angling is reduced or eliminated (Stelfox 1997). Adfluvial populations in lakes that do not have restricted access, and that have been stocked with other *Salvelinus* species are particularly vulnerable to extirpation (Donald and Stelfox 1997).

Unfortunately, opportunities for population enhancement are limited, and the major hope for restoring bull trout numbers lies with regulation (e.g., closures, gear restrictions, minimum size limits, harvest limits) (McPhail and Baxter 1996). In the Northwest Territories sport harvesters are allowed to catch 2 bull trout per day, and can only have 3 in their possession at any one time (G. Low, DFO Hay River, pers. comm. 2005).

4.5 Climate change

Elevated temperature is considered a major factor in the decline of southern bull trout populations (Rieman *et al*. 1997), some of which already migrate into headwater streams early in the season to avoid unfavourably warm temperatures (Swanberg 1997a). Climatic warming could change the availability of suitable thermal habitat to bull trout. In the south this might significantly restrict the species' range over its current distribution (Rieman and McIntyre 1993). In the north, it might facilitate northward colonization by bull trout and subsequent sympatry and hybridization with Dolly Varden (Reist 1994; Mochnacz 2002). In both areas, it could increase competition or predation by other species that colonize cold bull trout habitat as it warms. Whether bull trout distributions would expand to the north and to higher elevations in the event of significant warming is unknown.

Winter flooding caused by heavy precipitation or glacial floods can damage bull trout habitat and extirpate populations (Goetz 1994). Under normal circumstances populations should recover over time, but those that are already depleted or limited by migratory barriers or other factors may not recover.

5.0 SUMMARY

Bull trout require cold, clean water. They have complex life histories and, in some cases, very large home ranges. Their populations can be resident or migratory, and the latter can follow fluvial, adfluvial or anadromous life histories. Spawning occurs in shallow, fast-flowing tributary streams, often in areas fed by groundwater that maintains suitable incubation and rearing conditions through the winter. Spawning streams have stable channels with suitable substrate (gravel-boulder) for redd construction and rearing, and abundant cover. The migratory populations require uninterrupted migratory corridors that connect suitable spawning and overwintering habitats that may be

hundreds of kilometers apart. The species' relatively specific habitat requirements, particularly for spawning and rearing, make populations vulnerable to extirpation by habitat fragmentation and disruption. As slow-maturing but voracious predators bull trout are also vulnerable to overharvesting. They do not compete well with other trout species at temperatures above 12°C, and are vulnerable to the introduction of other trout species.

Based on the limited data available, habitats used by bull trout for spawning and rearing in the Northwest Territories appear to be similar to those used elsewhere. However, they may make less use of large woody debris for cover, as it is less abundant in the region.

Efforts to understand and conserve key processes likely to influence the persistence of populations may be more likely to conserve bull trout populations than efforts to design minimal habitat reserves (Rieman and Dunham 2000). Land management for bull trout protection should be site-specific (Watson and Hillman 1997), due to the species' patchy seasonal habitat use, extensive migratory movements, and narrow spawning and rearing requirements.

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7.0 REFERENCES

Adams, S.B. 1994. Bull trout distribution and habitat use in the Weiser River drainage, Idaho. M. Sc. Thesis, University of Idaho. x + 84 pp.

Adams, S.B., and Bjornn, T.C. 1997. Bull trout distributions related to temperature regimes in four central Idaho streams, p. 371-380. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Allan, J.H. 1980. Life history notes on the Dolly Varden char (*Salvelinus malma*) in the upper Clearwater River, Alberta. Alberta Energy and Natural Resources, Fish and Wildlife Division, Red Deer, AB. iv + 59 p.

Allan, J.H. 1987. Fisheries investigations in Line Creek - 1987. Prepared for Line Creek Resources Ltd., Sparwood, BC. 67 p.

Bahr, M.A., and Shrimpton, J.M. 2004. Spatial and quantitative patterns of movement in large bull trout (*Salvelinus confluentus*) from a watershed in north-western British Columbia, Canada, are due to habitat selection and not differences in life history. Ecol. Freshw. Fish **13**: 294-304.

Baxter, C.V., and Hauer, F.R. 2000. Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (*Salvelinus confluentus*). Can. J. Fish. Aquat. Sci. **57**: 1470-1481.

Baxter, C.V., Frissell, C.A., and Hauer, F.R. 1999. Geomorphology, logging roads, and the distribution of bull trout spawning in a forested river basin: implications for management and conservation. Trans. Am. Fish. Soc. **128**: 854-867.

Baxter, J.S. 1997a. Aspects of the reproductive ecology of bull trout (*Salvelinus confluentus*) in the Chowade River, British Columbia. M.Sc. Thesis, University of British Columbia, Vancouver, BC. xii + 97 p.

Baxter, J.S. 1997b. Summer daytime microhabitat use and preference of bull trout fry and juveniles in the Chowade River, British Columbia. University of British Columbia, Department of Zoology, Fisheries Management Report No. 107: ii + 36 p.

Baxter, J.S., and McPhail, J.D. 1996. Bull trout spawning and rearing habitat requirements: summary of the literature. University of British Columbia, Department of Zoology, Fisheries Technical Circular No. **98**: 1-27.

Baxter, J.S., and McPhail, J.D. 1997. Diel microhabitat preferences of juvenile bull trout in an artificial stream channel. N. Am. J. Fish. Manage. **17**: 975-980.

Baxter, J.S., and McPhail, J.D. 1999. The influence of redd site selection, groundwater upwelling, and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. Can. J. Zool. **77**: 1233-1239.

Baxter, J.S., Taylor, E.B.D.R.H., Hagen, J., and McPhail, J.D. 1997. Evidence for natural hybridization between Dolly Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*) in a northcentral British Columbia watershed. Can. J. Fish. Aquat. Sci. **54**: 421-429.

Beak Consultants Limited. 1981. Prairie Creek Project - fall fisheries study, 1981. Report prepared by Beak Consultants Limited, Vancouver, B.C. for Cadillac Explorations Ltd., Calgary, Alberta. iii + 10 p. + Tables, Figures, and Appendix.

Boag, T.D. 1987. Food habits of bull char, *Salvelinus confluentus*, and rainbow trout, *Salmo gairdneri*, coexisting in a foothills stream in northern Alberta. Can. Field-Nat. **101**: 56-62.

Boag, T.D., and Hvenegaard, P.J. 1997. Spawning movements and habitat selection of bull trout in a small Alberta foothills stream, p. 317-323. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.). Friends of the Bull Trout Conference Proceedings, Calgary, AB.

Bonneau, J.L. 1994. Seasonal habitat use and changes in distribution of juvenile bull trout and cutthroat trout in small, high gradient streams. M.Sc. Thesis, University of Idaho. ix + 92 p.

Bonneau, J.L., and Scarnecchia, D.L. 1996. Distribution of juvenile bull trout in a thermal gradient of a plunge pool in Granite Creek, Idaho. Trans. Am. Fish. Soc. **125**: 628-630.

Bonneau, J.L., and Scarnecchia, D.L. 1998. Seasonal and diel changes in habitat use by juvenile bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarki*) in a mountain stream. Can. J. Zool. **76**: 783-790.

Bonneau, J.L., Thurow, R.F., and Scarnecchia, D.L. 1995. Capture, marking, and enumeration of juvenile bull trout and cutthroat trout in small, low-conductivity streams. N. Am. J. Fish. Manage. **15**: 563-568.

Brenkman, S.J., and Corbett, S.C. 2005. Extent of anadromy in bull trout and implications for conservation of a threatened species. N. Am. J. Fish. Manage. **25**: 1073-1081.

Brenkman, S.J., Larson, G.L., and Gresswell, R.E. 2001. Spawning migration of lacustrine-adfluvial bull trout in a natural area. Trans. Am. Fish. Soc. **130**: 981-987.

Brenkman, S.J., Corbett, S.C., and Volk, E.C. 2007. Use of otolith chemistry and radiotelemetry to determine age-specific migratory patterns of anadromous bull trout in the Hoh River, Washington. Trans. Am. Fish. Soc. **136**: 1-11.

Brown, L.G. 1992. Draft management guide for the bull trout *Salvelinus confluentus* (Suckley) on the Wenatchee National Forest. Prepared for Wenatchee National Forest, Wenatchee, Washington. viii + 104 p.

Brown, L.G. 1994. On the zoogeography and life history of Washington's native char - Dolly Varden: *Salvelinus malma* (Walbaum), bull trout: *Salvelinus confluentus* (Suckley). Washington Department of Fish and Wildlife Report **94-04**: ii + 41 p.

Bruce, P.G., and Starr, P.J. 1985. Fisheries resources and fisheries potential of Williston Reservoir and its tributary streams. Vol. II, Fisheries resources and fisheries potential of the Williston Reservoir and its tributary streams - a preliminary overview. British Columbia Ministry of the Environment, Fish. Tech. Circ. No. **69**: v + 101 p. + appendices.

Burrows, J., Euchner, T., and Baccante, N. 2001. Bull trout movement patterns: Halfway River and Peace River progress, p. 153-157. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Bustard, D., and Schell, C. 2002. Conserving Morice Watershed fish populations and their habitat, Stage II Biophysical profile, Section 3.8 Bull Trout, p. 97-110. Prepared by David Bustard and Associates Ltd. for Community Futures Development Corporation of Nadina, Nadina, BC.

Cannings, S.G., and Ptolemy, J. 1998. Bull trout, p. 18-26. In S.G. Cannings and J. Ptolemy (ed.) Rare freshwater fish of British Columbia. BC Environment.

Carl, L.M., Kraft, M., and Rhude, L. 1989. Growth and taxonomy of bull charr, *Salvelinus confluentus*, in Pinto Lake, Alberta. Environ. Biol. Fishes **26**: 239-246.

Carson, R.J. 2001. Bull trout spawning movements and homing behaviour back to pre-spawning locations in the McLeod River, Alberta, p. 137-140. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Chandler, J.A., Fedora, M.A., and Walters, T.A. 2001. Pre- and post-spawn movements and spawning observations of resident bull trout in the Pine Creek watershed, eastern Oregon, p. 167-172. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Chang-Kue, K.T.J., and Cameron, R.T. 1980. A survey of the fish resources of the Great Bear River, Northwest Territories, 1974. Can. Fish. Mar. Serv. Manuscr. Rep. **1510**: vi + 59 p.

Clayton, T.B. 2001. Movements and status of bull trout (*Salvelinus confluentus*) in the Belly River, Alberta and Montana, p. 141-145. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Connor, E., Reiser, D., Binkley, K., Paige, D., and Lynch, K. 1997. Abundance and distribution of an unexploited bull trout population in the Cedar River watershed, Washington, p. 403-411. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Cope, R., Morris, M., and Bisset, J. 2002. Wigwam River juvenile bull trout and fish habitat monitoring program, annual report 2001. Bonneville Power Administration, Portland, Oregon. v + 119 p. [Project No. 2000-00400. BPA Report DOE/BP-00005672-1].

Craig, S.D. 1997. Habitat conditions affecting bull trout, *Salvelinus confluentus*, spawning areas within the Yakima River basin, Washington. M.Sc. Thesis, Central Washington University. x + 74 p.

Craig, S.D. 2001. Bull trout, baseflows and water temperatures: quantifying minimum surface water discharges in small groundwater influenced catchments, p. 129-135. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Cross, D., and Everest, L. 1995. Fish habitat attributes of reference and managed watersheds with special reference to the location of bull charr (*Salvelinus confluentus*) spawning sites in the upper Spokane River ecosystem, northern Idaho. USDA Forest Service, Fish Habitat Relationships Technical Bulletin **17**: ii + 6 p.

Dambacher, J.M., and Jones, K.K. 1997. Stream habitat of juvenile bull trout populations in Oregon and benchmarks for habitat quality, p. 353-360. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

de Graff, N. 1999. Compiled fisheries information for the La Biche River, Yukon. Unpublished report prepared by Can-nic-a-Nick Environmental for Canadian Wildilfe Service. 12 p.

Donald, D.B., and Alger, D.J. 1993. Geographic distribution, species displacement, and niche overlap for lake trout and bull trout in mountain lakes. Can. J. Zool. **71**: 238-247.

Donald, D.B., and Stelfox, J.D. 1997. Effects of fisheries enhancement and access on adfluvial bull trout populations in mountain lakes of southern Alberta, p. 227-234. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the Bull Trout Conference Proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Dunham, J.B., and Chandler, G.L. 2001. Models to predict suitable habitat for juvenile bull trout in Washington State. Final Report. U.S. Forest Service, Boise, Idaho. 75 p.

Dunham, J., Rieman, B., and Chandler, G. 2003. Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. N. Am. J. Fish. Manage. **23**: 894-904.

Earle, J.E., and McKenzie, J.S. 2001. Habitat use by juvenile bull trout in mountain streams in the Copton Creek drainage, Alberta and its relation to mining activity, p. 121-128. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Erman, D.C., Andrews, E.D., and Yoder-Williams, M. 1988. Effects of winter floods on fishes in the Sierra Nevada. Can.J. Fish. Aquat. Sci. **45**: 2195-2200.

Fairless, D.M., Herman, S.J., and Rhem, P.J. 1994. Characteristics of bull trout (*Salvelinus confluentus*) spawning sites in five tributaries of the upper Clearwater River, Alberta. Alberta Environmental Protection, Fish and Wildlife Services, Rocky Mountain House, AB. vii + 49 p.

Fernet, D.A., and Bjornson, C.P. 1997. A delphi analysis of bull trout habitat preference criteria with comparison to information collected from Smith-Dorrien Creek, Alberta, p. 435-442. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Fernet, D.A., and O'Neil, J. 1997. Use of radio telemetry to document seasonal movements and spawning locations for bull trout in relation to a newly created reservoir, p. 427-434. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Ford, B.S., Higgins, P.S., Lewis, A.F., Cooper, K.L., Watson, T.A., Gee, C.M., Ennis, G.L., and Sweeting, R.L. 1995. Literature reviews of the life history, habitat requirements and mitigation / compensation strategies for thirteen sport fish species in the Peace, Liard, and Columbia river drainages of British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. **2321**: xxiv + 342 p.

Fraley, J.J., and Shepard, B.B. 1989. Life history, ecology and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and River system, Montana. Northwest Sci. **63**: 133-143.

Gamett, B.L. 2002. The relationship between water temperature and bull trout distribution and abundance. M.Sc. Thesis, Utah State University, Logan, Utah. xi + 83 p.

Giles, M.A., and Van der Zweep, M. 1996. Dissolved oxygen requirements for fish of the Peace, Athabasca and Slave River basins: a laboratory study of bull trout (*Salvelinus confluentus*) and mountain whitefish (*Prosopium williamsoni*). Northern River Basins Study Project Report **120**: ix + 153 p.

Goetz, F. 1989. Biology of the bull trout *Salvelinus confluentus* a literature review. USDA Forest Service, Wilamette National Forest, Eugene, Oregon. iii + 53 p.

Goetz, F.A. 1994. Distribution and juvenile ecology of bull trout (*Salvelinus confluentus*) in the Cascade Mountains. M.Sc. Thesis, Oregon State University, Corvallis, Oregon. xv + 173 p.

Goetz, F.A. 1997a. Diel behavior of juvenile bull trout and its influence on selection of appropriate sampling techniques, p. 387-402. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Goetz, F.A. 1997b. Habitat use of juvenile bull trout in Cascade Mountain streams of Oregon and Washington, p. 339-351. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Haas, G. 2001. The mediated associations and preferences of native bull trout and rainbow trout with respect to maximum water temperatures, its measurement standards, and habitat, p. 53-55. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, AB.

Haas, G.R., and McPhail, J.D. 1991. Systematics and distributions of Dolly Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*) in North America. Can. J. Fish. Aquat. Sci. **48**: 2191-2211.

Haas, G.R., and McPhail, J.D. 2001. The post-Wisconsinan glacial biogeography of bull trout (*Salvelinus confluentus*): a multivariate morphometric approach for conservation biology and management. Can. J. Fish. Aquat. Sci. **58**: 2189-2203.

Hagen, J., and Taylor, E.B. 2001. Resource partitioning as a factor limiting gene flow in hybridizing populations of Dolly Varden char (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*). Can. J. Fish. Aquat. Sci. **58**: 2037-2047.

Hanzel, L. 1985. Past and present status of bull trout in Flathead Lake, p. 19-24. In D.D. Macdonald (ed.) Proceedings of the Flathead River basin bull trout biology and population dynamics modelling information exchange. Fisheries Branch, B.C. Ministry of the Environment, Cranbrook, BC.

Hauer, F.R., Poole, G.C., Gangemi, J.T., and Baxter, C.V. 1999. Large woody debris in bull trout (*Salvelinus confluentus*) spawning streams of logged and wilderness watersheds in northwest Montana. Can. J. Fish. Aquat. Sci. **56**: 915-924.

Hemmingsen, A.R., Bellerud, B.L., Buchanan, D.V. , Gunckel, S.L., Shappart, J.K., and Howell, P.J. 2001. Bull trout life history, genetics, habitat needs, and limiting factors in central and northeast Oregon. 1997 Annual Report. Prepared for U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon. 37 p. [Project Number 95-54, Contract Number 94B134342].

Herman, S.J. 1997. The unique bull trout spawning population of Pinto Lake, Alberta, p. 217-226. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Hvenegaard, P.J., and Thera, T.M. 2001. Monitoring the bull trout (*Salvelinus confluentus*) spawning run in Lynx Creek, a tributary to the Kakwa River, west central Alberta, p. 147-151. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, AB.

Jakober, M.J. 1995. Autumn and winter movement and habitat use of resident bull trout and westslope cutthroat trout in Montana. M.Sc. Thesis, University of Montana, Bozeman, Montana. xii + 110 p.

Jakober, M.J., McMahon, T.E., Thurow, R.F., and Clancy, C.G. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Trans. Am. Fish. Soc. **127**: 223-235.

Jakober, M.J., McMahon, T.E., and Thurow, R.F. 2000. Diel habitat partitioning by bull charr and cutthroat trout during fall and winter in Rocky Mountain streams. Environ. Biol. Fishes **59**: 79-89.

James, P.W., and Sexauer, H.M. 1997. Spawning behaviour, spawning habitat and alternative mating strategies in an adfluvial population of bull trout, p. 325-329. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Kitano, S., Maekawa, K., Nakano, S., and Fausch, K.D. 1994. Spawning behavior of bull trout in the upper Flathead drainage, Montana, with special reference to hybridization with brook trout. Trans. Am. Fish. Soc. **123**: 988-992.

Knotek, W.L., Deleray, M., and Marotz, B. 1997. Hungry Horse Dam Fisheries Mitigation Program: fish passage and habitat improvement in the upper Flathead River basin. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. vii + 60 p. + apps. [DOE/BP-60559-4].

Leary, R.F., and Allendorf, F.W. 1997. Genetic confirmation of sympatric bull trout and Dolly Varden in western Washington. Trans. Am. Fish. Soc. **126**: 715-720.

Markle, D.F. 1992. Evidence of bull trout x brook trout hybrids in Oregon, p. 58-67. In P.J. Howell and D.V. Buchanan (ed.) Proceedings of the Gearhart Mountain bull trout workshop. Oregon Chapter of the American Fisheries Society, Corvallis, Oregon.

Marshall, I.B. and Schut, P.H. 1999. A national ecological framework for Canada. Ecosystems Science Directorate, Environment Canada and Research Branch, Agriculture and Agri-Food Canada, Ottawa, ON. [http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html, Accessed 28 May 2007].

McCart, D. 1982. An assessment of the fisheries resources of the Great Bear and Mackenzie Rivers in the vicinity of proposed IPL Pipeline crossings. Aquatic Environments Limited for Inter Provincial Pipelines Ltd, Calgary, AB. 33 p. + tables, figures.

McCart, P.J., Griffiths, W., Gossen, C., Bain, H., and Tripp, D. 1974. Catalogue of lakes and streams in Canada along routes of the proposed Arctic gas pipeline from the Alaskan/Canadian border to the 60th parallel. Canadian/Alaskan Arctic Gas Study Limited Biological Report Series **16**: 251 p. + 11 maps.

McCullough, D.A., and Spalding, S. 2002. Multiple lines of evidence for determining upper optimal temperature thresholds for bull trout. Columbia River Inter-Tribal Fish Commission (CRITFC) Techncial Report **02-4**: 25 p.

McLeod, C., and Clayton, T. 1993. Fish radio telemetry demonstration project, upper Athabasca River, May to August, 1992. Northern River Basins Study Project Report **11**: 41 p.

McLeod, C.L., and Clayton, T.B. 1997. Use of radio telemetry to monitor movements and locate critical habitats for fluvial bull trout in the Athabasca River, Alberta, p. 413-419. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the Bull Trout Conference Proceedings. Trout Unlimited Canada, Calgary, Alberta.

McMahon, T., Zale, A., Selong, J., and Barrows, R. 1999. Growth and survival temperature criteria for bull trout. Annual Report 1999 (year two). Prepared for the National Council for Air and Stream Improvement.

McMahon, T., Zale, A., Selong, J., and Barrows, R. 2001. Growth and survival temperature criteria for bull trout. Annual Report 2000 (year three). Prepared for the National Council for Air and Stream Improvement. 31 p.

McPhail, J.D., and Baxter, J.S. 1996. A review of bull trout (*Salvelinus confluentus*) life-history and habitat use in relation to compensation and improvement opportunities. University of British Columbia, Department of Zoology, Fisheries Management Report **104**: 1-35.

McPhail, J.D., and Murray, C.B. 1979. The early life history and ecology of Dolly Varden (*Salvelinus malma*) in the upper Arrow Lakes. Department of Zoology and Institute of Animal Resources, University of British Columbia, Vancouver, BC. 113 p.

Meehan, W.R., and Bjornn, T.C. 1991. Salmonid distributions and life histories, p. 47-82. In W.R. Meehan (ed.) Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Mochnacz, N. 2001. Life history stages of bull trout, *Salvelinus confluentus*, a literature review. Prepared for Canada Department of Fisheries and Oceans, Winnipeg, MB. 23 p.

Mochnacz, N.J. 2002. Bull trout distribution, life history, and habitat requirements in the southern and central Mackenzie River Valley, Northwest Territories. A report prepared for the Habitat Stewardship Program for Species at Risk, Government of Canada [Edmonton, AB]. ii + 52 p.

Mochnacz, N.J., Reist, J.D., Cott, P., Low, G., and Wastle, R. 2004. Biological and habitat data for bull trout (*Salvelinus confluentus*) and associated species from stream surveys conducted in the southern and central Mackenzie River Valley, Northwest Territories, 2000 to 2001. Can. Data. Rep. Fish. Aquat. Sci. **1131**: iv + 38 p.

Mogen, J.T. and Kaeding, L.R. 2005. Identification and characterization of migratory and nonmigratory bull trout populations in the St. Mary River drainage, Montana. Trans. Am. Fish. Soc. **134**: 841-852.

Mongillo, P.E. 1993. The distribution and status of bull trout/Dolly Varden in Washington State, June 1992. Washington Department of Wildlife, Fisheries Management Division Report No. **93-22**: iii + 45 p.

Montana Bull Trout Scientific Group. 1995. The role of removal and suppression of non-native fish in bull trout recovery. Prepared for the Montana Bull Trout Restoration Team. ii + 41 p.

Muhlfeld, C.C., and Marotz, B. 2005. Seasonal movement and habitat use by subadult bull trout in the upper Flathead River system, Montana. N. Am. J. Fish. Manage. **25**: 797-810.

Mushens, C.J., and Post, J.R. 2000. Population dynamics of the lower Kananaskis Lake bull trout: 1999 progress report. Prepared by University of Calgary, Department of Biological Sciences, Calgary, AB, for Alberta Conservation Association and TransAlta Utilities. xii + 65 p. + tables, figures.

Nakano, S., Fausch, K.D., Furukawa-Tanaka, T., Maekawa, K., and Kawanabe, H. 1992. Resource utilization by bull char and cutthroat trout in a mountain stream in Montana, U.S.A. Jpn. J. Ichthyol. **39**: 211-217.

Nakano, S., Kitano, S., Nakai, K., and Fausch, K.D. 1998. Competitive interactions for foraging microhabitat among introduced brook charr, *Salvelinus fontinalis*, and native bull charr, *S. confluentus*, and westslope cutthroat trout, *Oncorhynchus clarki lewisi*, in a Montana stream. Environ. Biol. Fishes **52**: 345-355.

Oliver, G. 1985. Habitat requirements of Dolly Varden char in the Wigwam River drainage, p. 36. In D.D. Macdonald (ed.) Proceedings of the Flathead River basin bull trout biology and population dynamics modelling information exchange. Fisheries Branch, B.C. Ministry of the Environment, Cranbrook, BC.

Olmsted, W.R., den Biesen, D., and Birch, G.J. 2001. Migration timing and abundance trends in an adfluvial bull trout population in Kootenay Lake, British Columbia, p. 159-166. In M.K. Brewin, A.J. Paul, and M. Monita (ed.) Bull trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Parkinson, E.A., and Haas, G.R. 1996. The role of macrohabitat and temperature in defining the range of bull trout. Province of British Columbia, Fisheries Project Report **RD51**: 15 p.

Pattenden, R., McLeod, C., and Ash, G. 1991. Peace River Site C hydroelectric development. Fish movements and population status. Prepared by R.L.&L. Environmental Services Ltd., Edmonton, for B.C. Hydro, Environmental Resources Division, Vancouver, BC.

Paul, A.J., and Bustard, D. 2004. Study designs for environmental impact assessment: an example using the bull trout (*Salvelinus confluentus*) and the South Kerness Mine Project, p. 17-18. In G.J. Scrimgeour, G. Eisler, B. McCulloch, U. Silins, and M. Monita (ed.) Forest Land-Fish Conference II - Ecosystem Stewardship through Collaboration. Proc. Forest-Land-Fish Conf. II, April 26-28, 2004, Edmonton, AB.

Paul, A.J., and Post, J.R. 2001. Spatial distribution of native and nonnative salmonids in streams of the eastern slopes of the Canadian Rocky Mountains. Trans. Am. Fish. Soc. **130**: 417-430.

Pearsons, T.N., Li, H.W., and Lamberti, G.A. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. Trans. Am. Fish. Soc. **121**: 427-436.

Pillipow, R., and Williamson, C. 2004. Goat River bull trout (*Salvelinus confluentus*) biotelemetry and spawning assessments 2002-03. BC J. Ecosyst. Manage. **4**: 1-9.

Porter, T.R., Rosenberg, D.M., and McGowan, D.K. 1974. Winter studies of the effects of a highway crossing on the fish and benthos of the Martin River, N.W.T. Can. Fish. Mar. Serv. Tech. Rep. Ser. CEN-T **74-3**: vii + 50 p.

Post, J.R., and Johnston, F.D. 2002. Status of the bull trout (*Salvelinus confluentus*) in Alberta. Alberta Wildlife Status Report No. **39**: viii + 40 p.

Pratt, K.L. 1984. Habitat use and species interactions of juvenile cutthroat (*Salmo clarki lewisi*) and bulltrout (*Salvelinus confluentus*) in the upper Flathead River Basin. M.Sc. Thesis, University of Idaho, Moscow, ID. xi + 95 p.

Pratt, K.L. 1992. A review of bull trout life history, p. 1-4. In P.J. Howell and D.V. Buchanan (ed.) Proceedings of the Gearhart Mountain bull trout workshop. Oregon Chapter of the American Fisheries Society, Corvallis, Oregon.

Ratliff, D.E., Thiesfeld, S.L., Weber, W.G., Stuart, A.M., Riehle, M.D., and Buchanan, D.V. 1996. Distribution, life history, abundance, harvest, habitat, and limiting factors of bull trout in the Metolius River and Lake Billy Chinook, Oregon, 1983-1994. Oregon Department of Fish and Wildlife, Fish Division, Information Reports **96-7**: ii + 44 p.

Reiser, D.W., Connor, E., Binkley, K., Lynch, K., and Paige, D. 1997. Evaluation of spawning habitat used by bull trout in the Cedar River watershed, Washington, p. 331-338. In W.C. Mackay, M.K. Brewin, M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Reist, J.D. 1994. An overview of the possible effects of climate change on northern freshwater and anadromous fishes, p. 377-385. In S.J. Cohen (ed.) Mackenzie Basin Impact Study (MBIS) Interim Report 2. Environment Canada, Downsview, ON.

Reist, J.D., Low, G., Johnson, J.D., and McDowell, D. 2002. Range extension of bull trout, *Salvelinus confluentus*, to the central Northwest Territories, with notes on identification and distribution of Dolly Varden, *Salvelinus malma,* in the western Canadian Arctic. Arctic **55** : 70-76.

Rich, C.F. 1996. Influence of abiotic and biotic factors on occurrence of resident bull trout in fragmented habitats, western Montana. M.Sc. Thesis, Montana State University, Bozeman, Montana. viii + 53 p.

Rieman, B.E., and Chandler, G.L. 1999. Empirical evaluation of temperature effects on bull trout distribution in the northwest. Prepared by U.S. Forest Service, Boise, Idaho for U.S. Environmental Protection Agency, Boise, Idaho. 31 p. [Contract No. 12957242-01-0].

Rieman, B.E., and Dunham, J.B. 2000. Metapopulations and salmonids: a synthesis of life history patterns and empirical observations. Ecol. Freshw. Fish **9**: 51-64.

Rieman, B.E., and McIntyre, J.D. 1993. Demographic and habitat requirements for conservation of bull trout. U.S. Department of Agriculture, Forest Service, Intermountain Research Station (Ogden, UT), General Technical Report **INT-302**: i + 38 p.

Rieman, B.E., and McIntyre, J.D. 1995. Occurrence of bull trout in naturally fragmented habitat patches in varied sizes. Trans. Am. Fish. Soc. **124**: 285-296.

Rieman, B.E., Lee, D.C., Chandler, G., and Myers, D. 1997. Does wildfire threaten extinction for salmonids? Responses of redband trout and bull trout following recent large fires on the Boise National Forest, p. 47-47. In J. Greenlee (ed.) Proceedings - Fire effects on rare and endangered species and habitats conference. International Association of Wildlands Fire, Fairfield, Washington.

Ripley, T., Scrimgeour, G., and Boyce, M.S. 2005. Bull trout (*Salvelinus confluentus*) occurrence and abundance influenced by cumulative industrial developments in a Canadian boreal forest watershed. Can. J. Fish. Aquat. Sci. **62**: 2431-2442.

Roberge, M., Hume, J.M.B., Minns, C.T., and Slaney, T. 2002. Life history characteristics of freshwater fishes occurring in British Columbia and the Yukon, with major emphasis on stream habitat characteristics. Can. Manuscr. Rep. Fish. Aquat. Sci. **2611**: xiv + 248 p.

Saffel, P.D., and Scarnecchia, D.L. 1995. Habitat use by juvenile bull trout in belt-series geology watersheds of northern Idaho. Northwest Sci. **69** : 304-317.

Sawatzky, C.D., Michalak, D., Reist, J.D., Carmichael, T.J., Mandrak, N.E., and Heuring, L.G. 2007. Distributions of freshwater and anadromous fishes from the mainland Northwest Territories, Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. **2793**: xiv + 239 p.

Selong, J.H., McMahon, T.E., Zale, A.V., and Barrows, F.T. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Trans. Am. Fish. Soc. **130**: 1026-1037.

Sexauer, H.M. 1994. Life history aspects of bull trout, *Salvelinus confluentus*, in the eastern Cascades, Washington. M.Sc. Thesis, Central Washington University, Ellensburg, WA. ix + 85 p.

Sexauer, H.M., and James, P.W. 1997. Microhabitat use by juvenile bull trout in four streams located in the eastern Cascades, Washington, p. 361-370. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Shepard, B. 1985. Habitat variables related to bull trout spawning site selection and thermal preference exhibited in a thermal gradient, p. 18. In D.D. Macdonald (ed.) Proceedings of the Flathead River Basin bull trout biology and population dynamics modelling information exchange. Fisheries Branch, B.C. Ministry of the Environment, Cranbrook, BC.

Shepard, B.B., and Graham, P.J. 1982. Monitoring spawning bed material used by bull trout on the Glacier View District Flathead National Forest. Completion Report. Montana Department of Fish, Wildlife and Parks, Region 1, Kalispell, Montana. v + 37 p. + apps.

Shepard, B.B., and Graham, P.J. 1983a. Flathead River fisheries study. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana.

Shepard, B.B., and Graham, P.J. 1983b. Fish resource monitoring program for the upper Flathead Basin. Montana Department of Fish, Wildlife and Parks, Kalispell, Montana. 61 p.

Shepard, B.B., Leathe, S.A., Weaver, T.M., and Enk, M.D. 1984. Monitoring levels of fine sediment within tributaries to Flathead Lake, and impacts of fine sediment on bull trout recruitment, p. 146-156. In F. Richardson and R. H. Hamre (ed.) Wild Trout III: Proceedings of the Symposium, September 24-25, Yellowstone National Park.

Sigma Resource Consultants Ltd. 1976. Study of aquatic biology and water quality of Flat River, NWT. Prepared for Canada Tungsten Mining Corporation Ltd., variously paginated.

Spangler, R.E., and Scarnecchia, D.L. 2001. Summer and fall microhabitat utilization of juvenile bull trout and cutthroat trout in a wilderness stream, Idaho. Hydrobiologia **452**: 145-154.

Stein, J.N., Jessop, C.S., Porter, T.R., and Chang-Kue, K.T.J. 1973. Fish Resources of the Mackenzie River Valley, Interim Report II. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development Rep. **2**: xvii + 260 p.

Stelfox, J.D. 1997. Seasonal movements, growth, survival and population status of the adfluvial bull trout population in Lower Kananaskis Lake, Alberta, p. 309-316. In W.C. Mackay, M.K. Brewin, and M. Monita (ed.) Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary, AB.

Stelfox, J.D., and Egan, K.L. 1995. Bull trout investigations in the Smith-Dorrien Creek/Lower Kananaskis Lake system. Report prepared by Fisheries Management Division, Alberta Environmental Protection, and by Golder Associates Limited, Calgary, AB. xi + 148 p.

Stewart, D.B., Mochnacz, N.J., Sawatzky, C.D., Carmichael, T.J., and Reist, J.D. 2007. Fish diets and food webs in the Northwest Territories: bull trout (*Salvelinus confluentus*). Can. Manuscr. Rep. Fish. Aquat. Sci. **2800**: vi + 18 p.

Swanberg, T.R. 1997a. Movements of and habitat use by fluvial bull trout in the Blackfoot River, Montana. Trans. Am. Fish. Soc. **126**: 735-746.

Swanberg, T.R. 1997b. Movements of bull trout (*Salvelinus confluentus*) in the Clark Fork River system after transport upstream of Milltown Dam. Northwest Sci. **71**: 313-317.

Thiesfeld, S.L., Stuart, A.M., Ratliff, D.E., and Lampman, B.D. 1996. Migration patterns of adult bull trout in the Metolius River and Lake Billy Chinook, Oregon. Oregon Department of Fish and Wildlife, Fish Division, Information Reports No. **96-1**: i + 18 p.

Thurow, R.F. 1997. Habitat utilization and diel behavior of juvenile bull trout (*Salvelinus confluentus*) at the onset of winter. Ecol. Freshw. Fish **6**: 1-7.

Underwood, K.D., Martin, S.W., Schuck, M.L., and Scholz, A.T. 1995. Investigations of bull trout (*Salvelinus confluentus*), steelhead trout (*Oncorhynchus mykiss*), and spring chinook salmon (*O. tshawytscha*) interactions in southeast Washington Streams, 1992 Final Report. Prepared by Department of Biology, Eastern Washington University and Washington Department of Wildlife for U.S. Department of Energy, Bonneville Power Administration, Portland, OR. viii + 173 p.

USFWS (U.S. Fish and Wildlife Service). 2000. Bull trout occurrence and habitat selection. A White Paper addressing bull trout distribution and habitat requirements as related to potentially occupied habitats. U.S. Fish and Wildlife Service, Western Washington Office. 3 p.

USFWS (U.S. Fish and Wildlife Service). 2001. US Fish and Wildlife Service bull trout workshop: Yakima Basin case history for bull trout (*Salvelinus confluentus*). USFWS, Columbia River Fisheries Program Office, Vancouver, Washington. 32 p.

Watson, G., and Hillman, T.W. 1997. Factors affecting the distribution and abundance of bull trout: an investigation at hierchical scales. N. Am. J. Fish. Manage. **17**: 237-252.

Weaver, T., and Fraley, J. 1991. Fisheries habitat and fish populations. Flathead Basin Forest Practices, Water Quality and Fisheries Cooperative Program. Flathead Basin Commission, Kalispell, Montana. viii + 47 p.

Weaver, T.M., and White, R.G. 1985. Coal Creek fisheries monitoring study number III. Quarterly progress report to the United States Department of Agriculture, Forest Service, Montana State Cooperative Fisheries Research Unit, Bozeman, Montana. 94 p.

Weber, L.A., Hickey, E., Hargis, M., and Costa, D. 2001. Heat shock protein induction temperature as a predictor of the thermal injury in bull trout, *Salvelinus confluentus*. Prepared by Biology Department and Center for Conservation Genetics, University of Nevada, Reno, for the National Council of the Paper Industry for Air and Stream Improvement. 25 MS p.

Wickstrom, R.D. 1977. Limnological survey of Nahanni National Park, 1975-1976 progress report. Unpublished report prepared for Parks Canada by the Canadian Wildlife Service, Winnipeg. MB. vii + 42 p.

Wickstrom, R.D. 1979. Limnological survey of Nahanni National Park, N.W.T., 1978 progress report. unpublished report prepared for Parks Canada by the Canadian Wildlife Service, Winnipeg. MB. viii + 23 p.

Wickstrom, R.D., and Lutz, A. 1981. Tungsten and copper analysis of fish and sediments from the lower Flat River, Nahanni National Park, N.W.T. Unpublished report prepared for Parks Canada by the Canadian Wildlife Service, Winnipeg. MB. vi + 34 p.

Wilhelm, F.M., Parker, B.R., Schindler, D.W., and Donald, D.B. 1999. Seasonal food habits of bull trout from a small alpine lake in the Canadian Rocky Mountains. Trans. Am. Fish. Soc. **128**: 1176-1192.

Wissmar, R.C., and Craig, S. 1997. Bull trout spawning activity, Gold Creek, Washington. Fisheries Research Institute University of Washington **FRI-UW-9701**: v + 15 p.

Zurstadt, C.F. 2000. Relationships between relative abundance of resident bull trout (*Salvelinus confluentus*) and habitat characteristics in central Idaho mountain streams. M.Sc. Thesis, Oregon State University. ix + 65 p.

8.0 ABBREVIATIONS

FL = fork length—distance from the tip of the fish's snout to the notch in its tail.

MDMT = Maximum daily maximum temperature is the warmest daily maximum temperature recorded during a given year or survey period.

MWMT = Maximum weekly maximum temperature is the mean of daily maximum temperatures measured over the warmest consecutive seven-day period (typically during a given year).

NTU = Nephelometric turbidity units or NTU are a measure of light scattered by suspended particles in water. High NTU measurements indicate low water clarity (i.e. high turbidity).

SL = standard length—distance from the tip of the snout to the base of the caudal fin rays.

TL = total length—distance from the tip of the fish's snout to the tip of its tail.

UUILT = ultimate upper incipient lethal temperature.

YOY = young-of-the-year.

9.0 GLOSSARY

Adfluvial fish populations move between lake and river or stream environments.

Alevins are newly hatched, incompletely developed fishes (usually salmonids) still in the nest or inactive on the bottom and living off stored yolk.

Allopatric species occur in geographical isolation from one another.

Anadromous fish populations move downstream into marine waters to feed, and return upstream into fresh water to spawn and/or overwinter.

Baseflow is stream flow derived from groundwater.

Fluvial fish populations remain in rivers and streams throughout their lives.

Fry are young fish, newly hatched, after yolk has been used up and active feeding has commenced.

Iteroparous fish spawn more than once in their lives.

Piscivores eat fish.

Profundal species occupy deep water habits near the lake bottom, below the effective depth of light penetration.

Larval fishes (plural larvae) are young fish, newly hatched, before the yolk has been used up (see also **Alevins**).

Redds are gravel nests constructed by salmonid fishes.

Sympatric species occur in the same or overlapping areas.

Temperature units are Centigrade degree days above 0°C.

Appendix 1. Life history and habitat parameters

The emphasis of this work is on observations from within the Mackenzie Valley region. Terms such as “dominant”, “preferred” and “optimum”, which have been used in other summaries (e.g., Ford *et al*. 1995; Roberge *et al*. 2002), are avoided unless they are supported by directed research studies. This is because sampling observations may not accurately reflect a species’ preferences unless the spatial and temporal biases related to sampling design and gear are carefully controlled. The following sections define what is meant by the various life history and habitat use parameters used in the text and tables and in the appendices that follow. Some parameters described here may not be used in this report because this description applies to all of the habitat use reports in the series.

TABLES 2 and 3

Habitat use and requirements

These tables summarize habitat associations during the life history stages of the species. Separate tables may be included for stream, river, and lake environments. Observations from areas within the Mackenzie River watershed are in bold type. The following parameters are included, with the units of measurement typically used:

- **Habitat type** – habitat type most commonly associated with observations of the life history stage (e.g., streams–pools, runs, riffles; lakes–littoral, pelagic, benthic);
- **Stream gradient** – percent (%) slope;
- **Depth range (m)** – range of depths from which the species has been reported;
- **Substrate** – substrate type(s) most commonly associated with observations of the species;
- **Cover** – cover type(s) most commonly associated with observations of the species:
- **Habit** – typical distribution within the habitat type (e.g., surface, midwater, benthic, above or below thermocline, inshore or offshore);
- **Velocity range** – water velocities (cm/s) wherein the species is most commonly observed;
- **Turbidity (NTU):**
    - **range** – turbidity range wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Oxygen (mg/L):**
    - **range** – dissolved oxygen levels wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Temperature (°C):**
    - **range** – water temperatures wherein the species has been reported;
    - **limits** – upper and lower lethal limits as tested experimentally;
- **Prey:**
    - **Primary** – taxa or taxon typically comprising the majority (by weight/volume/food value) of the food found in the stomachs of fishes sampled, or that were seen to be eaten during *in situ* behavioural studies;
    - **Secondary** – taxa or taxon comprising the minority (by weight/volume/food value) of food found in the stomach of fish sampled, or that were seen to be eaten during *in situ* behavioural studies. [Note: Differences in prey selection (i.e. primary/secondary) may reflect changes in the seasonal availability rather than the relative importance of food items.];
- **Duration** – number of seasons, months, or years in which each specific life stage exists or occurs;
- **Size/Age range** – average and/or maximum size range (mm) of the life history stage; or maximum size range (mm); FL = fork length, SL = standard length, TL = total length. A fish is age 0 until December 31 of the year it was hatched unless otherwise indicated.

Reproduction

This table summarizes habitat and life history parameters related to the species' reproduction. Observations from areas outside the Mackenzie River watershed are italicized. The following parameters are included:

- **Reproductive strategy** – *oviparous* species produce eggs that hatch outside the body of the mother; *iteroparous* species produce their young in annual or seasonal batches (most fishes); *semeloparous* species (e.g., salmon) produce all of their offspring at one time and then usually die; *annual* spawners reproduce each year following maturity until they die or reach reproductive senescence; under marginal conditions a portion of the reproductive population may rest for a year or more between spawning events (*% resting*);
- **Age at maturity** – range of ages at which males (M) and females (F) become sexually mature, with any estimate of the most common age at maturity provided in brackets;
- **Fecundity** – range in the number of eggs produced by females;
- **Spawning habitat** – habitat types wherein spawning has been observed, ripe and running fish have been caught, ripe and spent fish have been caught together, or eggs or sac larvae have been found. The presence of mobile young-of-the-year was used to identify nursery areas, and sometimes "suspected" spawning areas;
- **Spawning habit** – some species *build a nest* by altering the bottom substrates to meet their requirements before spawning; others *use existing nests* constructed by other species; *broadcast spawners* spread their eggs over suitable areas of unaltered bottom substrates; some species *care for the eggs* or *care for the young*;
- **Spawning temperature** – temperature range at which spawning has been observed;
- **Spawning depth** – depth range at which spawning has been observed;
- **Spawning substrate** – substrate type(s) observed at spawning locations;
- **Spawning current velocity** – current velocity observed at spawning locations;
- **Maximum age** – life expectancy of the species;
- **Reproductive senescence** – age at which the species stops reproducing.

APPENDICES 2 and 3

The seasonal habitat requirements for each life history stage are presented below in separate appendices for stream and lake environments. Within these appendices, observations from the Mackenzie River watershed are in bold type.

Life history stage

Observations on habitat use are summarized by life history stage. Four stages are recognized:

- **Spawning/eggs** – includes habitats on the spawning grounds where adults spawn and eggs mature and hatch;
- **Young-of-the-year (YOY)** – larvae and fry less than age 1 (age 0 until December 31 of the year they are hatched);
- **Juveniles** – sexually immature fish older than age 1;
- **Adults** – include fish that have attained sexual maturity.

Seasons

Habitat use was divided into four seasons, which correspond to the environmental conditions rather than to the calendar seasons. Calendar months are also provided if possible, but the correspondence between environmental variables and calendar months varies from south to north and from year to year. In the north of the Mackenzie watershed (Inuvik; S. Stephenson, DFO, pers. comm.), the seasons used are:

- **Spring (Sp)** – the period of ice breakup and spring runoff, typically late April to mid June;
- **Summer (Su)** – the period of open water, typically mid-June to late September;

- **Fall (Fa)** – the period of ice formation, typically late September to late November;
- **Winte**r **(Wi)** – the period of ice cover, typically late November to late April.

In the south (Hay River; G. Low, DFO, pers. comm.) they are:

- **Spring (Sp)** – the period of ice breakup and spring runoff, mid-April to early June;
- **Summer (Su)** – the period of open water, typically early June to late-September;
- **Fall (Fa)** – the period of ice formation, typically late-September to mid-November;
- **Winte**r **(Wi)** – the period of ice cover, typically mid-November to mid-April.

These date ranges are averages, since the timing of breakup varies from river to river and lake to lake depending upon factors such as stream gradient, exposure to sunlight, and lake size.

Water depth

Five water depth categories area used for stream environments: 0–0.2, >0.2–0.6, >0.6–1, >1–2, and >2 m. Depth represents the distance from the surface of the water downwards. The depth association of a fish found in the upper metre of the water column, for example, would be reported as 0–0.2, >0.2–0.6 and >0.6–1.0. Depth is reported as stated in the reference, but if "shallow" water was the only descriptor, a depth of 0–20 cm was used to represent "shallow" water. A broader range of depths is used to describe lake environments: 0–1, >1–2, >2–5, >5–10, and >10 m.

Substrate type

Substrate type was reported as stated in the reference. However, if particle size was provided, substrate type was classified as follows:

- **bedrock** = uniform continuous substrate;
- **boulder** = >25 cm;
- **cobble** = 17–<25 cm;
- **rubble** = 6.4–<17 cm;
- **gravel** = 0.2–<6.4 cm;
- **sand** = <0.2 cm;
- **silt/clay** = finer than sand with fine organic content;
- **muck (detritus)** = mud with coarse organic content;
- **hard-pan clay** = clay; and
- **pelagic** = open water.

Cover type

Cover features that may provide protection, or a refuge, from predators, competitors, and adverse environmental conditions include:

- **None** – no cover;
- **Submergent vegetation** – aquatic plants that grow entirely below the surface and are attached to the bottom by roots or rhizomes;
- **Emergent vegetation** – aquatic plants with foliage that is partly or entirely borne above the water surface (e.g., cattail *Typha* spp.) or float on the surface of the water (e.g., milfoil);
- **Algae** – aquatic algae present on the bottom or within the water column;
- **Wood** – large (LWD) or smaller woody debris (SWD) on the bottom or within the water;
- ***In situ*** – submerged cavities and/or crevices, undercut banks;
- **Substrate** – interstitial spaces between any size of substrate (boulder-sand);
- **Overhead** – cover originating outside the riparian zone that overhangs the stream and/or banks, which includes overhanging banks or riparian vegetation, woody debris outside the channel, or anything above the surface that provides shade.

Habitat

In flowing water, habitat refers to the type of channel unit, and typical water velocity within the unit that the species inhabits, including:

- **Pool** – velocity range <0.25 $m \cdot s^{-1}$;
- **Run** – velocity range 0.25–0.50 $m \cdot s^{-1}$;
- **Riffle** – velocity range 0.50–1.00 $m \cdot s^{-1}$;
- **Rapid** – velocity range >1.00 $m \cdot s^{-1}$;
- **River margin** – habitat along the banks of the mainstem channel, often low velocity;
- **Off-channel** – any habitat that is outside the mainstem flow including side channels, backwaters, and off channel habitats, often low or no velocity.

Water velocity differences are not used to differentiate lake habitats; rather they are differentiated on the basis of their proximity to flowing water or shorelines, as follows:

- **Lake inlet** – near or within stream or river plumes entering the lake;
- **Lake outlet** – near or within the channel that drains the lake;
- **Inshore** – typically associated with littoral habitat along the edges, rather than the middle of the lake;
- **Offshore** – typically associated with the middle, rather than the edges of the lake. Where possible their typical position in the water column is described (e.g., surface, midwater, benthic, above or below thermocline).

Appendix 2. Stream habitat requirements for bull trout. Data from the Northwest Territories are in bold type.

Stream habitat features:	**LIFE STAGES** [Season of use (reference)]				**LEGEND/COMMENTS/REFERENCES**
	Spawn/egg	**YOY**	**Juvenile**	**Adult**	**Season of use:**
Depth (m)					Sp = spring
0-0.2	Fa, Wi (2a,b)	**Su** (**1**,6), Fa (6)	**Su** (**1**,6), Fa (6)	**Su (1)**	Su = summer
>0.2-0.6	Fa, Wi (2a,b)	**Su (1)**, Fa (6)	**Su** (**1**,6), Fa (6), Wi (5)	**Su (1)**, Wi (5)	Fa = fall
>0.6-1	Fa, Wi (2a,b)	**Su (1)**	**Su** (**1**,6), Fa (6), Wi (5)	**Su (1)**, Wi (5)	Wi = winter
>1-2			**Su (1)**, Fa (6), Wi (5)	**Su (1)**, Wi (5)	
>2				**Su (1)**	
Substrate					
Bedrock					
Boulder		Wi (5*)	**Su** (**1**,8)	**Su (3)**, Wi (5)	*In areas without surface flow, YOY may winter in the interstices of the substrate where there is sub-surface flow (5)
Cobble	Fa, Wi (2b)	**Su (1)**, Wi (5*)	**Su** (**1**,8)	**Su (3)**, Wi (5)	
Rubble	Fa, Wi (2b)		Su (8)	**Su (3)**	
Gravel	Fa, Wi (2a,b, 4, 5)		Su (8)	**Su (3)**	
Sand	Fa, Wi (2b)		Su (8)		
Silt/Clay	Fa, Wi (4)				Some spawning sites have appreciable amounts of silt (4)
Muck (Detritus)					
Hard-pan clay					
Pelagic					
Cover					Use of submerged cover decreases after formation of surface ice (7)
None					
Submergents					
Emergents					
Algae					
Wood			Su (8)		
In situ					
Substrate		**Su (1)**	**Su** (**1**,8)	**Su (1)**	Boulder, cobble
Undercut bank/overhang	Fa, Wi (4)			**Su (1)**	Shallow redds excavated within 2.5 m of the banks of the Wigwam R. (4)
Overhead					
Other				**Su (1)**	Depth, turbulence
Velocity/Habitat					
Pool	Fa, Wi (2b)	**Su (1)**	**Su** (**1**,8)	**Su (1)**	
Run	Fa, Wi (2a,b)	**Su (1)**	**Su** (**1**,8)	**Su (1)**	
Riffle	Fa, Wi (2b)		**Su** (**1**,8)	**Su (1)**	
Rapid					
River Margin					
Off-channel					

1 = Mochnacz *et al*. 2004 – Northwest Territories.

2 = Baxter and McPhail 1999 – a) Chowade River, Peace R. drainage, British Columbia, b) various systems throughout the range 49-56°N.
3 = Beak Consultants Inc. 1981 – Prairie Creek, Northwest Territories.
4 = Oliver 1985 – Wigwam River, British Columbia.
5 = Boag and Hvenegaard 1997 – West Castle River, a tributary of the Oldman River, Alberta.
6 = Spangler and Scarnecchia 2001 – South fork Clearwater River, Idaho.
7 = Jakober *et al*. 1998 – Bitterroot River drainage, Montana.
8 = Sexauer 1994, Sexauer and James 1997 – Yakima and Wenatchee river drainages, Washington.

Appendix 3. Lake habitat requirements for bull trout.

Lake habitat features:	LIFE STAGE [Season of use (reference number)]				LEGEND/COMMENTS/REFERENCES
	Spawn/egg	**YOY**	**Juvenile**	**Adult**	**LEGEND**
Depth (m)					**Season of use:**
0-1				All (1)	Sp = spring
>1-2				All (1)	Su = summer
>2-5				All (1)	Fa = fall
>5-10				All (1)	Wi = winter
>10				All (1)	All = year-round
Substrate					
Bedrock					
Boulder					
Cobble					
Rubble					
Gravel					
Sand					
Silt/Clay					
Muck (Detritus)					
Hard-pan clay					
Pelagic					
Cover					
None					
Submergents					
Emergents					
Algae					
Wood					
In situ					
Substrate					
Undercut bank/overhang					
Overhead					
Other					
Habitat					
Lake inlet					
Lake outlet					
Inshore (littoral)				All (1,2)	
Offshore-surface					
Offshore-midwater					
Offshore-benthic				All (1,2)	

1 = Connor *et al*. 1997 – Chester Morse Lake, Washington.

2 = Hanzel 1985 – Flathead Lake, Montana.

INFLUENCE OF LAND COVER, FIRE AND HUMAN DISTURBANCE ON HABITAT SELECTION BY BOREAL CARIBOU IN THE NWT

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EXECUTIVE SUMMARY

Population declines of boreal caribou in Canada are thought to be linked to habitat disturbance from human development activity and wild fires. Both national and NWT recovery strategies for this threatened species recommend developing range plans to manage habitat disturbance at levels that can support self-sustaining populations. To meet critical habitat requirements defined in the national recovery strategy, at least 65% undisturbed habitat must be maintained within each local population range. Range planning also requires identifying areas that provide the habitat attributes that boreal caribou need to survive and reproduce. Currently, the definition of critical habitat for boreal caribou considers any fires less than 40 years old to be disturbed habitat. Unlike many boreal caribou ranges in southern Canada, wildfire is the main source of habitat disturbance in the NWT boreal caribou range. This project sought to better understand seasonal and annual habitat selection of boreal caribou in the NWT as a function of land-cover type, fire age, and human disturbance. Location data collected from >300 adult female boreal caribou collared between May 2002 and March 2018 within five regional monitoring areas were used in Resource Selection Function (RSF) models to assess habitat selection during 7 seasonal activity periods and on a year-round basis. Habitat selection was assessed at two spatial scales by defining habitat availability within: 1) broad scale polygons describing North and South NWT groups of caribou (2nd order selection), and 2) within individual annual home ranges (3rd order selection). RSF models included variables characterizing burn age (by decade) within specific land-cover types, landscape context (the proportion of sparse conifer and broadleaf land cover within a 1-km radius), and impacts from human disturbance (distance to major roads, settlements, and other polygonal features, and linear feature density (km/km^2)). Caribou generally showed higher selection for younger burns (<10 years old) and older burns (>30 years old) and avoided middle-aged burns (11–30 years old). Selection for burns by caribou in the NWT appeared to be strongest during the snow-free seasons, followed by increasing avoidance of burns ≤40 years old from early to late-winter. Preference for recent burns during the snow-free season may be associated with greater forage abundance or quality in these areas and the higher nutritional demands experienced by lactating females during this period. Human disturbance features also influenced caribou habitat selection. Caribou generally selected areas further away from major roads and polygonal disturbances such as well pads and cutblocks, but occurred closer to settlements than expected, perhaps an artifact of logistical constraints on deploying collars on animals far from settlements. Caribou avoided areas with high linear feature density during the snow-free season, but this trend was reversed during mid- to late winter. Second-order RSF models had excellent predictive performance, but there was greater seasonal variability in predictive performance of third-order RSF models, which likely reflects higher variability in habitat available to each individual at this scale. Our findings generally agree with recent research questioning the relative importance of fire effects on caribou demography and distribution. Animals are assumed to select habitat in a way that enhances their individual fitness, and in the NWT, female caribou appear to seek out recently burned land-cover types during the snow-free season, suggesting that these areas may have some benefit to caribou. Range plans should consider maintaining a mix of recently burned and unburned areas to meet the shifting seasonal requirements of caribou. Predictive habitat selection maps generated by this study can be used in range planning and other applications to help identify important areas for boreal caribou that may require more careful management of both human and fire disturbance.

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INTRODUCTION

Boreal caribou are currently listed as a threatened species both nationally (in 2003) and in the Northwest Territories ([NWT] in 2014) under federal and territorial species at risk legislation (Environment Canada 2012, Northwest Territories Conference of Management Authorities 2013). Declines of boreal caribou throughout most of Canada are thought to be caused by habitat disturbance and fragmentation (Environment Canada 2012). The hypothesized link between habitat disturbance and boreal caribou declines is through apparent competition, whereby human-caused disturbances and forest fires creates early-seral (or young forest) habitat that can support higher densities of other ungulate species (e.g., moose and deer), in turn leading to higher densities of predators (e.g. wolves), which subsequently prey on caribou at unsustainable rates (Environment Canada 2012). Linear disturbances such as roads and seismic lines can also facilitate movements of predators (and people) into boreal caribou habitat, making it more difficult for boreal caribou to maintain spatial separation from predators and harvesters (DeMars and Boutin 2018, Mumma et al. 2018). Wolves have been observed to travel farther and faster on linear features through forested habitat which increases the likelihood that they will encounter and kill boreal caribou (Dickie et al. 2017b).

In developing the national recovery strategy for boreal caribou (Environment Canada 2012), Environment and Climate Change Canada (ECCC) assessed the relationship between habitat disturbance and demographic performance of boreal caribou in order to define critical habitat (Environment Canada 2011). Critical habitat for boreal caribou is defined as:

- *"The area within the boundary of each boreal caribou range that provides an overall ecological condition that will allow for an ongoing recruitment and retirement cycle of habitat, which maintains a perpetual state of a minimum of 65% of the area as undisturbed habitat; and*
- *Biophysical attributes required by boreal caribou to carry out life processes."*

(Environment Canada 2012, p. vii)

Undisturbed habitat is considered any areas that have not been disturbed by fire within the last 40 years, and areas that are >500 m from human disturbance features digitized at a 1:50,000 scale from Landsat imagery (Environment Canada 2012). Disturbed habitat is thus defined as areas that are ≤40 years post-fire old, and areas that are within a 500 m buffer around human disturbance features.

The national recovery strategy identified the need for provinces and territories to develop range plans that would demonstrate how habitat disturbance from fire and human development activity will be managed in order to achieve or maintain at least 65% undisturbed habitat within each local population within their jurisdiction (Environment Canada 2012, Environment and Climate Change Canada 2016). The NWT recovery strategy for boreal caribou also recognizes the need to meet the management threshold for undisturbed habitat that defines critical habitat, and recommends that range plans be developed for the NWT to ensure that adequate habitat is maintained for boreal caribou. In 2019, the Government of the Northwest Territories (GNWT) developed a framework for boreal caribou range planning in the NWT, which states that the goal of the range plans as is "*to manage natural and human disturbance in order to provide adequate caribou habitat to ensure a healthy and sustainable boreal caribou population across their NWT range that offers harvesting opportunities for present and future generations*" (Government of the Northwest Territories 2019).

The NWT has one continuous boreal caribou range (called "NT1 in the national recovery strategy) that stretches from the border with Alberta and British Columbia north to the Inuvialuit Settlement Region, with the eastern and western boundaries of the range primarily defined by the extent of the Taiga Plains ecoregion (Ecosystem Classification Group 2009). As of fall 2017, the NT1 range had 69% undisturbed habitat, meaning there is some flexibility in defining which areas contribute to the 65% that is considered critical habitat. The second component of critical habitat includes "biophysical attributes", which the national recovery strategy defines as "*habitat characteristics required by boreal caribou to carry out life processes necessary for survival and recovery*" (Environment Canada 2012). Appendix H of the national recovery strategy describes the biophysical attributes of critical habitat in the Taiga Plains ecoregion according to different seasonal activity periods (Environment Canada 2012), but the GNWT lacks current range-wide maps of areas that might provide these biophysical attributes. Both the national boreal caribou range planning guidance (Environment and Climate Change Canada 2016) and NWT range planning Framework (Government of the Northwest Territories 2019) recommend identifying, describing and mapping important areas for boreal caribou. The national range planning guidance (Environment and Climate Change Canada 2016) further recommends using maps of habitat types that provide biophysical attributes to ensure that the 65% undisturbed habitat that is considered critical habitat is made up of habitat that includes these biophysical attributes. One of the challenges to translating the descriptions of biophysical attributes (Environment Canada 2012) into maps of habitat types that provide these attributes across the NT1 range is that they are partially based on previous studies of boreal caribou habitat selection that used land-cover data sets that were only available in limited areas of the range (e.g., Nagy et al. 2005, 2006) and which used different terminology and classifications than more up-to-date land-cover data sets that do provide range-wide coverage. The descriptions of biophysical attributes are also based on traditional knowledge, which can include very detailed, fine-scale descriptions of habitat features that are not easily translated to coarser resolution spatial data sets that provide broad-scale coverage.

Resource selection functions (RSFs) are a common analytical framework used to model and generate predictive maps of animal habitat selection (Manly et al. 2002, Morris et al. 2016). RSFs typically compare resource units associated with locations "used" by individuals to resource units associated with a random sample of locations that are available to individuals within a certain spatial scale of interest using logistic regression. Resource units are typically grid or pixel cells that can be characterized by a number of environmental attributes (e.g., land-cover type, distance to nearest forest edge; Lele et al. 2013). Outputs from RSF models can then be used to predict the relative probability that a resource unit is selected (i.e., used) or avoided by an individual animal when encountered (Lele et al. 2013). Most studies using RSFs are based on GPS locations of animals obtained by telemetry using VHF or satellite collars, with resource attributes derived from remotely sensed data layers in a Geographic Information System (GIS). There have been previous studies evaluating boreal caribou habitat selection in the NWT using RSFs, but they have been limited to sub-areas of the NT1 range and are not easily updated or extrapolated to the range as a whole. Nagy et al. (2005, 2006) used RSFs to evaluate habitat selection by boreal caribou in the Gwich'in region, using data developed by Ducks Unlimited to characterize land-cover. In 2014, RSFs were developed for an expanded study area that included the Gwich'in, Inuvialuit and Sahtu regions (Stantec Consulting Ltd 2014). This project used a longer time-series of boreal caribou collar data from a larger sample of individuals and modeled habitat selection the Earth Observation for Sustainable Development of Forests (EOSD; circa year 2000; Wulder et al. 2008) land cover data. The only NT1-wide RSF model for boreal caribou developed to date is from the science assessment in

support of the national recovery strategy (Environment Canada 2011). Environment Canada (2011) developed both national-scale and ecozone-specific RSF models using satellite telemetry data provided by jurisdictions across Canada. These models included data from 169 individual boreal caribou collared in the NWT that were monitored for various periods between 2000 and 2010. Although the national RSF model performed fairly well at predicting withheld collar locations within the Taiga Plains ecozone, the Taiga Plains-specific model had poor predictive performance (Environment Canada 2011). Since these earlier RSF studies took place, the GNWT has continued several of its collar-based monitoring programs for boreal caribou and has initiated programs in new areas of the NT1 range. There is now a much larger data set spanning a longer time period with which to develop an updated NT1-wide RSF model for boreal caribou to support range planning.

In addition to developing up-to-date boreal caribou RSF models for the NT1 range, there is also a need to develop a more in-depth understanding of how wildfires and post-fire vegetation succession influence boreal caribou habitat selection and distribution. Within the NT1 range, wildfires are the main type of disturbance. As of fall 2017, which is close to the endpoint of the data used in this project (31 March 2018—see *Caribou Spatial Data* below), 31% of the NT1 range was considered disturbed habitat, of which wildfires accounted for 24% and 500 m-buffered human disturbance made up only 9% (note the "total disturbance" footprint is less than the sum of fire and human disturbance due to overlapping footprints; Government of the Northwest Territories 2019). The model used to define critical habitat for boreal caribou treats fire disturbance as a binary variable, with fires ≤40 years old considered as disturbed habitat, and those >40 years old considered as undisturbed (Environment Canada 2011). This classification is consistent with how wildfires were included as a covariate in the national and ecozone-specific RSF models developed by Environment Canada (2011), which found that boreal caribou consistently avoided fires <40 years old on an annual time scale. Avoidance of fire-disturbed habitat by boreal caribou has been attributed to either increased predation risk due to preference for recent fires by alternate prey such as moose (Courtois et al. 2007, Courbin et al. 2013), or to reduced availability of lichens, which are the primary winter forage of caribou (Schaefer and Pruitt Jr 1991, Dunford et al. 2006). The description of biophysical attributes of critical habitat for the Taiga Plains ecoregion (Environment Canada 2012, Table H-1 therein) suggests, however, that boreal caribou may select recently burned habitat in calving, post-calving and rutting seasons. This finding is likely based on Nagy et al. (2005), who found that boreal caribou used burns 10-29 years old more than expected by chance between June and November in the Gwich'in region of the NWT, and on evidence from traditional knowledge studies of boreal caribou from different regions of the NWT (Benson 2011, Dehcho First Nations 2011, Species at Risk Committee 2012).

There is also some skepticism that 40 years is an appropriate cut-off at which fires become undisturbed habitat again, given the shorter growing season and colder climate which may delay post-fire succession in the north. Less productive growing conditions may delay the period during which fires are attractive to alternate prey species such as moose, and delay the recovery of winter forage species for boreal caribou, which are mainly slow-growing terrestrial and arboreal lichens. However, there is recent evidence suggesting that fires may not contribute significantly to apparent competition between moose and boreal caribou, at least in some regions. DeMars et al. (2019) found that moose avoided fires ≤25 years in both upland and peatland habitat within boreal caribou ranges in northern British Columbia, Alberta, and Saskatchewan, but avoidance for burned peatlands was generally stronger than for burned uplands. They also found that there was no relationship between moose density and the proportion of

fires ≤40 years old within a moose survey unit. Similarly, McLoughlin et al. (2019) found that high levels of fire disturbance do not necessarily lead to a high availability of early-seral deciduous or mixedwood forests suitable for moose. They also found that boreal caribou populations can be self-sustaining in ranges with high levels of fire disturbance, and that lichens can recover after fires as early as 35-years post-disturbance. These findings all point to the need to better understand the role of fire in boreal caribou habitat selection, distribution and demographics, given that it is the dominant source of disturbance with the NT1 range.

Although anthropogenic disturbance makes up a smaller proportion of the total disturbance footprint within the NT1 range, previous studies within the NWT have found that it may affect boreal caribou habitat selection and movement behavior (Nagy et al. 2005, Nagy 2011, Stantec Consulting Ltd 2014). A review of traditional knowledge on boreal caribou also indicates that industrial development is thought to be responsible for the largest impacts on boreal caribou in some regions of the NWT, and that boreal caribou are relatively intolerant of noise, light and habitat disturbance from industrial activities (Species at Risk Committee 2012). Seismic lines account for the vast majority (~84%) of linear disturbance within the NT1 range, whereas public and industry all-season and winter roads, pipeline and utility corridors account for <16% (based on Environment and Climate Change Canada's 2015 anthropogenic disturbance data). Polygonal human disturbances are primarily from settlements, mining, oil and gas and timber harvesting, but contribute much less to the human disturbance footprint than linear features. Both Nagy et al. (2005) and Stantec Consulting Ltd (2014) found that boreal caribou avoided areas with higher densities of linear features, and were less likely to use areas close to seismic lines or where roads are present. The strength of avoidance of seismic lines by boreal caribou appears to vary according to the time of year, density of seismic lines, and predator/alternate prey diversity (Nagy 2011, also summarized in Species at Risk Committee 2012). Boreal caribou in the southern part of the NWT range (Dehcho and South Slave regions) avoided seismic lines more strongly in the summer, whereas caribou in the northern part of the range (Gwich'in region) avoided them during winter (Nagy 2011). The length of the avoidance period was longer where there was a higher density of seismic lines and a higher diversity of predators and alternate prey (Nagy 2011). Females also crossed seismic lines less than expected by chance, traveled faster when they did cross them, and used areas >400 m from seismic lines more than expected by chance during the avoidance period when they had access to such areas (i.e., when seismic line density was low enough that areas >400 m away from lines were available; Nagy 2011). To date, there has not been an evaluation of how boreal caribou respond to human-created polygonal disturbances in the NWT.

The objectives of this project are to gain a better understanding of how land-cover type, fire and human habitat disturbance influences seasonal habitat selection patterns of boreal caribou across the NT1 range, and to generate predictive maps of seasonal habitat selection to help identify important areas for boreal caribou and support the development of regional boreal caribou range plans within the NWT. Specifically, we sought to:

- Evaluate whether boreal caribou habitat selection varies according to fire age, and whether the fire occurred in upland versus lowland land-cover types;
- Evaluate whether selection for different post-fire age classes and land-cover types varies across different seasonal activity periods for boreal caribou; and,

- Evaluate whether habitat selection depends on the density or distance to different types of human disturbance.

METHODS

Study Area

The study area for this project was defined by a combination of the GNWT`s 2016 version of the NT1 boreal caribou range boundary, the extent of available collar data from different NWT boreal caribou monitoring programs (which includes areas within adjacent boreal caribou ranges in northern Alberta and northeastern British Columbia) and the extent of EOSD land-cover data (Wulder et al. 2008) that was updated by the GNWT and Natural Resources Canada (NRCan) in 2007 and 2010 (Natural Resources Canada and Government of Northwest Territories 2017; Fig. 1). The study area boundary was primarily defined by the extent of the circa 2007/2010 EOSD land-cover dataset, which covers the majority of the NT1 boreal caribou range except the northwestern corner of the range that extends into the Yukon territory, and the southeastern corner of the range which falls within Wood Buffalo National Park. Most of the western edge of the circa 2007/2010 EOSD data set extends beyond the western edge of the NT1 range boundary, but given some uncertainty about the western extent of the range it was not clipped to the range boundary. The eastern extent of the EOSD data also extends several kilometers east of the NT1 range boundary; however south of Great Bear Lake it extends significantly beyond the range boundary into the Taiga Shield ecoregion. Within this area south of Great Bear Lake, the NT1 range boundary was buffered by 15 km, and the edge of the buffer was used to clip the extent of the EOSD layer to keep it within a similar distance of the range boundary as the remainder of the study area. The NT1 range boundary is also clipped to the shoreline of Great Bear and Great Slave lakes; however, telemetry data and traditional knowledge indicate that there are offshore islands along within these lakes that are used by boreal caribou. To capture these areas, an internal buffer of 15 km was created within Great Bear and Great Slave lakes, and the EOSD layer was clipped to include a 15 km swath along the shore of each lake. The interior of Great Bear and Great Slave lakes beyond this 15 km buffer were omitted from the study area to prevent a large proportion of random locations used in the RSF analyses from falling within these lakes.

The study area encompasses five regional monitoring areas for boreal caribou: Inuvik, Sahtu, Dehcho, North Slave, and South Slave (Fig. 2). These regions are further divided into ten sub-regions (region in which the sub-region occurs in brackets): Gwich'in North (Inuvik), Gwich'in South (Inuvik), Sahtu (Sahtu), Dehcho North (Dehcho), Dehcho South (Dehcho), North Slave (North Slave), Mackenzie (South Slave), Hay River Lowlands (South Slave), Pine Point-Buffalo Lake (South Slave), and Cameron Hills (South Slave).

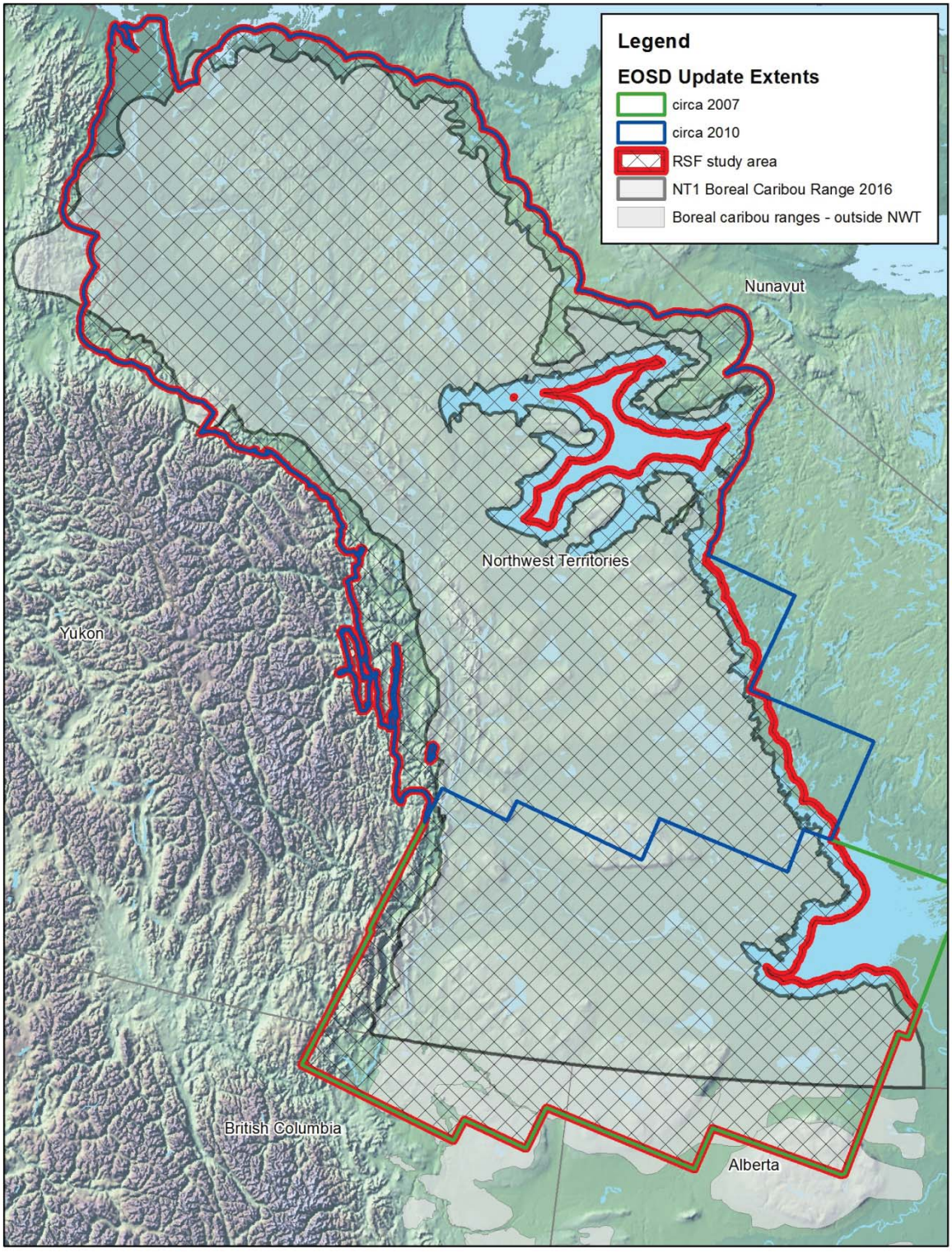


Figure 1: Study area for boreal caribou RSF analyses and predictive mapping (cross-hatched area). Study area boundaries were defined based on a combination of the extent of circa 2007 and 2010 EOSD land-cover data, the NT1 boreal caribou range boundary, and an interior buffer of 15 km along the shorelines of Great Bear and Great Slave lakes.

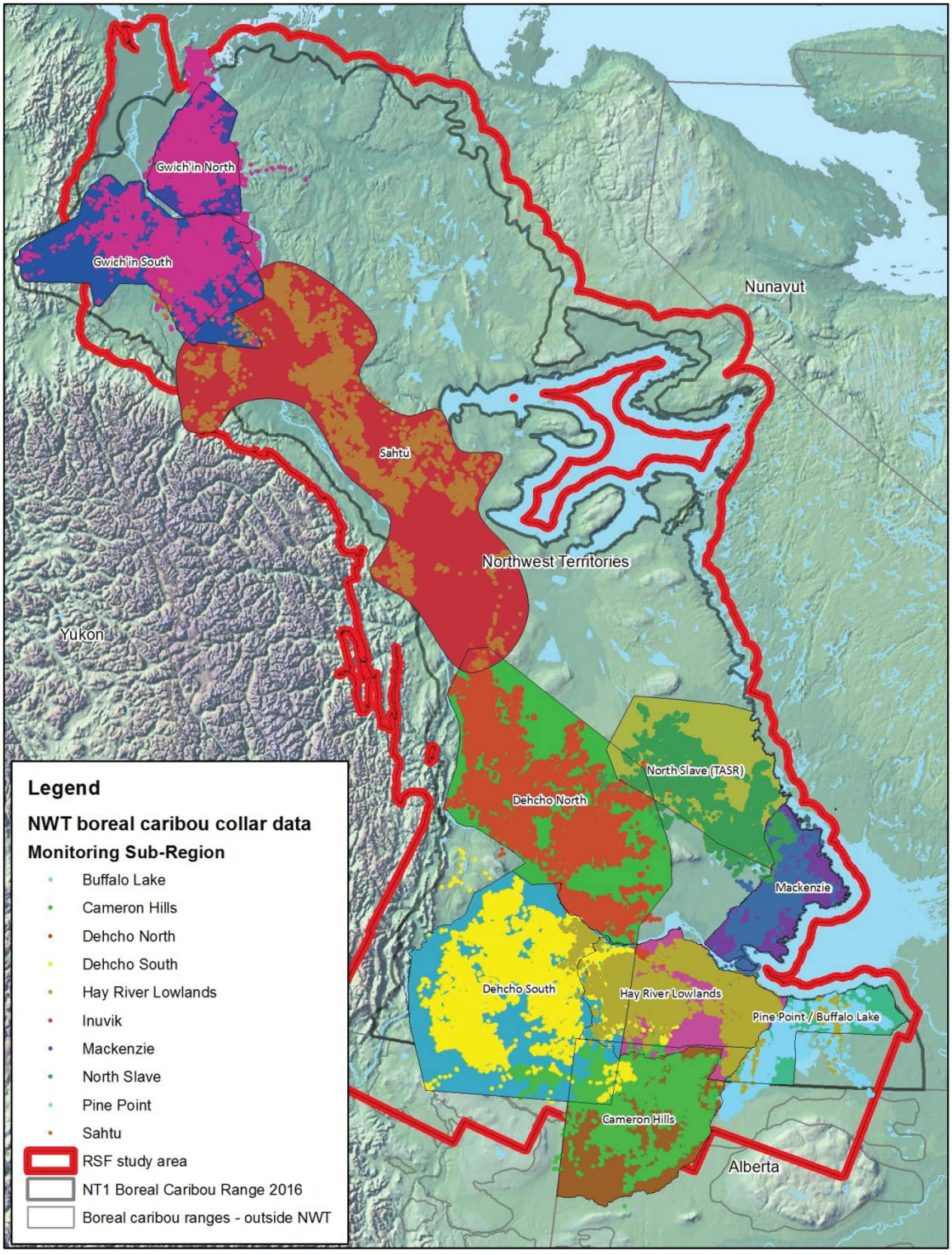


Figure 2: Regional boreal caribou monitoring areas within the NWT and extent of collar data from each sub-region (different coloured points represent collar locations from individuals collared within each sub-region).

Caribou Spatial Data

We used GPS location data collected from radio-collared boreal caribou captured in the Northwest Territories and monitored for various periods between 1 May 2002 and 31 March 2018. These data were accessed from the Movebank data repository (https://www.movebank.org/) where they were initially screened to exclude duplicate records, pre- and post-deployment locations (i.e., locations recorded when the collar was not on the animal), and erroneous locations that exceeded biologically plausible movement (see Appendix A). For our analyses, we excluded any locations that fell outside of the study area. This initial data set included 681,561 GPS locations distributed among 435 individual caribou (regional breakdown: Dehcho = 147 caribou, Inuvik = 43, North Slave = 25, Sahtu = 20, South Slave = 200). The mean monitoring interval per collar was 690 days (SD = 479, minimum = 3, maximum = 1969).

The acquisition rate of GPS locations (i.e., the fix rate) varied among radio-collars, ranging from one location per hour to one location every five days (for Doppler-shift collars), and many collars had fix rates that varied seasonally. Because we used statistical techniques that accounted for unequal sample sizes among individual caribou, we did not standardize the data to a common fix rate (e.g., every five days). However, within a given season (see *Defining Seasons* below), we standardized each individual's data set by subsampling to the collar's coarsest fix rate, which minimized potential spatiotemporal bias when inferring seasonal resource selection. To ensure a consistent sampling interval within the time-series of each individual-season, we assigned a missing value to locations removed by Movebank's screening procedures or when a scheduled GPS fix was not recorded by the radio-collar. To further minimize potential spatiotemporal bias, we also excluded individuals that were not monitored for at least half of the seasonal interval. For analyses using data across the entire year, we also excluded those individuals monitored for ≤231 days, a threshold where estimated sizes of annual home ranges reached an asymptote (see *Evaluating Resource Selection: General Framework* and Appendix B). From these data, we calculated the fix success rate (number of recorded GPS fixes / number of scheduled GPS fixes) of each individual collar for each season-year. For the seven seasons considered, the mean fix success rate was 0.88 for calving, 0.85 for summer, 0.88 for early fall, 0.88 for late fall, 0.88 for early winter, 0.90 for mid-winter and 0.91 for late winter (Table 1). Across caribou-years, the mean fix success rate was 0.90. For all analyses of resource selection, we excluded individual season-years with fix success rates <90% as rates below this threshold may result from habitat-induced biases (e.g., higher fix success rates in some land-cover types versus others), which can impact inferences on resource selection (Frair et al. 2010). Additional information on data screening and further statistics detailing radio-collar performance can be found in Appendix A.

Prior to analyses, we elected to exclude data from caribou in the Mackenzie sub-region. This area experienced large fires that occurred in 2014 and 2015 and radio-collars were deployed on caribou after these fires. Because much of the area available to these caribou consisted of these recent burns, we expected that the inclusion of the Mackenzie data might bias our models of resource selection towards recent burns. Exclusion of the Mackenzie caribou yielded final data sets of 448 caribou-seasons[1] for calving (*n* = 252 caribou), 336 caribou-seasons for summer (*n* = 211 caribou), 364 caribou-seasons for early fall (*n* = 221 caribou), 405 caribou-seasons for late fall (*n* = 242 caribou), 432 caribou-seasons for

[1] Many caribou were monitored for multiple years. A "caribou-season" refers to the number of caribou monitored within the season of interest within a given year.

early winter (*n* = 268 caribou), 623 caribou-seasons for mid-winter (*n* = 340 caribou), 659 caribou-seasons for late winter (*n* = 350 caribou), and 301 caribou-years (*n* = 194 caribou) for analyses conducted over the entire year (Table 1).

Table 1: Summary statistics of fix success rates (FSR) for radio-collars deployed on boreal caribou in the Northwest Territories and monitored between May 2002 and March 2018.

		FSR				FSR >90%		Final Data Set (FSR >90%;Mackenzie caribou excluded)	
Time Period	No. of Season-Years[†]	$\bar{x}$	SD	Min.	Max.	No. of Season-Years	No. of Caribou	No. of Season-Years	No. of Caribou
Calving	873	0.88	0.14	0.08	1.00	480	276	444	249
Summer	737	0.85	0.17	0.08	1.00	371	238	336	211
Early Fall	699	0.88	0.15	0.22	1.00	396	247	364	221
Late Fall	681	0.88	0.18	0.15	1.00	446	270	405	242
Early Winter	741	0.88	0.17	0.11	1.00	478	301	432	268
Mid-Winter	912	0.90	0.16	0.13	1.00	677	373	623	340
Late Winter	1001	0.91	0.14	0.18	1.00	718	383	659	350
All Year	1201[δ]	0.90	0.09	0.55	1.00	338	222	301	194

[†] The number of season-years meeting the minimum monitoring threshold for each season.

[δ] For All Year analyses, this value refers to the number of caribou-years

Evaluating Resource Selection: General Framework

We evaluated seasonal selection of habitat by boreal caribou using resource selection functions (RSFs), a widely used modelling approach that compares environmental attributes (or resources) associated with GPS (or "used") locations to environmental attributes of random (or "available") locations generated within the spatial scale of interest (Manly et al. 2002). Collectively, the environmental attributes considered are those thought to be important indicators of a species' habitat requirements. Individual attributes may be selected or avoided by the species. Selection occurs when the proportion of used locations associated with a given attribute is higher than the proportion of random locations associated with the same attribute (i.e., random expectation); avoidance occurs when use is proportionally lower than random expectation.

We estimated RSFs for caribou at second- and third-order scales (*sensu* Johnson 1980; Figs.3–4). Second-order selection generally evaluates how areas are selected within a population's range. Because spatial delineations of boreal caribou populations within the Northwest Territories are not well-defined, we used expert input from regional government biologists to define availability at this scale. We considered caribou occurring within the Inuvik and Sahtu monitoring regions to be part of a Northern group and caribou occurring within the Dehcho, North Slave and South Slave monitoring regions to be

part of a Southern group. For each group, we defined availability by fitting a minimum convex polygon (MCP) around all GPS locations pooled from radio-collared caribou within the group (Fig. 3; note: caribou GPS locations were all those available post-screening procedures and included caribou from the Mackenzie sub-region). We then buffered each MCP by 15-km, which approximated the maximum distance that caribou moved in a 24-hr period based on the GPS data (Appendix B), and clipped these buffered MCPs to the boundaries of the study area. Seasonal RSFs at a second-order scale therefore entailed a comparison of resources associated with caribou GPS locations falling within a given seasonal period to resources associated with random locations sampled within these buffered MCPs (Fig. 3).

Third-order selection evaluated how caribou selected seasonal areas within their annual home ranges (Fig. 4). For each individual caribou, the annual home range defined availability at this scale and we estimated home ranges using kernel density estimates (KDEs; also called utilization distributions; Worton 1989, Börger et al. 2006, Fleming et al. 2015), which represent a probability surface of an animal's space use (i.e., the probability of relocating an animal at a given spatial coordinate). Compared to MCPs, KDEs provide more robust estimates of animal home ranges because they are less sensitive to changes in collar fix rates and do not include areas where animal use may be low, which can occur with MCPs (Worton 1987, Börger et al. 2006). We estimated KDEs using recently developed methods that account for the autocorrelation that is inherent in GPS location data (Fleming et al. 2015). KDEs were calculated using all GPS locations collected from an individual caribou during a biological year, which we defined as starting on 1 May, a date that corresponds to the onset of the calving season, and ending on 30 April. We used the 95% isopleth (or contour line) from the KDE to spatially delineate the annual home range. Third-order RSFs therefore entailed a comparison of resources associated with caribou GPS locations falling within a given seasonal period to resources associated with random locations sampled within these estimated annual home ranges (Fig. 4). Because KDEs—and other home range estimators—are sensitive to monitoring time (i.e., the length of time an animal is monitored; Börger et al. 2006), we conducted a sensitivity analysis to determine the minimum monitoring time required for estimates of home range size to stabilize (Appendix B). This analysis suggested that the estimated area of annual KDEs stabilized after 231 days; therefore, we excluded caribou-years that did not meet this threshold from third-order resource selection analyses.

For each RSF scale, we used random points to sample availability. Because the number of random points sampled can influence RSF results (Northrup et al. 2013), we conducted sensitivity analyses to determine the minimum number of random points that needed to be sampled per caribou for RSF coefficients to stabilize (Appendix C). Based on these analyses, we used 3000 random points per caribou sampled within each population-level MCP for second-order RSFs and 3000 random points sampled within each individual caribou's annual home range for third-order RSFs.

Defining Seasons

In temperate climates, seasonal changes in resources (e.g., forage, thermal cover, refugia) and life history status (e.g., breeding versus the birthing season) can alter how a species selects habitat throughout the year (Nielsen et al. 2003, McLoughlin et al. 2010). We therefore evaluated how resource selection by boreal caribou potentially changed across seasonal periods that were thought to be biologically relevant for caribou. To identify such periods, we evaluated for breaks in the year-long distribution of mean daily movement rates (m/hr) of caribou in the Northern and Southern groups (Appendix D). To reduce potential spatial bias in movement behaviour (e.g., animals in one area may move more than those in another area), mean rates of daily movement were calculated across

individual caribou within each monitoring region (Dehcho, North Slave, South Slave, Inuvik and Sahtu). We then fit a generalized additive model to each group's data (Northern [Inuvik and Sahtu] and Southern [Dehcho, North Slave and South Slave]) and used the model predictions in a piecewise (or segmented) regression to identify break points in the temporal distribution of movement rates. These break points were assumed to be indicative of seasonal changes in caribou behaviour. Results from this analysis suggested minor differences in seasonal movement behaviour between the two regions with Southern caribou calving earlier and experiencing longer summers and shorter winters. The final delineation of seasons considered these results and seasons were further adjusted based on expert input from regional government biologists as well as seasonal delineations from other studies on boreal caribou (Ferguson and Elkie 2004a, Nagy 2011, Rudolph and Drapeau 2012). Eight seasons were identified—pre-calving dispersal, calving, summer, early fall, late fall, early winter, mid-winter, and late winter—with the start and end dates varying between the Northern and Southern groups (Table 2). Of these seasons, we developed RSF models for seven, excluding pre-calving dispersal when caribou movement rates are generally highest as females are dispersing to solitary calving sites (Ferguson and Elkie 2004b). We also developed an all-year model which included collar locations from throughout the year, including the pre-calving dispersal season.

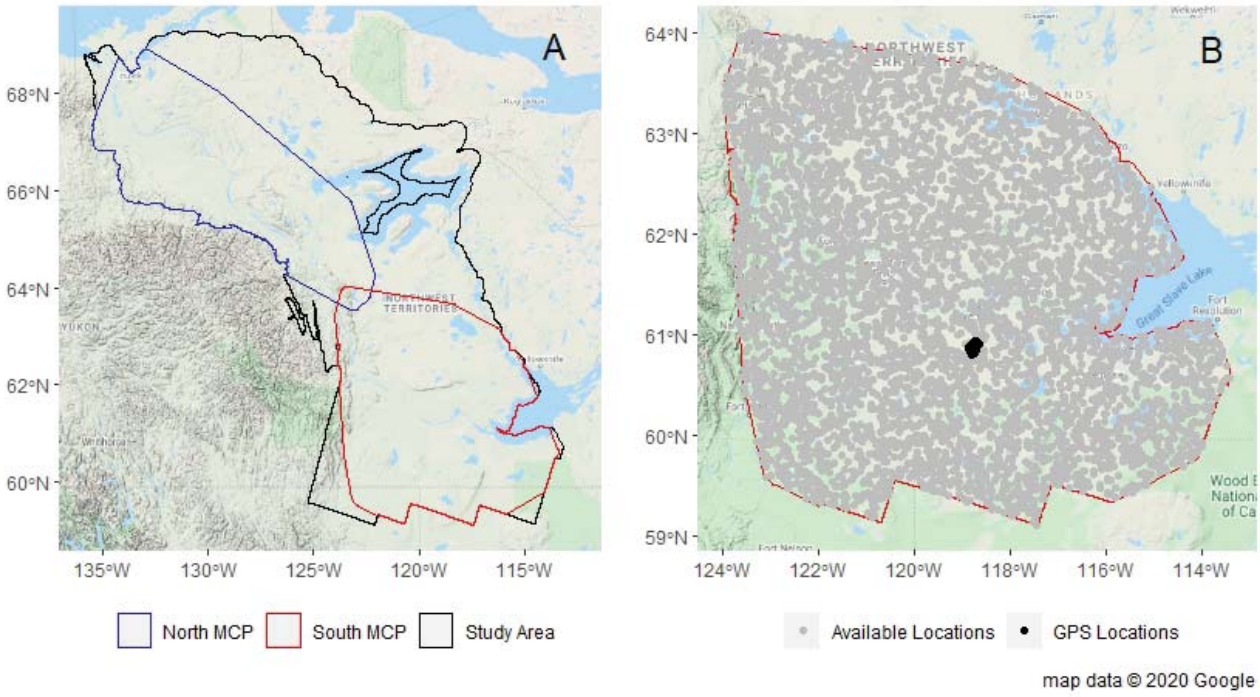


Figure 3: The spatial scale of second-order selection. Availability at this scale was delineated by two 100% minimum convex polygons (MCPs): one fit around all GPS locations from caribou in the Southern group and one fit around all GPS locations from caribou in the Northern group (panel A). These MCPs were then buffered by 15-km, the estimated maximum distance caribou moved in a 24-hr period. In panel B, GPS locations collected during the calving season for an individual caribou from the Southern group are shown within the South MCP. Availability within each MCP is sampled using random locations.

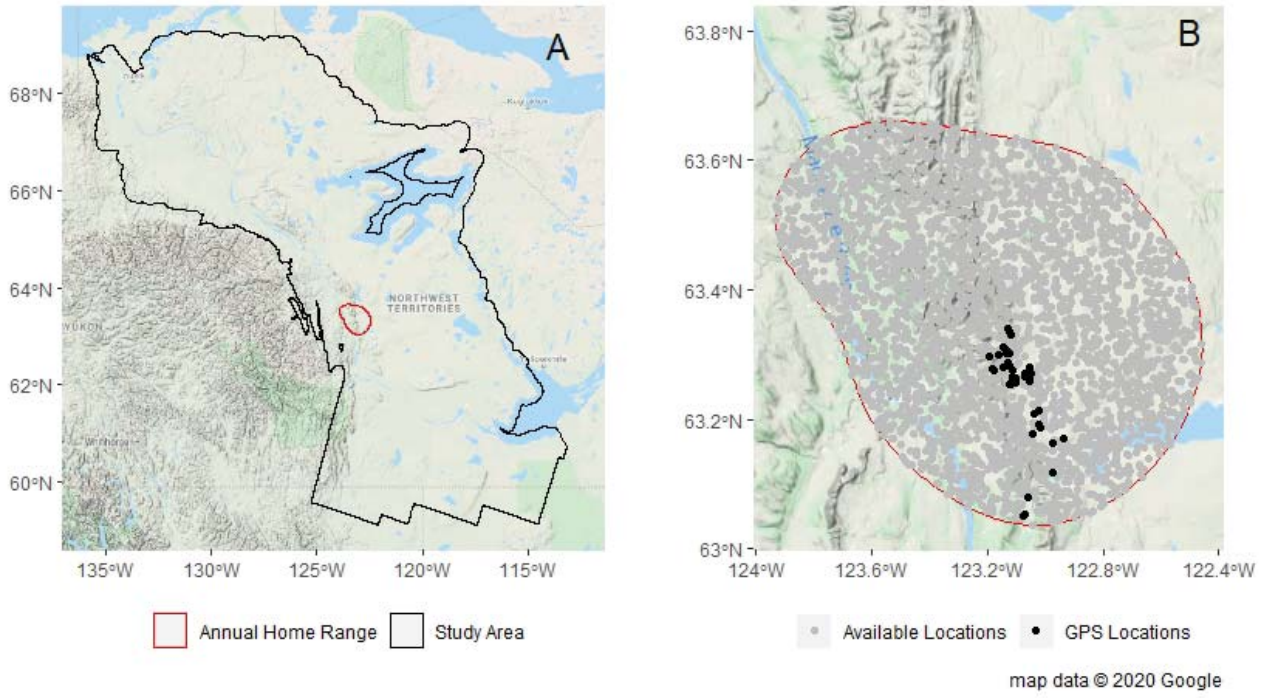


Figure 4: The spatial scale of third-order selection. For each individual caribou, availability at this scale is defined by the annual home range, which is characterized by the 95% isopleth (or contour line) of a kernel density estimate calculated using all of an individual's GPS locations collected during a biological year (1 May–30 April). In panel A, the estimated annual home range of an individual caribou is shown within the study area. In panel B, GPS locations collected during the calving season for this individual caribou are shown within the annual home range. Availability within the home range is sampled using random locations.

Table 2: Seasonal delineations for modelling resource selection by boreal caribou in the Northwest Territories.

	Region			
	South		North	
Season	Date Range	No. of Days		No. of Days
Pre-calving Dispersion[†]	2 Apr–30 Apr	28	6 Apr– 30 Apr	24
Calving	1 May–30 Jun	60	1 May–12 Jul	72
Summer	1 Jul–12 Sept	73	13 Jul–8 Sept	57
Early Fall	13 Sep–20 Oct	37	9 Sept–25 Sept	16
Late Fall	21 Oct–30 Nov	40	26 Sept–25 Oct	29
Early Winter	1 Dec–25 Jan	55	26 Oct –12 Jan	78
Mid-Winter	26 Jan–15 Mar	48	13 Jan–21 Mar	67
Late Winter	16 Mar– 1 Apr	16	22 Mar–5 Apr	14

[†] RSF models were not developed for pre-calving dispersion

Environmental Variables

We used circa 2007/2010 EOSD land-cover data (Natural Resources Canada and Government of Northwest Territories 2017; Fig. 5) to characterize different land-cover types available to boreal caribou. The original EOSD land-cover data (Wulder et al. 2008), which included 21 different land-cover classes, was generated from Landsat satellite data at a 25-m resolution and reflected land-cover across Canada's forested ecozones as they existed in circa year 2000. The GNWT and NRCan updated the EOSD data within the Taiga Plains ecozone of the NWT in three phases (Natural Resources Canada and Government of Northwest Territories 2017). Phase 1 (circa 2007) covered the southern NWT and was undertaken using Landsat TM imagery from 2006 to 2008. Phase 2 and 3 (circa 2010) covered the northern portion of the Taiga Plains ecozone and was undertaken using Landsat TM imagery collected from 2007 to 2013. The updated EOSD layer (circa 2007/2010) was validated using a large collection of aerial survey data, forest inventory datasets and high resolution satellite imagery, and represented the most up-to-date and validated land -over data available for the Taiga Plains ecozone. The extent of the circa 2007/2010 EOSD data generally exceeded the extent of the NT1 boreal caribou range boundary, and captured the majority of the extent of collar data available for boreal caribou within the NWT. Small portions of the northwestern and southeastern corners of the NT1 range were not covered by the updated EOSD data, and were omitted from the study area for this project. The 2007/2010 EOSD data contains 24 land-cover classes, 23 of which occur within the study area (the "Broadleaf Sparse" class was deemed absent from the Taiga Plains). The "Snow/Ice", "Rock/Rubble", "Exposed land", and "Developed" categories were combined into a "Non-Vegetated" category, which accounted for ~1% of the study area. Areas classified as "NoData", "Shadow", and "Cloud" represented ~0.04% of the study area and were also collapsed into the "Non-Vegetated" category.

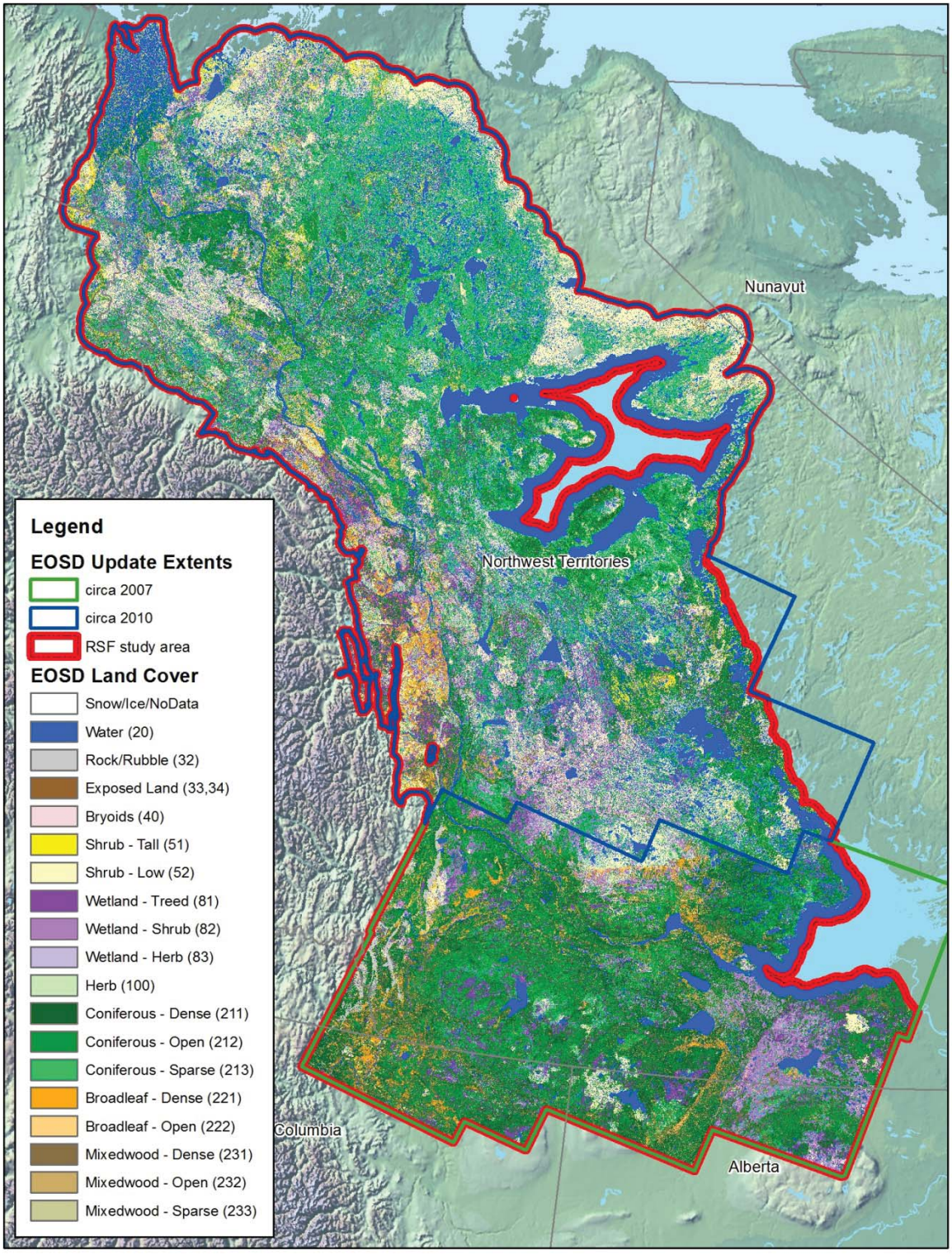


Figure 5: Earth Observation for Sustainable Development (EOSD) land-cover data updated using circa 2007 (area outlined in orange) and circa 2010 (area outlined in blue) Landsat TM imagery.

We accessed two data sources to model historical fires in the study area. For fires occurring between 1955 and 1985, we accessed fire perimeter data (polygons) from the Canadian National Fire Database (NFDB; Natural Resources Canada: https://cwfis.cfs.nrcan.gc.ca/ha/nfdb). For fires occurring between 1986 and 2017, we accessed fire perimeter data from the National Burn Area Composite (NBAC; Natural Resources Canada: http://cwfis.cfs.nrcan.gc.ca/datamart/datarequest/nbac; 2017b; Skakun et al. 2017; Fig. 6). Both datasets represent a compilation of fire boundaries provided by provinces, territories and Parks Canada. The NBAC data provides more precise fire polygons for fires occurring from 1986 onwards, using a semi-automated process that compares Landsat TM imagery before and after fires occur and excludes residual unburned terrestrial habitat and water bodies within the fire polygons. The combined NFDB/NBAC data set was converted from polygons to raster format. Where there were overlaps between fire polygons from different years, we assigned the most recent fire year to the raster cell value.

Anthropogenic disturbance within the study area (Fig. 7) was based on linear and polygonal disturbance features mapped from 30-m resolution Landsat imagery by ECCC in 2010 (methodology described in Appendix 7.2 of Environment Canada (2011)) and 2015 (Environment and Climate Change Canada: http://data.ec.gc.ca/data/species/developplans/2015-anthropogenic-disturbance-footprint-within-boreal-caribou-ranges-across-canada-as-interpreted-from-2015-landsat-satellite-imagery/). The 2015 data did not cover the entire extent of the study area, leaving small gaps near the southern boundary. Where such gaps existed, we backfilled the 2015 data with data from 2010. Polygonal disturbances included cutblocks, mines, reservoirs, built-up areas, well sites, agriculture, oil and gas facilities, and unknown features. Linear disturbances included roads, railways, powerlines, seismic exploration lines, pipelines, dams, air strips, and unknown features. As the public road network within the NWT represents the only type of linear feature that has seen continuous vehicular traffic throughout the duration of the collar data, we were particularly interested in how they influenced habitat selection. We used major road segments merged from the National Road Network data (Natural Resources Canada: https://open.canada.ca/data/en/dataset/2dac78ba-8543-48a6-8f07-faeef56f9895) from across the NWT, Yukon, Alberta and BC to represent the public road network, as the ECCC human disturbance data does not distinguish between public vs. private sector roads.

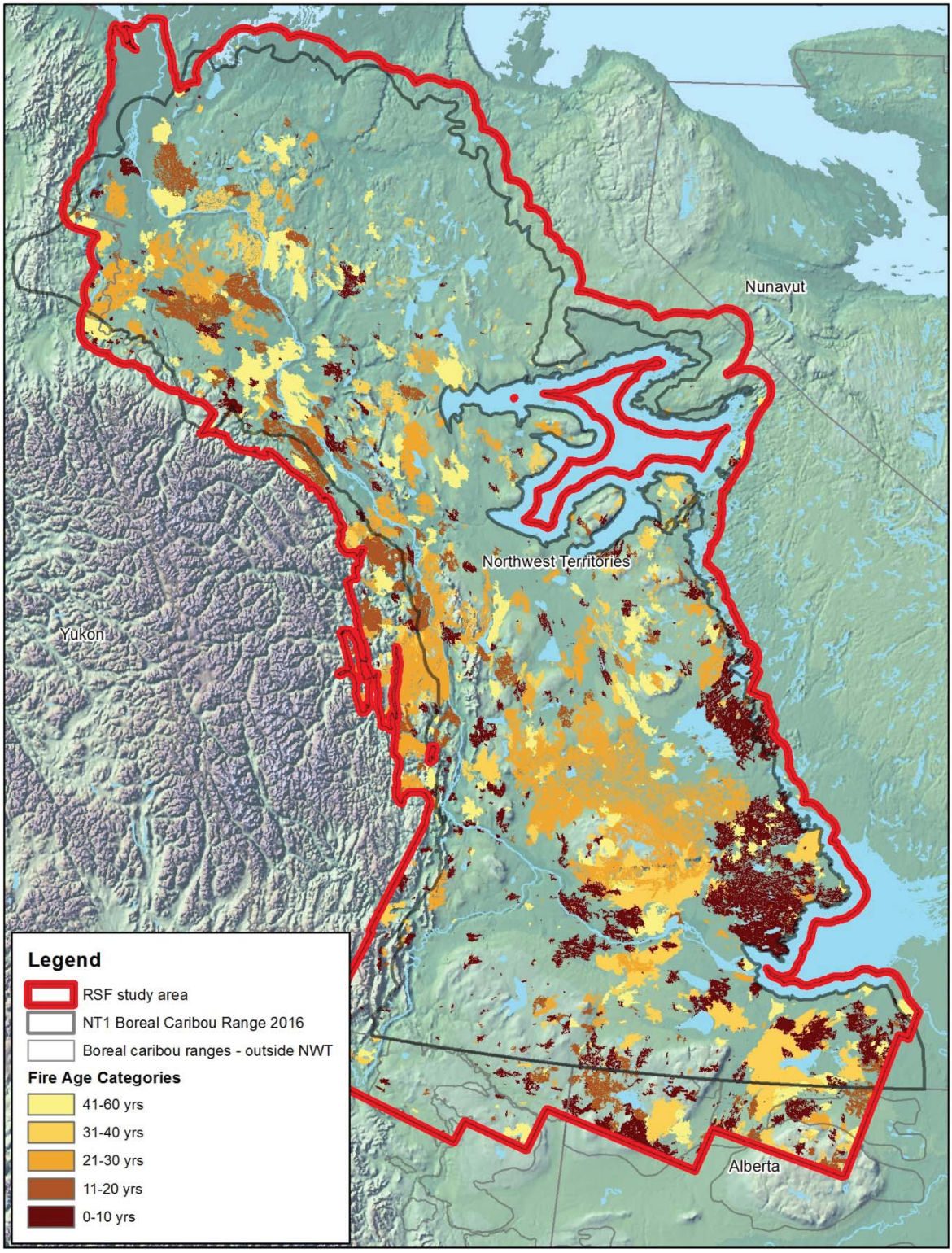


Figure 6: Fires by decadal age category within the study area based on fire polygons from 1955-1985 the Canadian National Fire Database, and fire polygons from 1986-2017 from National Burn Area Composite data. Fire age categories displayed in the figure were calculated based on a reference year of 2017.

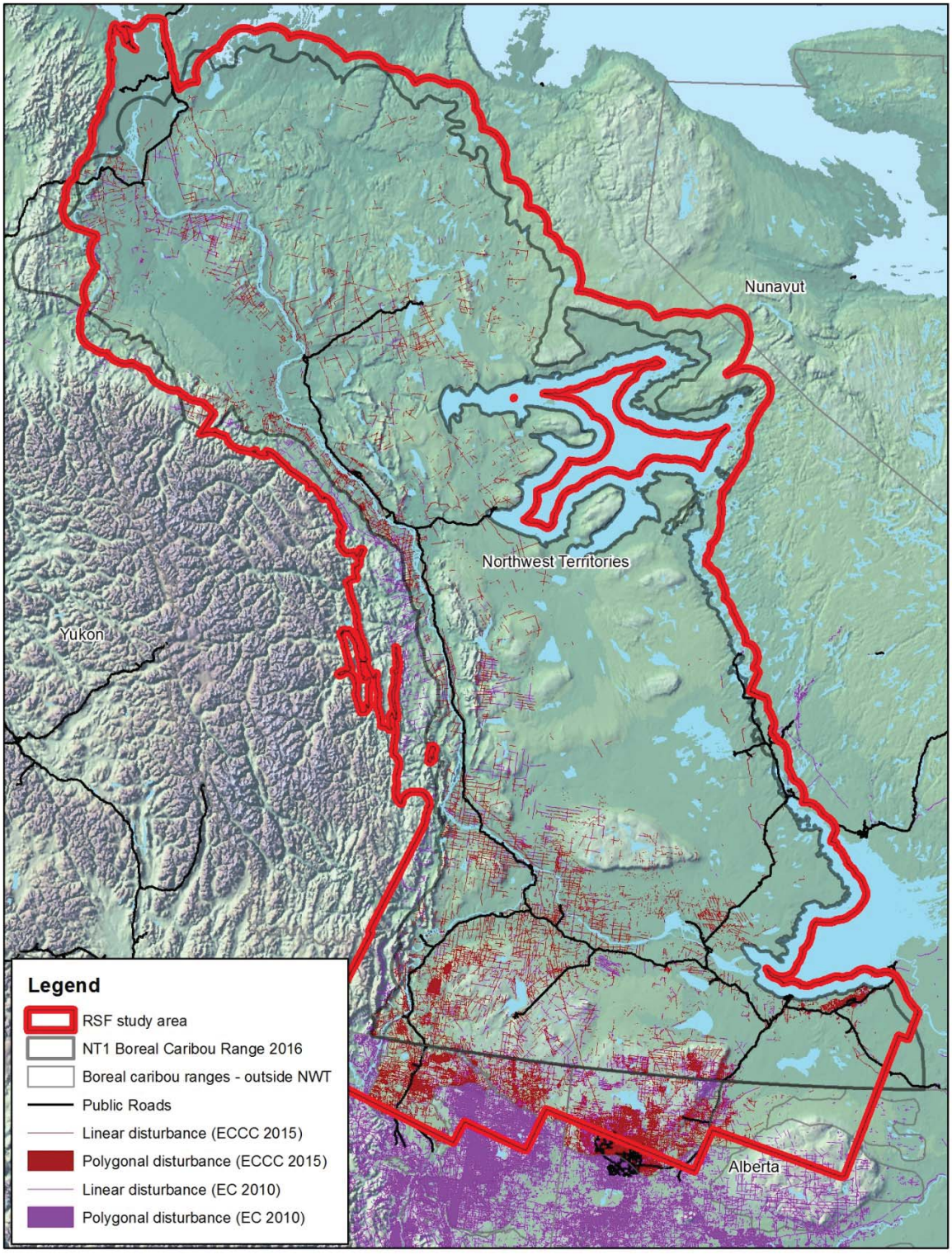


Figure 7: Linear and polygonal anthropogenic disturbance as mapped by ECCC in 2010 and 2015, and the public road network within the RSF study area.

Data Analyses

We estimated seasonal RSFs using generalized linear mixed effect models (GLMMs; Gillies et al. 2006, Zuur et al. 2009), which account for the hierarchical structure inherent in GPS location data (i.e., caribou are grouped within a monitoring sub-region, each caribou has a unique set of GPS locations) and unequal sample sizes among individual caribou. For all second- and third order GLMMs, we assigned individual caribou-year as a random grouping effect (i.e., a random intercept). These models took the form

$$ln\left[\frac{\pi(y_i=1)}{1-\pi(y_i=1)}\right] = \beta_0 + \beta_1 x_{1ij} + \ldots + \beta_n x_{nij} + \gamma_{0j} \qquad \text{(Eqn. 1; Gillies et al. 2006)}$$

where the left-hand side of the equation is the logit transformation for location y_i, β_0 is the fixed-effect intercept, β_n is the fixed-effect coefficient for each resource covariate x_n, and γ_{0j} is the random intercept for caribou-year j. From this base model, we also tested for hierarchical (or "groups within groups") structures of random grouping effects. We considered caribou-year grouped within monitoring sub-region, caribou-year grouped within the subpopulations defined for second-order RSFs analyses (i.e., North and South), and a three-level structure with caribou-year grouped within monitoring sub-region grouped within North or South group. Using the summer data, which constituted the longest season for the more data-rich Southern group, we fit second-order RSFs with each of these random-effect structures—keeping the fixed-effect structure the same for all models—and used Akaike's Information Criterion (AIC) to identify the structure with the most explanatory power (Zuur et al. 2009). The top model structure was caribou-year grouped within monitoring sub-region with this structure being 1.3 AIC units lower than the three-level structure and >57 AIC units lower than the other two structures [note: lower AIC values equate to better model performance; Burnham and Anderson 2002). Although the three-level structure was competitive with the top structure, the additional complexity did not significantly improve model performance (Arnold 2010). We therefore used caribou-year grouped within monitoring sub-region as the random effects structure and kept this structure constant across all RSF models to make seasonal comparisons of model outputs more straightforward.

The fixed-effect coefficients of the GLMMs yield insights as to how a typical caribou selects resources and can be interpreted within the classic use-availability design of

$$\omega(x_i) = \exp(\beta_1 x_1 + \beta_2 x_2 + \ldots \beta_n x_n) \qquad \text{(Eqn. 2; Manly et al. 2002)}$$

where $\omega(x_i)$ is the relative selection value of a resource unit (or pixel) in category i as a function of the explanatory covariates (x_n) and their estimated coefficients (β_n). We caution that robust inferences on caribou response to specific covariates usually requires fitting GLMMs with random coefficients for each covariate of interest (i.e., random slopes) as random-intercept-only GLMMs produce standard errors that are too narrow and do not reflect the individual animal as the sampling unit (Schielzeth and Forstmeier 2009, Muff et al. 2020). Fitting a maximal GLMM (i.e. a random slope for each covariate; Barr et al. 2013), however, was computationally infeasible with our large data set. Nonetheless, outputs from random-intercept-only GLMMs can be useful for generating predictions of animal space use (Schielzeth and Forstmeier 2009) and a primary objective of our project was to generate predictive maps of seasonal space use by caribou.

To assess how resource selection varied seasonally, we used the same fixed-effects structure for each seasonal RSF at both the second- and third-order scales (Table 3). We developed this model structure using summer data at a second-order scale and considered explanatory covariates that included local land-cover type (the EOSD data; 30-m pixel scale), landscape context variables, burn variables, and four variables characterizing anthropogenic disturbance: linear feature density, distance-to-major road, distance-to-polygonal disturbance, and distance-to-settlement. For variables with time-dependent data sets, we matched the time stamp of the caribou location to the appropriate data set. For example, caribou locations occurring in 2010 and earlier were matched to ECCC 2010 disturbance data whereas caribou locations occurring after 2010 were matched to ECCC 2015 disturbance data. Similarly, burn age variables (see below) were matched to time stamp of the caribou location (e.g. for a caribou location occurring in 2007, a fire that burned in 1995 would be classified as 12 years old). For local land-cover type, we created a binary variable for each type and set 'conifer dense' as the reference category by omitting it from the models. For landscape context, we calculated the proportion of each land-cover type in a 1-km radius around each 30-m pixel in the study area. We then estimated univariate RSFs with each landscape context variable and used AIC to select the variable with the most explanatory power. Because variables with a broadleaf component were four of the top five variables and all were negative, we combined the proportions of 'broadleaf dense', 'broadleaf open', 'mixedwood open', and 'mixedwood dense' into one landscape variable describing the proportion of forest with a broadleaf component in a 1-km radius. We retained this variable and the proportion of 'spare conifer forest' in a 1-km radius, which showed the strongest selection by caribou among landscape context variables, for all seasonal RSF models.

For burns and linear feature density, we considered multiple formulations of each variable and used AIC to identify the formulation with the most explanatory power. For burns, we considered four formulations:

i. a decadal formulation where burns were partitioned into age classes (1–10 years old, 11–20 years old, 21–30 years old, 31–40 years old and 41–60 years old) but the type of land-cover burned was not considered (hereafter, 'burn-decade-only');

ii. a decadal formulation with the above age classes but also identified whether the burn was in an upland conifer forest (EOSD categories 'conifer dense' and 'conifer open'), upland broadleaf forest (EOSD categories 'broadleaf dense', 'broadleaf open', 'mixedwood open', and 'mixedwood dense'), non-treed upland (EOSD categories 'bryoids', ' tall shrub', and 'short shrub') or lowland (EOSD categories 'treed wetland', 'shrub wetland', 'herb wetland', 'herb', and 'sparse conifer forest') (hereafter, 'burn-decade-by-land-cover');

iii. a continuous formulation that interacted the four broad land-cover classes above (upland conifer, upland broadleaf, non-treed upland and lowland) with time since fire (in years) (hereafter, 'continuous-by-land-cover');

iv. a continuous formulation that interacted the four broad land-cover classes above (upland conifer, upland broadleaf, non-treed upland and lowland) with time since fire (in years) as a quadratic (hereafter, 'quadratic-by-land-cover').

In the first two formulations, burns—and their interactions with land-cover—became new local land-cover types. Among the four formulations, the 'burn-decade-by-land-cover' (formulation ii above) had

the most explanatory power as it was >1200 AIC units lower than the next best formulation ('burn-decade-only'; note: as a general rule, only models within 2 AIC units are considered suitable for inference, Burnham and Anderson 2002). We therefore used the 'burn-decade-by-land-cover' formulation in all subsequent RSF models.

For linear feature density, we considered two formulations: one where density was measured in a 400-m radius and one where it was measured in a 1-km radius. The smaller radius reflects a common spacing for natural resource exploration lines (i.e., seismic lines) whereas the larger radius reflects the most common metric for quantifying linear feature density (km/km^2). To determine which scale was more relevant to predicting caribou space use, we estimated univariate RSFs with each variable and compared AIC values. Caribou response was stronger for the 1-km radius (>1000 AIC units lower) and we retained this scale for all seasonal RSFs.

For the remaining anthropogenic disturbance variables—distance-to-major-road, distance-to-polygonal-disturbance, and distance-to-settlement—, we used exponential decay transformations to place increased emphasis on areas in close proximity to the feature (Nielsen et al. 2009; Fig. 8). These transformations took the form

$$1 - e^{-\alpha d} \qquad \text{(Eqn. 3; Nielsen et al. 2009)}$$

where d is the distance (in meters) to the feature and α is the decay rate. By subtracting the decay function from 1, distances at the feature have a value of 0 whereas very large distances away from the feature have values approaching 1. We consulted the available literature to determine appropriate values for α for each variable. For distance-to-major-road, Leblond et al. (2011) found that boreal caribou in Quebec avoided roads by 1.25-km so we set α at 0.0025, which caused values to erode precipitously beyond 1.25-km. For distance-to-polygonal-disturbance, caribou response has varied depending on the type of disturbance (e.g. well pad versus cut block) and responses have varied by subpopulation (Johnson et al. 2015). Given that reported values ranged from 1-km (Smith et al. 2000) to >13-km (Vors et al. 2007, Boulanger et al. 2012), we used a conservative value of 0.003 for α, which resulted in values decaying rapidly after 1-km. For distance-to-settlement, Polfus et al. (2011) suggested that northern mountain caribou avoided settlements by 3-9-km, depending on the season. We therefore set α at 0.000625, which resulted in values decaying rapidly after an intermediate distance of 5-km. We acknowledge that further research is likely warranted to determine the potential zone of influence for various types of disturbances on boreal caribou in the Northwest Territories.

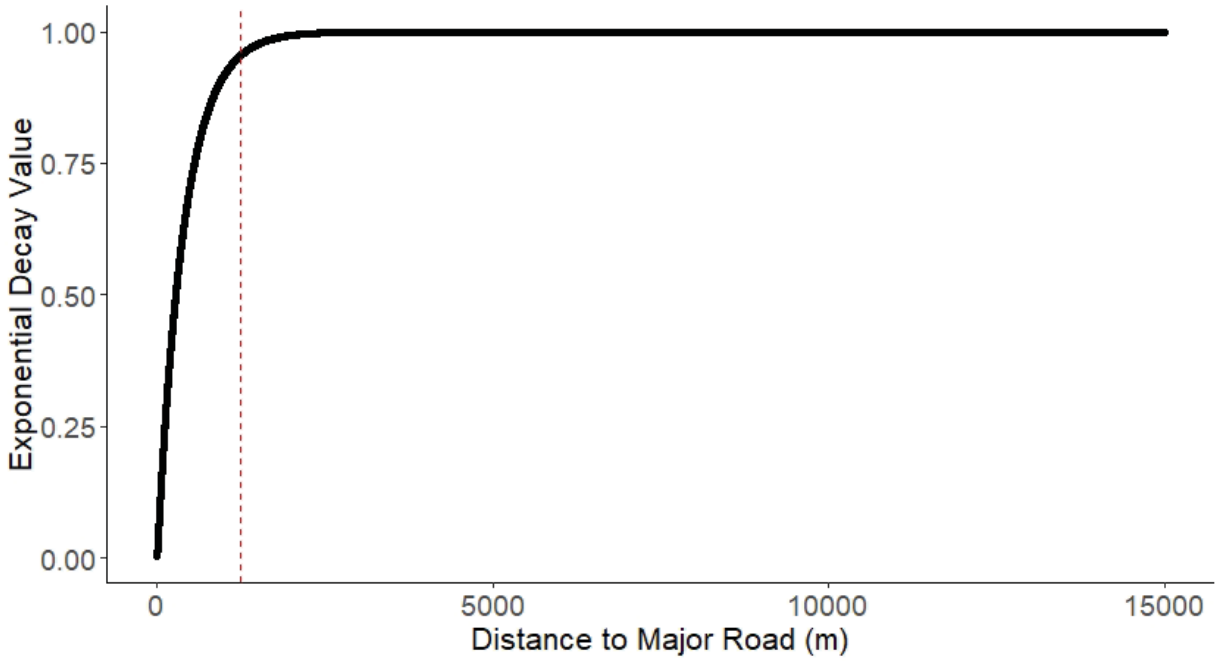


Figure 8: Example of an exponential decay transformation applied to a continuous "distance-to" variable. For distance to major roads, the shape parameter (or α) of the exponential decay function (see Eqn. 3 in main text) was set to 0.0025 to ensure that distances beyond 1250-m (red dashed line) decayed rapidly and transformed to similar values.

For each seasonal RSF, we assessed predictive performance using *k*-fold cross validation (Boyce et al. 2002). This iterative process entailed randomly partitioning the data by individual caribou into five folds, using four folds (i.e., data from 80% of the individuals) to estimate the RSF (i.e., the training set), then testing model predictions on the GPS locations from withheld caribou (i.e., the testing set). We tested model predictions using two different methods, which primarily differed in how RSF values were partitioned into discrete bins (Fig. 9). In the first, which we term model-based cross validation, we used the fixed-effects output from the RSF (Eqn. 2) to predict values for the random locations and the GPS locations for each individual caribou in the testing set. Recall that the random locations for each individual caribou index that individual's spatial domain of availability—at the second-order scale, availability was the buffered MCPs created for the Northern and Southern groups whereas the third-order scale, availability was an individual's annual home range. For each caribou, predicted values for the random locations were partitioned into decile bins (i.e., 10 ordinal bins containing an equal number of random locations) and we then calculated the number of caribou GPS locations falling within each bin. The frequency of caribou GPS locations within each bin were summed across all testing caribou and model prediction was assessed by comparing the proportional frequency of predicted values for caribou locations falling within a bin to bin rank using Spearman's correlation coefficient (r_S; DeCesare *et al.* 2012). In the second method, which we term map-based cross validation, we used random locations (*n* = 40,000) sampled from the combined North and South MCPs (Fig. 9). As with the other method, we used the fixed-effects from the RSF to predict values for these random locations, partitioned these into decile bins, then calculated $\bar{r}_S$ by comparing the proportional frequency of predicted values of testing caribou locations falling within a bin to bin rank. For all seasonal RSFs, we completed 10 iterations of the validation process then calculated $\bar{r}_S$ for each method with higher $\bar{r}_S$ values indicating better predictive performance. The two methods yield different inferences. Model-based cross validation assesses predictive performance while allowing for changing availability (i.e., availability is specific to each caribou) whereas map-based cross validation assesses predictive performance when binning is conducted over a larger area that is constant across caribou. Lower $\bar{r}_S$ values for model-based validation compared to map-based validation may be indicative of functional responses in resource selection (i.e., selection changes as a function of availability; Mysterud and Ims 1998).

We used RSF outputs and the most recent year of data available for each resource covariate (e.g., 2017 for fire data) to generate seasonal predictive maps of caribou habitat selection. These maps covered the entire extent of the study area (Fig. 1). For each map, we partitioned the pixels (30-m resolution) into 10 bins to improve visual interpretation of seasonal resource selection by caribou (Morris et al. 2016). Cut points between bins were delineated using an approach as was done for k-fold cross validation. Specifically, outputs from a given RSF model were used to predict values for the random locations (*n* = 40,000) sampled within the combined North and South MCPs then these locations were partitioned into decile bins (i.e., 10 bins with each bin having an equal number of points, which equates to an equal-area binning approach; Morris et al. 2016). We also computed the selection ratio for each bin, defined as the proportion of caribou GPS locations falling within a bin divided by the bin's proportion of random points. Ratios > 1 indicate areas that are relatively selected (i.e., where caribou use exceeds random expectation) while ratios < 1 indicate areas that are relatively avoided.

We also evaluated the predictive performance of each seasonal map at a finer scale by assessing how well each map predicted caribou use within each monitoring sub-region. To do so, we used r_S to assess

the correlation between bin rank and the proportional frequency of caribou locations falling within each bin. As with *k*-fold cross validation, higher r_S values indicate better predictive performance.

All statistical analyses were performed in R and the code for estimating and validating second- and third-order RSFs is contained in Appendix E.

Table 3: Explanatory (fixed-effect) variables included in seasonal models of resource selection by boreal caribou in the Northwest Territories.

Variable Category	Variable Name	Variable Type
Local land-cover[†]	Bryoids	Categorical
	Tall shrub	Categorical
	Short shrub	Categorical
	Treed wetland	Categorical
	Shrub wetland	Categorical
	Herb wetland	Categorical
	Herb	Categorical
	Open conifer forest	Categorical
	Sparse conifer forest	Categorical
	Dense broadleaf forest	Categorical
	Open broadleaf forest	Categorical
	Dense mixedwood forest	Categorical
	Open mixedwood forest	Categorical
	Water	Categorical
	Non-vegetated	Categorical
	Burned lowlands (1-10 years old)	Categorical
	Burned lowlands (11-20 years old)	Categorical
	Burned lowlands (21-30 years old)	Categorical
	Burned lowlands (31-40 years old)	Categorical
	Burned lowlands (41-60 years old)	Categorical
	Burned upland conifer (1-10 years old)	Categorical
	Burned upland conifer (11-20 years old)	Categorical
	Burned upland conifer (21-30 years old)	Categorical
	Burned upland conifer (31-40 years old)	Categorical
	Burned upland conifer (41-60 years old)	Categorical
	Burned upland broadleaf (1-10 years old)	Categorical
	Burned upland broadleaf (11-20 years old)	Categorical
	Burned upland broadleaf (21-30 years old)	Categorical
	Burned upland broadleaf (31-40 years old)	Categorical
	Burned upland broadleaf (41-60 years old)	Categorical
	Burned upland non-treed (1-10 years old)	Categorical
	Burned upland non-treed (11-20 years old)	Categorical
	Burned upland non-treed (21-30 years old)	Categorical
	Burned upland non-treed (31-40 years old)	Categorical
	Burned upland non-treed (41-60 years old)	Categorical
Landscape context	Proportion of broadleaf (1-km radius)	Continuous
	Proportion of sparse conifer forest (1-km radius)	Continuous
Anthropogenic disturbance	Linear feature density (1-km radius)	Continuous
	Distance to nearest major road	Continuous
	Distance to nearest polygonal disturbance	Continuous
	Distance to nearest settlement	Continuous

[†] For local land-cover, conifer dense is the reference category in all resource selection models. Local land-cover not designated as "burned" are areas that have not burned within the last 60 years.

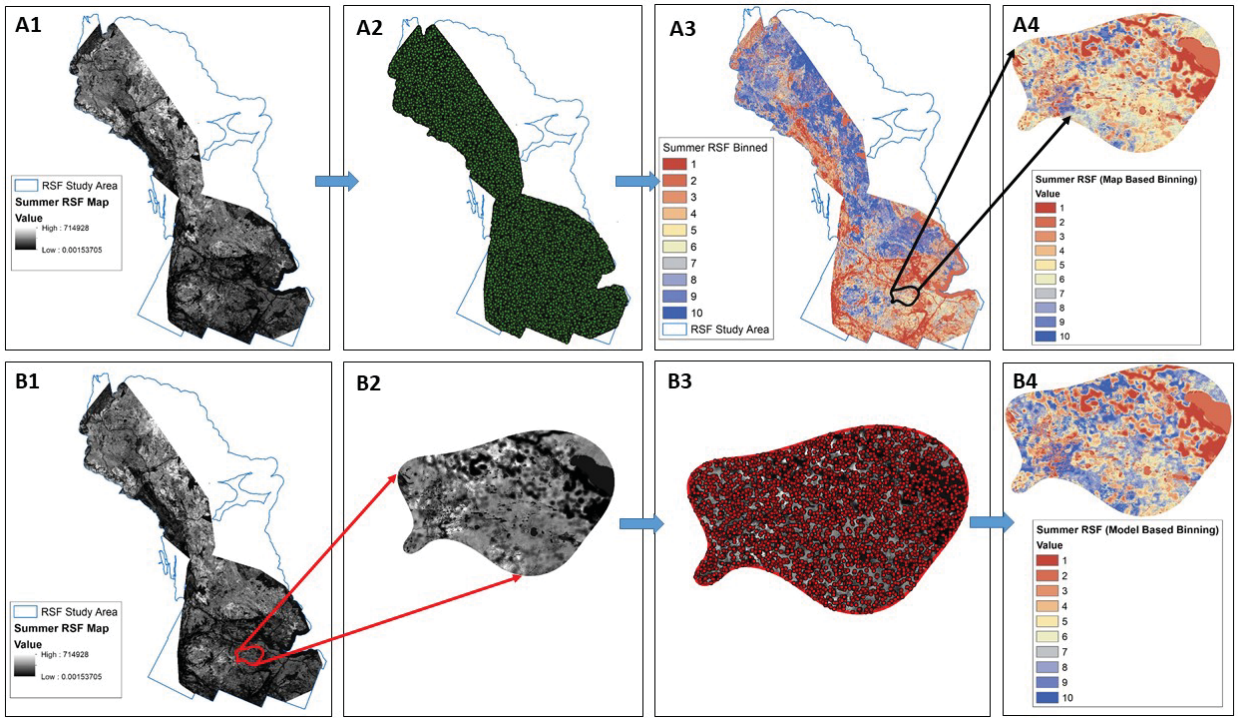


Figure 9: Schematic representation of map-based versus model-based *k*-fold cross validation at a third-order scale. In map-based validation, outputs from RSF models are used to generate predicted values of habitat selection by caribou within the MCPs of the Northern and Southern groups (A1). Random points are then used to sample these predicted values (A2). Based on these values, the random points are partitioned into decile bins and the cut points between bins are used to create a binned map (A3; i.e. 10 bins with each bin containing the same number of points. If 80,000 random points are generated, each bin would contain 8,000 points. Bin 1 would contain the points with the lowest 8,000 values; bin 10 would contain the top 8,000 values). A portion of this binned RSF map is shown clipped to the annual home range of an individual caribou (A4). In model-based validation, the unbinned RSF predictions are first clipped to the individual's home range (B1, B2). Random points are generated within the home range only (B3) and partitioned into decile bins as described above to create a binned map that is constrained to this home range (B4). Although the underlying RSF values remain the same, the two approaches differ in how these values are binned (compare B4 with A4). In both approaches, the proportional frequency of caribou locations falling within a bin is compared to bin rank.

RESULTS

Caribou Response to Local Land-cover

At both second- and third-order scales, boreal caribou demonstrated seasonal differences in resource selection. These differences were particularly evident in the responses of caribou to local land-cover (Figs. 10–17). In this section, caribou responses to burned local land-covers are presented first followed by their responses to unburned local land-covers.

Burned Local Land-cover

During the snow-free seasons (calving, summer and early fall), caribou showed relatively strong selection for burned land-covers. During calving, the five highest-ranked land-covers at the second-order scale were burns (lowland burn 1–10 years old, upland conifer burn 31–-40 years old, lowland burn 31–40 years old, non-treed burn 1–10 years old and upland broadleaf burn 31–40 years old) and four of the top six ranked land-covers at third-order scale were burns (lowland burn 1–10 years old, upland broadleaf burn 1–10 years old, non-treed burn 11–20 years old and upland conifer burn 11–20 years old).

During summer, burns remained highly selected as the six highest ranked land-covers at the second-order scale were burns, though the composition of types differed from calving with only lowland burns 1–10 years old, lowland burns 31–40 years old and upland conifer burns 31–40 years old being in the top-ranked set in both seasons. At the third-order scale during summer, burns comprised five of the eight highest ranked land-covers, with three of these burn classes being non-treed burns.

The trend of burns being highly ranked continued into early fall, though the age classes of these burns were generally older. At the second-order scale, the top three ranked land-covers were burns 31–40 years old situated in lowlands, upland conifer forest, and non-treed areas. This same age class was also represented in two of the top four ranked land-covers (non-treed and lowland burns) at the third-order scale. In late fall, caribou started to show decreasing selection for burns, particularly those of younger age classes (i.e., ≤30 years old). At the second-order scale, the top-ranked land-cover was lowland burns 31–40 years old but the next four highest-ranked were unburned classes. Burns with age classes ≤30 years old were generally ranked below the reference category (dense conifer forest), the exceptions being non-treed and lowland burns 1–10 years old. Third-order scale selection in early fall still had three of the top four ranked classes being burns but these were all >30 years old and either in lowlands or non-treed areas.

In the winter seasons, caribou selection for burns continued to weaken, particularly for burns ≤40 years old. In early winter, only one burn class—non-treed burns 41–60 years old—was among the top five ranked land-covers at the second-order scale. Two burn classes were among the top five ranked land-covers at the third-order scale but again these were burns >40 years old (lowland burns and non-treed burns 41–60 years old). In mid-winter, no burn classes were within the top five ranked land-covers at either scale as the burn class with the highest selection—41–60 years old burns in upland conifer forest— ranked eighth and ninth at the second- and third-order scales, respectively. This burn class was also the most selected burn class by caribou in late winter and was the second ranked land-cover at the second order scale.

Unburned Local Land-cover

Caribou also showed seasonal variation in the selection of non-burned land-covers (Figs. 10–17), though this variation was perhaps less pronounced than for burns. Among non-burned land-covers, bryoids, wetlands (treed, shrub, and herb) and conifer forests with minimal canopy cover (open and sparse) were generally among the top selected across all seasons and at both scales. Tall and short shrubs were also selected at rates higher than the reference class (dense conifer forest). Broadleaf forests, in contrast, were generally among the lowest ranked land-covers across all seasons and at both scales. Alongside these general trends, a few notable seasonable differences were evident. During calving and summer, caribou showed strong selection for herb and non-vegetated land-covers, particularly at the third-order scale whereas during mid- and late winter, caribou showed increasing selection for forested areas as mixedwood forests and dense conifer forest became more highly ranked.

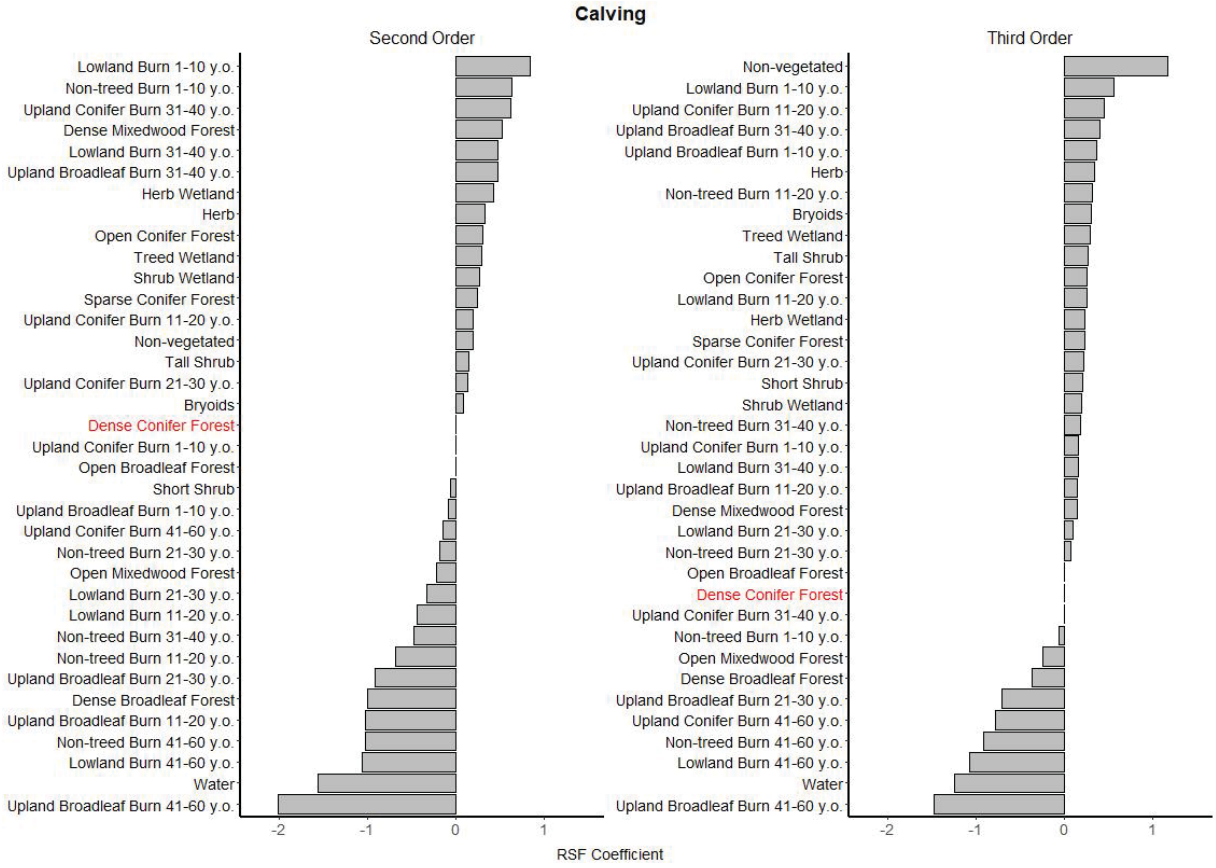


Figure 10: Model coefficients for land-cover variables (see Table 3) from resource selection functions estimated at second- and third-order scales during the calving season of boreal caribou in the Northwest Territories. Variables are ordered by their ranking relative to the reference category (dense conifer forest, shown in red).

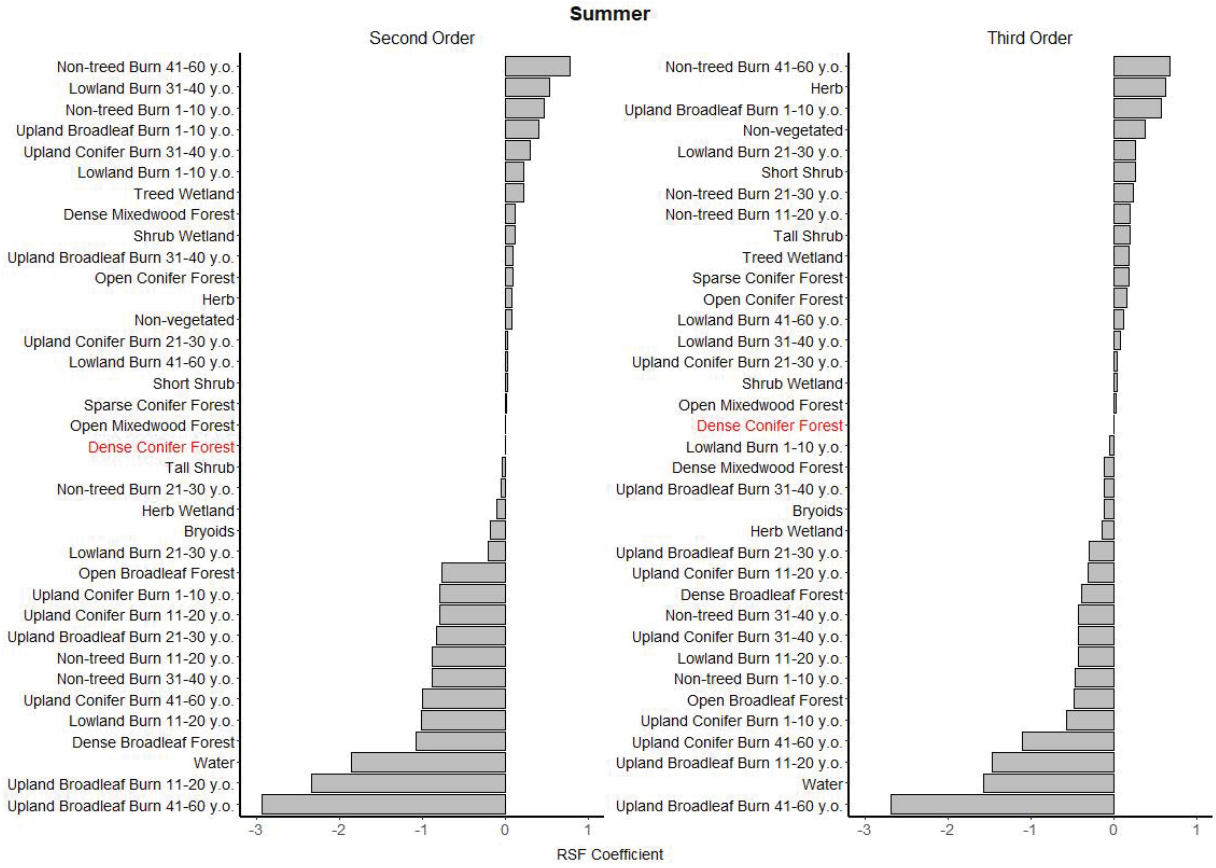


Figure 11: Model coefficients for land-cover variables (see Table 3) from resource selection functions estimated at second- and third-order scales during the summer season of boreal caribou in the Northwest Territories. Variables are ordered by their ranking relative to the reference category (dense conifer forest, shown in red).

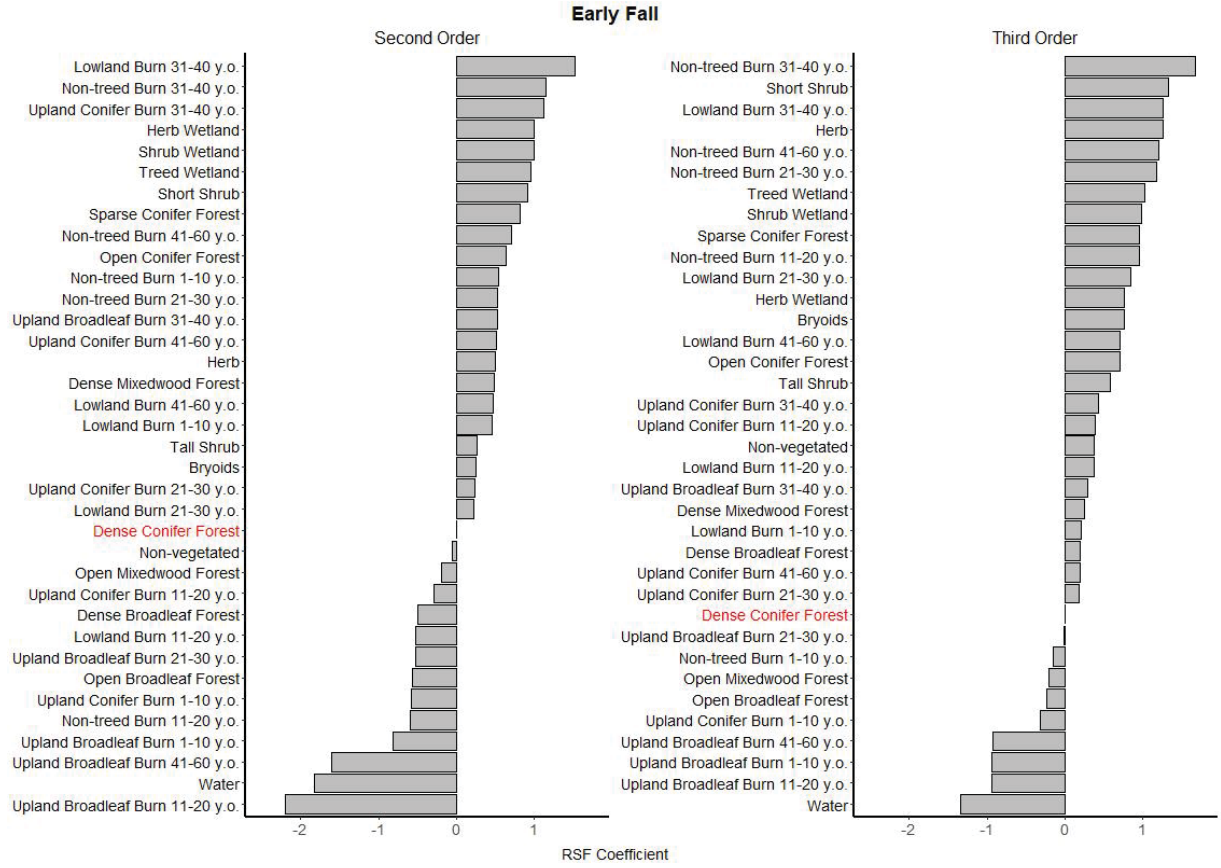


Figure 12: Model coefficients for land-cover variables (see Table 3) from resource selection functions estimated at second- and third-order scales during the early fall season of boreal caribou in the Northwest Territories. Variables are ordered by their ranking relative to the reference category (dense conifer forest, shown in red).

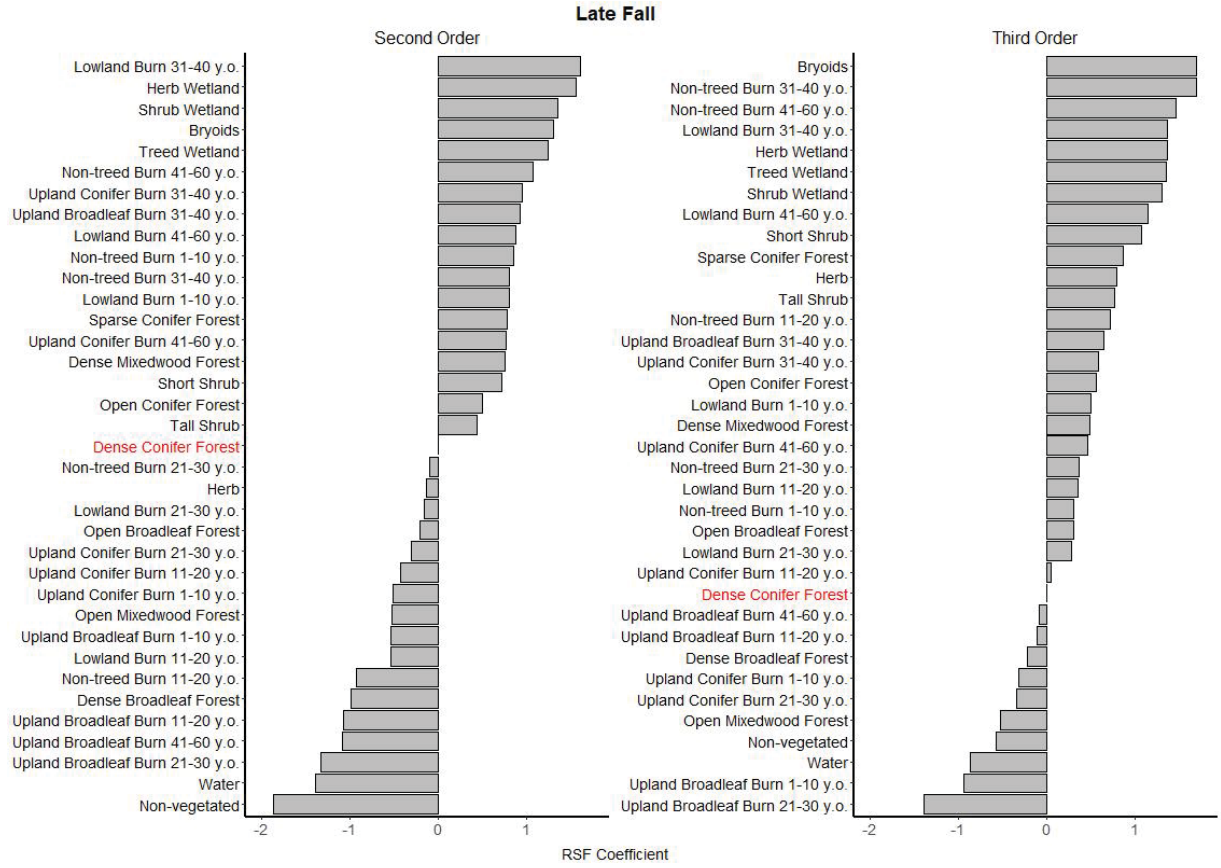


Figure 13: Model coefficients for land-cover variables (see Table 3) from resource selection functions estimated at second- and third-order scales during the late fall season of boreal caribou in the Northwest Territories. Variables are ordered by their ranking relative to the reference category (dense conifer forest, shown in red).

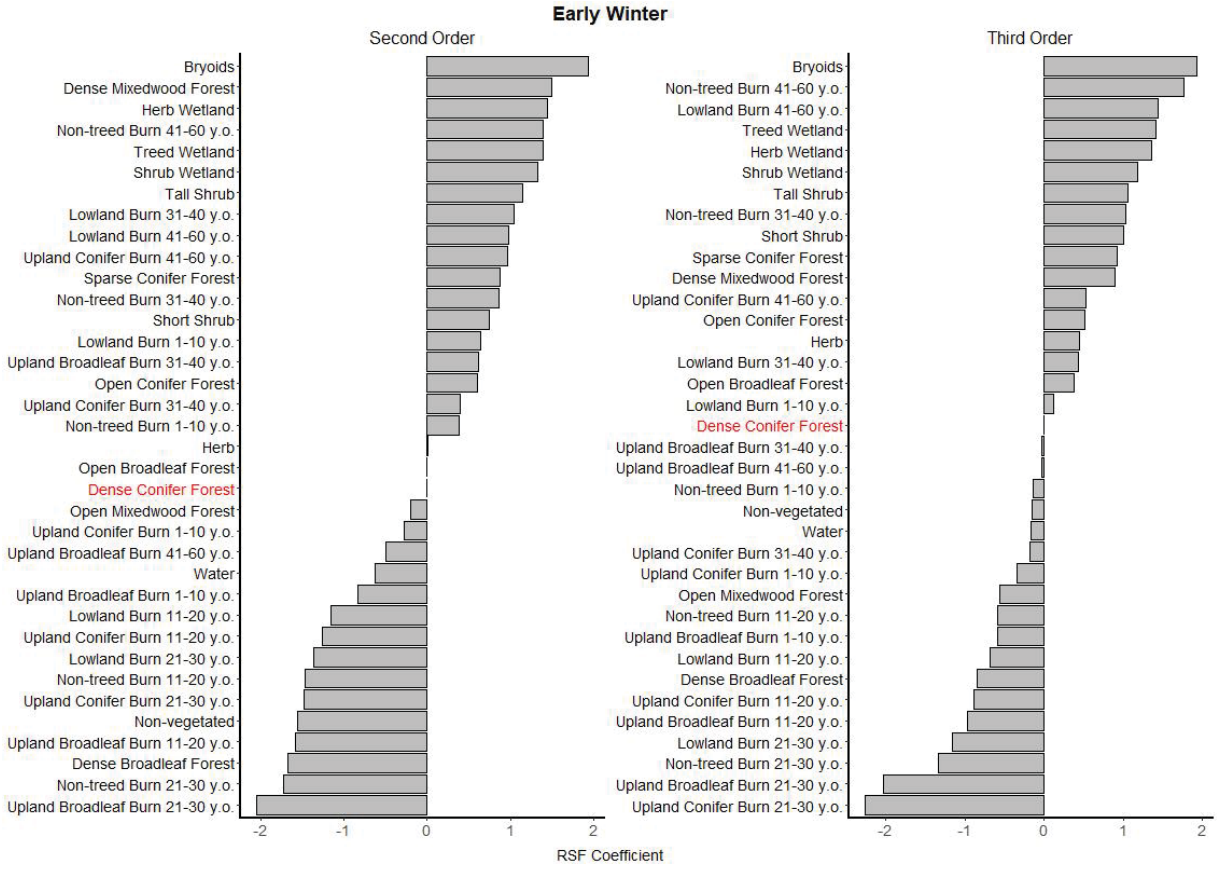


Figure 14: Model coefficients for land-cover variables (see Table 3) from resource selection functions estimated at second- and third-order scales during the early winter season of boreal caribou in the Northwest Territories. Variables are ordered by their ranking relative to the reference category (dense conifer forest, shown in red).

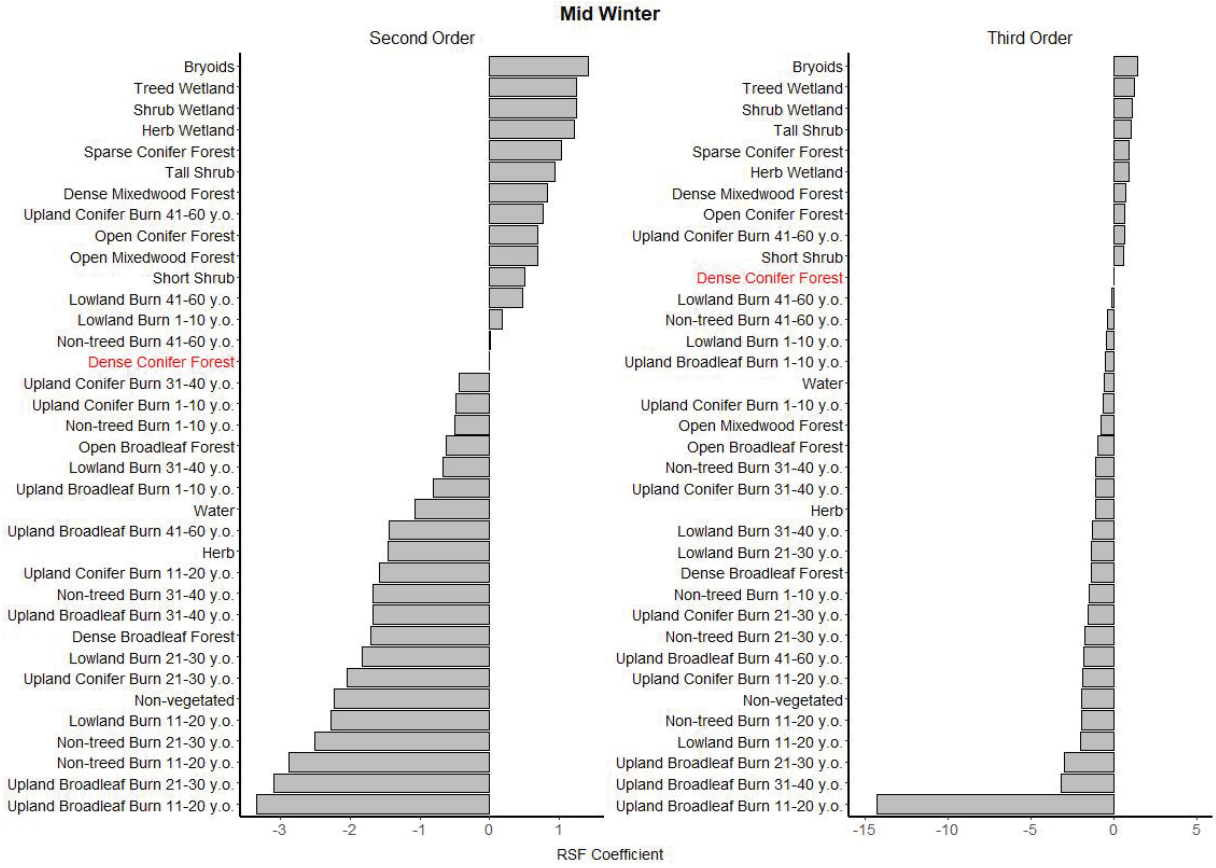


Figure 15: Model coefficients for land-cover variables (see Table 3) from resource selection functions estimated at second- and third-order scales during the mid-winter season of boreal caribou in the Northwest Territories. Variables are ordered by their ranking relative to the reference category (dense conifer forest, shown in red). Note that x-axis differs between second- and third-order bar charts.

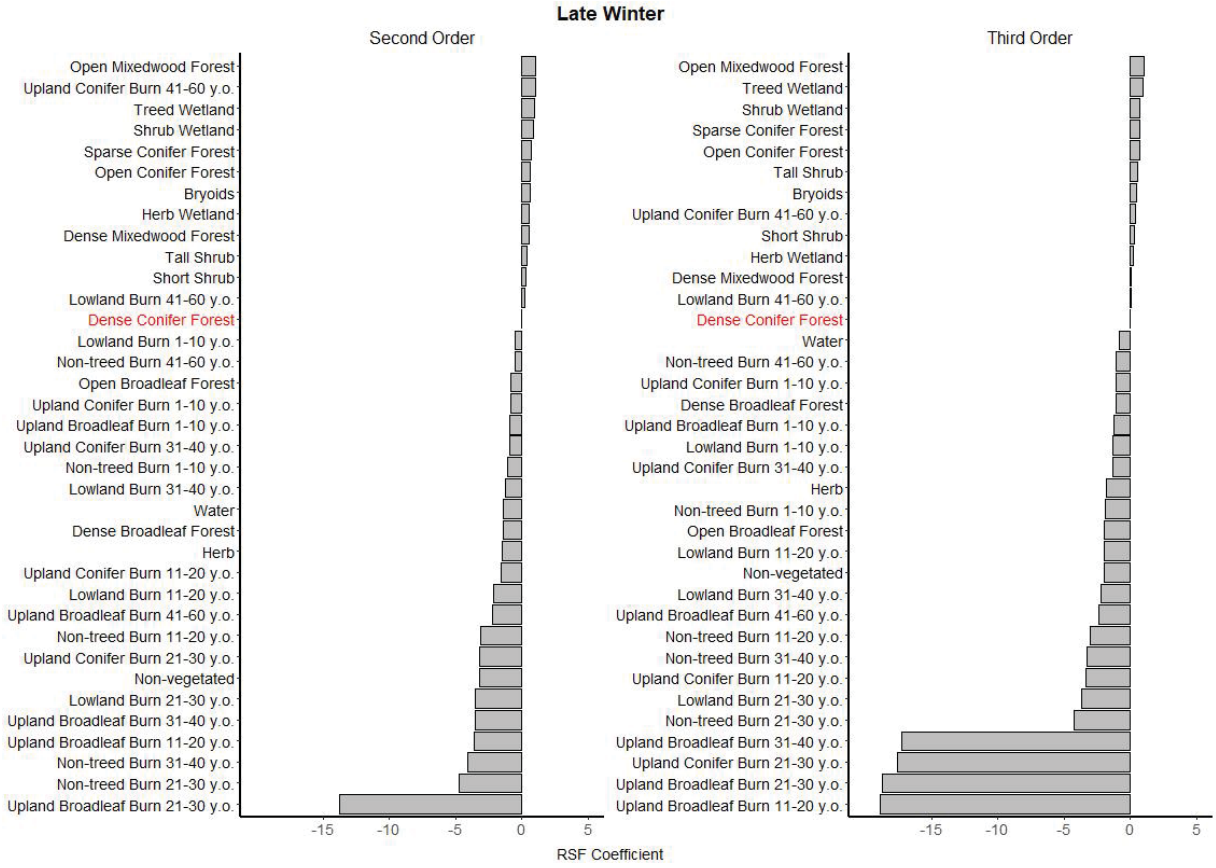


Figure 16: Model coefficients for land-cover variables (see Table 3) from resource selection functions estimated at second- and third-order scales during the late winter season of boreal caribou in the Northwest Territories. Variables are ordered by their ranking relative to the reference category (dense conifer forest, shown in red).

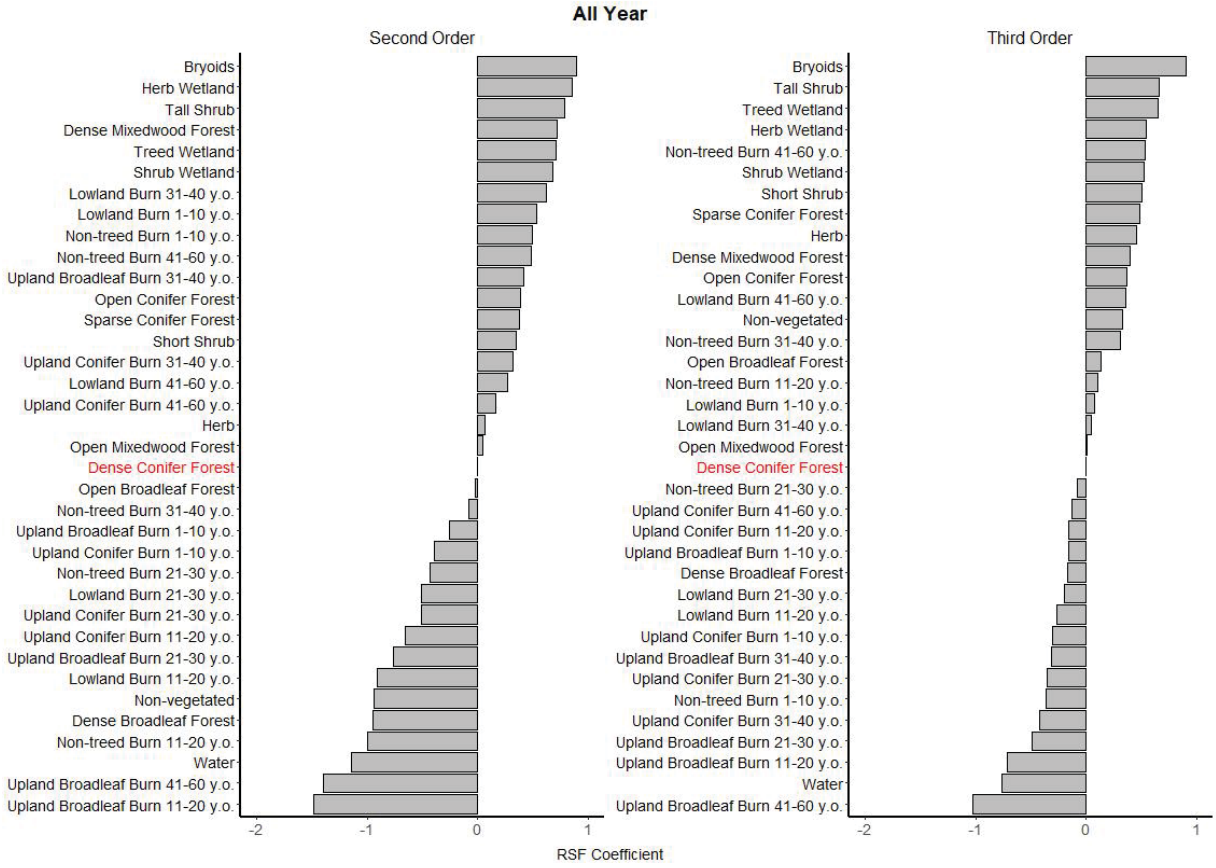


Figure 17: Model coefficients for land-cover variables (see Table 3) from resource selection functions estimated at second- and third-order scales across the entire year of boreal caribou in the Northwest Territories. Variables are ordered by their ranking relative to the reference category (dense conifer forest, shown in red).

Seasonal Trends in Caribou Response to Burns

As noted previously, caribou response to burns varied seasonally and these responses also varied by the land-cover that was burned (or the land-cover type that regenerated post-fire, if the fire predates the 2007/2010 EOSD data) and burn age (Figs. 18–21). Seasonal trends in caribou response to burns, however, were similar between the two scales of selection. In general, burn age influenced seasonal selection of burns by caribou. During calving, caribou showed stronger selection for younger burns (i.e., ≤20 years old), a response that was consistent across all burned land-covers considered (lowlands, upland conifer, upland broadleaf, and non-treed). After calving, caribou selection for burns generally declined during summer then increased during the fall. Despite this, burns still made up the top 6 land cover classes at the second-order scale, and 5 of the top 8 land cover classes at the third-order scale during the summer season. Selection for burns was generally lowest during mid- to late winter, particularly at the third-order scale where a few burn classes (e.g., upland conifer burn 21–30 years old) were perfectly avoided (i.e., no caribou GPS locations occurred within that class). One notable exception to this trend was upland conifer burns > 40 years old, which had relatively strong selection by caribou compared to other seasons. Among the four burned land-covers, caribou generally showed the weakest selection for upland broadleaf burns regardless of burn age.

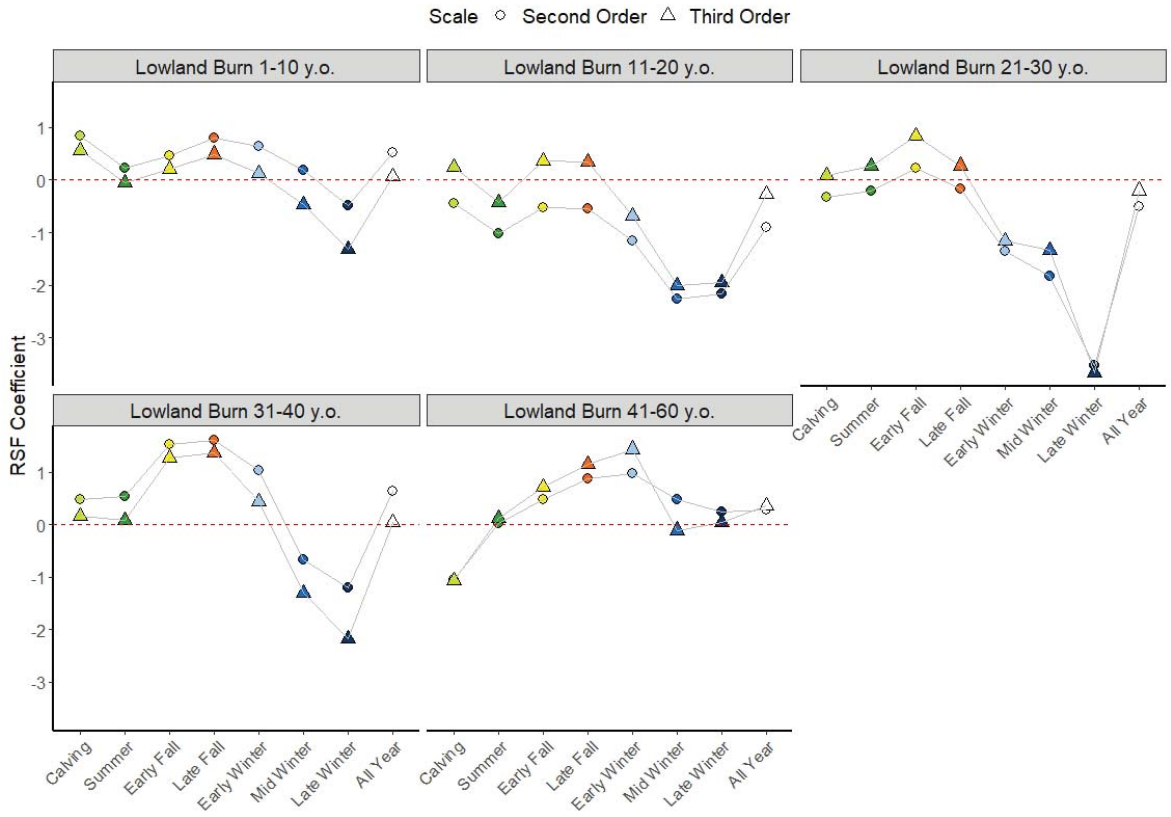


Figure 18: Seasonal trends in the response of boreal caribou to burned lowlands of various age classes (1-10 years post-fire, 11-20 years post-fire, 21-30 years post-fire, 31-40 years post-fire and 41-60 years post-fire). Coefficients >0 indicate selection for the burned land-cover type relative to dense conifer forest (the reference category) whereas coefficients <0 indicate relative avoidance. Note that season lengths differ (see Table 2).

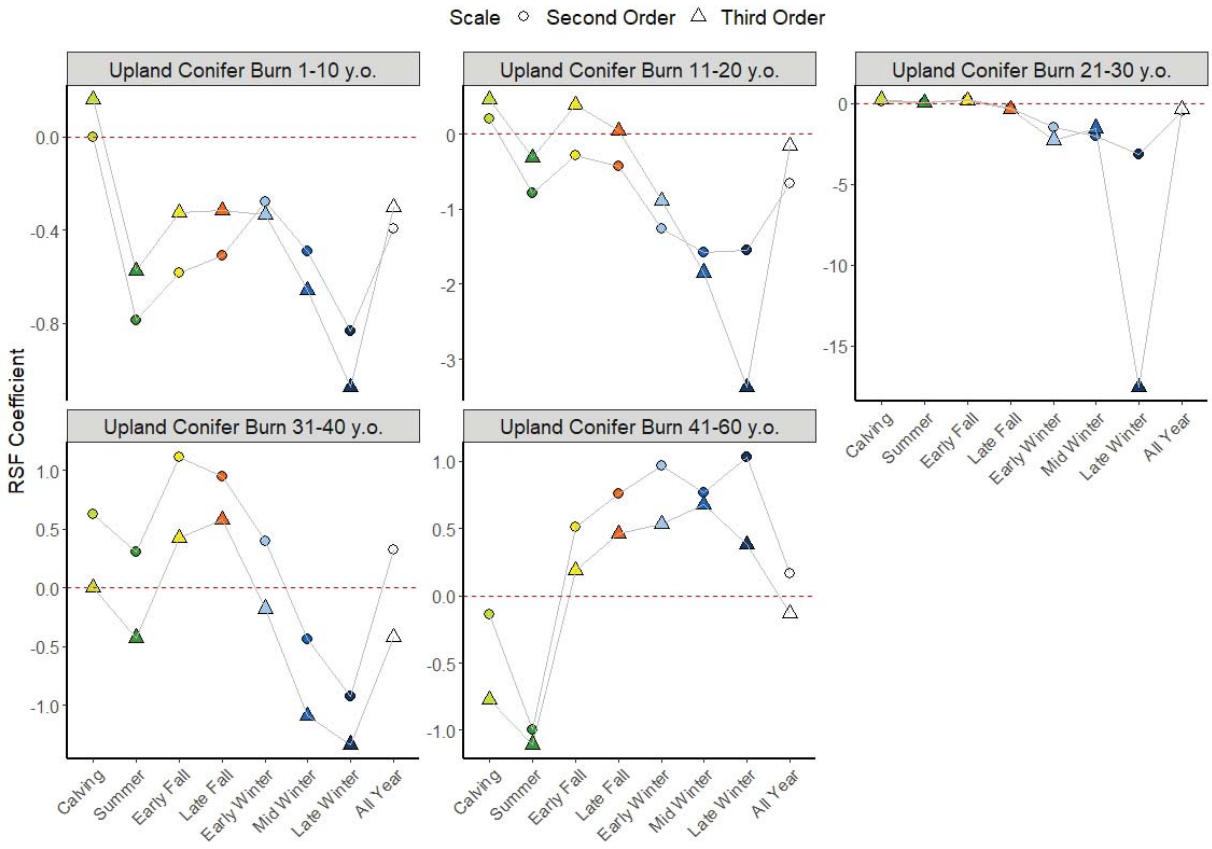


Figure 19: Seasonal trends in the response of boreal caribou to burned upland conifer forest of various age classes (1-10 years post-fire, 11-20 years post-fire, 21-30 years post-fire, 31-40 years post-fire and 41-60 years post-fire). Note that the y-axis varies among subplots and that season lengths differ (see Table 2).

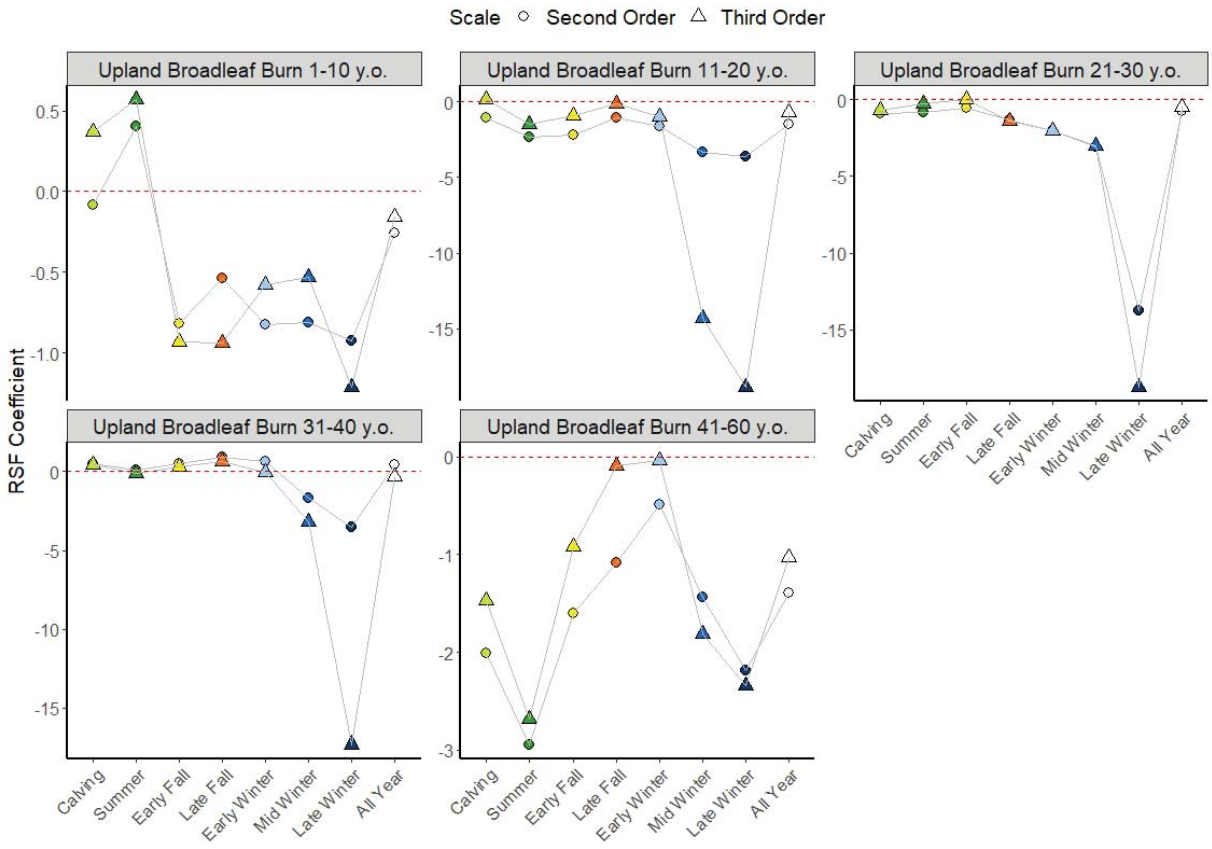


Figure 20: Seasonal trends in the response of boreal caribou to burned upland broadleaf forest of various age classes (1-10 years post-fire, 11-20 years post-fire, 21-30 years post-fire, 31-40 years post-fire and 41-60 years post-fire). Note that the y-axis varies among subplots and that season lengths differ (see Table 2).

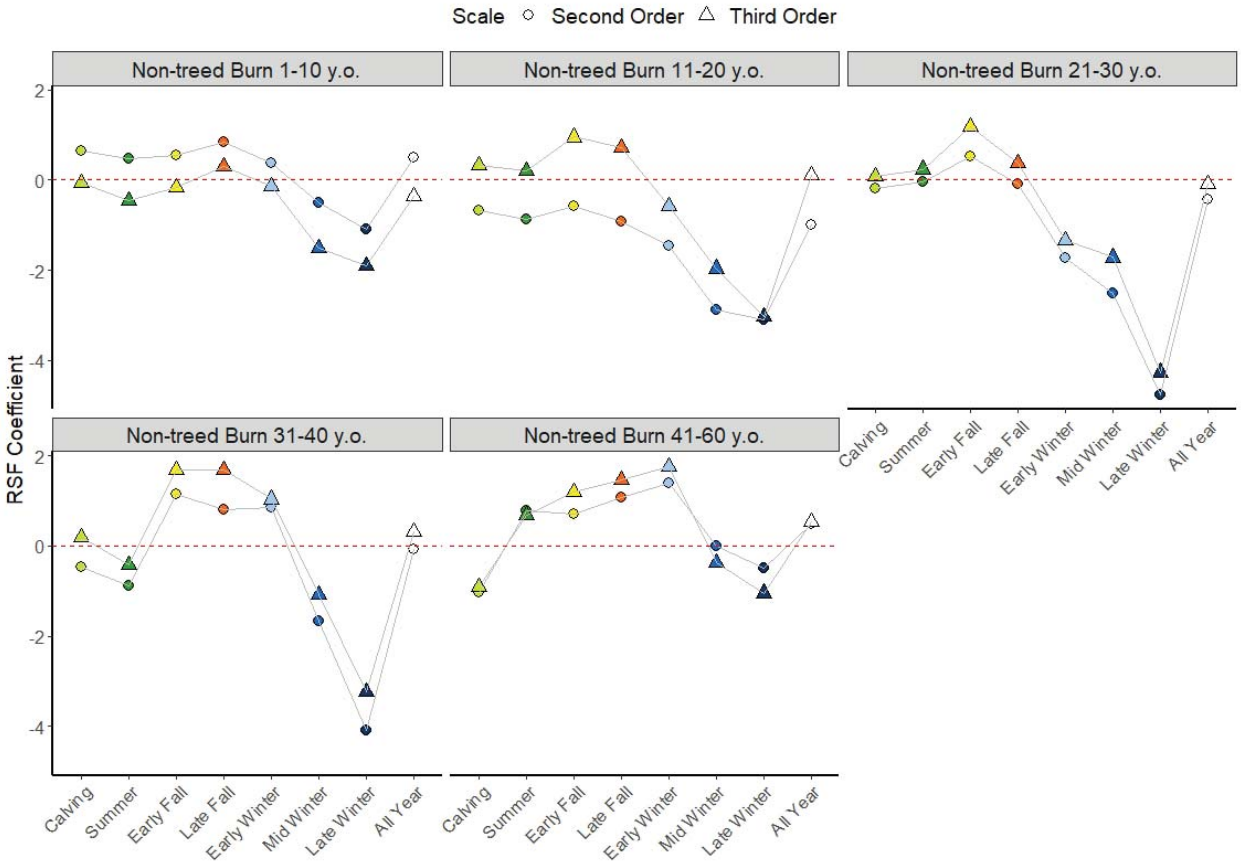


Figure 21: Seasonal trends in the response of boreal caribou to burned non-treed land-cover of various age classes (1-10 years post-fire, 11-20 years post-fire, 21-30 years post-fire, 31-40 years post-fire and 41-60 years post-fire). Note that season lengths differ (see Table 2).

Caribou Response to Landscape Context

The two landscape context variables considered—the proportion of sparse conifer forest in a 1-km radius and the proportion of broadleaf forest in a 1-km radius—had differing effects on seasonal resource selection by caribou (Fig. 22). At the third-order scale, caribou generally selected for landscapes with a higher proportion of sparse conifer forest with the strongest selection occurring in summer and early fall. However, at the second-order scale caribou seemed to be avoiding landscapes with high proportions of sparse conifer forest. Caribou response to broadleaf forest was generally more consistent as landscapes with higher densities of this forest type were avoided across all seasons and at both scales with the strongest avoidance occurring at calving.

Caribou Response to Anthropogenic Disturbances

Anthropogenic disturbances had variable effects on seasonal resource selection by caribou, though consistent trends were evident for some disturbance types (Fig. 23). Across all seasons and at both scales, caribou were generally located farther away from major roads and polygonal disturbances than would be randomly expected. For polygonal disturbances, the strength of avoidance by caribou was strongest during calving and summer then steadily diminished in the fall and into late winter. For major roads, caribou response was somewhat bimodal, with relatively strong avoidance evident in calving then diminishing in summer and early fall before increasing again during late fall and early winter and subsequently decreasing to the weakest avoidance in late winter.

The proximity of caribou to settlements varied by season and scale. Seasonally, caribou were furthest from settlements during late fall and closest during calving. At a second-order scale, caribou were generally closer to settlements than would be expected, except during late fall. In contrast, third-order selection analyses showed that caribou were generally farther from settlements when compared to the average distance of random locations sampled within their home ranges.

Caribou response to linear feature density also varied by the season. From calving to early winter, caribou generally avoided areas with high densities of linear features (as measured in a 1-km radius). From mid- to late winter, however, caribou showed increased selection of areas with higher densities of linear features, particularly at the third-order scale.

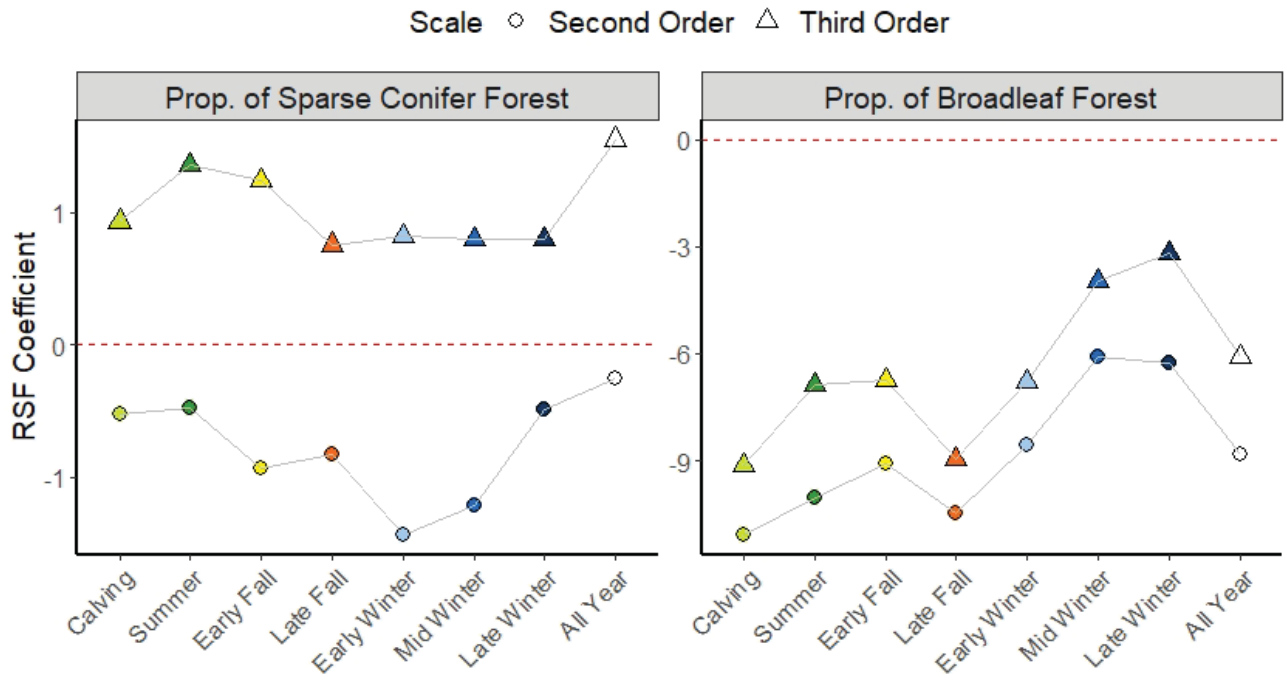


Figure 22: Seasonal responses of boreal caribou in the Northwest Territories to continuous variables describing the proportion of sparse conifer forest in a 1-km radius and the proportion of broadleaf forest in a 1-km radius. Positive RSF coefficients indicate that caribou are selecting for areas with a higher proportion of the land-cover type. Note that the y-axis differs among plots and that season lengths differ (see Table 2).

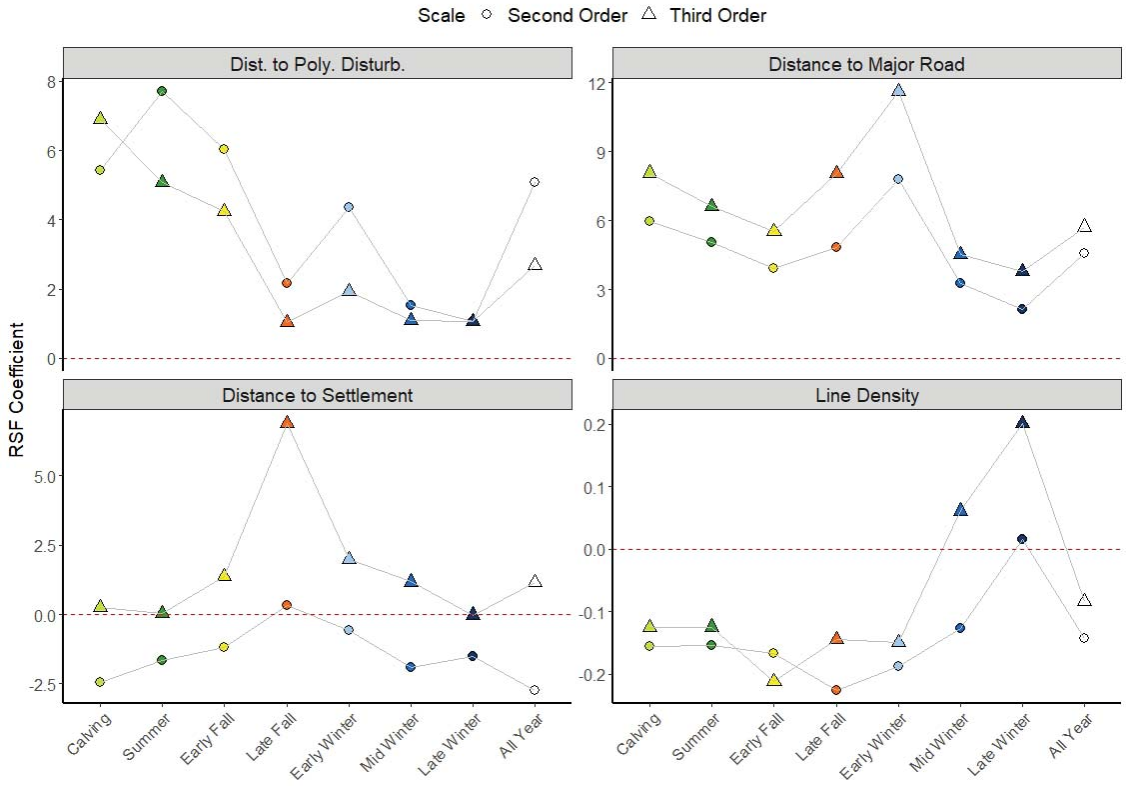


Figure 23: Seasonal responses of boreal caribou in the Northwest Territories to variables characterizing anthropogenic disturbances. All variables were included in resource selection functions estimated at second- and third-order scales. For "distance to" variables, positive RSF coefficients indicate that caribou are farther away from the feature than expected. Positive coefficients for line density indicate caribou are selecting for areas with relatively higher densities of linear features. Note that the y-axis differs among plots and that season lengths differ (see Table 2).

Predictive Performance of Seasonal RSF Models

In general, second-order RSFs had excellent predictive performance with all models having map-based $\bar{r}_s$ values exceeding 0.88 and seven of the eight models exceeding 0.94 (Table 4). Differences between map-based $\bar{r}_s$ values and model-based $\bar{r}_s$ values were also minimal (see Fig. 9 for how these approaches differ). Third-order RSFs, in contrast, had seasonal variation in their predictive performance. RSFs estimated for late fall through late winter generally had very good to excellent map-based predictive performance (all with $\bar{r}_s \geq 0.86$) whereas map-based predictive performance was low during calving, summer and early fall. Predictive performance improved when using model-based validation (all $\bar{r}_s \geq 0.93$), suggesting that functional responses in selection likely affected prediction at this scale.

Table 4: Predictive performance of seasonal models of resource selection by boreal caribou in the Northwest Territories. Models were estimated at second- and third-order scales. Predictive performance was evaluated using *k*-fold cross validation where four folds (or 80%) of the individual caribou were used for model estimation and model outputs were used to generate predictions for the GPS locations from the withheld caribou (20% of the individuals). The proportional frequency of these predictions falling within RSF bins (1–10) was compared to bin rank using Spearman's correlation coefficient ($\bar{r}_s$). Higher values of $\bar{r}_s$ equate to better predictive performance.

	Second Order $\bar{r}_s$		Third Order $\bar{r}_s$	
Season	Map	Model	Map	Model
Calving	0.97	0.98	0.66	0.95
Summer	0.88	0.93	0.46	0.93
Early Fall	0.99	0.98	0.61	0.99
Late Fall	0.99	0.99	0.91	1.00
Early Winter	0.99	0.98	0.91	0.99
Mid Winter	0.99	0.99	0.86	0.99
Late Winter	0.97	0.98	0.91	0.99
All Year	0.94	0.97	0.69	1.00

Second-order RSFs also had better predictive performance within sub-regional monitoring areas than third-order RSFs (Tables 5–6). Although prediction varied by season within sub-regions, predictive performance was generally low within the Mackenzie region across all seasons, which supports the exclusion of these caribou from RSF models. In most instances, sub-regional prediction was improved if the original RSF bins (i.e., those delineated by the full RSF model) were adjusted by their relative area within a sub-region or by re-delineating RSF bins to an equal area for each bin within a sub-region. For the former approach ("area-adjusted"), recall that RSF bins were delineated into equal areas using the entire study area as the spatial extent (i.e., RSF Bin 1 would cover an area that is equal to RSF Bin 2, etc.). If the spatial extent is narrowed to a specific sub-regional monitoring area, it is unlikely that the originally delineated RSF bins will continue to have equal area representation (i.e., in a given sub-regional monitoring area, RSF Bin 1 could cover more (or less) area than Bin 2). We can account for this unequal representation by calculating the selection ratio for a given RSF bin as

$$Selection\ ratio\ of\ RSF\ Bin_i = \frac{proportion\ of\ caribou\ GPS\ locations\ in\ bin_i}{proportional\ area\ of\ bin_i}$$

These selection ratios are then compared to bin rank using $\bar{r}_s$, as was done for all other approaches evaluating predictive performance.

Examples of predictive RSF maps at the second- and third-order scales of selection are provided in Figures 24–27 using the All Year models. A full set of predictive maps for each seasonal activity period and each scale of selection are provided in Appendix I. Figures 24 and 26 display predicted RSF values from second- and third-order models partitioned into 10 bins. Bins were specified using an "equal area" approach where the RSF predictions from random points (n = 40,000) sampled within the 2nd-order scale of availability (North and South polygons—see Figure 3) were assigned to one of 10 bins with each bin having an equal number of points. Note that extrapolating the RSF model to the full study area causes some inequality in the number of map pixels contained in each category. Figures 25 and 27 display the same predictive RSF maps focused in on the Dehcho North sub-region. The predictive RSF maps represent the relative likelihood (Bin 1 represents the weakest selection and Bin 10 represents strongest selection) that a given habitat pixel in the landscape would be selected by an "average" adult female boreal caribou moving through the landscape, based on conditions as of 2017 (i.e. including fire data up to and including 2017 and anthropogenic disturbance as measured in 2015). In general, areas falling in Bin 7 and higher are selected by boreal caribou, and areas in Bins 6 and lower are used in proportion to availability or less than expected by chance.

Table 5: Predictive performance of seasonal models of resource selection by boreal caribou within each of the 10 sub-regional monitoring areas in the Northwest Territories. Models were estimated at a second-order scale and predictive performance was measured by the strength of correlation (Spearman's correlation coefficient; r_S) between the rank of binned selection values (10 total bins) and the proportional frequency of caribou locations falling within each bin ("Full Model"). Post-hoc correlation coefficients were also estimated where the proportional frequency of caribou locations within a bin was scaled by the bin's area within a sub-region ("area-adjusted") and where bins were re-delineated into deciles of equal area within a sub-region ("equal area").

			r_S		
Season	Sub-region	No. of Caribou[2]	Full Model	Sub-region Area-adjusted	Sub-region Equal Area
Calving	Gwich'in North	17	0.94	0.85	0.81
	Gwich'in South	14	0.82	0.94	0.73
	Sahtu	12	0.89	0.95	0.93
	North Slave	19	0.85	0.90	0.84
	Mackenzie[1]	27	0.75	0.82	0.72
	Dehcho North	43	0.75	0.84	0.88
	Dehcho South	42	0.98	0.99	1.00
	Hay River Lowlands	49	0.98	1.00	1.00
	Pine Point / Buffalo Lake	25	0.99	0.92	0.88
	South Cameron	28	0.89	0.98	0.96
Summer	Gwich'in North	14	0.89	0.92	0.82
	Gwich'in South	15	0.73	0.81	0.53
	Sahtu	15	0.89	0.93	0.89
	North Slave	19	0.83	0.82	0.83
	Mackenzie[1]	27	0.52	0.44	0.54
	Dehcho North	33	0.73	0.78	0.68
	Dehcho South	38	0.76	0.99	1.00
	Hay River Lowlands	32	0.99	0.98	0.99
	Pine Point / Buffalo Lake	24	0.88	0.95	0.88
	South Cameron	21	0.62	0.78	0.94
Early Fall	Gwich'in North	12	0.94	0.88	0.65
	Gwich'in South	16	0.84	0.89	0.70
	Sahtu	11	0.78	0.79	0.68
	North Slave	14	0.88	0.85	0.83
	Mackenzie[1]	26	0.08	0.44	0.45
	Dehcho North	36	0.98	0.90	0.78
	Dehcho South	40	0.87	0.99	1.00
	Hay River Lowlands	45	0.90	1.00	0.99
	Pine Point / Buffalo Lake	22	0.99	0.98	0.82
	South Cameron	25	0.60	0.85	0.92
Late Fall	Gwich'in North	13	0.92	0.92	0.72
	Gwich'in South	14	0.71	0.85	0.70
	Sahtu	14	0.81	0.84	0.81
	North Slave	18	0.94	0.99	0.93
	Mackenzie[1]	28	0.58	0.66	0.58
	Dehcho North	37	0.99	0.88	0.89
	Dehcho South	46	0.81	1.00	1.00
	Hay River Lowlands	51	0.94	1.00	1.00
	Pine Point / Buffalo Lake	24	0.99	0.94	0.78
	South Cameron	25	0.95	0.99	0.95

(*cont'd*)

Season	Sub-region	No. of Caribou[2]	r_S Full Model	r_S Sub-region Area-adjusted	r_S Sub-region Equal Area
Early Winter	Gwich'in North	13	0.90	0.84	0.52
	Gwich'in South	16	0.83	0.96	0.94
	Sahtu	11	0.81	0.73	0.73
	North Slave	18	0.94	0.96	0.82
	Mackenzie[1]	33	0.37	0.73	0.68
	Dehcho North	38	0.96	1.00	1.00
	Dehcho South	50	0.95	1.00	1.00
	Hay River Lowlands	65	0.96	1.00	1.00
	Pine Point / Buffalo Lake	32	0.90	0.87	0.67
	South Cameron	25	0.96	0.99	0.95
Mid Winter	Gwich'in North	13	0.90	0.96	0.85
	Gwich'in South	16	0.94	0.96	0.95
	Sahtu	14	0.71	0.75	0.78
	North Slave	17	0.95	0.83	0.82
	Mackenzie[1]	33	0.38	0.62	0.44
	Dehcho North	59	0.98	1.00	1.00
	Dehcho South	72	0.99	1.00	1.00
	Hay River Lowlands	85	0.94	1.00	0.99
	Pine Point / Buffalo Lake	32	0.88	0.92	0.90
	South Cameron	32	0.98	0.99	1.00
Late Winter	Gwich'in North	16	0.87	0.85	0.82
	Gwich'in South	19	0.93	0.95	0.98
	Sahtu	16	0.71	0.72	0.67
	North Slave	24	0.93	0.94	0.95
	Mackenzie[1]	33	0.60	0.78	0.65
	Dehcho North	55	1.00	0.95	0.98
	Dehcho South	74	0.98	0.99	1.00
	Hay River Lowlands	81	0.96	0.99	0.98
	Pine Point / Buffalo Lake	34	0.81	0.84	0.88
	South Cameron	31	0.96	0.96	0.99
All Year	Gwich'in North	12	0.87	0.92	0.78
	Gwich'in South	10	0.89	0.81	0.66
	Sahtu	10	0.79	0.82	0.78
	North Slave	19	0.82	0.93	0.90
	Mackenzie[1]	31	0.76	0.99	1.00
	Dehcho North	32	0.90	0.88	0.87
	Dehcho South	18	0.65	0.85	0.90
	Hay River Lowlands	39	0.93	0.98	0.99
	Pine Point / Buffalo Lake	28	0.65	0.79	0.65
	South Cameron	23	0.92	0.85	0.68

[1] Radio-collar data from Mackenzie caribou were excluded from the data used to estimate second- and third-order RSF models.
[2] Data from all available caribou (post-data screening procedures) within a given sub-region were used in this process.

Table 6: Predictive performance of seasonal models of resource selection by boreal caribou within each of the 10 sub-regional monitoring areas in the Northwest Territories. Models were estimated at a third-order scale and predictive performance was measured by the strength of correlation (Spearman's correlation coefficient; r_S) between the rank of binned selection values (10 total bins) and the proportional frequency of caribou locations falling within each bin ("Full Model"). Post-hoc correlation coefficients were also estimated where the proportional frequency of caribou locations within a bin was scaled by the bin's area within a sub-region ("area-adjusted") and where bins were re-delineated into deciles of equal area within a sub-region ("equal area").

			r_S		
Season	Subregion	No. of Caribou[2]	Full Model	Study Area Area-adjusted	Study Area Equal Area
Calving	Gwich'in North	13	0.99	0.92	0.84
	Gwich'in South	12	0.83	0.96	0.96
	Sahtu	8	0.76	0.76	0.77
	North Slave	18	0.92	0.95	0.98
	Mackenzie[1]	27	0.90	0.89	0.88
	Dehcho North	33	0.89	0.94	0.93
	Dehcho South	34	0.55	0.92	0.99
	Hay River Lowlands	38	-0.02	0.78	0.99
	Pine Point / Buffalo Lake	23	0.49	0.92	0.96
	South Cameron	15	0.14	0.61	0.88
Summer	Gwich'in North	11	0.93	0.92	0.72
	Gwich'in South	13	0.72	0.81	0.58
	Sahtu	8	0.79	0.78	0.82
	North Slave	18	0.89	0.99	0.98
	Mackenzie[1]	27	0.25	0.41	0.53
	Dehcho North	28	0.76	0.77	0.72
	Dehcho South	30	0.35	0.83	0.90
	Hay River Lowlands	26	-0.18	0.55	0.99
	Pine Point / Buffalo Lake	24	-0.18	0.44	0.99
	South Cameron	12	0.13	0.95	0.98
Early Fall	Gwich'in North	11	0.92	0.58	0.52
	Gwich'in South	14	0.83	0.88	0.60
	Sahtu	11	0.90	0.92	0.77
	North Slave	13	0.93	0.99	0.99
	Mackenzie[1]	26	0.42	0.38	0.54
	Dehcho North	33	0.94	0.90	0.90
	Dehcho South	36	0.52	0.98	0.98
	Hay River Lowlands	41	0.42	0.95	0.99
	Pine Point / Buffalo Lake	22	0.48	0.87	0.89
	South Cameron	14	-0.45	0.88	0.94
Late Fall	Gwich'in North	10	0.93	0.82	0.52
	Gwich'in South	12	0.70	0.82	0.67
	Sahtu	13	0.88	0.88	0.82
	North Slave	17	0.90	0.98	0.97
	Mackenzie[1]	28	0.32	0.54	0.56
	Dehcho North	30	0.99	0.99	0.99
	Dehcho South	40	0.70	0.99	1.00
	Hay River Lowlands	48	0.70	1.00	1.00
	Pine Point / Buffalo Lake	24	0.87	0.96	0.99
	South Cameron	15	0.47	0.94	0.99

(*cont'd*)

Season	Subregion	No. of Caribou[2]	r_S Full Model	Study Area Area-adjusted	Study Area Equal Area
Early Winter	Gwich'in North	12	0.94	0.76	0.68
	Gwich'in South	13	0.83	0.78	0.84
	Sahtu	11	0.98	0.95	0.78
	North Slave	18	0.85	0.94	0.93
	Mackenzie[1]	28	0.36	0.56	0.50
	Dehcho North	34	0.96	1.00	0.99
	Dehcho South	47	0.79	1.00	1.00
	Hay River Lowlands	44	0.59	1.00	1.00
	Pine Point / Buffalo Lake	25	0.55	0.92	0.96
	South Cameron	21	0.54	0.99	0.99
Mid Winter	Gwich'in North	11	0.87	0.76	0.84
	Gwich'in South	11	0.81	0.98	0.80
	Sahtu	7	0.86	0.85	0.83
	North Slave	0	-	-	-
	Mackenzie[1]	23	0.47	0.52	0.42
	Dehcho North	32	0.95	1.00	1.00
	Dehcho South	51	0.87	0.99	0.99
	Hay River Lowlands	51	0.81	1.00	0.96
	Pine Point / Buffalo Lake	25	0.72	0.82	0.96
	South Cameron	21	0.67	0.96	1.00
Late Winter	Gwich'in North	13	0.87	0.77	0.78
	Gwich'in South	15	0.78	0.87	0.94
	Sahtu	8	0.89	0.89	0.93
	North Slave	18	0.95	0.98	0.94
	Mackenzie[1]	28	-0.10	0.10	0.26
	Dehcho North	39	0.98	0.99	0.98
	Dehcho South	53	0.91	0.98	0.98
	Hay River Lowlands	48	0.68	0.98	0.95
	Pine Point / Buffalo Lake	24	0.75	0.88	0.88
	South Cameron	22	0.75	0.96	0.98
All Year	Gwich'in North	12	0.92	0.88	0.82
	Gwich'in South	10	0.93	0.95	0.93
	Sahtu	10	0.96	0.94	0.93
	North Slave	19	0.98	1.00	0.99
	Mackenzie[1]	31	0.61	0.95	0.95
	Dehcho North	32	0.95	0.98	0.96
	Dehcho South	18	-0.13	0.98	1.00
	Hay River Lowlands	39	0.03	0.70	0.99
	Pine Point / Buffalo Lake	28	0.27	0.50	0.59
	South Cameron	23	-0.10	0.73	0.95

[1] Radio-collar data from Mackenzie caribou were excluded from the data used to estimate second- and third-order RSF models.
[2] Data from all available caribou (post-data screening procedures) within a given sub-region were used in this process.

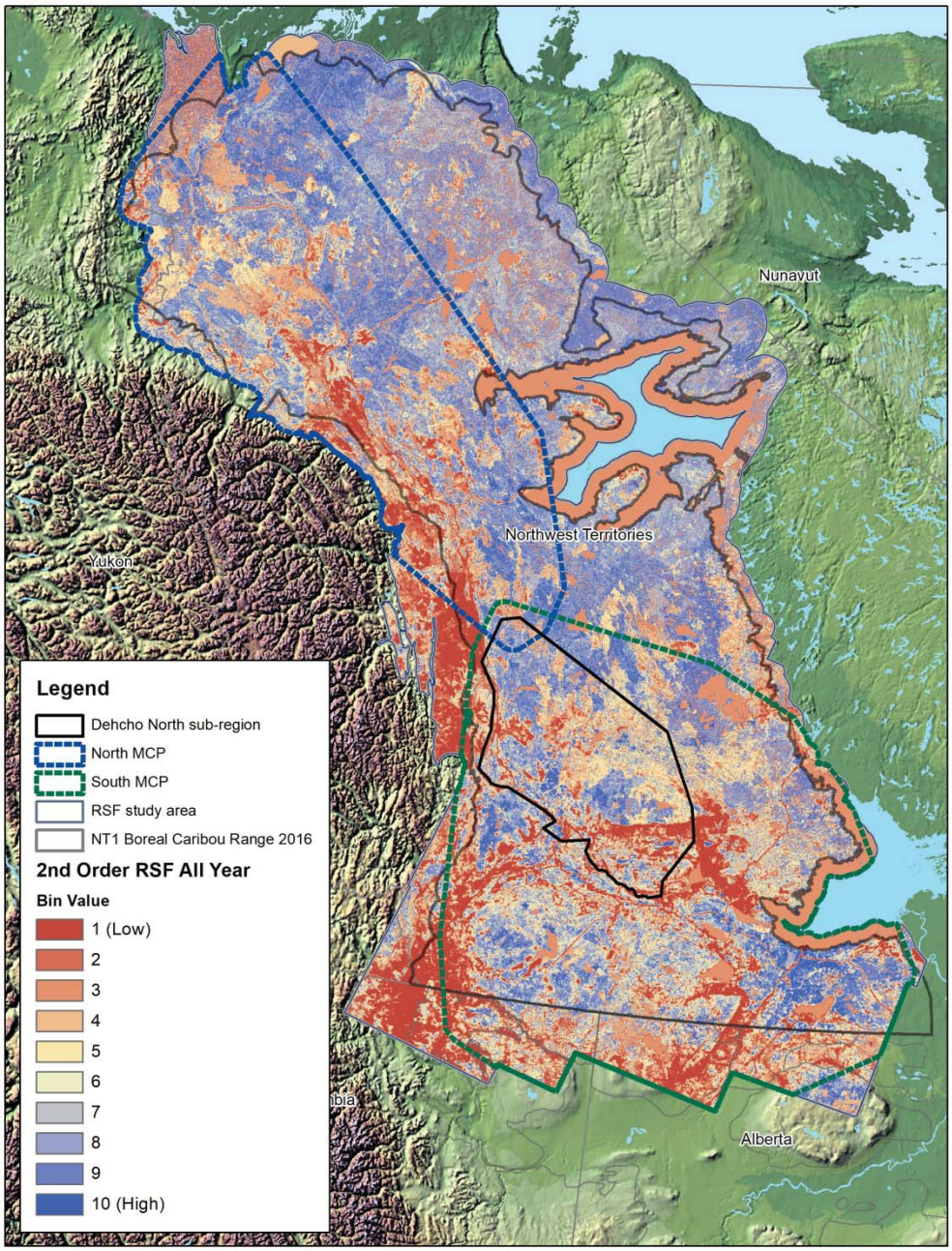


Figure 24: Predictive map of habitat selection from the 2nd-order All Year RSF model. Predicted RSF values were partitioned into 10 bins. Bins were specified using an "equal area" approach where the RSF predictions from random points (*n* = 40,000) sampled within the 2nd-order scale of availability (North and South polygons—see Figure 3) were assigned to one of 10 bins with each bin having an equal number of points. Bin 1 (dark red) represents the least selected habitat and Bin 10 (dark blue) represents the most highly selected habitat. Note that extrapolating the RSF model to the full study area causes some inequality in the number of map pixels contained in each category. Areas outside of the North and South MCP polygons represent areas where the RSF predictions have been extrapolated beyond the extent of the collar data. Predicted 2nd-order habitat selection within the Dehcho North sub-region is displayed in Figure 25.

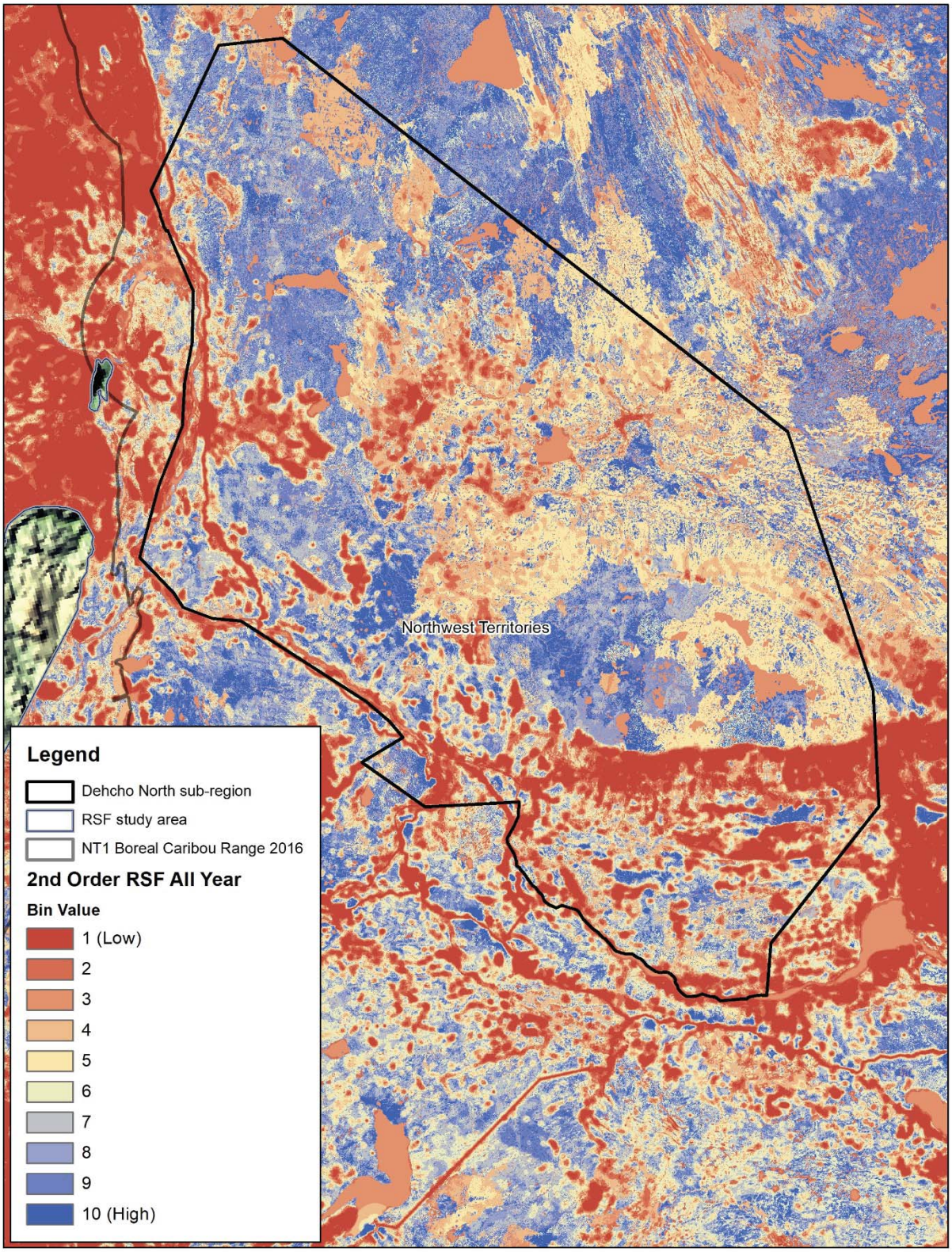


Figure 25: Predictive map of habitat selection from the 2nd-order All Year RSF model focused in on the Dehcho North sub-region.

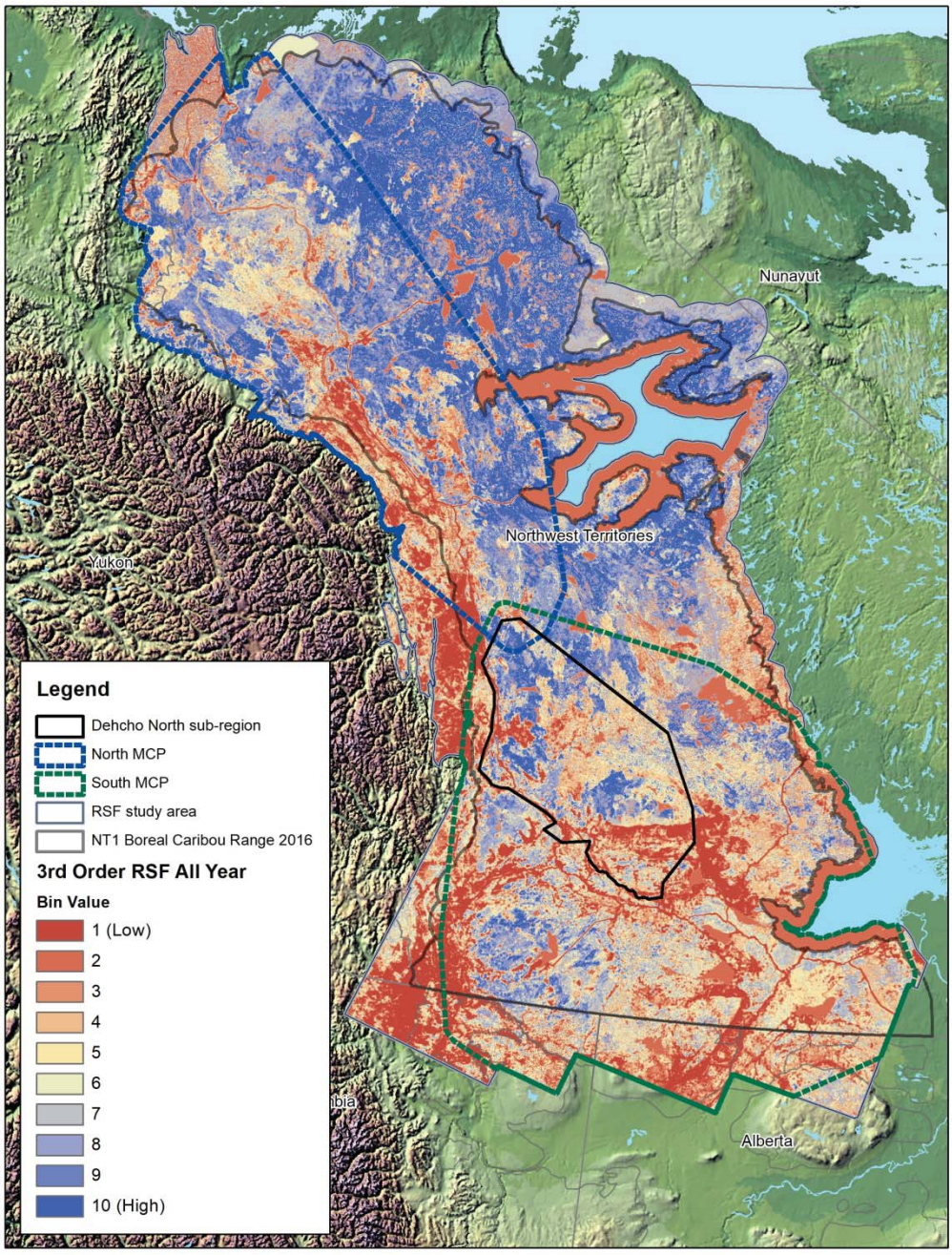


Figure 26: Predictive map of habitat selection from the 3rd-order All Year RSF model. Predicted RSF values were partitioned into 10 bins. Bins were specified using an "equal area" approach where the RSF predictions from the random points (*n* = 40,000) sampled within the North and South MCPs were assigned to one of 10 bins with each bin having an equal number of points. Bin 1 (dark red) represents the most strongly avoided habitat and Bin 10 (dark blue) represents the most highly selected habitat. Note that extrapolating the RSF model to the full study area causes some inequality in the number of map pixels contained in each category. Areas outside of the North and South MCP polygons represent areas where the RSF predictions have been extrapolated beyond the extent of the collar data. Predicted 3rd-order habitat selection within the Dehcho North sub-region is displayed in Figure 27.

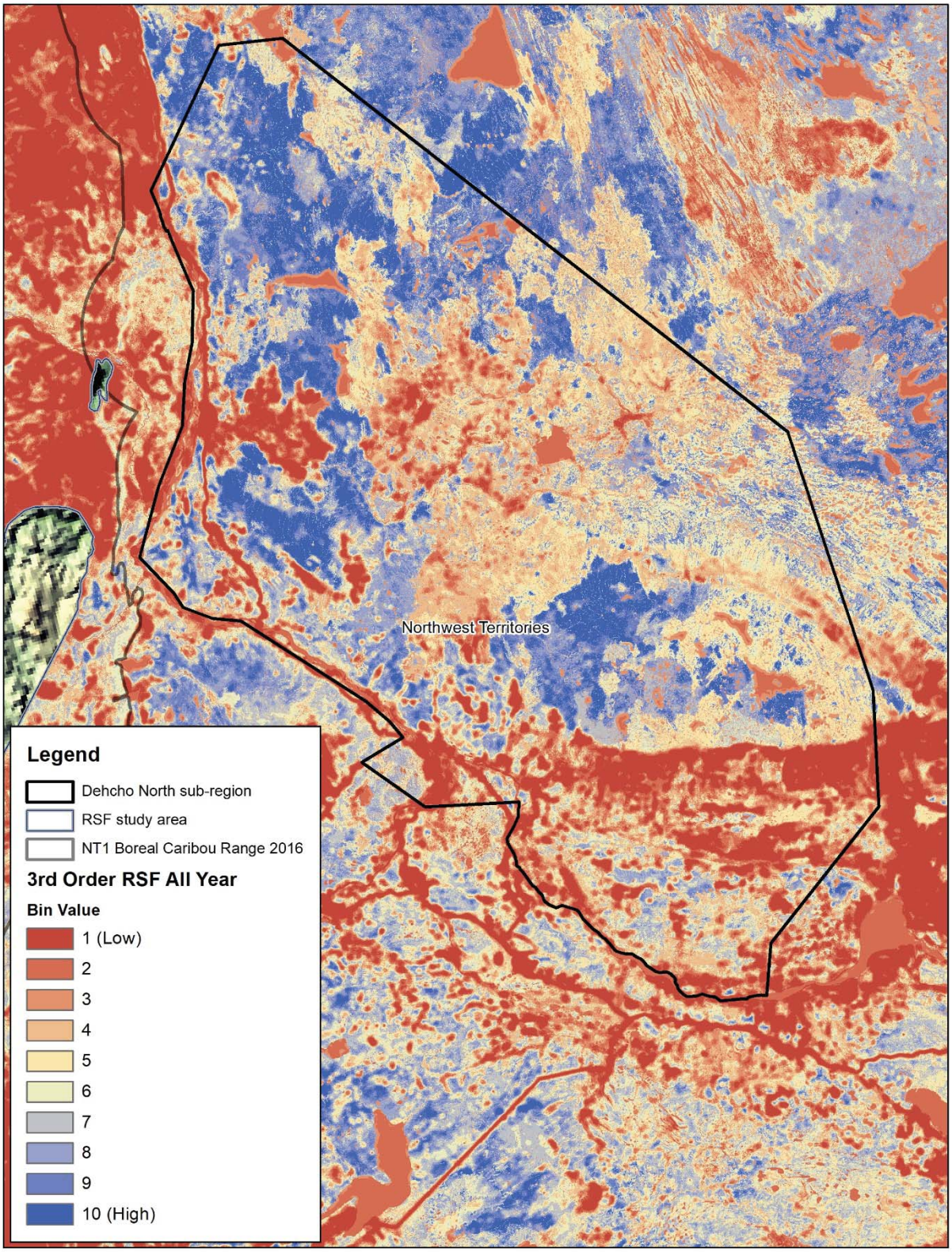


Figure 27: Predictive map of habitat selection from the 3rd-order All Year RSF model focused in on the Dehcho North sub-region.

DISCUSSION

In Canada's boreal forest, fire is the dominant form of natural disturbance and its effects influence the distribution and abundance of organisms through space and time (Sousa 1984, Fisher and Wilkinson 2005). For boreal caribou, previous literature has suggested that fire may alter their range use (Dalerum et al. 2007, Faille et al. 2010) and negatively affect their demography (Sorensen et al. 2008, Environment Canada 2011, 2012). Because of these relationships, current recovery strategies for caribou have considered fires <40 years old as a key factor in determining habitat quality at the range scale for caribou (Environment Canada 2011, 2012, Environment and Climate Change Canada 2019). Recent research, however, has questioned the relative importance of fire effects on caribou demography and distribution (Skatter et al. 2017, DeMars et al. 2019, Johnson et al. 2020). To increase our understanding of fire effects on boreal caribou, particularly for those populations occurring in the NWT, we assessed seasonal patterns of habitat selection by female boreal caribou in fire-disturbed landscapes. In general, our results did not show consistent avoidance of fires <40 years old by caribou, suggesting that these fires may have a lower effect on caribou space use than previously hypothesized. Patterns of selection for burns were also influenced by a number of factors including burn age, season, the land-cover type burned, and, to a lesser extent, by the scale of analysis.

Burn age seemed to be a key factor influencing caribou response to burns, particularly during the snow-free seasons. Caribou generally showed higher selection for younger burns (<10 years old) and older burns (>30 years old) and avoided middle-aged burns (11–30 years old). This variability in caribou response to burn age is somewhat consistent with findings from Traditional Knowledge (TK) studies conducted in the NWT. In the Gwich'in region, hunters and elders reported that boreal caribou often used burns for the first few years post-fire then avoided these areas for the next 2–4 decades (Benson 2011). Traditional knowledge from the Dehcho region also indicates that boreal caribou may use younger burns during the calving seasons, as such burns often impede predators movements, and during the summer for foraging on shrubs and morel mushrooms (Dehcho First Nations 2011, Species at Risk Committee 2012). Tlicho elders stated that boreal caribou do not return to burned areas for at least 20–30 years post-fire as it takes time for lichen to recover after fires and also time for vegetation to regrow sufficiently to provide protection from predators (Legat et al. 2019).

Compared to studies conducted in other areas of Canada, boreal caribou in the NWT showed relatively high selection for burned areas, although our findings are similar to caribou responses in nearby northeastern British Columbia (Mumma et al. 2018). In Manitoba, caribou avoided burns <10 years old, though this behaviour was only studied during the winter season (Schaefer and Pruitt Jr 1991). The proposed mechanisms underlying caribou avoidance included post-fire reductions in lichen abundance, thicker and harder snow cover in burned areas, and a lowered ease of travel due to accumulated deadfall. In Quebec, caribou also avoided disturbed landscapes, which included fire and logging effects over a 20–30 year period, during winter (Courtois et al. 2007). Caribou avoidance in the Quebec study was not attributed to food limitations as lichen biomass was found to be sufficient post-disturbance; rather, avoidance was more likely due to a higher mortality risk for caribou in disturbed landscapes. In some respects, our results mirrored the above findings as burns became increasingly avoided by caribou in the NWT during the winter months (Figs. 14–16); however, by extending our analyses to other seasonal periods, our results show that burns are not consistently avoided by caribou year-round and in certain seasons may become highly selected, at least in the NWT.

Selection for burns by caribou in the NWT appeared to be strongest during the snow-free seasons. This difference could arise for a few reasons. First, boreal caribou are known to disperse from groups just prior to calving and through the summer they remain as individuals, calf-cow pairs or in groups that are smaller in size than at other times of the year (Bergerud and Page 1987, Stuart-Smith et al. 1997, Culling et al. 2006, Benson 2011, Dehcho First Nations 2011). This behaviour is a tactic to decrease predation risk to vulnerable calves (Legat et al. 2019) and likely evolved because it increases the individual fitness of females (DeMars et al. 2016). Dispersion results in females using a larger proportion of the landscape—indeed, the spatial extent at calving is often a key factor for defining range boundaries (Schaefer et al. 2001)—and spacing away from other females may influence how a female selects habitat at this time of the year. This larger use of the landscape likely results in females using a wider variety of land-cover types, including burns. Indeed, selection coefficients for land-cover types generally have a more even distribution during calving and summer compared to the winter seasonal periods (Figs. 10–17). Specific to calving, a second reason proposed for caribou selecting relatively open areas such as recent burns and clear-cuts is that these areas provided longer sight lines that facilitate the early detection of predators (Pinard et al. 2012).

A third factor potentially influencing caribou selection for burned areas during calving and summer is the nutritional requirements of females at this time of year. For females with calves, nutritional demands increase with the onset of lactation (Parker et al. 2009) and consequently females may select habitats that optimize forage quality and/or abundance (Denryter et al. 2020). During the snow-free season, caribou switch from a lichen-dominated winter diet to a more diverse and protein-rich diet that includes deciduous shrubs, forbs and sedges (Thompson and McCourt 1981, Thompson et al. 2015, Denryter et al. 2017). These types of summer forage become highly abundant in burned areas, at least within the first 10–20 years post-fire (Schaefer and Pruitt Jr 1991). As a result, female caribou in the NWT may be selecting burns to access higher quality and/or quantities of forage to meet nutritional demands post-calving. Skatter et al. (2017) reported similar findings as caribou in Saskatchewan showed selection for more productive bogs and fens (c.f. mature forest) within burns 11–20 years old during the post-calving period. Similarly, in the Gwich'in region, hunters noted that boreal caribou may use fires for the first few years after a burn because of the rapid growth of deciduous forage species, followed by a much longer period of avoidance until lichens recover (Benson 2011). Our results further show that selection for burns continues through summer and into the fall, a pattern that likely reflects the reproductive life history strategy of caribou. As capital breeders, females rely on accumulated energy reserves from the previous growing season for reproduction (Parker et al. 2009). To accumulate sufficient reserves, females may select for areas with higher quality and/or quantities of forage, such as burns, throughout the growing season.

Seasonal changes in diet can also explain why caribou selection for burns declined during the winter. Among ungulates in the boreal forest, caribou are uniquely adapted to subsist on a lichen-dominated diet, a dietary strategy that spatially separates them from other ungulates and may have evolved to reduce predation risk (Bergerud 1974, James et al. 2004). Within the boreal forest, lichen abundance is generally higher in forests >40 years old (Dunford et al. 2006, McMullin et al. 2011) and our results suggest a correlation between winter patterns of habitat selection by caribou and land-covers predicted to have higher lichen biomass. In mid- and late-winter, caribou increased their selection for mature wetlands, sparse conifer forests and upland conifer burns 41–60 years old and these land-covers generally have higher lichen biomass than younger forests (Schaefer and Pruitt Jr 1991, McMullin et al.

2011). The increased selection for older upland conifer forests and lowered selection for burns during mid- and late-winter is also consistent with TK, which suggests that caribou favor these older forests for their increased lichen availability and shallower snow conditions that increase mobility (Dehcho First Nations 2011, Species at Risk Committee 2012).

During the snow-free seasons, caribou in the NWT selected for burns occurring in all four broadly-defined land-cover classes (lowlands, upland conifer, upland broadleaf, and non-treed). The selection for burns in broadleaf land-covers is somewhat surprising given previous research showing that caribou generally avoid these types of forests because of their increased predation risk (James et al. 2004, McLoughlin et al. 2005, Peters et al. 2013). Much of this research, however, was conducted in caribou ranges highly disturbed by anthropogenic activities and with high densities of predators and alternate prey (Latham 2009, Latham et al. 2011b, Hervieux et al. 2014). In the NWT, where anthropogenic impacts and densities of predators and alternate prey are much lower (Serrouya et al. 2016), the relative risk of broadleaf land-covers to caribou may be considerably lower. Consequently, females in the NWT may select these high quality foraging areas because the trade-off has lower predation risk than it does for females in southern ranges. This reasoning does not imply that females in the NWT are able to forage relatively risk-free. During calving and summer, females generally selected young broadleaf burns (i.e., <10 years old) and, to a lesser extent, burns 31–40 years old and avoided broadleaf burns 11–20 years old. This selectivity to burn age suggests predation-sensitive foraging as this pattern is in direct contrast to the post-fire responses attributed to moose (e.g. avoidance of young burns and selection for middle-aged burns; Maier et al. 2005, Street et al. 2015, DeMars et al. 2019) and presumably their generalist predators (Robinson et al. 2012).

In addition to fires, anthropogenic disturbances influenced seasonal habitat selection by caribou in the NWT. In general, caribou were further away from polygonal disturbances (e.g. cutblocks, well pads) than expected across all seasons, a finding consistent with other studies conducted on populations of boreal caribou across Canada (Rettie and Messier 2000, Smith et al. 2000, Courbin et al. 2013, Mumma et al. 2018). Because polygonal disturbances are selected by moose (Rempel et al. 1997, Mumma et al. 2018), the avoidance of these features by caribou is thought to be a behaviour to reduce predation risk. This proposed mechanism is further supported by the seasonal variation in the strength of avoidance as the strongest avoidance occurred during calving and summer when many females are accompanied by vulnerable young calves.

Caribou were also further away from major roads than expected, a finding that is again consistent with caribou responses in other areas of Canada (Dyer et al. 2001, 2002, Leblond et al. 2013, Mumma et al. 2017). Proposed mechanisms for this response include avoiding areas with high human activity (Dyer et al. 2001, Leblond et al. 2013) and to reduce predation risk as roads may be used as travel corridors by predators (Dickie et al. 2017b, Mumma et al. 2017). Compared to these other studies, the density of major roads in the NWT is relatively low, especially in the northern half of the study area. As a result, during all seasons caribou were on average at least 15-km from the nearest major road (Appendix H). Because the potential zone of influence from roads is unlikely to extend this far (Polfus et al. 2011, Leblond et al. 2013), changes in the strength of avoidance seasonally likely do not reflect a biological mechanism and are more likely statistical artefacts attributable to seasonal changes in the spatial distribution of caribou (i.e. moving to late-winter areas that may be closer to roads than calving areas). Nevertheless, the raw distance-to data (e.g. Appendix H) suggests that caribou do not spend a lot of time in close proximity to roads.

A similar explanation likely applies to caribou response to settlements. On average, caribou were >20-km away from settlements during any given season (Appendix H), which likely exceeds the potential zone of influence (Polfus et al. 2011, Boulanger et al. 2012). Settlements are rare and widely spaced in the NWT, yet caribou at times may appear to be closer to settlements than expected because on average, random locations at the second-order scale were ~50-km away from settlements (random locations at the third order scale were ~35-km away on average). The relative 'closeness' of caribou to settlements compared to random expectation may be an artefact of how caribou are captured and radio-collared (second-order scale) or because of differences in seasonal intensities of use within their home range (third-order scale). Because of the vastness of the study area and the rarity of settlements, radio-collars were likely not deployed at random; rather, because capture crews necessarily base out of settlements, radio-collars were likely deployed closer to settlements than what would be randomly expected within the study area. In this project, we transformed distance-to measures to place more emphasis on locations actually occurring close enough to the feature to have a hypothesized biological effect (Nielsen et al. 2009). From a mapping perspective, this transformation improves the generality of the resulting maps (i.e., reduces 'over-fitting') but may limit quantifying the actual response of caribou to the feature of interest. If a better understanding of caribou response to settlements is a management objective (e.g. estimating a potential zone of influence), then transforming distance-to variables to a series of binary variables with different distances thresholds may be a preferable approach (e.g., Leblond et al. 2011).

Linear feature density seemed to have a relatively small effect on the seasonal selection of habitat by caribou, although a more robust comparison of the actual effect sizes among these variables requires transforming the variables to a common scale. Understanding caribou responses to linear features has garnered considerable research interest because of the ubiquity of linear features within many caribou ranges and their perceived negative effects on caribou demography (McKenzie et al. 2012, DeMars and Boutin 2018, Mumma et al. 2018). For the most part, the prevailing literature suggests that caribou avoid linear features in terms of proximity (e.g., Dyer et al. 2001, Nagy 2011, Leblond et al. 2011, DeMars and Boutin 2018) but it is unclear as to whether they can perceive and respond to linear feature density (DeMars and Boutin 2018, Mumma et al. 2019). For the few studies that reported caribou avoidance of areas with high linear feature density, the scale of density measurement was so small that the observed response was more likely avoidance by proximity than a response to linear feature density *per se* (e.g., 70-m radius, DeCesare et al. 2012). In our project, we elected to assess caribou response to linear feature density within a radius of 1-km because such scales are necessary to capture meaningful variation in density as the spacing of seismic lines can vary from 50-m to >2-km apart (Boyce 2006, Lankau 2014). Moreover, these larger scales are likely more meaningful to the management of wide-ranging species such as caribou (Boyce 2006). In general, caribou in the NWT appeared to avoid areas with high linear feature density during the snow-free season but this trend appeared to reverse during mid- to late winter, especially at a second-order scale (Fig. 23). These seasonal contrasts could reflect temporal changes in predation risk as predators have been shown to increase their selection of linear features during the snow-free season compared to the winter (Latham et al. 2011a, Dickie et al. 2017b). Univariate comparisons by region suggested that most of the avoidance behaviour was driven by the Dehcho and the North Slave regions, the latter of which had no GPS locations falling within areas containing linear features from calving through early winter (Appendix H, Figs. H40–H48). Caribou in the other three regions, in contrast, were largely ambivalent to variation in linear feature density, although this ambivalence could be masking caribou responses that could vary among sub-regional monitoring

areas. The varied seasonal responses also highlight an additional confounding factor that could influence inferences on caribou response to linear feature density: if linear feature densities vary by land-cover type, then disentangling the separate effects of land-cover and linear feature density can be problematic. For example, if linear features are more abundant in lichen-dominated mature forests, then caribou may appear to be selecting areas with high linear feature density in winter and avoiding them in the snow-free period, a response that may be driven by seasonal changes in diet more than a direct response to linear features *per se*. Currently, linear feature densities are relatively low in the NWT and their effect on caribou habitat selection appears small; however, if their densities continue to rise within caribou range, further research investigating caribou response to these features may be warranted, including whether they cause home range shifts as has been reported elsewhere for southern mountain caribou (MacNearney et al. 2016).

Patterns of habitat selection by caribou were generally similar for the second- and third-scales of analysis, although some key differences did emerge, perhaps in part due to differences in the selection processes evaluated by each scale. An example of these differences is the scale-dependent responses of caribou to middle-aged burns (i.e., 11–30 years old). Caribou appeared to avoid these burns at the second-order scale but weakly selected for them at the third-order scale, except for those in broadleaf forests (Figs. 18–21). These responses suggest that caribou were generally selecting home ranges that had lower densities of these burns compared to the study area at large but still occasionally used these burns when encountered, resulting in weak selection at the third-order scale. Avoidance of these burns at the second-order scale is consistent with habitat selection theory, which predicts that the coarsest scales of selection should be largely influenced by a species' primary limiting factors (Rettie and Messier 2000). For caribou, predation is a primary limiting factor (Bergerud 1996, Wittmer et al. 2005) and, as previously mentioned, middle-aged burns are associated with increased predation risk because they are selected by moose and their generalist predators (Maier et al. 2005, Robinson et al. 2012, Street et al. 2015). At finer spatial scales (e.g. third-order), selection is more likely to be influenced by multiple factors and, as such, can result in more individual variation in selection (Rettie and Messier 2000). Scale-dependent differences in selection also occurred for sparse conifer forest. Caribou did not appear to be situating their home ranges in landscapes with high densities of sparse conifer forest when compared to the larger area of availability that defines the second-order scale. Yet, sparse conifer forest was one of the most highly-used land-cover types across all seasons (Appendix H), resulting in its selection at a third-order scale. These examples illustrate the hierarchical nature of habitat selection and underscore the necessity of evaluating selection at multiple spatial scales (McGarigal et al. 2016).

Management Implications

A key component to the federal recovery strategy for boreal caribou is the recommendation to maintain or reduce the cumulative extent of disturbances to <35% of caribou range (Environment Canada 2012, Environment and Climate Change Canada 2019). Currently, the extent of fires <40 years old is included in the calculation of disturbance impacts. A primary mechanism linking fires to caribou population declines is that fires increase the extent of young forests that are favorable to moose, which leads to increased moose populations and subsequently increased predator populations that incidentally predate caribou at unsustainable rates. Recently, this mechanism has been questioned as fires of this age did not seem to facilitate population increases of moose in boreal forests of western Canada (DeMars et al. 2019) and these fires had a much smaller effect on survival of adult female caribou than anthropogenic disturbances (Johnson et al. 2020). Although our project did not directly test the

disturbance-mediated apparent competition hypothesis or directly link fires to caribou demography, our results still yield inferences on caribou-fire relationships and dynamics. In natural landscapes, patterns of resource selection should reflect individual fitness; that is, resources that are highly selected should be those that have a positive influence on survival and reproduction (Boyce and McDonald 1999). Within the boreal forest, caribou have evolved with fire and therefore caribou would not be selecting burned areas if they had a negative effect on fitness (i.e., 'natural' ecological traps do not occur; Schlaepfer et al. 2002). Our results showed that younger and older burns are selected by boreal caribou in the NWT, suggesting that these areas are not necessarily detrimental to individual fitness and, by extension, caribou demography. Our results, combined with those of DeMars et al. (2019) and Johnson et al. (2020), suggest that different disturbance types have differing effects on caribou distribution and demography. Further, the magnitude of disturbance effects may be context-specific, which may diminish the efficacy of management strategies that are broadly applied across the wide and geographically varied distribution of boreal caribou (Whittingham et al. 2007, Rudolph et al. 2017). Within the NWT, this context-specificity likely applies to caribou in the Mackenzie sub-regional monitoring area, which were excluded from RSF analyses because of the high availability of recent burns in this area. RSF models at both scales generally had poor predictive power when applied to the Mackenzie sub-region (Tables 5–6), suggesting that further research may be required to understand how caribou responses to burns change when the extent of burns is high.

We evaluated habitat selection by caribou at two spatial scales and each has direct links to management and the federal recovery strategy. At the broad scale, second-order selection analyses can inform delineations of critical habitat for caribou in the NWT. In the federal recovery strategy, the scale of measurement for critical habitat is a population's range (Environment Canada 2011, Environment and Climate Change Canada 2019), yet ranges and populations are coarsely defined in the NWT. Because second-order analyses evaluate how caribou select areas within a large spatial extent, results at this scale are useful for distinguishing between caribou habitat and other areas that may be suboptimal. From a range-planning perspective, these larger-scale inferences are most appropriate for updating and mapping the estimated distribution of caribou within the NWT (Boyce 2006). At a finer spatial scale, third-order analyses are useful for identifying potentially important areas within caribou range. While evidence is limited as to whether managing habitat below the range scale can positively impact caribou demography, the federal recovery strategy does stipulate that ranges need to contain the biophysical attributes necessary for caribou to complete life processes (Environment and Climate Change Canada 2019). Such attributes are best identified by assessing how an animal uses and selects habitat within its home range (Boyce 2006).

The usefulness of the scale-specific maps to guide management decisions depends somewhat on their predictive ability. For this project, second-order maps had consistently higher predictive power than those derived from third-order analyses. This difference is likely attributable to how availability was defined for each scale and how it varied within each scale. For second-order analyses, availability was the same for large groups of caribou (i.e., the North and South groups) and held constant across years. For third-order analyses, availability was unique to each caribou-year. This changing availability likely impacted predictive power because selection can change as a function of availability (i.e., a functional response in selection, Mysterud and Ims 1998), which is a well-known potential confounding factor with RSFs (Beyer et al. 2010). In our analyses, functional responses in selection were likely the reason why prediction was lowest for third-order maps during calving and summer as these seasons are when

caribou are most widely distributed, creating more variability in habitat use. Changing availability also likely influenced the decrease in predictive power when RSF maps were applied to the finer-scale sub-regional monitoring areas (Table 6). Although the loss of predictive power at these finer-scales of selection may be initially problematic from a management perspective, our map validation approach revealed that predictive power could be improved in most cases by re-delineating RSF map bins based on the actual availabilities of the scale of interest (rather than setting RSF bin thresholds based on availability of the larger study area). This approach may be more efficient than estimating new RSF models and maps for each region and sub-region of interest.

In recent years, a number of different modelling approaches have been proposed to improve prediction when functional responses are evident. These approaches include: *i*) using random-slope GLMMs that interact use with availability, the latter of which is constrained and contingent upon each time step (Moreau et al. 2012); and, *ii*) interacting each environmental attribute with its mean value calculated over the spatial scale of interest (generalized functional response models, (Matthiopoulos et al. 2011). For the former, computing limitations restricted the use of random-slope GLMMs because of the large number of covariates included in our models. Moreover, such fine-scale interactions of use and availability can place increased selective importance on environmental attributes when they are within a small spatial context, which may diminish prediction over large spatial scales. The other approach, generalized functional response models, is more appropriate for models primarily using continuous variables and, given our objectives of assessing caribou response to burn-by-land-cover interactions, we elected to use a high number of categorical variables. If generating maps that explicitly account for functional responses becomes a future management objective, then an alternative modelling framework may be to transform all categorical variables into continuous ones, perhaps by calculating proportions within a biologically meaningful radius.

Habitat selection is known to vary seasonally for many species and understanding such variation can be important for developing effective management strategies (Boyce 2006). For boreal caribou in the NWT, we developed maps of habitat selection for seven seasons as well as maps that predicted space use on a year-round basis. These seasonal RSF models and maps revealed seasonal differences in habitat selection by caribou, particularly in their response to burns, but we caution against assigning more importance to one season over another in terms of management implications. Assigning importance would require demographic models that identify those seasons with high influence on population dynamics (Crouse et al. 1987) and/or explicitly linking individual fitness to habitat selection (e.g., Nielsen et al. 2010, DeCesare et al. 2014). In the absence of such information, year-round RSF maps showed good predictive performance, indicating that they were able to capture meaningful variation in seasonable space use by caribou.

RSF maps represent a static 'snapshot' of predicted space use based on the most current year of the explanatory data (e.g., land-cover type, fire age and distribution, linear feature density, etc.). Because of this, the predictive power of RSF maps generally decreases through time (Beyer et al. 2010). To maintain their usefulness for management, the seasonal maps of habitat selection by caribou will need to be updated on a regular basis as new data become available. These updates will be particularly necessary if human-caused disturbances continue to increase in caribou ranges. Such disturbances can create evolutionarily novel disturbances (i.e., features that an organism has not experienced in its evolutionary past), which can cause distributional changes and/or create ecological traps when an organism does not recognize cues associated with such features that negatively impact fitness (Schlaepfer et al. 2002, Sih et

al. 2011). This latter reason has increasingly led to recommendations that habitat selection be linked to fitness or demography to better inform management in human-modified landscapes. With the rich data set of caribou radio-collar data in the NWT, such analyses should be considered as a next step to build upon the RSF modelling completed to date.

Caveats / Limitations to Interpretation and Use of Predictive RSF Maps

The predictive performance and utility of the seasonal RSF maps are contingent on the accuracy and reliability of their input variables. In many RSF studies, the primary limitation is usually a small sample size of individuals within the population of interest. For this project, our data set of caribou GPS locations was a key strength as these data were collected from individuals sampled over a large portion of the NT1 range and each seasonal RSF analysis used a minimum of 194 caribou, many of which had data spanning multiple years. These data allowed for a detailed assessment of caribou response to burns over multiple seasons and at two spatial scales. Importantly, these data provided the ability to perform the first detailed evaluation of how caribou response to burns was shaped by interactions of burn-age with land-cover.

The utility of RSF maps are also frequently dependent on the accuracy, reliability and assumptions of their spatial covariate data. In our analyses, a primary input was the EOSD land-cover data, which had issues with accuracy. Also, these data were based on 2007 and 2010 remote imagery, a time frame that only coincides with a small portion of the caribou radio-collar data. By using the EOSD data, our analyses implicitly relied on two assumptions: *i*) that a pixel assigned a land-cover type remained unchanged over the course of the study unless it burned (e.g., a pixel classified as 'tall shrub' remained 'tall shrub'); and *ii*) that the post-fire trajectory for each pixel was a return to its pre-fire land-cover type, which is generally true but may be changing as the climate warms globally (Johnstone et al. 2010). Similar assumptions applied to the anthropogenic disturbance data; for example, polygonal and linear feature disturbances were treated as static and our models did not account for the age of disturbance nor the state of its regeneration (van Rensen et al. 2015, Dickie et al. 2017a). For fires, we modeled fire age as a series of categorical variables, using age delineations primarily taken from existing literature on moose-fire relationships (e.g., Maier et al. 2005, Street et al. 2015, DeMars et al. 2019). We assumed these delineations were biologically relevant to caribou—they did perform better than treating fire as a continuous variable—, but future modelling might consider alternate age class delineations. We also note that our analyses were restricted to fires <60 years old because this time frame was the limit of historical fire data. Our analyses therefore exclude inferences on potential variation in caribou response to burns as these areas age beyond sixty years old.

We further note that our inferences on caribou response to a given environmental attribute should be viewed cautiously at the population-level as our modelling framework did not allow for estimates of variability that maintained individual caribou as the sampling unit (see Data Analysis; Arnqvist 2020). Nevertheless, our analyses still yielded a relative ranking of land-cover variables, including those representing burn-age-by-land-cover interactions, and we are confident that these rankings would remain similar if alternative modeling approaches (e.g., random-slope GLMMs) could have been used. In addition, we used a model validation approach that explicitly tested predictions on a sample of withheld caribou. Predictive power was generally good to excellent, particularly at the second-order scale, suggesting that outputs based on the entire model were able to capture and account for individual variation within the NWT population of boreal caribou.

Finally, we highlight that habitat selection is not the sole metric for evaluating a species' habitat requirements. Selection analyses typically evaluate an organism's habitat requirements by comparing the environmental attributes (or "resources") used by the organism to the availability of these attributes in the spatial scale of interest, which is generally defined by the researcher (Manly et al. 2002). Because of this scaling of use by availability, selection does not necessarily equate to the intensity of use of a given resource. For example, caribou in the Inuvik region spent the highest amount of time in sparse conifer forest, but because this land-cover was also the most abundant type, selection for sparse conifer forest was relatively weak (Appendix H, Fig. H2). In contrast, selection for herb land-cover by Inuvik caribou was relatively strong during summer even though they spent comparatively little time in this land-cover type, a result that occurred because herb land-cover was relatively rare at the second-order scale of availability. This example illustrates that using only selection coefficients to infer the relative importance of environmental attributes is problematic. To assist in the interpretation of our selection analyses, use-versus-availability graphs for all resources used in RSF models at a second-order scale are provided in Appendix H.

Below are further caveats and limitations to the interpretation of the seasonal RSF maps:

- Extrapolating RSF predictions beyond the extent of the radio-collar data (i.e., outside of the North and South availability polygons defined at the second-order scale) should be done cautiously as RSF predictive performance may change as the relative availability of environmental attributes changes through space (Beyer et al. 2010).

- Predictive maps represent a continuum of relative habitat suitability. They do not represent the absolute probability that a caribou will occur at a given location.

- Even in areas with apparently high suitability, the actual probability of caribou occurrence will be relatively low because boreal caribou normally occur at low densities throughout their range (e.g. ~ 3 caribou / 100 km^2).

- Caribou can – and probably do – occur in areas with relatively low suitability. Female caribou can show considerable individual variation in how they select habitat, particularly during calving and summer, and this variation is difficult to depict visually on a map.

- In intact natural landscapes, patterns of habitat selection likely reflect relative effects on individual fitness (Boyce and McDonald 1999); that is, highly selected habitats should equate to individuals within these areas having higher probabilities of surviving and reproducing, all else being equal. This assumption, however, may not hold in landscapes disturbed by human activities. Such disturbances can result in the creation of evolutionarily novel features (i.e., an organism has not interacted with these features in its evolutionary past) that may impact an individual's fitness, yet the individual may be behaviorally naïve to the cues associated with such impacts (Schlaepfer et al. 2002, Sih et al. 2011). Consequently, in these disturbed landscapes, an increase in habitat suitability does not necessarily equate to an increase in the probability of caribou survival. Other factors, such as predator space use, the number of predators, and disease, can influence caribou survival in addition to habitat suitability.

- The predictive maps do not yield inferences on the spatial requirements of caribou during a given season. For example, during calving females use space to distance themselves from

predators and other ungulate species (e.g. moose) and therefore space likely interacts with habitat to influence predation risk. The amount of space – or the areal extent of habitat with high suitability – required by females to effectively reduce predation risk is not currently known.

LITERATURE CITED

Arnold, T. W. 2010. Uninformative parameters and model selection using Akaike's Information Criterion. Journal of Wildlife Management 74:1175–1178.

Arnqvist, G. 2020. Mixed Models Offer No Freedom from Degrees of Freedom. Trends in Ecology & Evolution 35:329–335.

Barr, D. J., R. Levy, C. Scheepers, and H. J. Tily. 2013. Random effects structure for confirmatory hypothesis testing: Keep it maximal. Journal of Memory and Language 68:255–278.

Benson, K. 2011. Gwich'in traditional knowledge: woodland caribou, boreal population. Page 52. Gwich'in Social and Cultural Institute, Fort McPherson, NWT.

Bergerud, A. T. 1974. Decline of caribou in North America following settlement. The Journal of Wildlife Management 38:757–770.

Bergerud, A. T. 1996. Evolving perspectives on caribou population dynamics, have we got it right yet? Rangifer 16:95–116.

Bergerud, A. T., and R. E. Page. 1987. Displacement and dispersion of parturient caribou at calving as antipredator tactics. Canadian Journal of Zoology 65:1597–1606.

Beyer, H. L., D. T. Haydon, J. M. Morales, J. L. Frair, M. Hebblewhite, M. Mitchell, and J. Matthiopoulos. 2010. The interpretation of habitat preference metrics under use-availability designs. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2245–2254.

Börger, L., N. Franconi, G. De Michele, A. Gantz, F. Meschi, A. Manica, S. Lovari, and T. Coulson. 2006. Effects of sampling regime on the mean and variance of home range size estimates. Journal of Animal Ecology 75:1393–1405.

Boulanger, J., K. G. Poole, A. Gunn, and J. Wierzchowski. 2012. Estimating the zone of influence of industrial developments on wildlife: a migratory caribou *Rangifer tarandus groenlandicus* and diamond mine case study. Wildlife Biology 18:164–179.

Boyce, M. S. 2006. Scale for resource selection functions. Diversity and Distributions 12:269–276.

Boyce, M. S., and L. McDonald. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology & Evolution 14:268–272.

Boyce, M. S., P. R. Vernier, S. E. Nielsen, and F. K. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157:281–300.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer, New York, NY.

Courbin, N., D. Fortin, C. Dussault, V. Fargeot, and R. Courtois. 2013. Multi-trophic resource selection function enlightens the behavioural game between wolves and their prey. Journal of Animal Ecology 82:1062–1071.

Courtois, R., J.-P. Ouellet, L. Breton, A. Gingras, and C. Dussault. 2007. Effects of forest disturbance on density, space use, and mortality of woodland caribou. Ecoscience 14:491–498.

Crouse, D. T., L. B. Crowder, and H. Caswell. 1987. A stage-based population model for loggerhead sea turtles and implications for conservation. Ecology 68:1412.

Culling, D. E., Culling, Brad A., Raabis, Teresa J., and Creagh, Alex C. 2006. Ecology and seasonal habitat selection of boreal caribou in the Snake-Sahtaneh watershed, British Columbia 2000 to 2004. Page 88. Diversified Environmental Services, Fort St. John, BC.

Dalerum, F., S. Boutin, and J. S. Dunford. 2007. Wildfire effects on home range size and fidelity of boreal caribou in Alberta, Canada. Canadian Journal of Zoology 85:26–32.

DeCesare, N. J., M. Hebblewhite, M. Bradley, D. Hervieux, L. Neufeld, and M. Musiani. 2014. Linking habitat selection and predation risk to spatial variation in survival. Journal of Animal Ecology 83:343–352.

DeCesare, N. J., M. Hebblewhite, F. Schmiegelow, D. Hervieux, G. J. McDermid, L. Neufeld, M. Bradley, J. Whittington, K. G. Smith, and L. E. Morgantini. 2012. Transcending scale dependence in identifying habitat with resource selection functions. Ecological Applications 22:1068–1083.

Dehcho First Nations. 2011. Traditional knowledge assessment of boreal caribou (Mbedzih) in the Dehcho Region. Page 49. Dehcho First Nations, Fort Simpson, NWT.

DeMars, C. A., and S. Boutin. 2018. Nowhere to hide: Effects of linear features on predator-prey dynamics in a large mammal system. Journal of Animal Ecology 87:274–284.

DeMars, C. A., G. A. Breed, J. R. Potts, and S. Boutin. 2016. Spatial patterning of prey at reproduction to reduce predation risk: what drives dispersion from groups? The American Naturalist 187:678–687.

DeMars, C. A., R. Serrouya, M. A. Mumma, M. P. Gillingham, R. S. McNay, and S. Boutin. 2019. Moose, caribou, and fire: have we got it right yet? Canadian Journal of Zoology 97:866–879.

Denryter, K. A., R. C. Cook, J. G. Cook, and K. L. Parker. 2017. Straight from the caribou's (*Rangifer tarandus*) mouth: detailed observations of tame caribou reveal new insights into summer–autumn diets. Canadian Journal of Zoology 95:81–94.

Denryter, K., R. C. Cook, J. G. Cook, K. L. Parker, and M. P. Gillingham. 2020. State-dependent foraging by caribou with different nutritional requirements. Journal of Mammalogy 101:544-557.

Dickie, M., R. Serrouya, C. DeMars, J. Cranston, and S. Boutin. 2017a. Evaluating functional recovery of habitat for threatened woodland caribou. Ecosphere 8:e01936.

Dickie, M., R. Serrouya, R. S. McNay, and S. Boutin. 2017b. Faster and farther: wolf movement on linear features and implications for hunting behaviour. Journal of Applied Ecology 54:253–263.

Dunford, J. S., P. D. McLoughlin, F. Dalerum, and S. Boutin. 2006. Lichen abundance in the peatlands of northern Alberta: implications for boreal caribou. Ecoscience 13:469–474.

Dyer, S. J., J. P. O'Neill, S. M. Wasel, and S. Boutin. 2001. Avoidance of industrial development by woodland caribou. Journal of Wildlife Management 65:531–542.

Dyer, S. J., J. P. O'Neill, S. M. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Canadian Journal of Zoology 80:839–845.

Ecosystem Classification Group. 2009. Ecological regions of the Northwest Territories, Taiga Plains. Page viii + 173 pp. + folded insert map. Dept. of Environment and Natural Resources, Govt. of the Northwest Territories, Yellowknife.

Environment and Climate Change Canada. 2016. Range plan guidance for woodland caribou, boreal population. Species at Risk Act: Policies and Guidelines Series, Environment and Climate Change Canada, Ottawa, ON.

Environment and Climate Change Canada. 2019. Amended recovery strategy for the woodland caribou (Rangifer tarandus caribou), boreal population, in Canada [Proposed]. Page 157. Environment and Climate Change Canada, Ottawa, ON.

Environment Canada. 2011. Scientific assessment to inform the identification of critical habitat for woodland caribou (Rangifer tarandus caribou), boreal population, in Canada. Environment Canada, Ottawa, Ont.

Environment Canada. 2012. Recovery strategy for the woodland caribou (Rangifer tarandus caribou), boreal population, in Canada. Page xi + 138. Environment Canada, Ottawa, ON.
Faille, G., C. Dussault, J.-P. Ouellet, D. Fortin, R. Courtois, M.-H. St-Laurent, and C. Dussault. 2010. Range fidelity: The missing link between caribou decline and habitat alteration? Biological Conservation 143:2840–2850.
Ferguson, S. H., and P. C. Elkie. 2004a. Seasonal movement patterns of woodland caribou (Rangifer tarandus caribou). Journal of Zoology 262:125–134.
Ferguson, S. H., and P. C. Elkie. 2004b. Habitat requirements of boreal forest caribou during the travel seasons. Basic and Applied Ecology 5:465–474.
Fisher, J. T., and L. Wilkinson. 2005. The response of mammals to forest fire and timber harvest in the North American boreal forest. Mammal Review 35:51–81.
Fleming, C. H., W. F. Fagan, T. Mueller, K. A. Olson, P. Leimgruber, and J. M. Calabrese. 2015. Rigorous home range estimation with movement data: a new autocorrelated kernel density estimator. Ecology 96:1182–1188.
Frair, J. L., J. Fieberg, M. Hebblewhite, F. Cagnacci, N. J. DeCesare, and L. Pedrotti. 2010. Resolving issues of imprecise and habitat-biased locations in ecological analyses using GPS telemetry data. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2187–2200.
Gillies, C. S., M. Hebblewhite, S. E. Nielsen, M. A. Krawchuk, C. L. Aldridge, J. L. Frair, D. J. Saher, C. E. Stevens, and C. L. Jerde. 2006. Application of random effects to the study of resource selection by animals. Journal of Animal Ecology 75:887–898.
Government of the Northwest Territories. 2019. A framework for boreal caribou range planning. Page 87. Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, NT.
Hervieux, D., M. Hebblewhite, D. Stepnisky, M. Bacon, and S. Boutin. 2014. Managing wolves (Canis lupus) to recover threatened woodland caribou (*Rangifer tarandus caribou*) in Alberta. Canadian Journal of Zoology 92:1029–1037.
James, A. R., S. Boutin, D. M. Hebert, and A. B. Rippin. 2004. Spatial separation of caribou from moose and its relation to predation by wolves. Journal of Wildlife Management 68:799–809.
Johnson, C. A., G. D. Sutherland, E. Neave, M. Leblond, P. Kirby, C. Superbie, and P. D. McLoughlin. 2020. Science to inform policy: linking population dynamics to habitat for a threatened species in Canada. Journal of Applied Ecology.
Johnson, C. J., L. P. W. Ehlers, and D. R. Seip. 2015. Witnessing extinction – Cumulative impacts across landscapes and the future loss of an evolutionarily significant unit of woodland caribou in Canada. Biological Conservation 186:176–186.
Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.
Johnstone, J. F., T. N. Hollingsworth, F. S. Chapin, and M. C. Mack. 2010. Changes in fire regime break the legacy lock on successional trajectories in Alaskan boreal forest. Global Change Biology 16:1281–1295.
Lankau, H. E. G. 2014. Songbird Responses to Regenerating Seismic Lines in the Boreal Forest. M.Sc. thesis, University of Alberta, Edmonton, AB.
Latham, A. D. M. 2009. Wolf ecology and caribou-primary prey-wolf spatial relationships in low productivity peatland complexes in northeastern Alberta. Ph.D., University of Alberta, Edmonton, AB.
Latham, A. D. M., M. C. Latham, M. S. Boyce, and S. Boutin. 2011a. Movement responses by wolves to industrial linear features and their effect on woodland caribou in northeastern Alberta. Ecological Applications 21:2854–2865.

Latham, A. D. M., M. C. Latham, N. A. McCutchen, and S. Boutin. 2011b. Invading white-tailed deer change wolf-caribou dynamics in northeastern Alberta. The Journal of Wildlife Management 75:204–212.

Leblond, M., C. Dussault, and J.-P. Ouellet. 2013. Avoidance of roads by large herbivores and its relation to disturbance intensity: Avoidance of roads and disturbance intensity. Journal of Zoology 289:32–40.

Leblond, M., J. Frair, D. Fortin, C. Dussault, J.-P. Ouellet, and R. Courtois. 2011. Assessing the influence of resource covariates at multiple spatial scales: an application to forest-dwelling caribou faced with intensive human activity. Landscape Ecology 26:1433–1446.

Legat, A., M. McCreadie, C. Nitsiza, and C. Nitsiza. 2019. Tǫdzı (boreal caribou) and the state of their habitat. Page 109. Wek'eezhii Renewable Resources Board, Yellowknife, NT.

Lele, S. R., E. H. Merrill, J. Keim, and M. S. Boyce. 2013. Selection, use, choice and occupancy: clarifying concepts in resource selection studies. Journal of Animal Ecology 82:1183–1191.

MacNearney, D., K. Pigeon, G. Stenhouse, W. Nijland, N. C. Coops, and L. Finnegan. 2016. Heading for the hills? Evaluating spatial distribution of woodland caribou in response to a growing anthropogenic disturbance footprint. Ecology and Evolution 6:6484–6509.

Maier, J. A., J. M. Ver Hoef, A. D. McGuire, R. T. Bowyer, L. Saperstein, and H. A. Maier. 2005. Distribution and density of moose in relation to landscape characteristics: effects of scale. Canadian Journal of Forest Research 35:2233–2243.

Manly, B. F. J., L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Second edition. Kluwere Academic Publishers, New York, NY.

Matthiopoulos, J., M. Hebblewhite, G. Aarts, and J. Fieberg. 2011. Generalized functional responses for species distributions. Ecology 92:583–589.

McGarigal, K., H. Y. Wan, K. A. Zeller, B. C. Timm, and S. A. Cushman. 2016. Multi-scale habitat selection modeling: a review and outlook. Landscape Ecology.

McKenzie, H. W., E. H. Merrill, R. J. Spiteri, and M. A. Lewis. 2012. How linear features alter predator movement and the functional response. Interface Focus 2:205–216.

McLoughlin, P. D., J. S. Dunford, and S. Boutin. 2005. Relating predation mortality to broad-scale habitat selection. Journal of Animal Ecology 74:701–707.

McLoughlin, P. D., D. W. Morris, D. Fortin, E. Vander Wal, and A. L. Contasti. 2010. Considering ecological dynamics in resource selection functions. Journal of Animal Ecology 79:4–12.

McLoughlin, P. D., C. Superbie, K. Stewart, P. Tomchuk, B. Neufeld, D. Barks, T. Perry, R. Greuel, C. Regan, A. Truchon-Savard, S. Hart, J. Henkelman, and J. F. Johnstone. 2019. Population and habitat ecology of boreal caribou and their predators in the Saskatchewan Boreal Shield. Page 238. Department of Biology, University of Saskatchewan, Saskatoon, SK.

McMullin, R. T., I. D. Thompson, B. W. Lacey, and S. G. Newmaster. 2011. Estimating the biomass of woodland caribou forage lichens. Canadian Journal of Forest Research 41:1961–1969.

Moreau, G., D. Fortin, S. Couturier, and T. Duchesne. 2012. Multi-level functional responses for wildlife conservation: the case of threatened caribou in managed boreal forests: *Functional responses for wildlife conservation*. Journal of Applied Ecology 49:611–620.

Morris, L. R., K. M. Proffitt, and J. K. Blackburn. 2016. Mapping resource selection functions in wildlife studies: Concerns and recommendations. Applied Geography 76:173–183.

Muff, S., J. Signer, and J. Fieberg. 2020. Accounting for individual-specific variation in habitat-selection studies: Efficient estimation of mixed-effects models using Bayesian or frequentist computation. Journal of Animal Ecology 89:80–92.

Mumma, M. A., M. Gillingham, C. J. Johnson, and K. L. Parker. 2019. Functional responses to anthropogenic linear features in a complex predator-multi-prey system. Landscape Ecology 34:2575–2597.

Mumma, M. A., M. P. Gillingham, C. J. Johnson, and K. L. Parker. 2017. Understanding predation risk and individual variation in risk avoidance for threatened boreal caribou. Ecology and Evolution.

Mumma, M. A., M. P. Gillingham, K. L. Parker, C. J. Johnson, and M. Watters. 2018. Predation risk for boreal woodland caribou in human-modified landscapes: Evidence of wolf spatial responses independent of apparent competition. Biological Conservation 228:215–223.

Mysterud, A., and R. A. Ims. 1998. Functional responses in habitat use: availability influences relative use in trade-off situations. Ecology 79:1435–1441.

Nagy, J. A. 2011. Use of space by caribou in northern Canada. University of Alberta, Edmonton, AB.

Nagy, J. A., D. Auriat, W. Wright, T. Slack, I. Ellsworth, and M. Kienzler. 2005. Ecology of boreal woodland caribou in the Lower Mackenzie Valley, NT: work completed in the Inuvik Region April 2003 to November 2004. Page 62. Department of Resources, Wildlife, and Economic Development, Inuvik, NT.

Nagy, J. A., A. E. Derocher, S. E. Nielsen, W. H. Wright, and J. M. Heikkila. 2006. Modelling seasonal habitats of boreal woodland caribou at the northern limits of their range: A preliminary assessment of the Lower Mackenzie river valley, Northwest Terrritories, Canada. Page 36. Dept. of Environment and Natural Resources, Govt. of the Northwest Territories, Inuvik, NT.

Natural Resources Canada and Government of Northwest Territories. 2017. Monitoring forests in the Northwest Territories — Earth Observation for Sustainable Development of Forests (EOSD) land cover updates Phase 1, 2, and 3.

Nielsen, S. E., M. S. Boyce, G. B. Stenhouse, and R. H. M. Munro. 2003. Development and testing of phenologically driven grizzly bear habitat models. Écoscience 10:1–10.

Nielsen, S. E., J. Cranston, and G. B. Stenhouse. 2009. Identification of priority areas for grizzly bear conservation and recovery in Alberta, Canada. Journal of Conservation Planning 5:38–60.

Nielsen, S. E., G. McDermid, G. B. Stenhouse, and M. S. Boyce. 2010. Dynamic wildlife habitat models: Seasonal foods and mortality risk predict occupancy-abundance and habitat selection in grizzly bears. Biological Conservation 143:1623–1634.

Northrup, J. M., M. B. Hooten, C. R. Anderson Jr, and G. Wittemyer. 2013. Practical guidance on characterizing availability in resource selection functions under a use-availability design. Ecology 94:1456–1463.

Northwest Territories Conference of Management Authorities. 2013. Consensus agreement on listing boreal caribou. Page 12.

Parker, K. L., P. S. Barboza, and M. P. Gillingham. 2009. Nutrition integrates environmental responses of ungulates. Functional Ecology 23:57–69.

Peters, W., M. Hebblewhite, N. DeCesare, F. Cagnacci, and M. Musiani. 2013. Resource separation analysis with moose indicates threats to caribou in human altered landscapes. Ecography 36:487–498.

Pinard, V., C. Dussault, J.-P. Ouellet, D. Fortin, and R. Courtois. 2012. Calving rate, calf survival rate, and habitat selection of forest-dwelling caribou in a highly managed landscape. The Journal of Wildlife Management 76:189–199.

Polfus, J. L., M. Hebblewhite, and K. Heinemeyer. 2011. Identifying indirect habitat loss and avoidance of human infrastructure by northern mountain woodland caribou. Biological Conservation 144:2637–2646.

Rempel, R. S., P. C. Elkie, A. R. Rodgers, and M. J. Gluck. 1997. Timber-management and natural-disturbance effects on moose habitat: landscape evaluation. The Journal of Wildlife Management 61:517.

van Rensen, C. K., S. E. Nielsen, B. White, T. Vinge, and V. J. Lieffers. 2015. Natural regeneration of forest vegetation on legacy seismic lines in boreal habitats in Alberta's oil sands region. Biological Conservation 184:127–135.

Rettie, W. J., and F. Messier. 2000. Hierarchical habitat selection by woodland caribou: its relationship to limiting factors. Ecography 23:466–478.

Robinson, H. S., M. Hebblewhite, N. J. DeCesare, J. Whittington, L. Neufeld, M. Bradley, and M. Musiani. 2012. The effect of fire on spatial separation between wolves and caribou. Rangifer:277–294.

Rudolph, T. D., and P. Drapeau. 2012. Using movement behaviour to define biological seasons for woodland caribou. Rangifer 32:295–307.

Rudolph, T. D., P. Drapeau, L. Imbeau, V. Brodeur, S. Légaré, and M.-H. St-Laurent. 2017. Demographic responses of boreal caribou to cumulative disturbances highlight elasticity of range-specific tolerance thresholds. Biodiversity and Conservation 26:1179–1198.

Schaefer, J. A., and W. O. Pruitt Jr. 1991. Fire and woodland caribou in southeastern Manitoba. Wildlife Monographs 116:3–39.

Schaefer, J. A., A. M. Veitch, F. H. Harrington, W. K. Brown, J. B. Theberge, and S. N. Luttich. 2001. Fuzzy structure and spatial dynamics of a declining woodland caribou population. Oecologia 126:507–514.

Schielzeth, H., and W. Forstmeier. 2009. Conclusions beyond support: overconfident estimates in mixed models. Behavioral Ecology 20:416–420.

Schlaepfer, M. A., M. C. Runge, and P. W. Sherman. 2002. Ecological and evolutionary traps. Trends in Ecology & Evolution 17:474–480.

Serrouya, R., H. van Oort, C. DeMars, and S. Boutin. 2016. Human footprint, habitat, wolves and boreal caribou population growth rates. Alberta Biodiversity Monitoring Institute, Edmonton, AB.

Sih, A., M. C. O. Ferrari, and D. J. Harris. 2011. Evolution and behavioural responses to human-induced rapid environmental change. Evolutionary Applications 4:367–387.

Skakun, R., S. Rodrigues, R. Hall, and G. Castilla. 2017. Improving burned area information in the NWT for years 2004 to 2015. Page 13. Natural Rescources Canada, Canadian Forest Service, Ottawa, ON.

Skatter, H. G., M. L. Charlebois, S. Eftestøl, D. Tsegaye, J. E. Colman, J. L. Kansas, K. Flydal, and B. Balicki. 2017. Living in a burned landscape: woodland caribou (*Rangifer tarandus caribou*) use of postfire residual patches for calving in a high fire – low anthropogenic Boreal Shield ecozone. Canadian Journal of Zoology 95:975–984.

Smith, K. G., E. J. Ficht, D. Hobson, T. C. Sorensen, and D. Hervieux. 2000. Winter distribution of woodland caribou in relation to clear-cut logging in west-central Alberta. Canadian Journal of Zoology 78:1433–1440.

Sorensen, T., P. D. McLoughlin, D. Hervieux, E. Dzus, J. Nolan, B. Wynes, and S. Boutin. 2008. Determining sustainable levels of cumulative effects for boreal caribou. Journal of Wildlife Management 72:900–905.

Sousa, W. P. 1984. The role of disturbance in natural communities. Annual Review of Ecology and Systematics 15:353–391.

Species at Risk Committee. 2012. Status report for boreal caribou (Rangifer tarandus caribou) in the Northwest Territories. Species st Risk Committee, Yellowknife, NT.

Stantec Consulting Ltd. 2014. Multi-scale habitat selection by boreal woodland caribou in the Sahtu, Gwich'in and Inuvialuit regions of the Northwest Territories. Page 83. Prepared for Dept. of Environment and Natural Resources, Govt. of the Northwest Territories.

Street, G. M., L. M. Vander Vennen, T. Avgar, A. Mosser, M. L. Anderson, A. R. Rodgers, and J. M. Fryxell. 2015. Habitat selection following recent disturbance: model transferability with implications for management and conservation of moose (*Alces alces*). Canadian Journal of Zoology 93:813–821.

Stuart-Smith, K., C. J. A. Bradshaw, S. Boutin, D. M. Hebert, and A. B. Rippin. 1997. Woodland caribou relative to landscape patterns in northeastern Alberta. The Journal of Wildlife Management 61:622–633.

Thompson, D. C., and K. H. McCourt. 1981. Seasonal diets of the Porcupine caribou herd. American Midland Naturalist:70–76.

Thompson, I. D., P. A. Wiebe, E. Mallon, A. R. Rodgers, J. M. Fryxell, J. A. Baker, and D. Reid. 2015. Factors influencing the seasonal diet selection by woodland caribou (*Rangifer tarandus tarandus*) in boreal forests in Ontario. Canadian Journal of Zoology 93:87–98.

Vors, L. S., J. A. Schaefer, B. A. Pond, A. R. Rodgers, and B. R. Patterson. 2007. Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. Journal of Wildlife Management 71:1249–1256.

Whittingham, M. J., J. R. Krebs, R. D. Swetnam, J. A. Vickery, J. D. Wilson, and R. P. Freckleton. 2007. Should conservation strategies consider spatial generality? Farmland birds show regional not national patterns of habitat association: Conservation and generality. Ecology Letters 10:25–35.

Wittmer, H. U., A. R. E. Sinclair, and B. N. McLellan. 2005. The role of predation in the decline and extirpation of woodland caribou. Oecologia 144:257–267.

Worton, B. J. 1987. A review of models of home range for animal movement. Ecological Modelling 38:277–298.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70:164.

Wulder, M. A., M. M. Cranny, R. J. Hall, J. E. Luther, A. Beaudoin, J. C. White, D. G. Goodenough, and J. A. Dechka. 2008. Satellite land cover mapping of Canada's forests: the EOSD land cover project. Page (J. C. Campbell, K. D. Jones, J. H. Smith, and M. T. Koeppe, Eds.). American Association of Geographers, Washington, DC.

Zuur, A. F., E. Ieno, N. Walker, A. A. Saveliev, and G. M. Smith. 2009. Mixed effects models and extensions in ecology with R. Springer, New York, NY.

APPENDIX A: DATA SCREENING AND RADIO-COLLAR PERFORMANCE

To model seasonal resource selection by boreal caribou in the Northwest Territories, we accessed caribou spatial data from the Movebank data repository (https://www.movebank.org/). These data consisted of GPS locations collected from 435 radio-collared boreal caribou captured in the Northwest Territories and monitored for various periods between May 2002 and March 2018. Within Movebank, the data were subjected to a number of screening procedures (Davidson 2018). First, locations recorded by the radio-collar prior to its deployment on an animal or after its removal were removed. Second, duplicate records (i.e., those with identical time stamps) were removed. Third, outlying locations beyond the range of biologically plausible movement were identified and removed. Potential outliers were flagged by a speed filtering algorithm (>0.5 m/s) then visually inspected prior to their removal to confirm the record's status as a true outlier.

Prior to seasonal analyses of resource selection, we applied further screening procedures to the Movebank data. First, we excluded all locations falling outside of the study area. Next, we calculated the monitoring interval for each individual caribou within a given season and excluded those individuals that were not monitored for at least one of the seasonal period within a given year (see *Defining Seasons* in the main report) to limit potential spatiotemporal bias. For analyses using data across the entire year, we included only those individuals monitored for ≥231 days, a threshold where estimated sizes of annual home ranges reached an asymptote (see *Evaluating Resource Selection: General Framework* in the main report).

We also screened data based on radio-collar performance, specifically the mean rate of successfully acquiring a GPS location. Among individual caribou, the sampling interval for acquiring GPS locations (i.e., the fix-rate) differed due to differences in collar make, model and programming. For all collars, the programming schedule was unknown. Using the R code described later (see *R Code for Determining Collar Fix Rates*), we determined the fix rate of individual collars within a given season then created a 'regular' movement trajectory, which is a time-series of data where there is a constant time lag between each row (or entry) of data. The majority of data rows were associated with a GPS location acquired by the radio-collar. For time-steps removed by the Movebank screening procedures or when the radio-collar missed acquiring a GPS location, a row containing 'NA' values was inserted. For individual time-series where the fix rate varied within a season, we subsampled the data to the coarsest fix rate to ensure a consistent sampling interval. We then calculated the fix success rate for each caribou-season by dividing the number of rows with a successful GPS fix by the total number of rows in the time-series. Because fix success rates <90% can bias inferences on resource selection (Frair et al. 2010), we excluded caribou-seasons falling below this threshold from resource selection analyses.

After these screening procedures, the final data set consisted of 480 caribou-seasons for calving (n = 276 caribou), 371 caribou-seasons for summer (n = 238 caribou), 396 caribou-seasons for early fall (n = 247 caribou), 446 caribou-seasons for late fall (n = 270 caribou), 478 caribou-seasons for early winter (n = 301 caribou), 677 caribou-seasons for mid-winter (n = 373 caribou), 718 caribou-seasons for late winter (n = 383 caribou) and 338 caribou-years (n = 222 caribou) for analyses using data across the entire year. Note that these numbers include caribou in the Mackenzie sub-region, which were subsequently excluded from RSF analyses (see main report for details). The distribution of these caribou-seasons varied regionally with the Dehcho and South Slave regions having the highest representation (Fig. A 1).

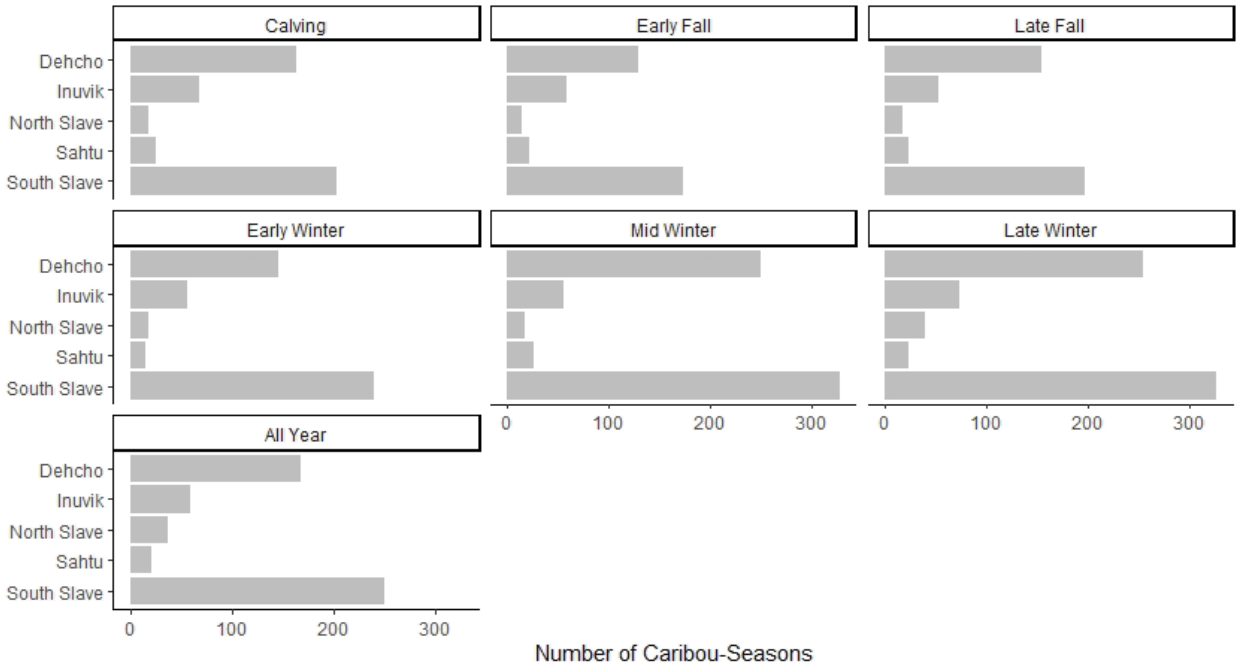


Figure A 1: The number of caribou-seasons by region used in seasonal analyses of resource selection by boreal caribou in the Northwest Territories from May 2002–March 2018.

To evaluate for potential biases in collar performance, we assessed for differences in fix success rate by year, region and among collar brands and models. For these analyses, we used all the Movebank location data including those locations falling outside of the RSF study area. Across the 15 years of monitoring (2002–2017), there was no evidence of a trend in fix success rates (p = 0.48, R^2 = 0.04, Fig. A 2). Six of the 15 years had mean rates >90% and only two years—2003 and 2004—had mean rates <70% (Table A 1). Fix success rates did vary by region and across seasons within regions (Table A 2). The North Slave region had the highest mean rate of fix success. Because all North Slave collars were deployed in 2017, this result may indicate better performance of newer collars, though the monitoring intervals for these collars were shorter compared to those in other regions (Figs. A 3-7). Comparisons of fix success rates among collar brands and models, however, also suggests better performance of newer collar models, such as those associated with Iridium satellite technology, which all had mean rates of fix success ≥97% (Table A 3).

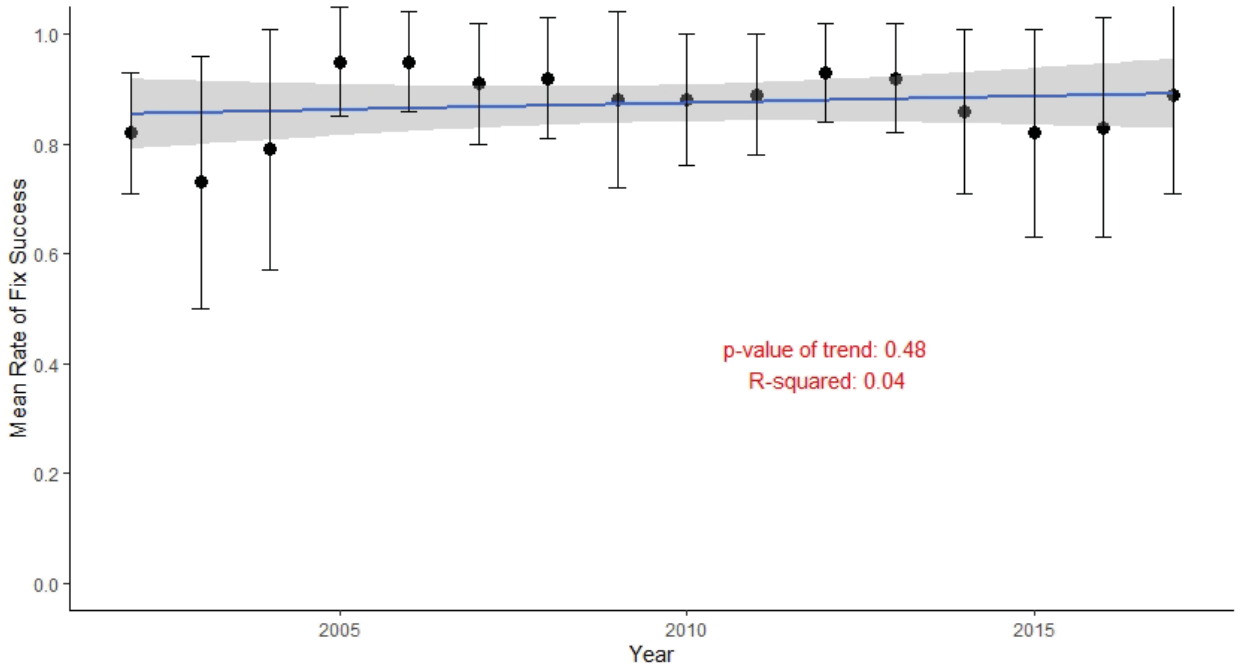


Figure A 2: The mean rates of fix success (with standard deviation bars) by year from radio-collars deployed on boreal caribou in the Northwest Territories between May 2002 and March 2018. Statistical evidence for a potential temporal trend in fix success rate was not significant.

Table A 1: The mean rate of fix success ($\bar{x}$ with standard deviation [SD]) by year among radio-collared boreal caribou (*n* = caribou-years) monitored in the Northwest Territories between May 2002 and March 2018.

	Fix Success Rate		
Year	$\bar{x}$	SD	*n*
2002	0.82	0.11	8
2003	0.73	0.23	44
2004	0.79	0.22	50
2005	0.95	0.10	212
2006	0.95	0.09	328
2007	0.91	0.11	437
2008	0.92	0.11	537
2009	0.88	0.16	460
2010	0.88	0.12	349
2011	0.89	0.11	200
2012	0.93	0.09	181
2013	0.92	0.10	311
2014	0.86	0.15	359
2015	0.82	0.19	457
2016	0.83	0.20	530
2017	0.89	0.18	806

Table A 2: The mean rates of fix success ($\overline{FSR}$ with standard deviation in brackets) from radio-collars deployed on boreal caribou in five regional study areas in the Northwest Territories. The number of caribou-seasons (n) used to calculate $\overline{FSR}$ per region is also listed.

		Season						
Region		Calving	Summer	Early Fall	Late Fall	Early Winter	Mid Winter	Late Winter
Dehcho	$\overline{\text{FSR}}$	0.87	0.83	0.86	0.90	0.88	0.90	0.91
		(0.14)	(0.15)	(0.18)	(0.14)	(0.15)	(0.15)	(0.18)
	n	328	273	252	238	359	344	285
Inuvik	$\overline{\text{FSR}}$	0.88	0.92	0.90	0.89	0.88	0.90	0.90
		(0.15)	(0.13)	(0.19)	(0.18)	(0.15)	(0.14)	(0.13)
	n	103	85	78	79	102	77	86
North Slave	$\overline{\text{FSR}}$	0.99	0.97	0.95	0.98	0.98	0.99	0.99
		(0.02)	(0.06)	(0.05)	(0.05)	(0.03)	(0.04)	(0.04)
	n	20	20	19	20	42	18	20
Sahtu	$\overline{\text{FSR}}$	0.88	0.86	0.89	0.85	0.73	0.88	0.82
		(0.08)	(0.19)	(0.28)	(0.18)	(0.21)	(0.17)	(0.15)
	n	57	39	45	47	38	44	52
South Slave	$\overline{\text{FSR}}$	0.88	0.84	0.89	0.91	0.90	0.92	0.92
		(0.15)	(0.14)	(0.15)	(0.14)	(0.14)	(0.15)	(0.18)
	n	365	302	350	300	458	439	317

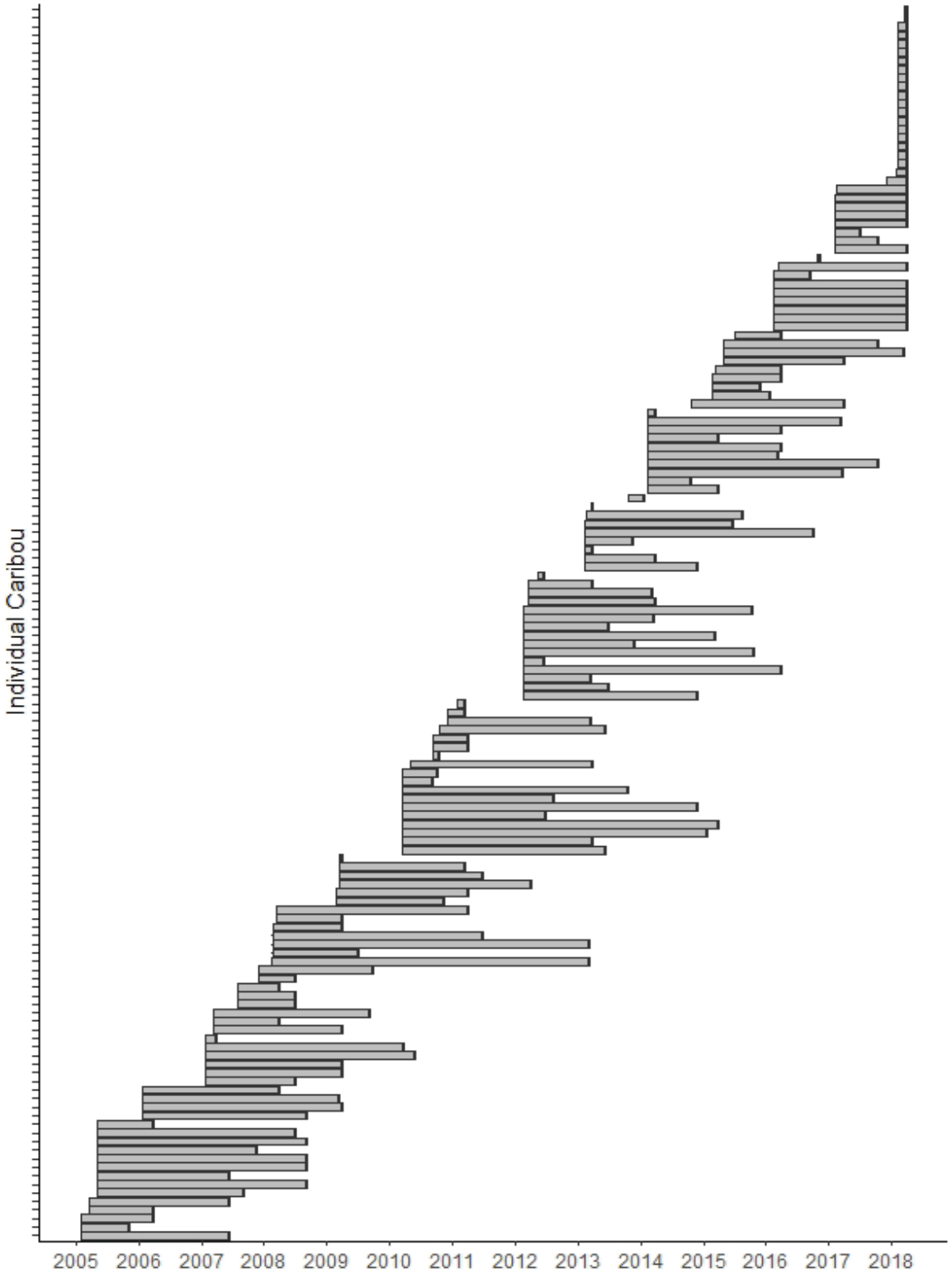


Figure A 3: The monitoring intervals for radio-collared boreal caribou in the Dehcho region of the Northwest Territories. Data from these individuals were included in analyses to infer seasonal resource selection by boreal caribou.

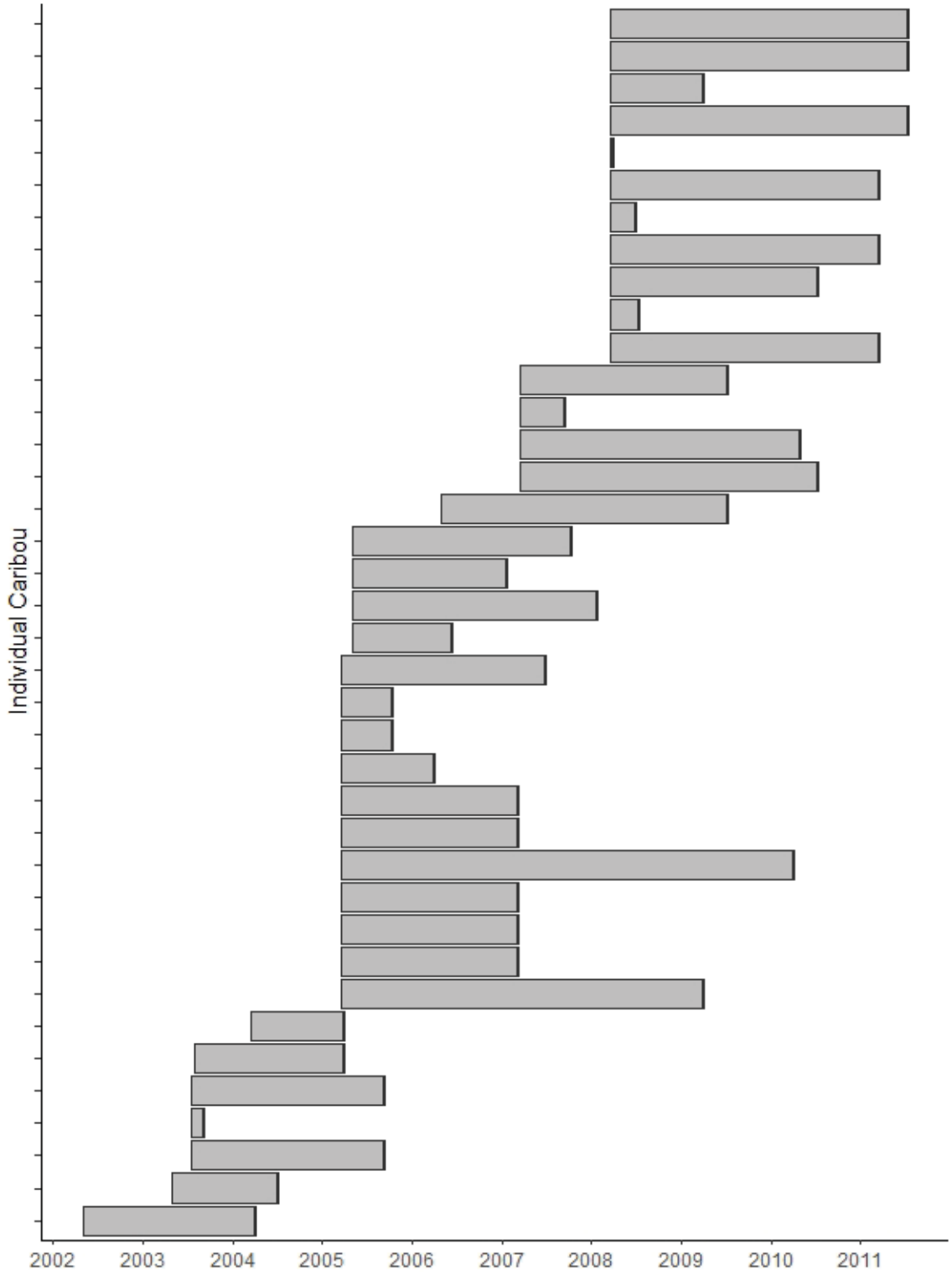


Figure A 4: The monitoring intervals for radio-collared boreal caribou in the Inuvik region of the Northwest Territories. Data from these individuals were included in analyses to infer seasonal resource selection by boreal caribou.

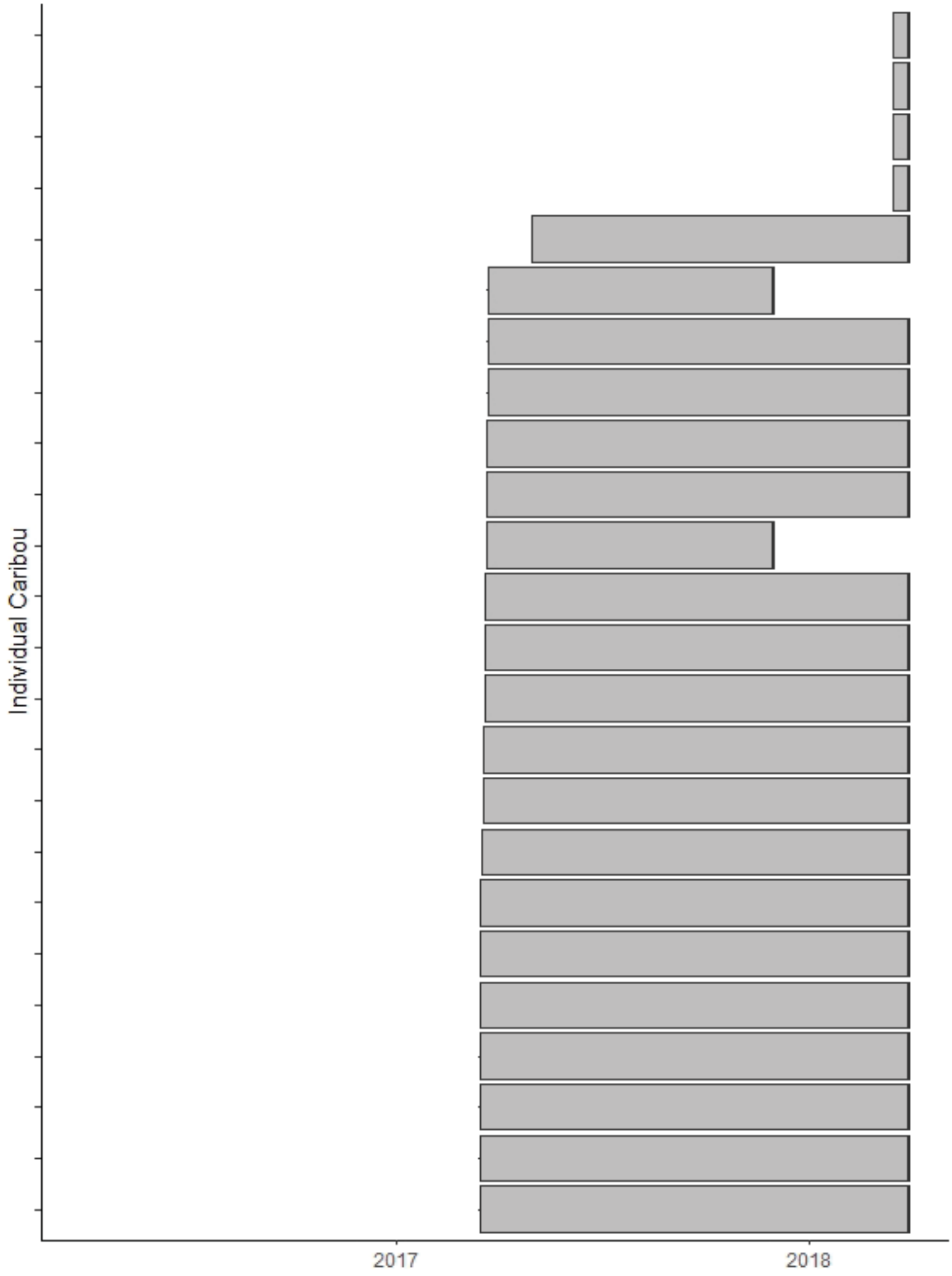


Figure A 5: The monitoring intervals for radio-collared boreal caribou in the North Slave region of the Northwest Territories. Data from these individuals were included in analyses to infer seasonal resource selection by boreal caribou.

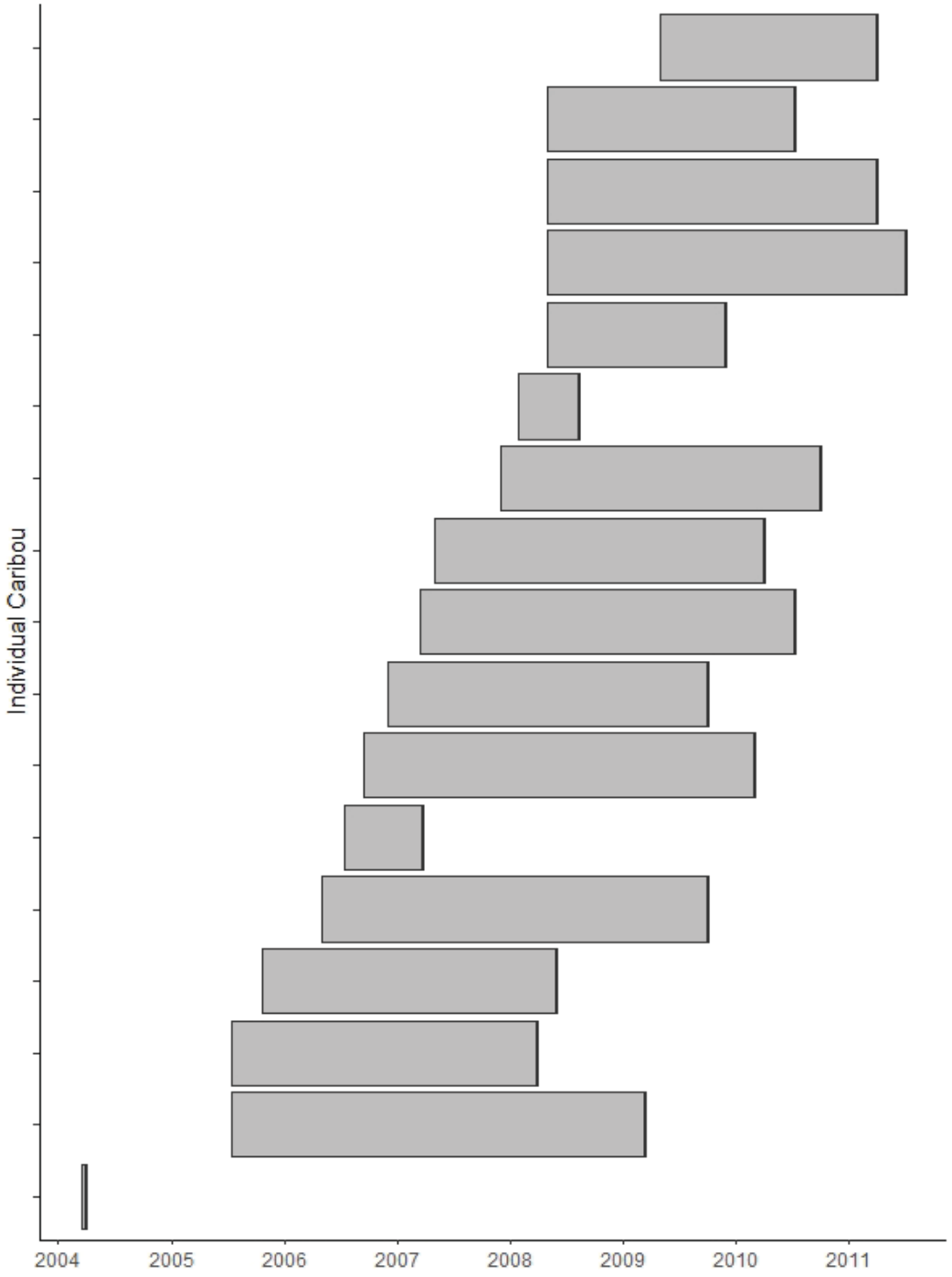


Figure A 6: The monitoring intervals for radio-collared boreal caribou in the Sahtu region of the Northwest Territories. Data from these individuals were included in analyses to infer seasonal resource selection by boreal caribou.

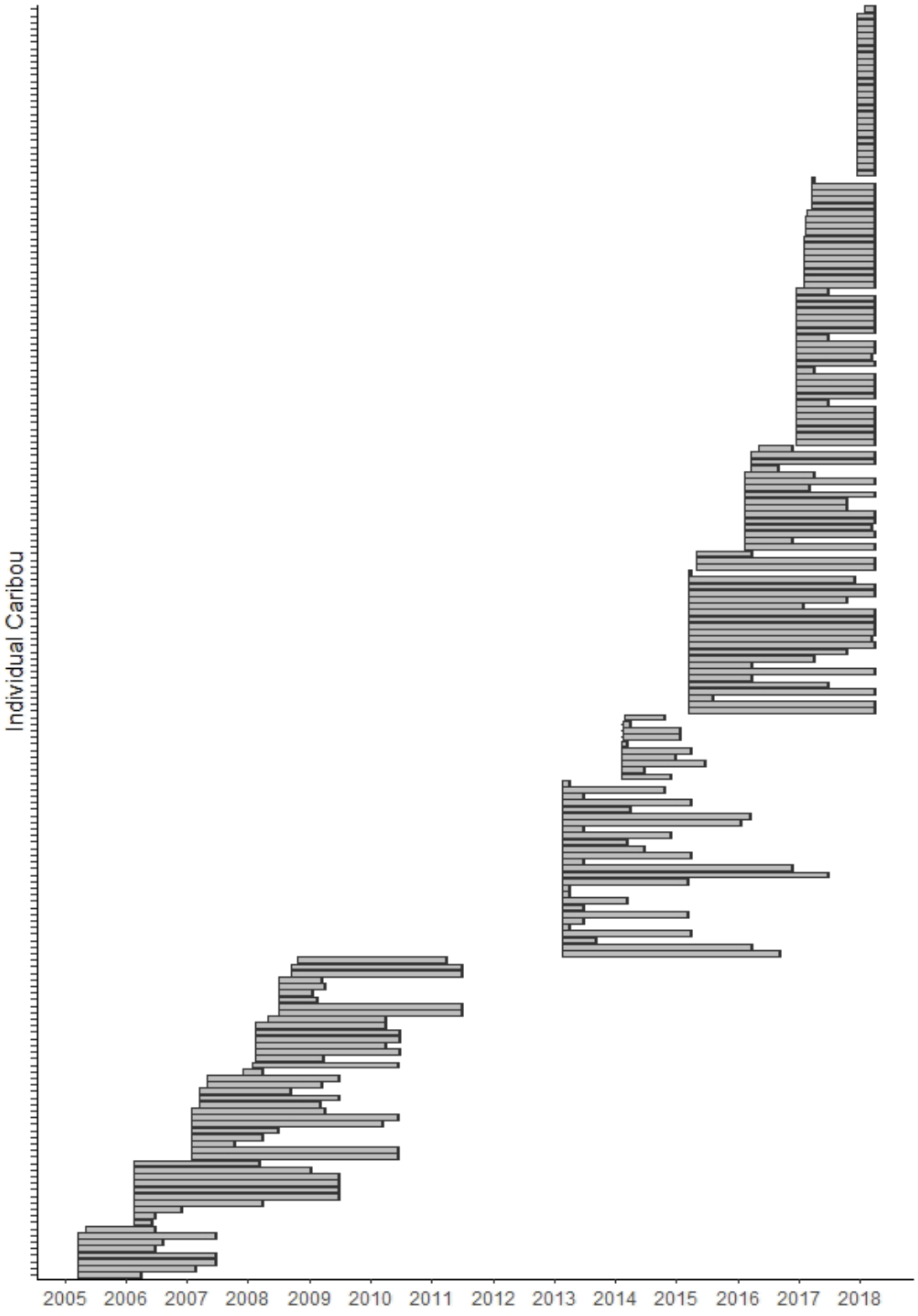


Figure A 7: The monitoring intervals for radio-collared boreal caribou in the South Slave region of the Northwest Territories. Data from these individuals were included in analyses to infer seasonal resource selection by boreal caribou.

Table A 3: The mean rate of fix success ($\overline{FSR}$ with standard deviation [SD]) by brand and model of radio-collars deployed on boreal caribou *(n* = caribou-years) in the Northwest Territories between May 2002 and March 2018.

		FSR		
Collar Brand	Model	$\bar{x}$	SD	*n*
Telonics	Argos	0.97	0.09	210
Telonics	GPS	0.90	0.07	559
Telonics	GPS Iridium	1.00	0.01	123
Telonics	GPS/Argos	0.87	0.16	1920
Telonics	GPS/Argos GPS4	0.81	0.19	937
Telonics	GPS/GlobalStar	0.86	0.13	55
Telonics	GPS/Iridium	0.98	0.05	631
Telonics	GPS/Iridium TGW-4677-4	0.98	0.04	159
Telonics	GPS/Iridium/Argos	0.97	0.08	135
Telonics	ST-10	0.92	0.11	65
Telonics	ST-14	0.94	0.12	84
Telonics	TGW-3680	0.88	0.16	467
Vectronic	GPS Plus 2	0.99	0.01	50
unknown	*n/a*	0.85	0.19	323

R Code for Determining Collar Fix Rates

The following code is used to determine the fix rate from GPS radio-collar data when the programmed fix rate for the collar is unknown. A key component of the code is the 'mk_track' function from the R package 'amt'.

```
#Load required packages
pcks <- c("move", "plyr", "tidyverse", "amt", "lme4", "adehabitatLT", "sp")
sapply(pcks, require, character = TRUE)
```

The first step is to import the Movebank data. The code for this step is not shown here.

To illustrate how fix rates are determined, data from the summer season are used as an example.

```
#Import Movebank data
#all.dat <- read.csv("your_directory\\Movebank_data.csv") #NOT RUN. Load data
from your directory

#Display the first two rows of data
head(all.dat, 2)

##   X   trackId individual_id local_identifier nick_name           timestamp
## 1 1 BWCA17600     469002982        BWCA17600   NS17600 2017-03-22 04:00:00
## 2 2 BWCA17600     469002982        BWCA17600   NS17600 2017-03-22 08:00:00
##       habitat Region location_long location_lat
## 1 North Slave nslave     -218717.7      2481535
## 2 North Slave nslave     -218707.8      2481526

#Transform into same projection as EOSD land cover data
lc.prj <- "+proj=aea +lat_1=50 +lat_2=70 +lat_0=40 +lon_0=-112 +x_0=0 +y_0=0
+ellps=GRS80 +towgs84=0,0,0,0,0,0,0 +units=m +no_defs"
coordinates(all.dat) <- c("location_long", "location_lat")
#These lines were not run as the Movebank data stored for this analysis have
already been transformed. If the data is directly imported from Movebank, the
n run these next two lines.
#proj4string(all.dat) <- CRS("+init=epsg:4326") #This is WGS84
#all.dat <- spTransform(all.dat, CRS(lc.prj))
proj4string(all.dat) <- CRS(lc.prj)


#Display the first two rows of data
head(all.dat, 2)

##   X   trackId individual_id local_identifier nick_name           timestamp
## 1 1 BWCA17600     469002982        BWCA17600   NS17600 2017-03-22 04:00:00
## 2 2 BWCA17600     469002982        BWCA17600   NS17600 2017-03-22 08:00:00
```

```
##       habitat Region
## 1 North Slave nslave
## 2 North Slave nslave
```

```
#Read in study area shapefile
studyarea <- st_read("I:\\Contract_Work\\ABMI\\NWT_RSF\\GIS_Data\\StudyArea\\
RSF_study_area_EOSD_update_extent_hand_edit_eosd_prj.shp")

#Ensure it is in the same projection as the EOSD data
studyarea <- st_transform(studyarea, crs = lc.prj)
studyarea <- sf::as_Spatial(studyarea)

#Select only those locations occurring in the study area

all.dat <- all.dat[studyarea,]
plot(studyarea, col='transparent')
plot(all.dat, add=TRUE)
```



```
all.dat <- as.data.frame(all.dat)

#Extract summer season data
northbou <- all.dat[all.dat$Region=="inuvik" | all.dat$Region=="sahtu", ]
southbou <- all.dat[all.dat$Region=="dehcho" | all.dat$Region=="nslave" | all
.dat$Region=="sslave", ]

#Because the dates of the summer season differ between the North and South re
```

```
gions, the data first need to be split.

#First, north caribou
summer.n <- data.frame()
for(i in 2002:2017){
  sumdat <- northbou[northbou$timestamp >= as.POSIXct(paste0(i, "-07-13 00:00
:00"), tz = "America/Edmonton") & northbou$timestamp <= as.POSIXct(paste0(i,
"-09-08 23:59:59"), tz = "America/Edmonton"),]
  summer.n <- rbind.data.frame(summer.n, sumdat)
}

summer.n$Yr <- as.numeric(strftime(summer.n$timestamp, format ="%Y"))
summer.n$AIDYr <- paste0(summer.n$nick_name, ".", summer.n$Yr) #creates a car
ibou-year identifier

#Assess monitoring times per caribou-season in North
mt1 <- ddply(summer.n, .(AIDYr), summarise, Start = timestamp[1], End = tail(
timestamp,1), N= n())
mt1$MT <- difftime(mt1$End, mt1$Start, units = "days")
head(mt1)

##         AIDYr               Start                 End   N            MT
## 1 IN0701.2007 2007-07-13 07:58:05 2007-09-09 00:00:00 163 57.66800 days
## 2 IN0701.2008 2008-07-13 08:03:42 2008-09-08 16:01:55 166 57.33209 days
## 3 IN0701.2009 2009-07-13 08:03:42 2009-09-09 00:00:00 159 57.66410 days
## 4 IN0701.2010 2010-07-13 08:03:42 2010-08-01 16:01:55  53 19.33209 days
## 5 IN0704.2007 2007-07-13 07:58:05 2007-09-09 00:00:00 168 57.66800 days
## 6 IN0704.2008 2008-07-13 08:03:42 2008-09-08 16:01:55 161 57.33209 days

nrow(mt1) #154

## [1] 154

#Get rid of those bou with less than 29 days of monitoring time (1/2 of total
monitoring period)
sboun <- mt1[mt1$MT > 29,]
sbounID <- unique(sboun$AIDYr)
length(sbounID) #133 bou-years

## [1] 133

summer.s <- data.frame()
for(i in 2002:2017){
  sumdat <- southbou[southbou$timestamp >= as.POSIXct(paste0(i, "-07-01 00:00
:00"), tz = "America/Edmonton") & southbou$timestamp <= as.POSIXct(paste0(i,
"-09-12 23:59:59"), tz = "America/Edmonton"),]
  summer.s <- rbind.data.frame(summer.s, sumdat)
}

summer.s$Yr <- as.numeric(strftime(summer.s$timestamp, format ="%Y"))
summer.s$AIDYr <- paste0(summer.s$nick_name, ".", summer.s$Yr) #creates a car
```

```
ibou-year identifier

#Assess monitoring times per caribou-season in the South
mt2 <- ddply(summer.s, .(AIDYr), summarise, Start = timestamp[1], End = tail(
timestamp,1), N= n())
mt2$MT <- difftime(mt2$End, mt2$Start, units = "days")
head(mt2)

##        AIDYr               Start                 End   N            MT
## 1 BI318.2013 2013-07-01 08:00:00 2013-09-13 00:00:00 214 73.66667 days
## 2 BI318.2014 2014-07-01 08:00:00 2014-09-13 00:01:00 184 73.66736 days
## 3 BI318.2015 2015-07-01 16:00:00 2015-08-23 00:01:00 126 52.33403 days
## 4 BI319.2013 2013-07-01 08:00:00 2013-09-13 00:00:00 184 73.66667 days
## 5 BI319.2014 2014-07-03 00:00:00 2014-09-11 00:00:00 134 70.00000 days
## 6 BI319.2015 2015-07-01 08:00:00 2015-09-13 00:00:00 131 73.66667 days

nrow(mt2) #673

## [1] 673

#Get rid of those bou with less than 37 days of monitoring time (1/2 of total
monitoring period)
sbous <- mt2[mt2$MT > 37,]
sbousID <- unique(sbous$AIDYr)
length(sbousID) #604 bou-years

## [1] 604

summer <- rbind.data.frame(summer.n, summer.s)
rm(summer.n, summer.s)

sbouID <- c(sbounID, sbousID)
length(sbouID) #737

## [1] 737

#Use 'mk_track' function from package 'amt' to get fix rate intervals for eac
h caribou-year.  It requires a data frame with XY coordinates and a coordinat
e reference system (CRS).

sumres <- data.frame()
for(i in sbouID){
  sdat <- summer[summer$AIDYr==i,]
  sdat <- sdat[complete.cases(sdat[, 8:9]),]
  tdat <- data.frame(x = sdat$location_long, y = sdat$location_lat, ts = sdat
$timestamp)
  tdat <- tdat[!duplicated(tdat$ts),]
  yrtrack <- mk_track(tdat, x, y, ts, crs = sp::CRS(lc.prj))
  df <- as.data.frame(summarize_sampling_rate(yrtrack, time_unit="hour"))
  df$AIDYr <- i
  df$AID <- str_sub(df$AIDYr, 1, str_length(df$AIDYr)-5)
  df$nrow <- nrow(sdat)
```

```
  df$Start.Date <- sdat$timestamp[1]
  df$End.Date <- tail(sdat$timestamp,1)

  sumres <- rbind.data.frame(sumres, df)
}
head(sumres)
```

```
##        min       q1   median     mean       q3      max       sd   n unit
## 1 7.968056 7.968056 7.970278 8.543407 8.061667 24.00000 2.213799 162 hour
## 2 7.968056 7.968056 7.970278 8.339214 8.061667 24.00000 1.840158 165 hour
## 3 7.968056 7.968056 7.970278 8.759103 8.061667 24.00000 2.515430 158 hour
## 4 7.874444 7.968056 7.970278 8.287616 8.061667 16.03194 1.490988 167 hour
## 5 7.968056 7.968056 7.970278 8.599814 8.062222 16.03194 2.111837 160 hour
## 6 7.968056 7.968056 7.968056 8.237728 8.061667 24.00000 1.623790 168 hour
##         AIDYr    AID nrow          Start.Date            End.Date
## 1 IN0701.2007 IN0701  163 2007-07-13 07:58:05 2007-09-09 00:00:00
## 2 IN0701.2008 IN0701  166 2008-07-13 08:03:42 2008-09-08 16:01:55
## 3 IN0701.2009 IN0701  159 2009-07-13 08:03:42 2009-09-09 00:00:00
## 4 IN0704.2007 IN0704  168 2007-07-13 07:58:05 2007-09-09 00:00:00
## 5 IN0704.2008 IN0704  161 2008-07-13 08:03:42 2008-09-08 16:01:55
## 6 IN0709.2007 IN0709  169 2007-07-13 08:03:42 2007-09-09 00:00:00
```

The median time difference between successive GPS locations identifies the likely programmed fix rate of the collar during the season. The summary below gives the number of caribou-years for some given fix rates.

```
sumres$roundMedian <- round(sumres$median, 0)

nrow(sumres)

## [1] 737

nrow(sumres[sumres$roundMedian==24,])

## [1] 71

nrow(sumres[sumres$roundMedian==12,])

## [1] 0

nrow(sumres[sumres$roundMedian==8,])

## [1] 459

nrow(sumres[sumres$roundMedian==6,])

## [1] 0

nrow(sumres[sumres$roundMedian==4,])
```

```
## [1] 25

nrow(sumres[sumres$roundMedian==2,])

## [1] 14
```

Identifying the fix rate allows for the creation of a regular movement trajectory. 'Regular' means that within an individual's time-series of data there is a row for every time step as specified by the fix rate. The majority of these rows will be associated with an actual GPS location. For steps where the collar did not record a GPS location or the location was removed by our data screening procedures, values within the row—other than the timestamp—are assigned a value of 'NA'. The fix success rate can then be calculated by dividing the number of rows having a GPS location by the total number of rows in the time-series. The R package 'adehabitatLT' is used to create the regular movement trajectory. The following code demonstrates how to create a regular trajectory for caribou with a 2-hour fix rate then calculates the fix success rate for each caribou-season.

```
#Extract caribou with 2-hour fix rates
fr2 <- sumres[sumres$roundMedian ==2,]
u2 <- unique(fr2$AIDYr)
length(u2)

## [1] 14

#Calculate fix rates and remove time-abherrant fixes.
traj2 <- data.frame()
bou2.dat <- data.frame()
for(i in u2){
  dat2 <- summer[summer$AIDYr==i,]
  dat2$AIDYr <- droplevels(dat2)$AIDYr

  #This section removes time-abherrant fixes, i.e. those that fall well beyon
d the 2-hr fix rate
  timediff <- as.numeric(diff(dat2$timestamp), units = "secs") #get time diff
erences between successive steps
  dat2$dt <- NA
  dat2$dt[2:length(dat2$dt)] <- as.numeric(abs(timediff))
  dat2$dt[1] <- as.numeric(difftime(dat2$timestamp[2], dat2$timestamp[1], uni
ts="secs"))
  dat2$dt2 <- dat2$dt %% 7200 #7200 is 2 hours (in seconds)
  dat2 <- filter(dat2, dt2 <= 1800 | dt2 >= 5401 & dt2 <= 8999) #keep those w
ithin 30 minutes of the 2-hr fix rate
  dat2 <- dat2[!(dat2$dt < 5400),]

  #This section creates the movement trajectory
  lt <- as.ltraj(dat2[,9:10], dat2$timestamp, id=dat2$AIDYr, proj4string = sp
::CRS(lc.prj))
  lt <- setNA(lt, dat2$timestamp[2], 2*60*60, tol=1800) #this function places
```

```
NA rows where fixes were missed or removed
  lt <- sett0(lt, dat2$timestamp[2], 2*60*60, tol=1800)
  df <- as.data.frame(summary(lt)) #store the summary of the movement traject
ory in a data frame
  df$Yr <- as.numeric(format(df$date.begin, "%Y"))

  #This section saves and formats the regular time-series of data
  ltdf <- as.data.frame(lt[[1]])
  ltdf <- ltdf[!is.na(ltdf$x),]
  ltdf$AIDYr <- i
  ltdf$AID <- str_sub(ltdf$AIDYr, 1, str_length(ltdf$AIDYr)-5)
  ltdf$Yr <- as.numeric(format(ltdf$date, "%Y"))
  ltdf$Month <- as.numeric(format(ltdf$date, "%m"))
  ltdf$Day <- as.numeric(format(ltdf$date, "%d"))
  ltdf$Hr <- as.numeric(format(ltdf$date, "%H"))
  ltdf$Min <- as.numeric(format(ltdf$date, "%M"))

  traj2<- rbind.data.frame(traj2, df)
  bou2.dat <- rbind.data.frame(bou2.dat, ltdf)
}
head(traj2)
```

```
##           id      burst nb.reloc NAs          date.begin            date.e
nd
## 1 MK709.2017 MK709.2017      888  10 2017-07-01 06:00:00 2017-09-13 04:00:
00
## 2 MK710.2017 MK710.2017      888  41 2017-07-01 06:00:00 2017-09-13 04:00:
00
## 3 MK711.2017 MK711.2017      888   1 2017-07-01 06:00:00 2017-09-13 04:00:
00
## 4 MK713.2017 MK713.2017      888  35 2017-07-01 06:00:00 2017-09-13 04:00:
00
## 5 MK714.2017 MK714.2017      888   7 2017-07-01 06:01:00 2017-09-13 04:01:
00
## 6 MK715.2017 MK715.2017      888  19 2017-07-01 06:00:00 2017-09-13 04:00:
00
##     Yr
## 1 2017
## 2 2017
## 3 2017
## 4 2017
## 5 2017
## 6 2017
```

```
head(bou2.dat)
```

```
##           x       y                date          dx          dy       dist
dt
## 1 -225775.0 2421877 2017-07-01 06:00:00    97.07548  289.337877  305.18856
7200
```

```
## 2 -225677.9 2422167 2017-07-01 08:00:00   611.85278 -684.258283  917.91788
7200
## 3 -225066.0 2421482 2017-07-01 10:00:00   -76.31866  -54.722501   93.91001
7200
## 4 -225142.3 2421428 2017-07-01 12:00:00 -1639.41353 -520.383083 1720.02188
7200
## 5 -226781.8 2420907 2017-07-01 14:00:00  -445.51405  183.414094  481.79196
7200
## 6 -227227.3 2421091 2017-07-01 16:00:00    10.66194    9.058112   13.99022
7200
##          R2n  abs.angle  rel.angle      AIDYr   AID   Yr Month Day Hr Min
## 1       0.00  1.2470889         NA MK709.2017 MK709 2017     7   1  6   0
## 2   93140.06 -0.8412038 -2.0882927 MK709.2017 MK709 2017     7   1  8   0
## 3  658541.41 -2.5195307 -1.6783269 MK709.2017 MK709 2017     7   1 10   0
## 4  602373.66 -2.8342316 -0.3147009 MK709.2017 MK709 2017     7   1 12   0
## 5 1954604.57  2.7510487 -0.6979051 MK709.2017 MK709 2017     7   1 14   0
## 6 2727985.76  0.7042470 -2.0468017 MK709.2017 MK709 2017     7   1 16   0
```

```
#Fix success rates by caribou-season
AIDYr.fr2 <- data.frame()
uidyr <- unique(traj2$id)
for(i in uidyr){
  bou <- traj2[traj2$id==i,]
  frdf <- data.frame(AIDYr = i, nb.reloc = bou$nb.reloc, NAs = bou$NAs, Fix.R
ate = (bou$nb.reloc - bou$NAs)/ bou$nb.reloc)
  AIDYr.fr2 <- rbind.data.frame(AIDYr.fr2, frdf)
}
head(AIDYr.fr2)
```

```
##        AIDYr nb.reloc NAs  Fix.Rate
## 1 MK709.2017      888  10 0.9887387
## 2 MK710.2017      888  41 0.9538288
## 3 MK711.2017      888   1 0.9988739
## 4 MK713.2017      888  35 0.9605856
## 5 MK714.2017      888   7 0.9921171
## 6 MK715.2017      888  19 0.9786036
```

```
nrow(AIDYr.fr2) #14
```

```
## [1] 14
```

```
nrow(AIDYr.fr2[AIDYr.fr2$Fix.Rate >= 0.9,])
```

```
## [1] 14
```

Literature Cited

Davidson, S. 2018. Notes on organizing GNWT boreal caribou telemetry datasets in Movebank. Movebank, Max Planck Institute of Animal Behaviour, Konstanz, Germany.

Frair, J. L., J. Fieberg, M. Hebblewhite, F. Cagnacci, N. J. DeCesare, and L. Pedrotti. 2010. Resolving issues of imprecise and habitat-biased locations in ecological analyses using GPS telemetry data. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2187–2200.

APPENDIX B: DEFINING AVAILABILITY FOR RESOURCE SELECTION FUNCTIONS

Resource selection is a hierarchical process (Rettie and Messier 2000, Boyce 2006) and an integral component to evaluating resource selection is identifying the area that is available to an individual animal. Differences in availability inform the spatial scales of resource selection (Boyce 2006). Here, we outline how availability was defined and sampled at the two scales used to assess seasonal selection of resources by boreal caribou in the Northwest Territories. R code is provided for all steps in this process.

SECOND-ORDER AVAILABILITY

For analyses evaluating resource selection at a second-order scale, availability is typically defined as regions containing populations of the species of interest (Meyer and Thuiller 2006). Spatial delineations of boreal caribou populations in the Northwest Territories are not well defined; therefore, we defined availability at this scale by examining movement patterns among radio-collared caribou across the study area and considering expert input from regional government biologists. This process yielded two regions of availability: a North region containing caribou radio-collared in the Inuvik and Sahtu regional study areas and a South region containing caribou radio-collared in the Dehcho, North Slave, and South Slave regional study areas. We spatially delineated these regions by first fitting 100% minimum convex polygons (MCPs) around all available GPS locations within each region. The following code was used to generate the MCPs. The first step, which is not shown, was to import the screened radio-collar data into R (see Appendix A).

```
#Load required R libraries

pcks <- c("move", "tidyverse", "sf", "sp", "lwgeom", "ggpubr")
sapply(pcks, require, character = TRUE)

#All modelling was done using the same projection as the EOSD land cover data

lc.prj <- "+proj=aea +lat_1=50 +lat_2=70 +lat_0=40 +lon_0=-112 +x_0=0 +y_0=0
+ellps=GRS80 +towgs84=0,0,0,0,0,0,0 +units=m +no_defs"



#Import screened radio-collar data

#all.dat <- read.csv("your_directory\\NWT_caribou_screened_GPS_data.csv")

#Display the first two rows of data
head(all.dat, 2)

##     trackId individual_id local_identifier nick_name location_lat location
_long
## 1 BWCA17600     469002982        BWCA17600   NS17600     62.25693     -116
.2770
## 2 BWCA17600     469002982        BWCA17600   NS17600     62.25686     -116
.2768
##             timestamp     habitat Region
```

```
## 1 2017-03-22 04:00:00 North Slave nslave
## 2 2017-03-22 08:00:00 North Slave nslave

#Re-project into same projection as EOSD data. First create a SpatialPointsDa
taFrame.
coordinates(all.dat) <- c("location_long", "location_lat")
proj4string(all.dat) <- CRS("+init=epsg:4326") #this is the projection of WGS
84
all.dat <- as.data.frame(spTransform(all.dat, CRS(lc.prj)))
all.dat <- all.dat[all.dat$timestamp <= as.POSIXct("2018-03-31 23:59:59"),]

#Extract regional data
northbou <- all.dat[all.dat$Region=="inuvik" | all.dat$Region=="sahtu", ]
southbou <- all.dat[all.dat$Region=="dehcho" | all.dat$Region=="nslave" | all
.dat$Region=="sslave", ]

#Create 100% MCPs
npts <- st_as_sf(northbou, coords = c("location_long", "location_lat"), crs =
lc.prj)
nmcp <- st_convex_hull(st_union(npts)) #to create one MCP

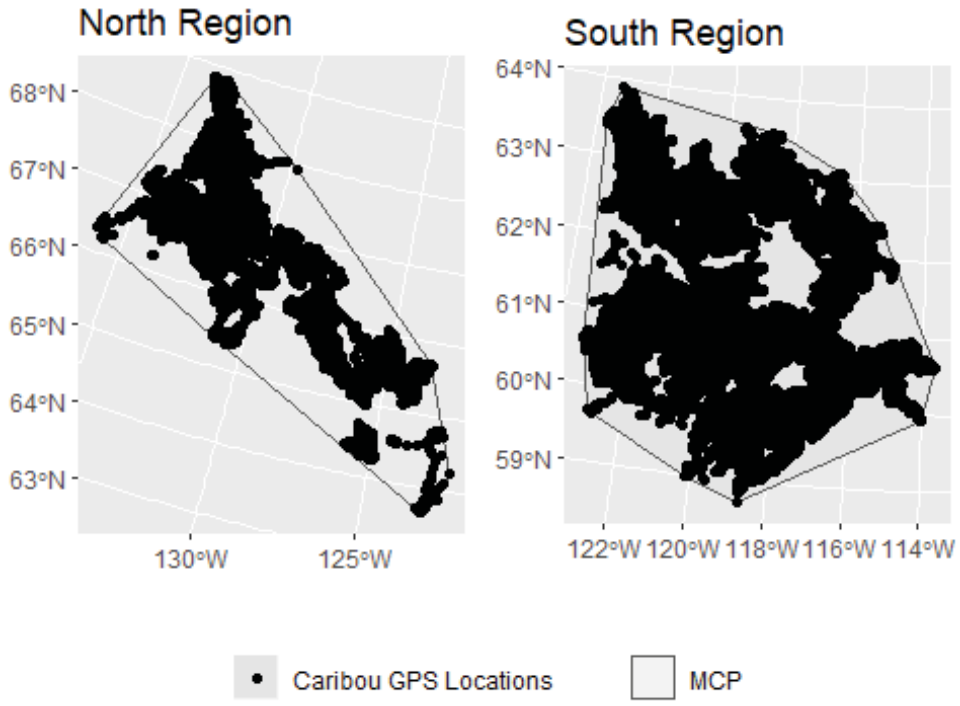
#Plot
colors <- c("Caribou GPS Locations" = "black")
f <- c("MCP" = NA)

n.plot <- ggplot() + geom_sf(data=nmcp, aes(fill = "MCP"), show.legend = "pol
ygon") + geom_sf(data=npts, aes(color="Caribou GPS Locations"), show.legend =
"point") + scale_color_manual(values = colors, guide = guide_legend(override.
aes = list(linetype = "blank"))) + scale_fill_manual(values = f, guide = guid
e_legend(override.aes = list(shape = NA)))+ theme(legend.position="bottom", l
egend.title = element_blank()) + labs(title="North Region")

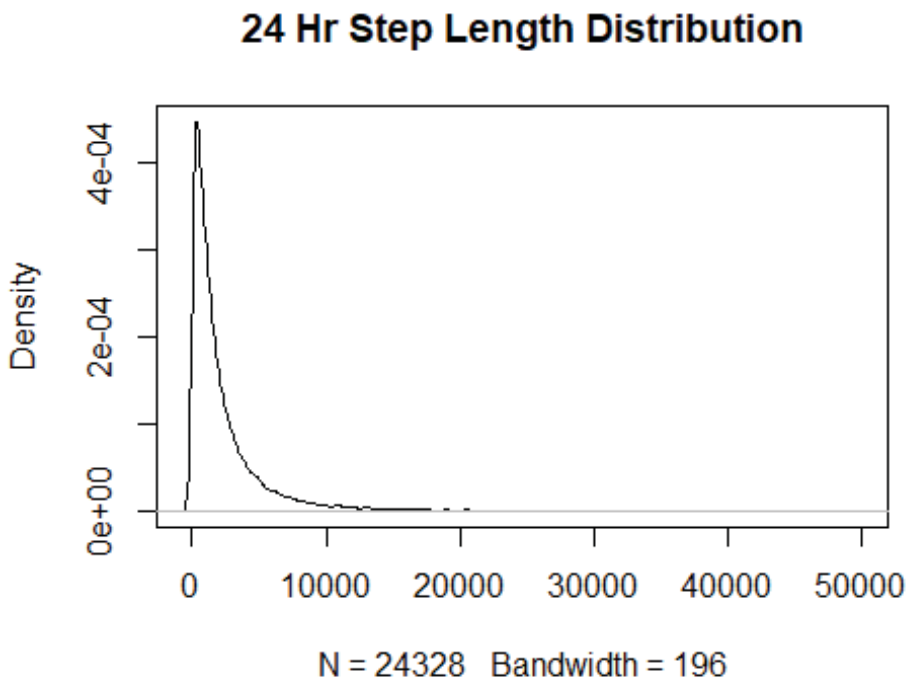
spts <- st_as_sf(southbou, coords = c("location_long", "location_lat"), crs =
lc.prj)
smcp <- st_convex_hull(st_union(spts)) #to create one MCP

s.plot <- ggplot() + geom_sf(data=smcp) + geom_sf(data=spts) + labs(title="So
uth Region")

ggarrange(n.plot, s.plot, ncol=2, common.legend = TRUE, legend="bottom")
```



Because the borders of the above MCPs are defined by the outermost GPS locations, availability becomes increasingly constrained at the outer edges of the MCP. To create a more biologically reasonable border, we buffered each MCP by an estimate of the maximum distance caribou moved in a 24-hr period. We estimated this buffer by evaluating the distribution of step lengths (i.e., the distance moved between successive GPS locations) from radio-collar data having a 24-hr fix rate, then used the 99% quantile of this distribution as the buffer distance. The following code outlines this analysis.



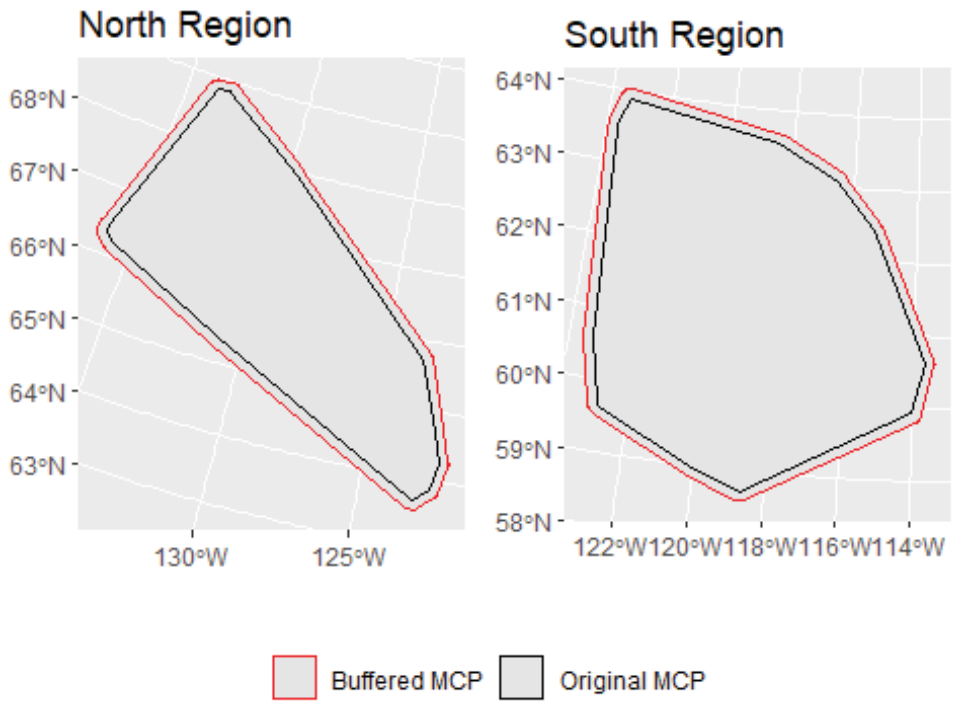

```
#Get 99% quantile of this distribution
quantile(d, probs=0.99, na.rm=TRUE)

##      99%
## 15124.71 # ~15-km


#Add 15-km buffer to MCPs
buff.cols <- c("Original MCP" = "black", "Buffered MCP" = "red")
nmcp.buff <- st_buffer(nmcp, dist=15000)
n.buff <- ggplot() + geom_sf(data=nmcp.buff, aes(color="Buffered MCP")) + geo
m_sf(data=nmcp, aes(color="Original MCP")) + labs(title="North Region") + sca
le_color_manual(values = buff.cols) + theme(legend.position="bottom", legend.
title = element_blank())

smcp.buff <- st_buffer(smcp, dist=15000)
s.buff <- ggplot() + geom_sf(data=smcp.buff, color = "red") + geom_sf(data=sm
cp, color="black") + labs(title="South Region")

ggarrange(n.buff, s.buff, ncol=2, common.legend = TRUE, legend="bottom")
```



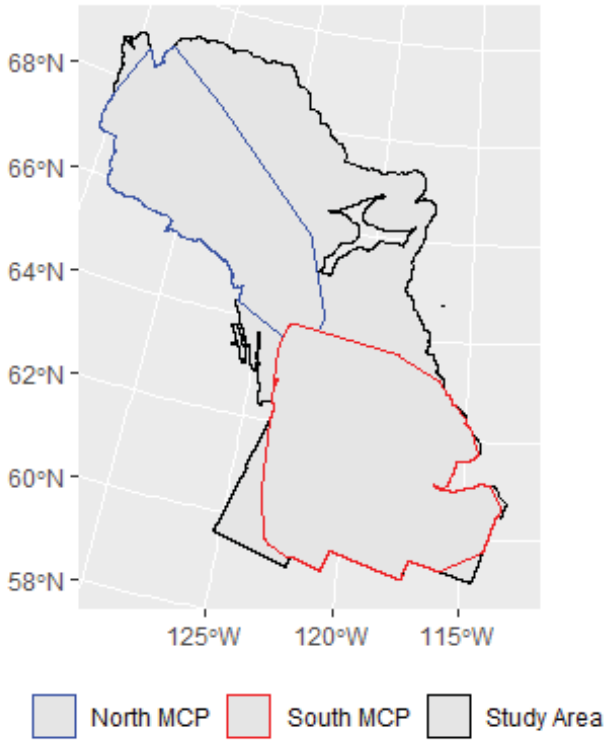
As a final step, the buffered MCPs were clipped to the boundaries of study area.

```
#Read in study area shapefile
sa <- st_read("I:\\Contract_Work\\ABMI\\NWT_RSF\\GIS_Data\\StudyArea\\RSF_study_area_EOSD_update_extent_hand_edit.shp")

#transform to EOSD projection
sa <- st_transform(sa, crs = lc.prj)

#Intersect buffered MCPs and study area
nmcp.buff <- st_intersection(nmcp.buff, sa)
smcp.buff <- st_intersection(smcp.buff, sa)
mcp.cols2 <- c("Study Area" = "black", "North MCP" = "blue", "South MCP" = "red")

#Plot
ggplot() + geom_sf(data=sa, aes(color="Study Area")) + geom_sf(data=nmcp.buff, aes(color="North MCP")) + geom_sf(data=smcp.buff, aes(color="South MCP")) + scale_color_manual(values = mcp.cols2) + theme(legend.position="bottom", legend.title = element_blank())
```



THIRD-ORDER AVAILABILITY

Third-order selection evaluates how animals select resources within their home ranges (Johnson 1980, Meyer and Thuiller 2006). For our analyses, we estimated home ranges annually, which meant that seasonal GPS locations within a given year were compared to random locations sampled within the home range of that same year. Annual home ranges for each individual caribou were estimated using all GPS locations collected from 1 May–30 April, a biological year with a start date that corresponds to the onset of the calving season. We characterized home ranges using kernel density estimates (KDEs), which represent a probability surface of an animal's space use (i.e., the probability of relocating an animal at a given spatial coordinate; Worton 1989). Compared to MCPs, KDEs provide more robust estimates of home ranges as they are less sensitive to fix rate and do not make assumptions of uniform space use (White and Garrott 1990, Börger et al. 2006). Because of these properties, KDEs were estimated using all of the MoveBank data and were not restricted to individual data sets with fix success rates > 90%. We estimated KDEs using recently developed methods that account for autocorrelation in GPS location data (Fleming et al. 2015). We used the 95% isopleth of the KDE to define the spatial boundaries of the annual home range. KDEs that partially extended beyond the study area were clipped to the study area boundary. The following code demonstrates home range estimation for an individual caribou.

```
#Load required packages
```

```
pcks <- c("move", "sf", "ggplot2", "ctmm") # 'ctmm' estimates KDEs
sapply(pcks, require, character = TRUE)

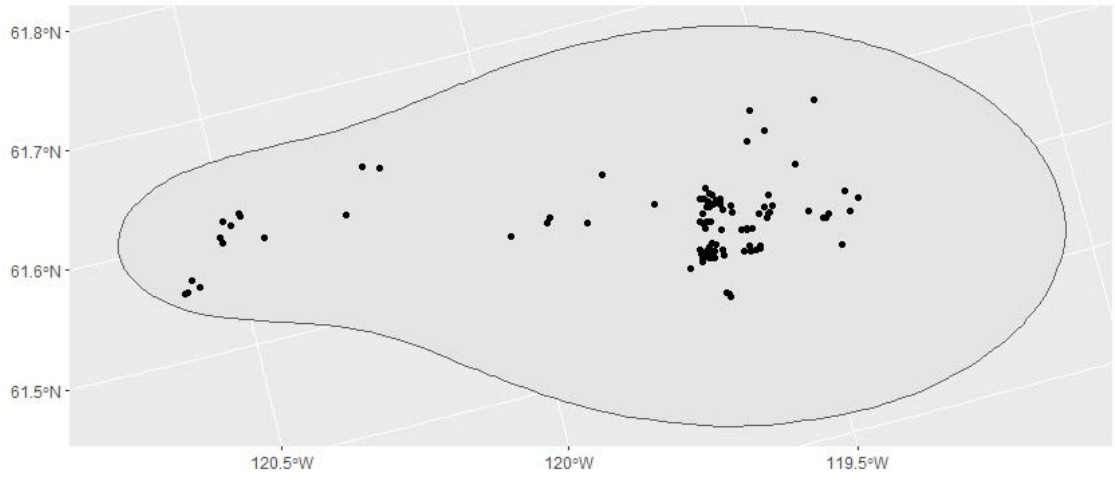
#Load Movebank data.  Accessing data from Movebank is not shown.

#dat <- read.csv("your_directory\\NWT_caribou_Movebank_GPS_data.csv")

#Select an individual caribou
bou <- dat[dat$local_identifier == "DN131" & dat$timestamp >= as.POSIXct("200
7-05-01 00:00:00", tz="UTC") & dat$timestamp <= as.POSIXct("2007-05-01 00:00:
00", tz="UTC") + (3600*24*365), ]
bou.pts <- st_as_sf(bou, coords = c("location_long", "location_lat"), crs = "
+init=epsg:4326")


bou$local_identifier <- droplevels(bou)$local_identifier
bou <- as.telemetry(bou) #transforms to a telemetery object
GUESS <- ctmm.guess(bou,interactive=FALSE)
control <- list(method='pNewton') #this is a better optimizer than the defaul
t
FIT <- try(ctmm.fit(bou,GUESS, control = control), TRUE)
#Compute akde object
UD.bou <- akde(bou,FIT)
udbou <- SpatialPolygonsDataFrame.UD(UD.bou) #transform AKDE into SPDF
udbou <- st_as_sf(udbou) #then into an sf object
udbou <- udbou[2,2]

ggplot(data = udbou) + geom_sf() + geom_sf(data=bou.pts)
```



Although KDEs are relatively robust to variation in fix rate, they can be sensitive to the monitoring interval (i.e., the total time an animal is monitored; Börger et al. 2006). For example, a KDE estimated using three months of data may substantially differ from one estimated using 12 months of data. We therefore conducted a sensitivity analysis to identify the minimum monitoring interval necessary to adequately estimate the annual home range. To do so, we used only those caribou that were monitored for at least 350 days and iteratively compared the area of KDEs estimated for each caribou as the length of monitoring time was increased from 30 days to 365 days. We used a mixed-effects piecewise regression approach to identify the minimum monitoring time after which the area of KDEs stabilized. This analysis suggested that the estimated area of annual KDEs stabilized after 231 days. The following code details this sensitivity analysis and produces a plot to illustrate the relationship between KDE size and monitoring time.

```
#Use 2009 as example
yr09 <- dat90[dat90$timestamp >= as.POSIXct("2009-05-01 00:00:00", tz="UTC")
& dat90$timestamp <= as.POSIXct("2009-05-01 00:00:00", tz="UTC") + (3600*24*3
65), ] #start year on May 1, start of calving season
yr09 <- arrange(yr09, local_identifier, timestamp)

mt <- ddply(yr09, .(local_identifier), summarise, St.date = timestamp[1], End
.date = tail(timestamp,1)) #assess monitoring times for each caribou
mt$MT <- difftime(mt$End.date, mt$St.date, unit = "days")
for.yr <- mt[mt$MT >=350,] #select only those monitored for >= 350 days
yrID <- unique(for.yr$local_identifier)

sensdat <- yr09[yr09$local_identifier %in% yrID,]
sensdat$local_identifier <- droplevels(sensdat)$local_identifier

#Run through bou with at least one year of monitoring
sensres <- data.frame()

for(i in c(30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 350, 365)){
  subdat <- sensdat[sensdat$timestamp <= as.POSIXct("2009-05-01 00:00:00", tz
="UTC") + (3600*24*i), ]

  subres <- data.frame()
  for(j in yrID){
    bou <- subdat[subdat$local_identifier==j,]
    bou$local_identifier <- droplevels(bou)$local_identifier
    bou <- as.telemetry(bou) #transforms to a telemetery object
    GUESS <- ctmm.guess(bou,interactive=FALSE)
    control <- list(method='pNewton') #this is a better optimizer than the de
fault
    FIT <- try(ctmm.fit(bou,GUESS, control = control), TRUE)
    #Compute akde object
    UD.bou <- akde(bou,FIT)
    udbou <- SpatialPolygonsDataFrame.UD(UD.bou) #transform AKDE into SPDF
```

```r
    udbou <- st_as_sf(udbou) #then into an sf object
    a <- st_area(udbou[[2]][1]) %>% set_units(km^2) %>% as.vector()
    df <- data.frame(AID = j, Area = a, MT = i)
    subres <- rbind.data.frame(subres, df)
  }
 sensres <- rbind.data.frame(sensres, subres)
}

##Plot##
p <- ggplot(sensres, aes(x = MT, y = Area, color = AID)) + geom_line() + them
e_classic() + theme(legend.position = "none") + xlab("Monitoring Time (Days)"
) + ylab("Area (km^2)")

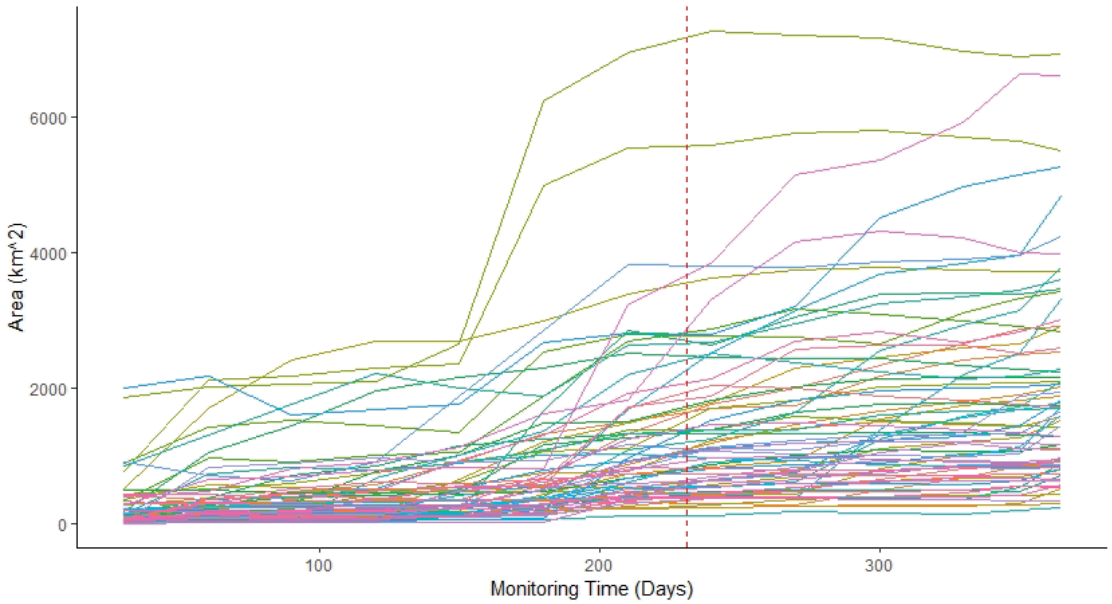
##Assess for breakpoint using a mixed-effects approach. See this webpage for
code: https://stats.stackexchange.com/questions/19772/estimating-the-break-po
int-in-a-broken-stick-piecewise-linear-model-with-rando

#Basis functions
bp = 250
b1 <- function(x, bp) ifelse(x < bp, bp - x, 0)
b2 <- function(x, bp) ifelse(x < bp, 0, x - bp)

#Wrapper for Mixed effects model with variable break point
foo <- function(bp)
{
  mod <- lmer(Area ~ b1(MT, bp) + b2(MT, bp) + (b1(MT, bp) + b2(MT, bp) | AID
), data = sensres)
  deviance(mod)
}

search.range <- c(min(sensres$MT)+0.5,max(sensres$MT)-0.5)
foo.opt <- optimize(foo, interval = search.range)
bp <- foo.opt$minimum

#add to plot
p <- p + geom_vline(xintercept = bp, lty = "dashed", color = "red")
p
```


6000
4000
2000
0
Area (km^2)
100
200
300
Monitoring Time (Days)

APPENDIX C: RANDOM POINT SENSITIVITY ANALYSES

To evaluate the seasonal selection of habitat by boreal caribou in the Northwest Territories, we estimated resource selection functions (RSFs) at second- and third-order scales. RSFs compare the environmental attributes associated with caribou GPS locations to those associated with random points sampled within each scale's area of availability. Determining the number of random points to sample is critical to RSFs as insufficient sampling can bias inferences whereas over-sampling can lead to protracted computing times, particularly when using large data sets (Benson 2013, Northrup et al. 2013). Here, we outline the sensitivity analyses used to determine the number of random points required to adequately characterize availability at each scale. Example R code is also provided.

For second-order RSFs, availability was defined by creating two buffered minimum convex polygons (MCPs): one around all caribou GPS locations from a north "population" (caribou in the Sahtu and Inuvik regional study areas) and one around all caribou GPS locations from a south "population" (caribou in the Dehcho, North Slave and South Slave regional study areas; see Appendix B). To identify the minimum number of random points required to adequately sample each MCP, we conducted repeated RSFs, varying the number of random points used, then determining the sample size of random points at which RSF coefficients stabilized. We considered a minimum sample size of 500 random points then progressively increased the sample size up to 5000. We also evaluated a sampling ratio where one random point was generated for every GPS location. At each sample size, we iteratively estimated the same RSF model 30 times, using a unique set of random points on each iteration, then estimated the mean and standard deviation of each RSF coefficient. This sensitivity analysis used data from the summer season (see main text for seasonal delineations) but inferences should apply across all seasons as availability remains constant across all seasonal analyses. Also, in contrast to the RSF analyses described in the main text, we used simplified burn variables where burned land covers were grouped together by burn age and not separated by land cover type.

Results from this second-order sensitivity analysis suggested that continuous variables such as "distance-to-nearest-settlement" required 3000 random points for their RSF coefficient to stabilize, although most other RSF coefficients stabilized prior to this sample size (~ 2000 random points; Figs. C 1). We therefore used 3000 random points sampled within each population-level MCP for all second-order RSF analyses.

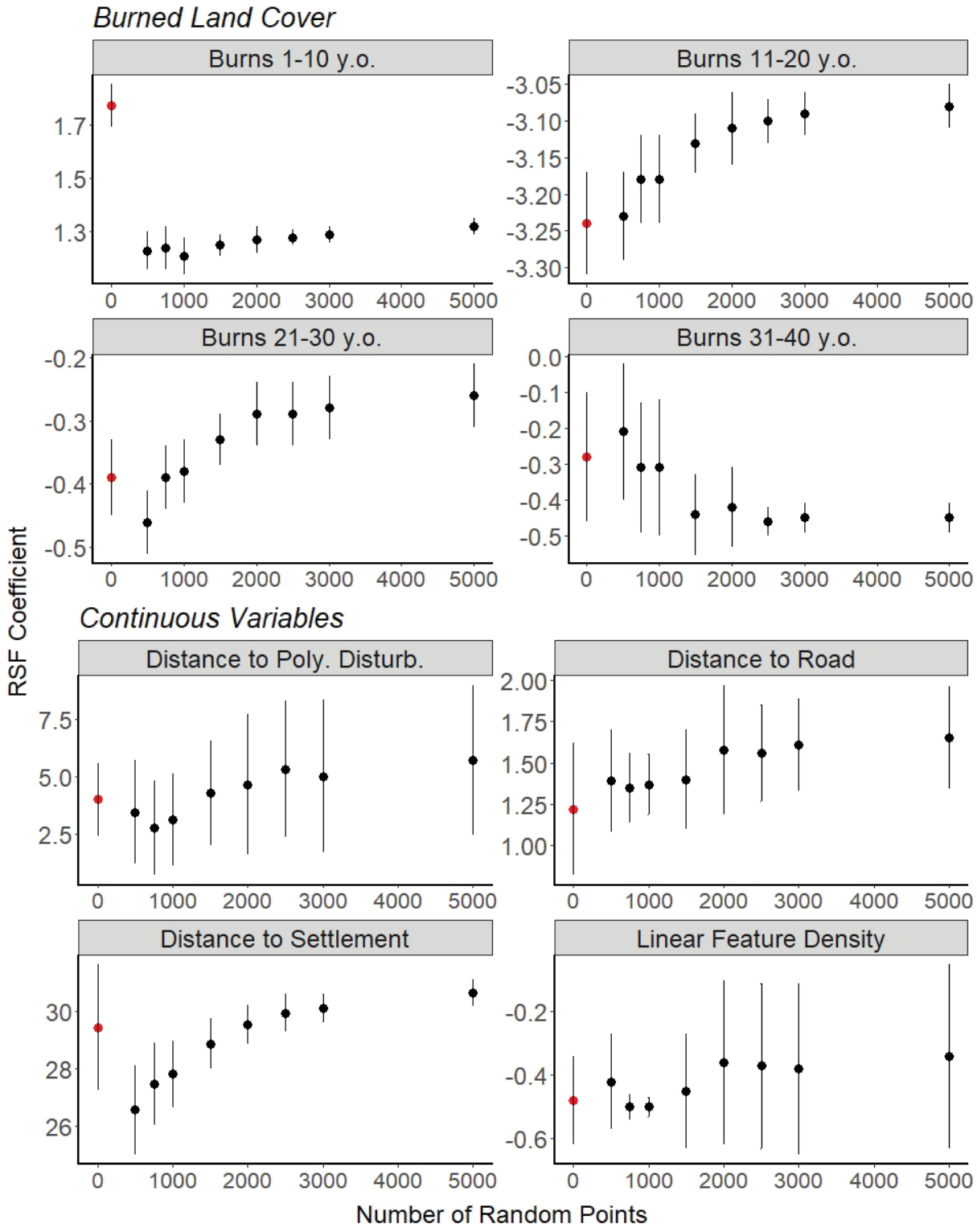


Figure C 1: Sensitivity analysis to determine the minimum sample size of random points required to achieve stable coefficients (mean value with standard deviation bars) for second-order resource selection functions. Sample sizes ranged from 500–5000 random points. A sampling regime where one random point was generated for every caribou GPS location was also considered (red point).

We followed the same process to determine the minimum number of random points required for third-order RSF analyses. At this scale, availability is defined as the annual home range for each individual caribou (see Appendix B). Results from this analysis suggested that RSF coefficients stabilized at a sample size of ~3000 random points (Fig. C 2). We therefore used 3000 random points sampled within each annual home range for all third-order RSF analyses.

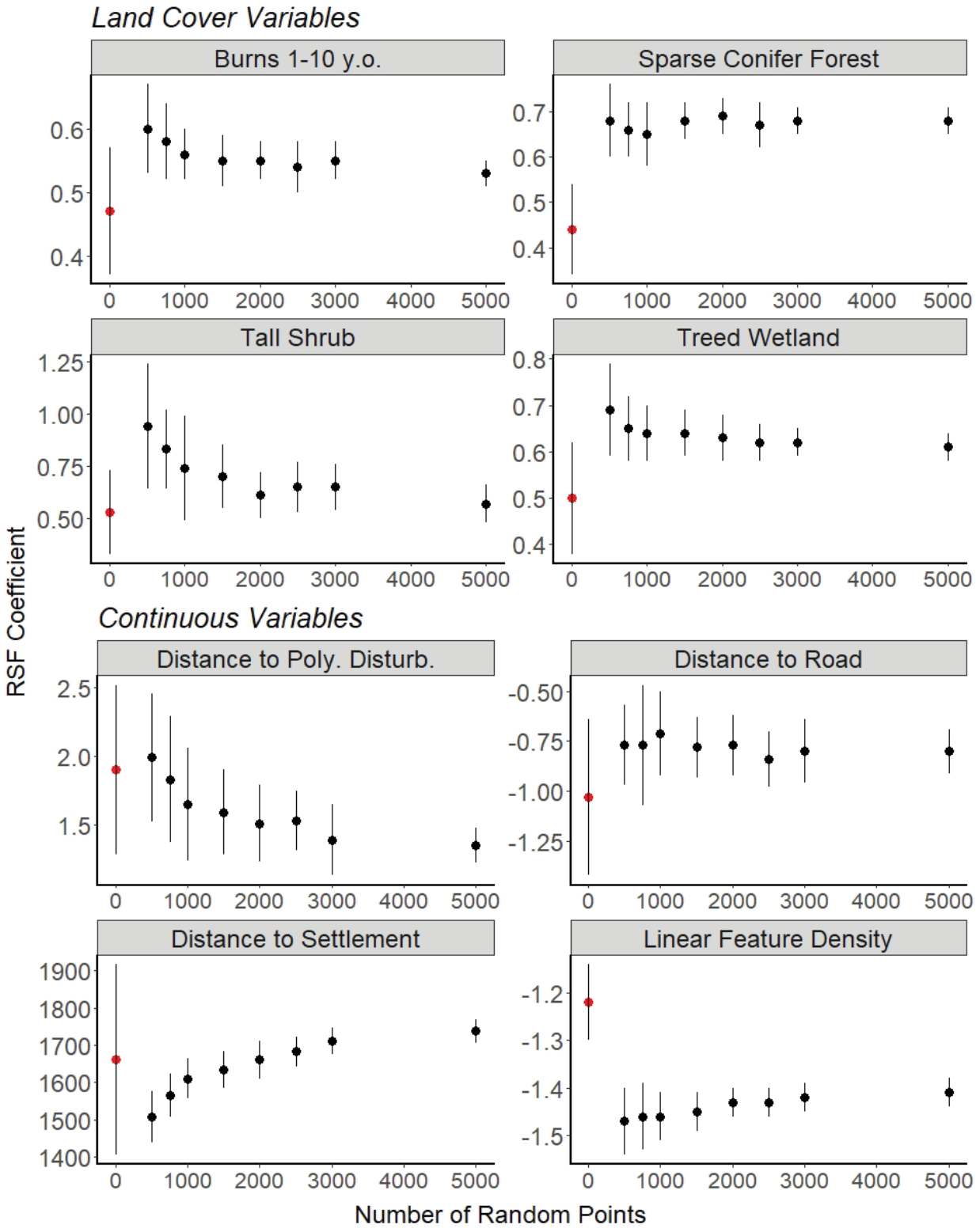


Figure C 2: Sensitivity analysis to determine the minimum sample size of random points required to achieve stable coefficients (mean value with standard deviation bars) for third-order resource selection functions. Sample sizes ranged from 500–5000 random points. A sampling regime where one random point was generated for every caribou GPS location was also considered (red point).

R Code for Random Point Sensitivity Analyses

The following R code outlines the steps used to conduct a sensitivity analysis to determine the minimum number of random points required for RSF coefficients to stabilize. The code uses data for second-order RSF analyses. Code for third-order analyses is not shown as these analyses used a similar process.

```
#Load packages
pcks <- c("tidyverse", "sf", "plyr", "glmmTMB")
sapply(pcks, require, character = TRUE)

setwd("Your_directory_where_data_are_stored.csv")

#Import GPS locations
s.bou <- read.csv("Summer_SouthRegion_UsePts_Extract.csv")

#For efficiency, select a sample of caribou
#First, get only those caribou with > 200 locations in a given year
mt <- ddply(s.bou, .(AIDYr), 'nrow')
mt200 <- mt[mt$nrow >=200,]
mt200$AIDYr <- droplevels(mt200)$AIDYr
#Then select a subsample of 60 caribou-years
sub.bou <- sample(levels(mt200$AIDYr), 60)
bou <- s.bou[s.bou$AIDYr %in% sub.bou,]
#check monitoring times
mt <- ddply(bou, .(AIDYr), 'nrow')
mt
bou$AIDYr <- droplevels(bou)$AIDYr

#Import random locations (100K). Environmental covariates were extracted to t
hese points in ArcGIS
rpts <- read.csv("SouthBou_100MCP_100KRpts_EV.csv")

#Bind GPS locations and random points together and run sensitivity analysis
uAID <- unique(bou$AIDYr)
res <- data.frame()
s.dat <- data.frame()

sens <- data.frame()
for(j in c(1, 500, 750, 1000, 1500, 2000, 2500, 3000, 5000)){
  res <- data.frame()
  for(k in 1:30){ #run 30 iterations of each sample size of random points
    bou.dat <- data.frame()
    for(i in uAID){
      caribou <- bou %>% dplyr::select(AIDYr, AID, Yr, Region, Habitat, lc, l
d1000_10:burn, p_broad_d, p_broad_o, p_mix_o, p_consparse, p_mix_dens) %>% dp
lyr::filter(AIDYr==i) %>% add_column(use = 1)
      avail <- rpts %>% dplyr::select(-c(FID, CID, POINT_X, POINT_Y)) %>% add
_column(AIDYr = i, AID = caribou$AID[1], Yr = caribou$Yr[1], Region = caribou
$Region[1], Habitat = caribou$Habitat[1], use = 0)
```

```
      avail2 <- if(j < 2){avail[sample(nrow(avail), nrow(caribou)),]}else{ava
il[sample(nrow(avail), j),]}
      bou.dat <- rbind.data.frame(bou.dat, caribou, avail2)
    }

    bou.dat$lc2 <- bou.dat$lc
    bou.dat$burn[is.na(bou.dat$burn)] <- 0
    bou.dat$burn[bou.dat$burn==-9999] <- 0

    #Format variables
    #Line Density Variables
    bou.dat <- bou.dat %>% mutate(ld1000 = if_else(Yr <= 2010, ld1000_10, ld1
000_15))

    #Distance to Roads Variable
    bou.dat <- bou.dat %>% mutate(dist_roads = if_else(Yr <= 2010, dist_roads
10, dist_roads15))
    #exponential decay of distance to roads (decays where 0.95 value occurs a
t 1250-m -> Leblond et al. 2011 reported road effects at 1.25 km)
    bou.dat$exp.rds <- 1- exp(-0.0025*bou.dat$dist_roads)

    #Distance to Polygonal Disturbance Variable
    bou.dat <- bou.dat %>% mutate(dist_poly = if_else(Yr <= 2010, dist_poly10
, dist_poly15))
    #exponential decay of distance to polygonal disturbance (decays to 0.95 b
y 1-km)
    bou.dat$exp.poly <- 1- exp(-0.003*bou.dat$dist_poly)

    #Distance to Settlements Variable
    #exponential decay of distance to settlements (decays to 0.95 by 5-km)
    bou.dat$exp.settle <- 1- exp(-0.000625*bou.dat$dto_settle)

    #To create burn variables in 10 year increments
    bou.dat$fire10 <- ifelse(bou.dat$burn >= bou.dat$Yr - 10 & bou.dat$burn <
bou.dat$Yr, 1, 0) #fires 1-10 y.o.
    bou.dat$fire20 <- ifelse(bou.dat$burn >= bou.dat$Yr - 20 & bou.dat$burn <
bou.dat$Yr - 10, 1, 0) #fires 11-20 y.o.
    bou.dat$fire30 <- ifelse(bou.dat$burn >= bou.dat$Yr - 30 & bou.dat$burn <
bou.dat$Yr - 20, 1, 0) #fires 21-30 y.o
    bou.dat$fire40 <- ifelse(bou.dat$burn >= bou.dat$Yr - 40 & bou.dat$burn <
bou.dat$Yr - 30, 1, 0) #fires 31-40 y.o.
    bou.dat$fire60 <- ifelse(bou.dat$burn >= bou.dat$Yr - 60 & bou.dat$burn <
bou.dat$Yr - 40, 1, 0) #fires 41-60 y.o.

    #then create burn classes  within land cover variable
    bou.dat$lc2 <- ifelse(bou.dat$fire10 == 1, 199, bou.dat$lc2)
    bou.dat$lc2 <- ifelse(bou.dat$fire20 == 1, 299, bou.dat$lc2)
    bou.dat$lc2 <- ifelse(bou.dat$fire30 == 1, 399, bou.dat$lc2)
    bou.dat$lc2 <- ifelse(bou.dat$fire40 == 1, 499, bou.dat$lc2)
    bou.dat$lc2 <- ifelse(bou.dat$fire60 == 1, 699, bou.dat$lc2)
```

```
    #create dummy variables. Need to transform back to data frame
    bou.dat <- as.data.frame(bou.dat)
    bou.dat <- dummy.data.frame(bou.dat, names="lc2")

    #rename variables
    bou.dat <- dplyr::rename(bou.dat, water = lc220, rock = lc232, exp.land =
lc233, exp.land2 = lc234, bryoids = lc240, t.shrub = lc251, s.shrub = lc252,
t.wet = lc281, s.wet = lc282, h.wet = lc283, herb = lc2100, con.dens = lc2211
, con.open = lc2212, con.sp = lc2213, broad.d = lc2221, broad.o = lc2222, mix
.dens = lc2231, mix.o = lc2232, burn10 = lc2199, burn20 = lc2299, burn30 = lc
2399, burn40 = lc2499, burn60 = lc2699)

    #create non-veg category
    bou.dat <- bou.dat %>% mutate(nonveg = rock + exp.land + exp.land2)
    bou.dat$nonveg <- ifelse(bou.dat$nonveg >= 1, 1, 0)

    bou.dat <- mutate(bou.dat, p_broad = p_broad_d + p_broad_o + p_mix_dens)

    #run RSF model
    mod <- glmmTMB(use ~ bryoids + t.shrub + s.shrub + t.wet + s.wet + h.wet
+ herb + con.open + con.sp + broad.d + broad.o + mix.o + mix.dens + water + n
onveg + p_broad + p_consparse + burn10 + burn20 + burn30 + burn40  + burn60 +
ld1000 + exp.rds + exp.poly + exp.settle + (1|Habitat/AIDYr), family=binomial
, data=bou.dat)
    #store results
    df <- as.data.frame(summary(mod)$coefficients$cond) %>% rownames_to_colum
n(var="Var")
    df$Rpts <- j
    df$Trial <- k
    res <- rbind.data.frame(res, df)
    }
  sens <- rbind.data.frame(sens, res)
}

head(sens)
```

```
##   X         Var     Estimate Std..Error     z.value     Pr...z.. Rpts Tria
l
## 1 1 (Intercept) -33.93262520 2.65871236 -12.7628042 2.645048e-37    1
1
## 2 2     bryoids  -1.61548477 0.38711709  -4.1731166 3.004610e-05    1
1
## 3 3     t.shrub  -1.22663995 0.39265413  -3.1239706 1.784283e-03    1
1
## 4 4     s.shrub  -0.89816672 0.10775285  -8.3354337 7.721463e-17    1
1
## 5 5       t.wet  -0.04252081 0.06170246  -0.6891266 4.907436e-01    1
1
```

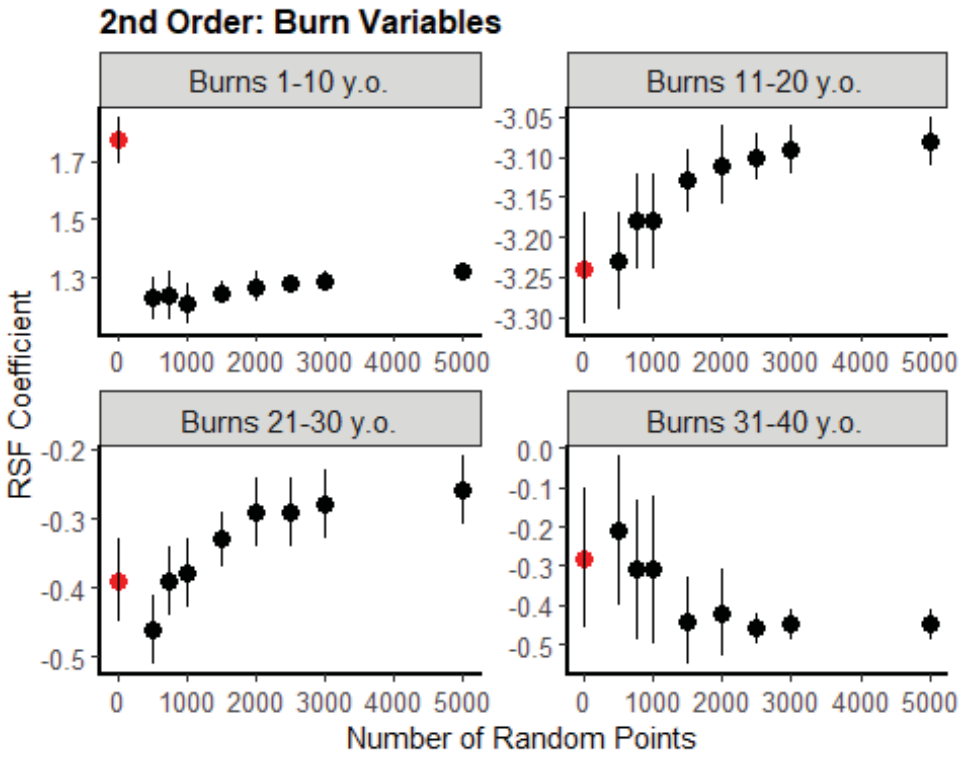
```
## 6 6       s.wet  -0.45956640 0.06908720  -6.6519762 2.891835e-11    1
1

#Get mean and standard deviation of each RSF coefficient for each sample size
of random points
beta <- ddply(sens, .(Var, Rpts), summarize, coef = round(mean(Estimate), 2),
sd = round(sd(Estimate), 2))
#Creat new column to specify where RSF was estimated using 1 random location
per 1 GPS location
beta <- mutate(beta, one_to_one = ifelse(Rpts <= 1, T, F))

#Burn variables
burn <- beta[beta$Var=="burn10" | beta$Var=="burn20" | beta$Var=="burn30" | b
eta$Var=="burn40",]

#Create better variable labels
levels(burn$Var)[levels(burn$Var)=="burn10"] <- "Burns 1-10 y.o."
levels(burn$Var)[levels(burn$Var)=="burn20"] <- "Burns 11-20 y.o."
levels(burn$Var)[levels(burn$Var)=="burn30"] <- "Burns 21-30 y.o."
levels(burn$Var)[levels(burn$Var)=="burn40"] <- "Burns 31-40 y.o."

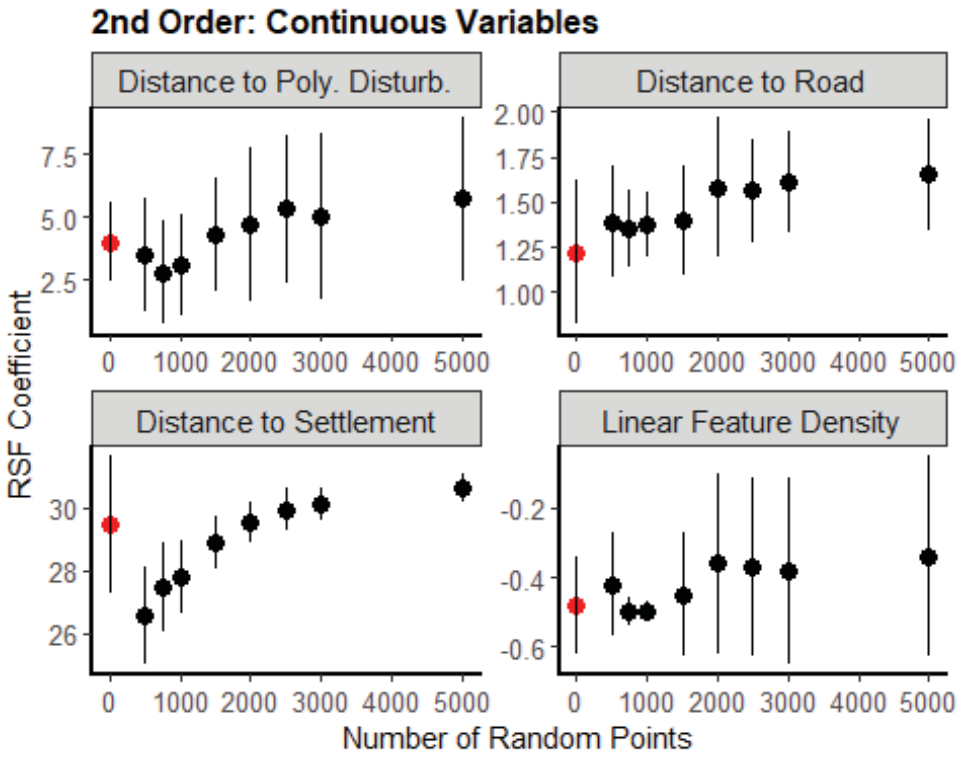
#Plot
b <- ggplot(burn, aes(x=Rpts, y=coef)) + geom_point(aes(color=one_to_one), si
ze=3) + facet_wrap(~Var, scales= "free")
b <- b + theme_bw() + theme(panel.grid.major = element_blank(), panel.grid.mi
nor=element_blank(), panel.border=element_blank(), axis.line.x = element_line
(color="black", size = 1), axis.line.y = element_line(color="black", size = 1
), axis.text.x=element_text(size=10), axis.text.y=element_text(size=10), axis
.title.y=element_text(size = 11), axis.title.x=element_text(size = 11), strip
.text.x=element_text(size=11), legend.position = 'none', plot.title = element
_text(size = 12, face="bold")) + scale_colour_manual(values = c('black', 'red
')) + geom_errorbar(aes(ymin = coef - sd, ymax = coef + sd), width=0.25, colo
r="black") + ylab("RSF Coefficient ") + xlab("Number of Random Points") + ggt
itle("2nd Order: Burn Variables")
b
```




```
#Continuous variables
cont <- beta[beta$Var=="ld1000" | beta$Var=="exp.settle" | beta$Var=="exp.pol
y" | beta$Var=="exp.rds",]

levels(cont$Var)[levels(cont$Var)=="ld1000"] <- "Linear Feature Density"
levels(cont$Var)[levels(cont$Var)=="exp.settle"] <- "Distance to Settlement"
levels(cont$Var)[levels(cont$Var)=="exp.poly"] <- "Distance to Poly. Disturb.
"
levels(cont$Var)[levels(cont$Var)=="exp.rds"] <- "Distance to Road"

c <- ggplot(cont, aes(x=Rpts, y=coef)) + geom_point(aes(color=one_to_one), si
ze=3) + facet_wrap(~Var, scales= "free")
c <- c + theme_bw() + theme(panel.grid.major = element_blank(), panel.grid.mi
nor=element_blank(), panel.border=element_blank(), axis.line.x = element_line
(color="black", size = 1), axis.line.y = element_line(color="black", size = 1
), axis.text.x=element_text(size=10), axis.text.y=element_text(size=10), axis
.title.y=element_text(size=11), axis.title.x=element_text(size=11), strip.tex
t.x=element_text(size=11), legend.position = 'none', plot.title = element_tex
t(size = 12, face="bold")) + scale_colour_manual(values = c('black', 'red'))
+ geom_errorbar(aes(ymin = coef - sd, ymax = coef + sd), width=0.25, color="b
lack") + ylab("RSF Coefficient ") + xlab("Number of Random Points") + ggtitle
("2nd Order: Continuous Variables")
c
```



Literature Cited

Benson, J. F. 2013. Improving rigour and efficiency of use-availability habitat selection analyses with systematic estimation of availability. R. B. O'Hara, editor. Methods in Ecology and Evolution 4:244–251.

Northrup, J. M., M. B. Hooten, C. R. Anderson Jr, and G. Wittemyer. 2013. Practical guidance on characterizing availability in resource selection functions under a use-availability design. Ecology 94:1456–1463.

APPENDIX D: MOVEMENT ANALYSES FOR DEFINING SEASONS

Seasonal changes in resource availability and life history status (e.g. rutting, calving) can cause habitat selection by boreal caribou to vary throughout the year. To assess for these potential changes, we used movement-based analyses to help inform the identification of seasonal periods that were biologically relevant to caribou. These analyses evaluated for changes in daily movement rates and assumed that such changes indicated seasonal changes in caribou behaviour. Here, we outline these analyses and provide R code for each step.

We first calculated mean rates of daily movement (m/hr) across individual caribou in each regional study area (Dehcho, Inuvik, North Slave, Sahtu, and South Slave). These rates were calculated by measuring the Euclidean distance travelled between successive GPS locations, summing these distances for each Julian day, then dividing by 24. The following code executes this process.

```
#Load necessary libraries
pcks <- c("plyr", "tidyverse", "sp", "sf", "lubridate", "adehabitatLT", "mgcv
", "segmented")
sapply(pcks, require, character = TRUE)

#Import MoveBank data
#all.dat <- read.csv("your_directory\\Movebank_data.csv") #NOT RUN. Load data
from your directory

head(all.dat)

##     trackId individual_id local_identifier location_lat location_long
## 1 BWCA17600     469002982        BWCA17600     62.25693     -116.2770
## 2 BWCA17600     469002982        BWCA17600     62.25686     -116.2768
## 3 BWCA17600     469002982        BWCA17600     62.25724     -116.2753
## 4 BWCA17600     469002982        BWCA17600     62.25744     -116.2757
## 5 BWCA17600     469002982        BWCA17600     62.25718     -116.2760
## 6 BWCA17600     469002982        BWCA17600     62.25646     -116.2687
##             timestamp Region
## 1 2017-03-22 04:00:00 nslave
## 2 2017-03-22 08:00:00 nslave
## 3 2017-03-22 12:00:00 nslave
## 4 2017-03-22 16:00:00 nslave
## 5 2017-03-22 20:00:00 nslave
## 6 2017-03-23 00:00:00 nslave

#Ensure timestamp column is in POSIXct format
all.dat$timestamp <- ymd_hms(all.dat$timestamp)
regs <- unique(all.dat$Region)

#Calculate mean rates of daily movement for each regional study area
movedat <- data.frame()
for(i in regs){
```

```
  d <- all.dat[all.dat$Region==i,]
  d <- d[!duplicated(d$timestamp),]
  d$local_identifier <- droplevels(d)$local_identifier
  coordinates(d) <- c("location_long", "location_lat")
  proj4string(d) <- CRS("+init=epsg:4326")
  d <- as.data.frame(spTransform(d, CRS("+proj=utm +zone=10 ellps=WGS84"))) #
convert to UTMs to get meters
  idf <- data.frame()
  lt <- as.ltraj(d[6:7], d$timestamp, id = d$local_identifier) #create moveme
nt trajectories for each individual
  for(j in 1:length(lt)){
    boudf <- as.data.frame(lt[[j]]) #store trajectories as data frame
    boudf$AID <- adehabitatLT::burst(lt[j])
    idf <- rbind.data.frame(idf, boudf)
  }
  idf$JD <- as.numeric(strftime(idf$date, format="%j"))
  msum <- ddply(idf, .(AID,JD), summarize, meanmov = sum(dist, na.rm=T)/24) #
individual means on each Julian day
  msum2 <- ddply(msum, .(JD), summarize, moveRate = mean(meanmov, na.rm=T)) #
mean across individuals on each Julian day
  msum2$region <- i
  movedat <- rbind.data.frame(movedat, msum2)
}
head(movedat)

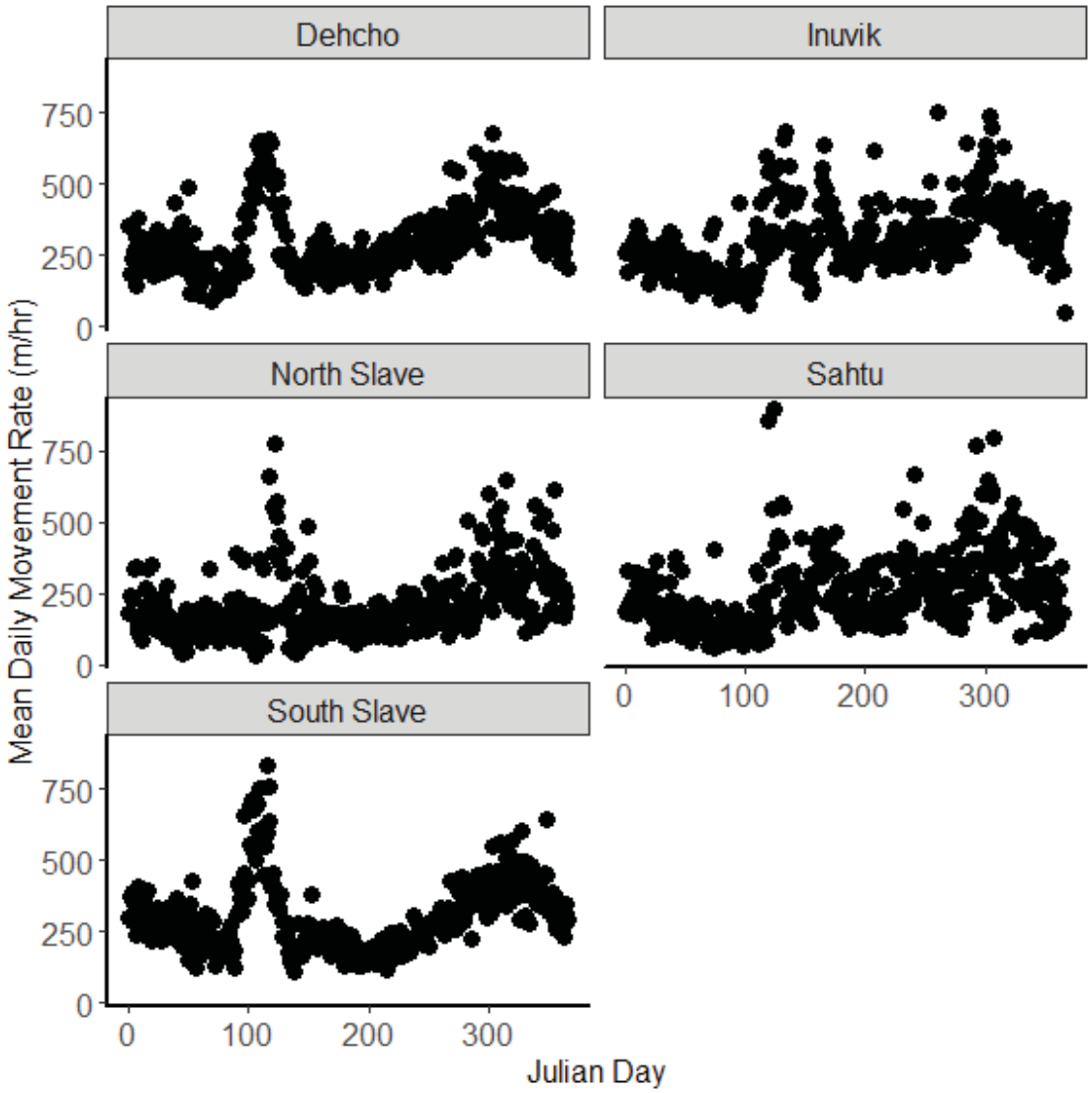
##   JD moveRate region
## 1  1 179.1217 nslave
## 2  2 240.8502 nslave
## 3  3 232.9673 nslave
## 4  4 227.4012 nslave
## 5  5 333.7590 nslave
## 6  6 344.5698 nslave
```

The following code generates a facet plot that shows the temporal trend in mean rates of daily movement for each regional study area.

```
#Facet plot of all regions
movedat$region <- as.factor(movedat$region)
levels(movedat$region)[levels(movedat$region)=="dehcho"] <- "Dehcho"
levels(movedat$region)[levels(movedat$region)=="nslave"] <- "North Slave"
levels(movedat$region)[levels(movedat$region)=="sslave"] <- "South Slave"
levels(movedat$region)[levels(movedat$region)=="inuvik"] <- "Inuvik"
levels(movedat$region)[levels(movedat$region)=="sahtu"] <- "Sahtu"

p <- ggplot(movedat, aes(x=JD, y=moveRate)) + geom_point(size=3) + facet_wrap
(~region, ncol=2)
p <- p + theme_bw() + theme(panel.grid.major = element_blank(), panel.grid.mi
```

```
nor=element_blank(), panel.border=element_blank(), axis.line.x = element_line
(color="black", size = 1), axis.line.y = element_line(color="black", size = 1
), axis.text.x=element_text(size=12), axis.text.y=element_text(size=12), axis
.title.y=element_text(size=12), axis.title.x=element_text(size=12), strip.tex
t.x=element_text(size=12)) + ylab("Mean Daily Movement Rate (m/hr)") + xlab("
Julian Day")
p
```



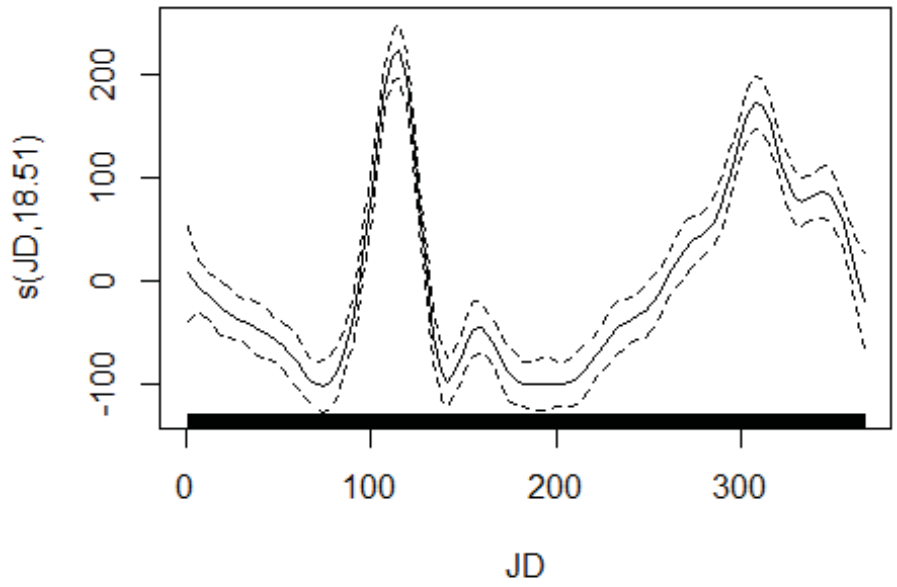
The above plots suggest similar movement patterns among the Dehcho, North Slave and South Slave regional study areas, which corresponds to South grouping identified for second-order resource selection analyses (see Appendix B), and similar movement patterns between the Inuvik and Sahtu regional study areas, which corresponds to the North grouping. We therefore evaluated for seasonal breaks in daily movements in each of these groupings. As noted in the main text, we maintained the estimated mean rates of daily movement for each regional study area and pooled these data into North

and South data sets. This approach reduces potential spatial bias in movement rates as some regional study areas had much larger sample sizes than others.

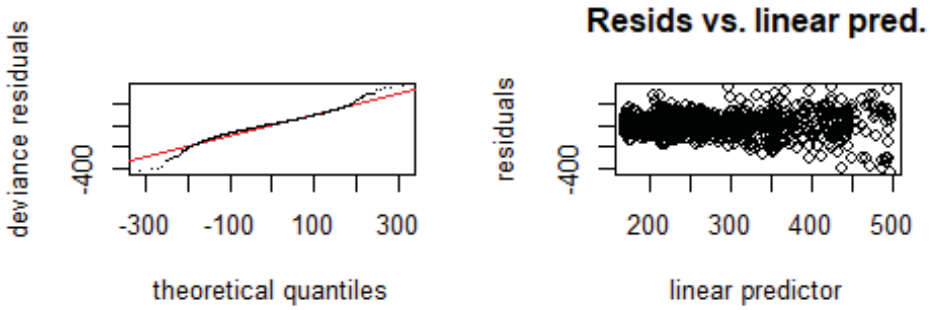
To identify break points in the temporal distribution of grouping's movement rates, we fit generalized additive models (GAMs) to each data set and used the model predictions in a piecewise (or segmented) regression. The estimated break points from these models were assumed to be indicative of seasonal changes in caribou behaviour. The following code demonstrates this modelling process.

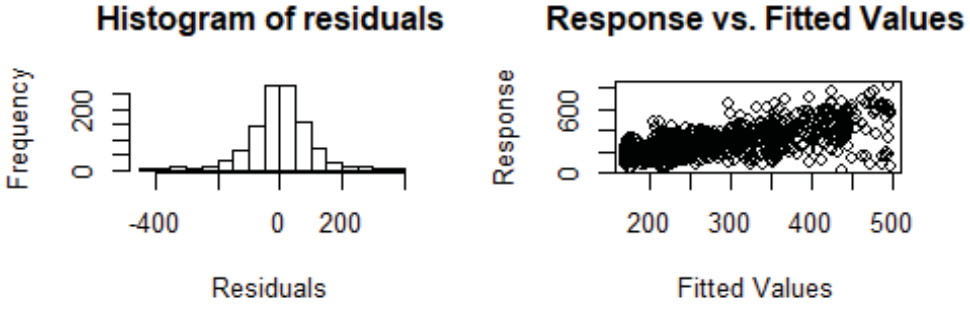
```
#South Region
south <- movedat[movedat$region == "South Slave" | movedat$region == "North S
lave" | movedat$region == "Dehcho",]
sr <- gam(moveRate ~ s(JD, bs = "cs", k = 20), data= south)


#plot GAM prediction
plot(sr)
```




```
#GAM diagnostic check
gam.check(sr)
```






```
##
## Method: GCV   Optimizer: magic
## Smoothing parameter selection converged after 7 iterations.
## The RMS GCV score gradient at convergence was 0.03375366 .
## The Hessian was positive definite.
## Model rank =  20 / 20
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##         k'  edf k-index p-value
## s(JD) 19.0 18.5    1.24       1
```

```r
#Create data frame to store GAM predictions
sr.df <- data.frame(JD = south$JD, pred = predict(sr))


#Piecewise regression model
lm.sr <- lm(pred~JD, data=sr.df)
seg.sr <- segmented(lm.sr, seg.Z = ~ JD, psi = c(15, 40, 80, 110, 140, 160, 2
00, 280, 305, 320, 340))
summary(seg.sr)
```

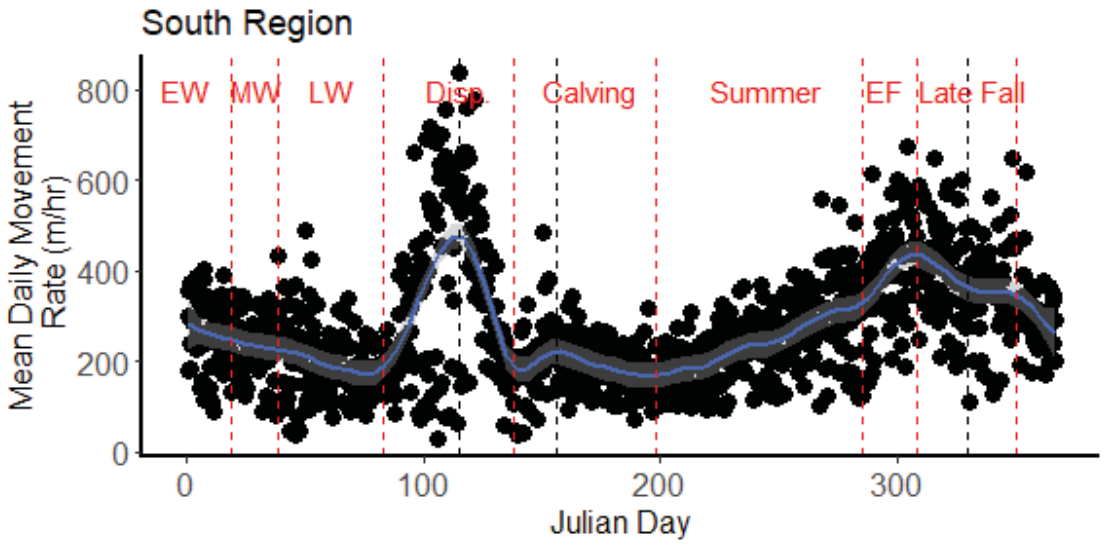
```
##
##  ***Regression Model with Segmented Relationship(s)***
##
## Call:
```

```
## segmented.lm(obj = lm.sr, seg.Z = ~JD, psi = c(15, 40, 80, 110,
##     140, 160, 200, 280, 305, 320, 340))
##
## Estimated Break-Point(s):
##              Est. St.Err
## psi1.JD   18.671  3.046
## psi2.JD   37.044  5.682
## psi3.JD   83.293  0.137
## psi4.JD  114.773  0.076
## psi5.JD  137.656  0.126
## psi6.JD  155.872  0.458
## psi7.JD  198.450  0.399
## psi8.JD  284.825  0.470
## psi9.JD  308.175  0.212
## psi10.JD 328.651  0.428
## psi11.JD 349.534  0.385
##
## Meaningful coefficients of the linear terms:
##              Estimate Std. Error  t value Pr(>|t|)
## (Intercept) 280.68007    1.85466  151.338   <2e-16 ***
## JD           -1.82891    0.17134  -10.674   <2e-16 ***
## U1.JD         0.81604    0.23305    3.502       NA
## U2.JD        -0.35481    0.16343   -2.171       NA
## U3.JD        12.85010    0.08654  148.481       NA
## U4.JD       -27.20747    0.14068 -193.401       NA
## U5.JD        18.86895    0.20836   90.560       NA
## U6.JD        -4.71390    0.17750  -26.557       NA
## U7.JD         3.52850    0.04916   71.781       NA
## U8.JD         3.65116    0.11241   32.479       NA
## U9.JD       -10.80641    0.18373  -58.816       NA
## U10.JD        5.51709    0.19965   27.633       NA
## U11.JD       -6.42014    0.23516  -27.301       NA
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.532 on 1073 degrees of freedom
## Multiple R-Squared: 0.9946,  Adjusted R-squared: 0.9945
##
## Convergence attained in 4 iter. (rel. change 5.8458e-06)

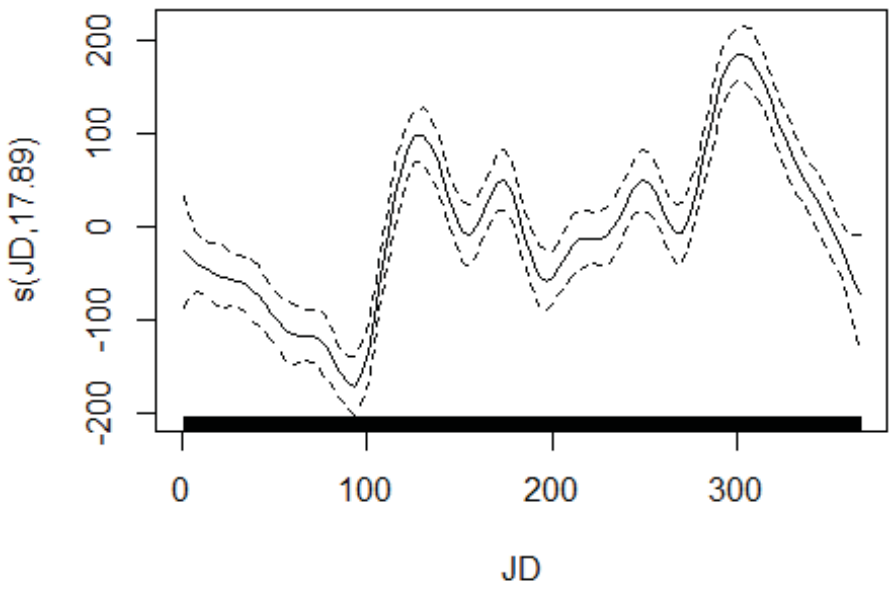


#Plot estimated seasonal breaks
sr.p <- ggplot(south, aes(x=JD, y=moveRate)) + geom_point(size=3) + geom_smoo
th(method="gam", formula = y ~ s(x, bs = "cs", k = 60))
sr.p <- sr.p + theme_bw() + theme(panel.grid.major = element_blank(), panel.g
rid.minor=element_blank(), panel.border=element_blank(), axis.line.x = elemen
t_line(color="black", size = 1), axis.line.y = element_line(color="black", si
ze = 1), axis.text.x=element_text(size=12), axis.text.y=element_text(size=12)
, axis.title.y=element_text(size=12), axis.title.x=element_text(size=12)) + y
```

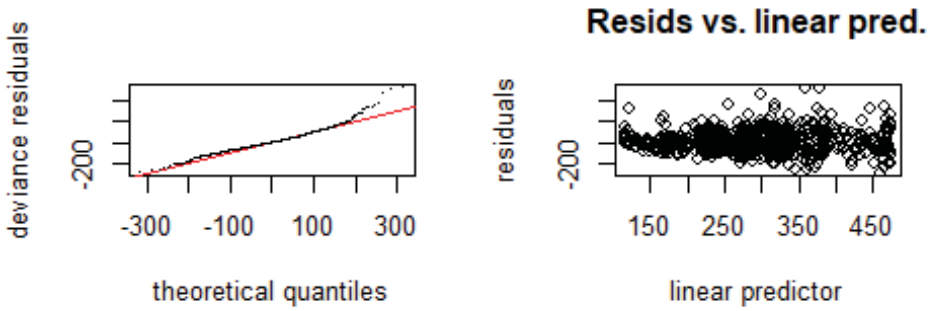
```
lab("Mean Daily Movement\n Rate (m/hr)") + xlab("Julian Day")
sr.p <- sr.p + geom_vline(xintercept = c(19, 39, 83, 138, 198, 285, 308, 350)
, linetype="dashed", color = "red")#12, 83, 112, 118, 137, 156, 198, 286, 304
sr.p <- sr.p + geom_vline(xintercept = c(115, 156, 329), linetype="dashed")
sr.p <- sr.p +  annotate("text", x = 170, y = 800, label = "Calving", color =
"red") + annotate("text", x = 0, y = 800, label = "EW", color = "red") + anno
tate("text", x = 30, y = 800, label = "MW", color = "red") + annotate("text",
x = 62, y = 800, label = "LW", color = "red") + annotate("text", x = 115, y =
800, label = "Disp.", color = "red") + annotate("text", x = 245, y = 800, lab
el = "Summer", color = "red") + annotate("text", x = 295, y = 800, label = "E
F", color = "red") + annotate("text", x = 332, y = 800, label = "Late Fall",
color = "red") + labs(title = "South Region")
sr.p
```

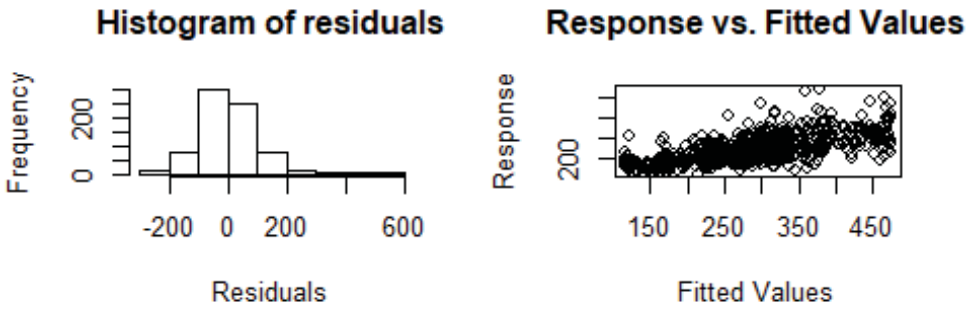



```
#North Region
north <- movedat[movedat$region == "Sahtu" | movedat$region == "Inuvik",]
nr <- gam(moveRate ~ s(JD, bs = "cs", k = 20), data= north)
plot(nr)
```


s(JD,17.89)
200
100
0
-100
-200
0
100
200
300
JD

```
gam.check(nr)
```


deviance residuals
-200
-300
-100
100
300
theoretical quantiles
Resids vs. linear pred.
residuals
-200
150
250
350
450
linear predictor


Histogram of residuals
Frequency
0
200
-200
0
200
600
Residuals
Response vs. Fitted Values
Response
200
150
250
350
450
Fitted Values

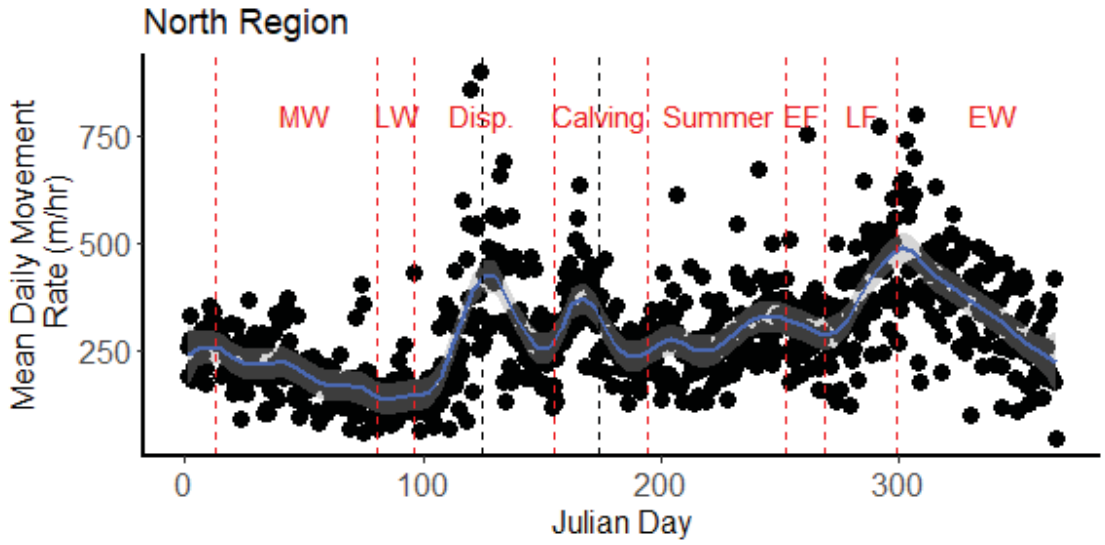
```
##
## Method: GCV   Optimizer: magic
## Smoothing parameter selection converged after 4 iterations.
## The RMS GCV score gradient at convergence was 0.01409022 .
## The Hessian was positive definite.
## Model rank =  20 / 20
##
## Basis dimension (k) checking results. Low p-value (k-index<1) may
## indicate that k is too low, especially if edf is close to k'.
##
##         k'  edf k-index p-value
## s(JD) 19.0 17.9    0.98    0.28
```

```
nr.df <- data.frame(JD = north$JD, pred = predict(nr))
lm.nr <- lm(pred~JD, data=nr.df)
seg.nr <- segmented(lm.nr, seg.Z = ~ JD, psi = c(40, 70, 90, 120, 150, 175, 2
00, 250, 270, 300))
seg.nr
```

```
## Call: segmented.lm(obj = lm.nr, seg.Z = ~JD, psi = c(40, 70, 90, 120,
##     150, 175, 200, 250, 270, 300))
##
## Meaningful coefficients of the linear terms:
## (Intercept)           JD        U1.JD        U2.JD        U3.JD        U4.
JD
##    260.2780      -0.7823      -0.6120      -1.3429      12.9985     -14.68
99
##       U5.JD        U6.JD        U7.JD        U8.JD        U9.JD       U10.
JD
##      8.3356      -9.9688       7.9420      -5.5936      11.3832     -11.75
90
##
## Estimated Break-Point(s):
##  psi1.JD   psi2.JD   psi3.JD   psi4.JD   psi5.JD   psi6.JD   psi7.JD   psi
8.JD
##     8.00     77.45     95.53    124.67    154.80    173.84    193.93     25
2.01
##  psi9.JD  psi10.JD
##   269.53    298.82
```

```
nr.p <- ggplot(north, aes(x=JD, y=moveRate)) + geom_point(size=3) + geom_smoo
th(method="gam", formula = y ~ s(x, bs = "cs", k = 60))
nr.p <- nr.p + theme_bw() + theme(panel.grid.major = element_blank(), panel.g
rid.minor=element_blank(), panel.border=element_blank(), axis.line.x = elemen
t_line(color="black", size = 1), axis.line.y = element_line(color="black", si
ze = 1), axis.text.x=element_text(size=12), axis.text.y=element_text(size=12)
, axis.title.y=element_text(size=12), axis.title.x=element_text(size=12)) + y
lab("Mean Daily Movement\n Rate (m/hr)") + xlab("Julian Day")
nr.p <- nr.p + geom_vline(xintercept = c(13, 81, 96, 155, 194, 252, 269, 299)
, linetype="dashed", color = "red")#12, 83, 112, 118, 137, 156, 198, 286, 304
```

```
nr.p <- nr.p + geom_vline(xintercept = c(125, 174), linetype="dashed")
nr.p <- nr.p +  annotate("text", x = 174, y = 800, label = "Calving", color =
"red") + annotate("text", x = 340, y = 800, label = "EW", color = "red") + an
notate("text", x = 50, y = 800, label = "MW", color = "red") + annotate("text
", x = 90, y = 800, label = "LW", color = "red") + annotate("text", x = 125,
y = 800, label = "Disp.", color = "red") + annotate("text", x = 225, y = 800,
label = "Summer", color = "red") + annotate("text", x = 260, y = 800, label =
"EF", color = "red") + annotate("text", x = 285, y = 800, label = "LF", color
= "red") + labs(title = "North Region")
nr.p
```



On the following page, the plots for the Northern and Southern groups are combined to allow for a more direct comparison of movement changes in both groups. Note that x-axis has been modified from Julian day to calendar date.

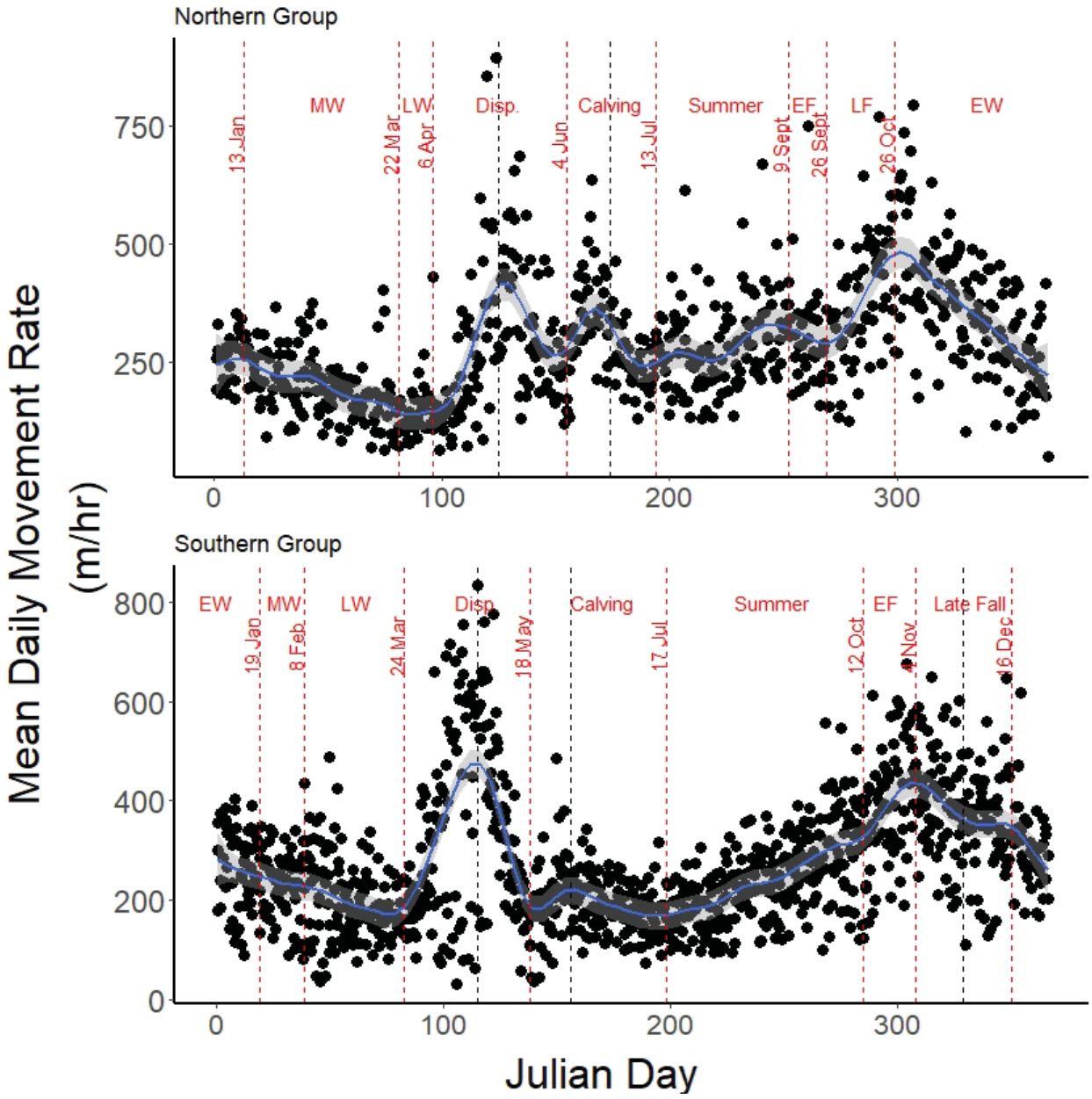


Figure D 1: Seasonal movement patterns of boreal caribou in the Northern and Southern groups (see main text) within the Northwest Territories. Each black dot represents the mean daily movement rate calculated across all individual caribou in a monitoring region (Northern group: Inuvik and Sahtu; Southern group: Dehcho, North Slave, South Slave). Break points indicative of seasonal changes in movement (red dashed lines) were identified using segmented regression applied to the predicted fit of a generalized additive model (blue line).

APPENDIX E: ESTIMATING AND VALIDATING RESOURCE SELECTION FUNCTIONS

We estimated resource selection functions (RSFs) to model seasonal habitat selection by boreal caribou in the Northwest Territories. This appendix illustrates the R code used to estimate and validate RSFs. As an example, we use data from the calving season and estimate an RSF at a second-order scale.

The first step is to load the necessary R packages.

```
pcks <- c("plyr", "tidyverse", "raster", "sf","glmmTMB", "lme4", "adehabitatH
R", "adehabitatLT", "lubridate", "rgdal", "sp", "dummies", "classInt", "caret
", "MuMIn", "forcats", "foreach", "doParallel")
sapply(pcks, require, character = TRUE)
```

Next, the caribou GPS locations and the second-order random locations are imported. These data have had data from all resource covariates previously extracted to them.

```
#Import caribou GPS locations for the calving season.
bou.use <- read.csv("YourFileSystem\\Calving_UsePts_Extract_20200310.csv")


length(unique(bou.use$AID))#Number of caribou

## [1] 276

length(unique(bou.use$AIDYr)) #Number of caribou-seasons

## [1] 480

colnames(bou.use)[31:32] <- c("POINT_X", "POINT_Y")
bou.use <- dplyr::select(bou.use, -X)
bou.use$date <- ymd_hms(bou.use$date)
bou.use$use <- 1


#Display first row of data.
head(bou.use, 1)

##                  date          dx         dy      dist    dt       R2n
## 1 2007-06-04 08:01:55   -8.649065 -292.71090 292.83865 28800      0.00
##     abs.angle  rel.angle       AIDYr    AID   Yr Month Day Hr Min Region
## 1 -1.60033588         NA IN0701.2007 IN0701 2007     6   4  8   1 inuvik
##         Habitat  lc burn      p_broad p_consparse ld1000_10 ld1000_15
## 1 Gwichin North 213   NA 0.0000000000   0.4699325 0.8171973 0.8171910
##   dist_roads10 dist_roads15 dist_maj_rds dist_poly10 dist_poly15 dto_settl
e
## 1     8233.401     8083.873     8247.764    8103.555    8103.555   17495.7
```

```
9
##     POINT_X POINT_Y use
## 1 -867965.0 3264431   1


#Separate into North and South locations.
n.bou <- bou.use[bou.use$Region=="inuvik" | bou.use$Region=="sahtu",]

s.bou <- bou.use[bou.use$Region=="nslave" | bou.use$Region=="sslave" | bou.us
e$Region=="dehcho",]


#Import random points.
#Random points from North MCP
n.rpts <- read.csv("YourFileSystem\\SecondOrder_NorthRegion_RanPts_Extract_Ma
jRds.csv")
colnames(n.rpts)[32:33] <- c("POINT_X", "POINT_Y")
n.rpts <- dplyr::select(n.rpts, -c(X, X.1, X.2))
n.rpts <- mutate(n.rpts, p_broad = p_broad_d + p_broad_o + p_mix_dens) #creat
e variable describing the proportion of broadleaf forest in a 1-km radius
n.rpts <- n.rpts[sample(nrow(n.rpts), 3000),] #subsample to 3000 random point
s based on sensitivity analysis

#Random points from South MCP
s.rpts <- read.csv("YourFileSystem \\SecondOrder_SouthRegion_RanPts_Extract_M
ajRds.csv")
colnames(s.rpts)[32:33] <- c("POINT_X", "POINT_Y")
s.rpts <- dplyr::select(s.rpts, -c(X, X.1, X.2))
s.rpts <- mutate(s.rpts, p_broad = p_broad_d + p_broad_o + p_mix_dens)
s.rpts <- s.rpts[sample(nrow(s.rpts), 3000),] #subsample to 3000 random point
s based on sensitivity analysis

#Next, bind the random points to each individual caribou.
#First, the northern caribou
n.bou <- as_tibble(n.bou)
n.rpts <- as_tibble(n.rpts)
nAIDYr <- unique(n.bou$AIDYr)
n.dat <- tibble()
for(i in nAIDYr){
  caribou <- n.bou %>% dplyr::select(AIDYr, AID, Yr, Region, Habitat, lc:use)
%>% dplyr::filter(AIDYr==i)
  avail <- n.rpts %>% dplyr::select(lc, ld1000_10:burn, p_consparse, p_broad,
dist_maj_rds, POINT_X, POINT_Y) %>% add_column(AIDYr = i, AID = caribou$AID[1
], Yr = caribou$Yr[1], Region = caribou$Region[1], Habitat = caribou$Habitat[
1], use = 0)
  n.dat <- rbind.data.frame(n.dat, caribou, avail)
}

#Then the southern caribou
s.bou <- as_tibble(s.bou)
```

```
s.rpts <- as_tibble(s.rpts)
sAIDYr <- unique(s.bou$AIDYr)
s.dat <- tibble()
for(i in sAIDYr){
  caribou <- s.bou %>% dplyr::select(AIDYr, AID, Yr, Region, Habitat, lc:use)
%>% dplyr::filter(AIDYr==i)
  avail <- s.rpts %>% dplyr::select(lc, ld1000_10:burn, p_consparse, p_broad,
dist_maj_rds, POINT_X, POINT_Y) %>% add_column(AIDYr = i, AID = caribou$AID[1
], Yr = caribou$Yr[1], Region = caribou$Region[1], Habitat = caribou$Habitat[
1], use = 0)
  s.dat <- rbind.data.frame(s.dat, caribou, avail)
}

#Bind the two data sets together
bou.dat <- rbind.data.frame(n.dat, s.dat)

rm(caribou, avail, n.dat, s.dat, s.rpts, n.rpts, bou.use)
```

Prior to estimating the RSF model, we formatted the data, including creating 'dummy' variables for local land-cover, creating exponential decay variables from 'distance-to' variables (see *Methods* in the main report), and matching the timestamp of the location data to the relevant timestamp of the covariate data.

```


#Create a duplicate land cover column to preserve the original data
bou.dat$lc2 <- bou.dat$lc
#Turn NAs in burn column to zeroes
bou.dat$burn[is.na(bou.dat$burn)] <- 0

#Line Density Variables
##Create a continuous variable whose values depend on the time stamp of the l
ocation
bou.dat <- bou.dat %>% mutate(ld1000 = if_else(Yr <= 2010, ld1000_10, ld1000_
15))

#Distance to Roads Variable
##Create a continuous variable whose values depend on the time stamp of the l
ocation
bou.dat <- bou.dat %>% mutate(dist_roads = if_else(Yr <= 2010, dist_roads10,
dist_roads15))
#Exponential decay of distance to roads (decays where 0.95 value occurs at 12
50-m -> Leblond et al. 2011 reported road effects at 1.25 km)
bou.dat$exp.rds <- 1- exp(-0.0025*bou.dat$dist_roads)

#Distance to Major Roads Variable
```

```r
#Exponential decay of distance to roads (decays where 0.95 value occurs at 12
50-m -> Leblond et al. 2011 reported road effects at 1.25 km)
bou.dat$exp.maj.rds <- 1- exp(-0.0025*bou.dat$dist_maj_rds)

#Distance to Polygonal Disturbance Variable
##Create a continuous variable whose values depend on the time stamp of the l
ocation
bou.dat <- bou.dat %>% mutate(dist_poly = if_else(Yr <= 2010, dist_poly10, di
st_poly15))
#Exponential decay of distance to polygonal disturbance (decays to 0.95 by 1-
km)
bou.dat$exp.poly <- 1- exp(-0.003*bou.dat$dist_poly)

#Distance to Settlements Variable
#Exponential decay of distance to settlements (decays to 0.95 by 5-km)
bou.dat$exp.settle <- 1- exp(-0.000625*bou.dat$dto_settle)

#Burn Variables
#Create burn age classes
bou.dat$fire10 <- ifelse(bou.dat$burn >= bou.dat$Yr - 10 & bou.dat$burn < bou
.dat$Yr, 1, 0) #fires 1-10 y.o.
bou.dat$fire20 <- ifelse(bou.dat$burn >= bou.dat$Yr - 20 & bou.dat$burn < bou
.dat$Yr - 10, 1, 0) #fires 11-20 y.o.
bou.dat$fire30 <- ifelse(bou.dat$burn >= bou.dat$Yr - 30 & bou.dat$burn < bou
.dat$Yr - 20, 1, 0) #fires 21-30 y.o
bou.dat$fire40 <- ifelse(bou.dat$burn >= bou.dat$Yr - 40 & bou.dat$burn < bou
.dat$Yr - 30, 1, 0) #fires 31-40 y.o.
bou.dat$fire60 <- ifelse(bou.dat$burn >= bou.dat$Yr - 60 & bou.dat$burn < bou
.dat$Yr - 40, 1, 0) #fires 41-60 y.o.

#then create new burn classes  within land cover variable
bou.dat$lc2 <- ifelse(bou.dat$fire10 == 1, 199, bou.dat$lc2)
bou.dat$lc2 <- ifelse(bou.dat$fire20 == 1, 299, bou.dat$lc2)
bou.dat$lc2 <- ifelse(bou.dat$fire30 == 1, 399, bou.dat$lc2)
bou.dat$lc2 <- ifelse(bou.dat$fire40 == 1, 499, bou.dat$lc2)
bou.dat$lc2 <- ifelse(bou.dat$fire60 == 1, 699, bou.dat$lc2)

#Create dummy variables. Need to first transform back to data frame
bou.dat <- as.data.frame(bou.dat)
bou.dat <- dummy.data.frame(bou.dat, names="lc2")

#Rename variables to something more intuitive
bou.dat <- dplyr::rename(bou.dat, snow = lc212, water = lc220, rock = lc232,
exp.land = lc233, exp.land2 = lc234, bryoids = lc240, t.shrub = lc251, s.shru
b = lc252, t.wet = lc281, s.wet = lc282, h.wet = lc283, herb = lc2100, con.de
ns = lc2211, con.open = lc2212, con.sp = lc2213, broad.d = lc2221, broad.o =
lc2222, mix.dens = lc2231, mix.o = lc2232, burn10 = lc2199, burn20 = lc2299,
burn30 = lc2399, burn40 = lc2499, burn60 = lc2699)
```

```r
#Create non-veg category
bou.dat <- bou.dat %>% mutate(nonveg = snow + rock + exp.land + exp.land2)
bou.dat$nonveg <- ifelse(bou.dat$nonveg >= 1, 1, 0)

#Create an indicator variables for lowlands (t.wet, s.wet, h.wet, herb, con.s
p), uplands non-treed, uplands conifer (con.dens, con.open), uplands broadlea
f.
bou.dat$low <- 0
bou.dat$low[bou.dat$lc==81 | bou.dat$lc==82 | bou.dat$lc==83| bou.dat$lc==100
| bou.dat$lc==213] <- 1

bou.dat$up.nt <- 0
bou.dat$up.nt[bou.dat$lc==40 | bou.dat$lc==51 | bou.dat$lc==52] <- 1

bou.dat$up.con <- 0
bou.dat$up.con[bou.dat$lc==211 | bou.dat$lc==212] <- 1

bou.dat$up.dec <- 0
bou.dat$up.dec[bou.dat$lc==221 | bou.dat$lc==222 | bou.dat$lc==231 | bou.dat$
lc==232] <- 1

#Burn in interactions.
#Burned lowlands
bou.dat$burn10low <- bou.dat$burn10 + bou.dat$low
bou.dat$burn10low <- ifelse(bou.dat$burn10low >= 2, 1, 0)
bou.dat$burn20low <- bou.dat$burn20 + bou.dat$low
bou.dat$burn20low <- ifelse(bou.dat$burn20low >= 2, 1, 0)
bou.dat$burn30low <- bou.dat$burn30 + bou.dat$low
bou.dat$burn30low <- ifelse(bou.dat$burn30low >= 2, 1, 0)
bou.dat$burn40low <- bou.dat$burn40 + bou.dat$low
bou.dat$burn40low <- ifelse(bou.dat$burn40low >= 2, 1, 0)
bou.dat$burn60low <- bou.dat$burn60 + bou.dat$low
bou.dat$burn60low <- ifelse(bou.dat$burn60low >= 2, 1, 0)
#to change 'low' variable to 'low unburned'
bou.dat$low <- ifelse(bou.dat$burn10low==1 | bou.dat$burn20low==1 | bou.dat$b
urn30low==1 | bou.dat$burn40low==1 | bou.dat$burn60low==1, 0, bou.dat$low)
#burn in lowland burn categories
bou.dat$t.wet <- ifelse(bou.dat$burn10low==1 | bou.dat$burn20low==1 | bou.dat
$burn30low==1 | bou.dat$burn40low==1 | bou.dat$burn60low==1, 0, bou.dat$t.wet
)
bou.dat$s.wet <- ifelse(bou.dat$burn10low==1 | bou.dat$burn20low==1 | bou.dat
$burn30low==1 | bou.dat$burn40low==1 | bou.dat$burn60low==1, 0, bou.dat$s.wet
)
bou.dat$h.wet <- ifelse(bou.dat$burn10low==1 | bou.dat$burn20low==1 | bou.dat
$burn30low==1 | bou.dat$burn40low==1 | bou.dat$burn60low==1, 0, bou.dat$h.wet
)
bou.dat$herb <- ifelse(bou.dat$burn10low==1 | bou.dat$burn20low==1 | bou.dat$
burn30low==1 | bou.dat$burn40low==1 | bou.dat$burn60low==1, 0, bou.dat$herb)
bou.dat$con.sp <- ifelse(bou.dat$burn10low==1 | bou.dat$burn20low==1 | bou.da
```

```
t$burn30low==1 | bou.dat$burn40low==1 | bou.dat$burn60low==1, 0, bou.dat$con.
sp)

#Burned non-treed uplands
bou.dat$burn10up.nt <- bou.dat$burn10 + bou.dat$up.nt
bou.dat$burn10up.nt <- ifelse(bou.dat$burn10up.nt >= 2, 1, 0)
bou.dat$burn20up.nt <- bou.dat$burn20 + bou.dat$up.nt
bou.dat$burn20up.nt <- ifelse(bou.dat$burn20up.nt >= 2, 1, 0)
bou.dat$burn30up.nt <- bou.dat$burn30 + bou.dat$up.nt
bou.dat$burn30up.nt <- ifelse(bou.dat$burn30up.nt >= 2, 1, 0)
bou.dat$burn40up.nt <- bou.dat$burn40 + bou.dat$up.nt
bou.dat$burn40up.nt <- ifelse(bou.dat$burn40up.nt >= 2, 1, 0)
bou.dat$burn60up.nt <- bou.dat$burn60 + bou.dat$up.nt
bou.dat$burn60up.nt <- ifelse(bou.dat$burn60up.nt >= 2, 1, 0)
#to change 'up.nt' variable to 'up.nt unburned'
bou.dat$up.nt <- ifelse(bou.dat$burn10up.nt==1 | bou.dat$burn20up.nt==1 | bou
.dat$burn30up.nt==1 | bou.dat$burn40up.nt==1 | bou.dat$burn60up.nt==1, 0, bou
.dat$up.nt)
#burn in not-treed upland burn categories
bou.dat$t.shrub <- ifelse(bou.dat$burn10up.nt==1 | bou.dat$burn20up.nt==1 | b
ou.dat$burn30up.nt==1 | bou.dat$burn40up.nt==1 | bou.dat$burn60up.nt==1, 0, b
ou.dat$t.shrub)
bou.dat$s.shrub <- ifelse(bou.dat$burn10up.nt==1 | bou.dat$burn20up.nt==1 | b
ou.dat$burn30up.nt==1 | bou.dat$burn40up.nt==1 | bou.dat$burn60up.nt==1, 0, b
ou.dat$s.shrub)
bou.dat$bryoids <- ifelse(bou.dat$burn10up.nt==1 | bou.dat$burn20up.nt==1 | b
ou.dat$burn30up.nt==1 | bou.dat$burn40up.nt==1 | bou.dat$burn60up.nt==1, 0, b
ou.dat$bryoids)

#Burned upland conifer
bou.dat$burn10up.con <- bou.dat$burn10 + bou.dat$up.con
bou.dat$burn10up.con <- ifelse(bou.dat$burn10up.con >= 2, 1, 0)
bou.dat$burn20up.con <- bou.dat$burn20 + bou.dat$up.con
bou.dat$burn20up.con <- ifelse(bou.dat$burn20up.con >= 2, 1, 0)
bou.dat$burn30up.con <- bou.dat$burn30 + bou.dat$up.con
bou.dat$burn30up.con <- ifelse(bou.dat$burn30up.con >= 2, 1, 0)
bou.dat$burn40up.con <- bou.dat$burn40 + bou.dat$up.con
bou.dat$burn40up.con <- ifelse(bou.dat$burn40up.con >= 2, 1, 0)
bou.dat$burn60up.con <- bou.dat$burn60 + bou.dat$up.con
bou.dat$burn60up.con <- ifelse(bou.dat$burn60up.con >= 2, 1, 0)
#to change 'up.con' variable to 'up.con unburned'
bou.dat$up.con <- ifelse(bou.dat$burn10up.con==1 | bou.dat$burn20up.con==1 |
bou.dat$burn30up.con==1 | bou.dat$burn40up.con==1 | bou.dat$burn60up.con==1,
0, bou.dat$up.con)
#burn in upland conifer burn categories
bou.dat$con.dens <- ifelse(bou.dat$burn10up.con==1 | bou.dat$burn20up.con==1
| bou.dat$burn30up.con==1 | bou.dat$burn40up.con==1 | bou.dat$burn60up.con==1
, 0, bou.dat$con.dens)
bou.dat$con.open <- ifelse(bou.dat$burn10up.con==1 | bou.dat$burn20up.con==1
| bou.dat$burn30up.con==1 | bou.dat$burn40up.con==1 | bou.dat$burn60up.con==1
```

```
, 0, bou.dat$con.open)

#Burned broadleaf (or deciduous)
bou.dat$burn10up.dec <- bou.dat$burn10 + bou.dat$up.dec
bou.dat$burn10up.dec <- ifelse(bou.dat$burn10up.dec >= 2, 1, 0)
bou.dat$burn20up.dec <- bou.dat$burn20 + bou.dat$up.dec
bou.dat$burn20up.dec <- ifelse(bou.dat$burn20up.dec >= 2, 1, 0)
bou.dat$burn30up.dec <- bou.dat$burn30 + bou.dat$up.dec
bou.dat$burn30up.dec <- ifelse(bou.dat$burn30up.dec >= 2, 1, 0)
bou.dat$burn40up.dec <- bou.dat$burn40 + bou.dat$up.dec
bou.dat$burn40up.dec <- ifelse(bou.dat$burn40up.dec >= 2, 1, 0)
bou.dat$burn60up.dec <- bou.dat$burn60 + bou.dat$up.dec
bou.dat$burn60up.dec <- ifelse(bou.dat$burn60up.dec >= 2, 1, 0)
#to change 'up.dec' variable to 'up.dec unburned'
bou.dat$up.dec <- ifelse(bou.dat$burn10up.dec==1 | bou.dat$burn20up.dec==1 |
bou.dat$burn30up.dec==1 | bou.dat$burn40up.dec==1 | bou.dat$burn60up.dec==1,
0, bou.dat$up.dec)
#burn in upland deciduous burn categories
bou.dat$broad.d <- ifelse(bou.dat$burn10up.dec==1 | bou.dat$burn20up.dec==1 |
bou.dat$burn30up.dec==1 | bou.dat$burn40up.dec==1 | bou.dat$burn60up.dec==1,
0, bou.dat$broad.d)
bou.dat$broad.o <- ifelse(bou.dat$burn10up.dec==1 | bou.dat$burn20up.dec==1 |
bou.dat$burn30up.dec==1 | bou.dat$burn40up.dec==1 | bou.dat$burn60up.dec==1,
0, bou.dat$broad.o)
bou.dat$mix.dens <- ifelse(bou.dat$burn10up.dec==1 | bou.dat$burn20up.dec==1
| bou.dat$burn30up.dec==1 | bou.dat$burn40up.dec==1 | bou.dat$burn60up.dec==1
, 0, bou.dat$mix.dens)
bou.dat$mix.o <- ifelse(bou.dat$burn10up.dec==1 | bou.dat$burn20up.dec==1 | b
ou.dat$burn30up.dec==1 | bou.dat$burn40up.dec==1 | bou.dat$burn60up.dec==1, 0
, bou.dat$mix.o)
```

With data formatted, the next step is to estimate the RSF. To do so, we fit a generalized linear mixed-effects model using the 'glmmTMB' function from the 'glmmTMB' package. Models were fit to the whole data set and a data set where caribou in the Mackenzie sub-region were excluded.

```
#Run mixed-effects model
full.m <- glmmTMB(use ~ bryoids + t.shrub + s.shrub + t.wet + s.wet + h.wet +
herb + con.open + con.sp + broad.d + broad.o + mix.o + mix.dens + water + non
veg + p_broad + p_consparse + burn10low + burn20low + burn30low + burn40low +
burn60low + burn10up.nt + burn20up.nt + burn30up.nt + burn40up.nt + burn60up.
nt + burn10up.con + burn20up.con + burn30up.con + burn40up.con + burn60up.con
+ burn10up.dec + burn20up.dec + burn30up.dec + burn40up.dec + burn60up.dec +
ld1000 + exp.maj.rds + exp.poly + exp.settle + (1|Habitat/AIDYr), family=bino
mial, data=bou.dat)

#Run model with Mackenzie caribou excluded
```

```
bou.dat.noMac <- bou.dat[bou.dat$Habitat != "Mackenzie",]
bou.dat.noMac$Habitat <- droplevels(bou.dat.noMac)$Habitat

noMac <- glmmTMB(use ~ bryoids + t.shrub + s.shrub + t.wet + s.wet + h.wet +
herb + con.open + con.sp + broad.d + broad.o + mix.o + mix.dens + water + non
veg + p_broad + p_consparse + burn10low + burn20low + burn30low + burn40low +
burn60low + burn10up.nt + burn20up.nt + burn30up.nt + burn40up.nt + burn60up.
nt + burn10up.con + burn20up.con + burn30up.con + burn40up.con + burn60up.con
+ burn10up.dec + burn20up.dec + burn30up.dec + burn40up.dec + burn60up.dec +
ld1000 + exp.maj.rds + exp.poly + exp.settle + (1|Habitat/AIDYr), family=bino
mial, data=bou.dat.noMac)
```

The final step is to evaluate the predictive performance of the RSF model. We used *k*-fold cross validation, which involves iteratively partitioning the data by individual caribou into a training set (4 folds or 80% of the individual caribou), estimating the RSF, then testing model predictions on the withheld caribou. See the *Methods* section in the main report for further details. Because RSF models with these large data sets can take > 2 hours to converge, we used parallel computing to speed up the process. The results are returned in list form, which is then transformed into a data frame.

```
#If not already done before
bou.dat.noMac <- bou.dat[bou.dat$Habitat != "Mackenzie",]
bou.dat.noMac$Habitat <- droplevels(bou.dat.noMac)$Habitat

#get range (available) points. these have already been formatted (year = 2017
)
rpts <- read.csv("I:\\Contract_Work\\ABMI\\NWT_RSF\\Tables\\SecondOrderRSFDat
a\\SecondOrderRandomPoints_Formatted_20200131.csv")

#Use parallel computing
detectCores() #My computer has 8 cores


#Specify that 5 cores be used
myCluster <- makeCluster(5, type = "PSOCK")
registerDoParallel(myCluster)

kAID <- unique(bou.dat.noMac$AID) #specify animal IDs


#Run the 10 iterations, which will be spread among the 5 cores.  Need to spec
ify the R packages to be used within the 'foreach' loop.
kfold.res <- foreach(i = 1:10, .packages = c("caret", "glmmTMB", "MuMIn", "cl
assInt"), .errorhandling = 'pass') %dopar% {
  folds <- createFolds(kAID, k=5) #creates 5 groups of data

  test <- kAID[folds[[1]][1:length(folds[[1]])]]
```

```
  train <- bou.dat.noMac[!(bou.dat.noMac$AID %in% test),]

  testpts <- bou.dat.noMac[(bou.dat.noMac$AID %in% test),]
  testrange <- testpts[testpts$use==0,]
  testpts <- testpts[testpts$use==1,]
  testpts <- testpts[complete.cases(testpts),]

  #train model
  km <- glmmTMB(use ~ bryoids + t.shrub + s.shrub + t.wet + s.wet + h.wet + h
erb + con.open + con.sp + broad.d + broad.o + mix.o + mix.dens + water + nonv
eg + p_broad + p_consparse + burn10low + burn20low + burn30low + burn40low +
burn60low + burn10up.nt + burn20up.nt + burn30up.nt + burn40up.nt + burn60up.
nt + burn10up.con + burn20up.con + burn30up.con + burn40up.con + burn60up.con
+ burn10up.dec + burn20up.dec + burn30up.dec + burn40up.dec + burn60up.dec +
ld1000 + exp.maj.rds + exp.poly + exp.settle + (1|Habitat/AIDYr), family=bino
mial, data=train)
  betas <- coefTable(km)

  #kfold (map-based): availability is constant for each caribou (see Methods
in main report)
  av <- rpts
  av <- av[complete.cases(av),]

  map <- exp(betas[2,1]*av$bryoids + betas[3,1]*av$t.shrub + betas[4,1]*av$s.
shrub + betas[5,1]*av$t.wet + betas[6,1]*av$s.wet + betas[7,1]*av$h.wet + bet
as[8,1]*av$herb + betas[9,1]*av$con.open + betas[10,1]*av$con.sp + betas[11,1
]*av$broad.d + betas[12,1]*av$broad.o + betas[13,1]*av$mix.o + betas[14,1]*av
$mix.dens + betas[15,1]*av$water + betas[16,1]*av$nonveg + betas[17,1]*av$p_b
road + betas[18,1]*av$p_consparse + betas[19,1]*av$burn10low + betas[20,1]*av
$burn20low + betas[21,1]*av$burn30low + betas[22,1]*av$burn40low + betas[23,1
]*av$burn60low + betas[24,1]*av$burn10up.nt + betas[25,1]*av$burn20up.nt + be
tas[26,1]*av$burn30up.nt + betas[27,1]*av$burn40up.nt + betas[28,1]*av$burn60
up.nt + betas[29,1]*av$burn10up.con + betas[30,1]*av$burn20up.con + betas[31,
1]*av$burn30up.con + betas[32,1]*av$burn40up.con + betas[33,1]*av$burn60up.co
n + betas[34,1]*av$burn10up.dec + betas[35,1]*av$burn20up.dec + betas[36,1]*a
v$burn30up.dec + betas[37,1]*av$burn40up.dec + betas[38,1]*av$burn60up.dec +
betas[39,1]*av$ld1000 + betas[40,1]*av$exp.maj.rds + betas[41,1]*av$exp.poly
+ betas[42,1]*av$exp.settle)

  #Standardize
  mapN <- (map - min(map))/(max(map)-min(map))

  #Split range points into equal intervals from min to max. This creates deci
le bins based on availability
  eq <- classIntervals(mapN, 10, style="quantile")
  eq <- eq$brks

  testpred <- exp(betas[2,1]*testpts$bryoids + betas[3,1]*testpts$t.shrub + b
etas[4,1]*testpts$s.shrub + betas[5,1]*testpts$t.wet + betas[6,1]*testpts$s.w
```

```
et + betas[7,1]*testpts$h.wet + betas[8,1]*testpts$herb + betas[9,1]*testpts$
con.open + betas[10,1]*testpts$con.sp + betas[11,1]*testpts$broad.d + betas[1
2,1]*testpts$broad.o + betas[13,1]*testpts$mix.o + betas[14,1]*testpts$mix.de
ns + betas[15,1]*testpts$water + betas[16,1]*testpts$nonveg + betas[17,1]*tes
tpts$p_broad + betas[18,1]*testpts$p_consparse + betas[19,1]*testpts$burn10lo
w + betas[20,1]*testpts$burn20low + betas[21,1]*testpts$burn30low + betas[22,
1]*testpts$burn40low + betas[23,1]*testpts$burn60low + betas[24,1]*testpts$bu
rn10up.nt + betas[25,1]*testpts$burn20up.nt + betas[26,1]*testpts$burn30up.nt
+ betas[27,1]*testpts$burn40up.nt + betas[28,1]*testpts$burn60up.nt + betas[2
9,1]*testpts$burn10up.con + betas[30,1]*testpts$burn20up.con + betas[31,1]*te
stpts$burn30up.con + betas[32,1]*testpts$burn40up.con + betas[33,1]*testpts$b
urn60up.con + betas[34,1]*testpts$burn10up.dec + betas[35,1]*testpts$burn20up
.dec + betas[36,1]*testpts$burn30up.dec + betas[37,1]*testpts$burn40up.dec +
betas[38,1]*testpts$burn60up.dec + betas[39,1]*testpts$ld1000 + betas[40,1]*t
estpts$exp.maj.rds + betas[41,1]*testpts$exp.poly + betas[42,1]*testpts$exp.s
ettle)

  testpredN <- (testpred - min(map))/(max(map)-min(map))

  #Classify predictions of range points
  bin <- ifelse(mapN < eq[[2]], 1, ifelse(mapN < eq[[3]], 2, ifelse(mapN < eq
[[4]], 3, ifelse(mapN < eq[[5]], 4, ifelse(mapN < eq[[6]], 5, ifelse(mapN < e
q[[7]] , 6, ifelse(mapN < eq[[8]], 7, ifelse(mapN < eq[[9]], 8, ifelse(mapN <
eq[[10]], 9, 10)))))))))
  #Classify predictions of test points
  pts.use <- ifelse(testpredN < eq[[2]], 1, ifelse(testpredN < eq[[3]], 2, if
else(testpredN < eq[[4]], 3, ifelse(testpredN < eq[[5]], 4, ifelse(testpredN
< eq[[6]], 5, ifelse(testpredN < eq[[7]] , 6, ifelse(testpredN < eq[[8]], 7,
ifelse(testpredN < eq[[9]], 8, ifelse(testpredN < eq[[10]], 9, 10)))))))))

  #Sum range predictions
  freq.a <- c(sum(bin==1), sum(bin==2), sum(bin==3), sum(bin==4), sum(bin==5)
, sum(bin==6), sum(bin==7), sum(bin==8), sum(bin==9), sum(bin==10))
  #Sum test pt predictions
  freq.u <- c(sum(pts.use==1), sum(pts.use==2), sum(pts.use==3), sum(pts.use=
=4), sum(pts.use==5), sum(pts.use==6), sum(pts.use==7), sum(pts.use==8), sum(
pts.use==9), sum(pts.use==10))

  #Selection ratios
  a <- freq.a/length(bin)
  u <- freq.u/length(pts.use)
  sr <- u/a

  #Calculate r for area-adjusted frequency
  spear <- cor.test(sr, 1:10, method='spearman')

  #kfold (model-based): availability is specific to each individual caribou (
see Methods section in main report).
  uAIDYr <- unique(testpts$AIDYr)
```

```
  freq.aM <- rep(0,10)
  freq.uM <- rep(0,10)
  binM.all <- vector()
  pts.useM.all <- vector()
  for(k in uAIDYr){
    submap <- testrange[testrange$AIDYr==k,]
    submap <- submap[complete.cases(submap),]

    mapM <- exp(betas[2,1]*submap$bryoids + betas[3,1]*submap$t.shrub + betas
[4,1]*submap$s.shrub + betas[5,1]*submap$t.wet + betas[6,1]*submap$s.wet + be
tas[7,1]*submap$h.wet + betas[8,1]*submap$herb + betas[9,1]*submap$con.open +
betas[10,1]*submap$con.sp + betas[11,1]*submap$broad.d + betas[12,1]*submap$b
road.o + betas[13,1]*submap$mix.o + betas[14,1]*submap$mix.dens + betas[15,1]
*submap$water + betas[16,1]*submap$nonveg + betas[17,1]*submap$p_broad + beta
s[18,1]*submap$p_consparse + betas[19,1]*submap$burn10low + betas[20,1]*subma
p$burn20low + betas[21,1]*submap$burn30low + betas[22,1]*submap$burn40low + b
etas[23,1]*submap$burn60low + betas[24,1]*submap$burn10up.nt + betas[25,1]*su
bmap$burn20up.nt + betas[26,1]*submap$burn30up.nt + betas[27,1]*submap$burn40
up.nt + betas[28,1]*submap$burn60up.nt + betas[29,1]*submap$burn10up.con + be
tas[30,1]*submap$burn20up.con + betas[31,1]*submap$burn30up.con + betas[32,1]
*submap$burn40up.con + betas[33,1]*submap$burn60up.con + betas[34,1]*submap$b
urn10up.dec + betas[35,1]*submap$burn20up.dec + betas[36,1]*submap$burn30up.d
ec + betas[37,1]*submap$burn40up.dec + betas[38,1]*submap$burn60up.dec + beta
s[39,1]*submap$ld1000 + betas[40,1]*submap$exp.maj.rds + betas[41,1]*submap$e
xp.poly + betas[42,1]*submap$exp.settle)

    #Standardize
    mapMN <- (mapM - min(mapM))/(max(mapM)-min(mapM))

    #Split range points into equal intervals from min to max. This creates de
cile bins based on availability
    eqM <- classIntervals(mapMN, 10, style="quantile")
    eqM <- eqM$brks

    yrpts <- testpts[testpts$AIDYr==k,]

    yrpred <- exp(betas[2,1]*yrpts$bryoids + betas[3,1]*yrpts$t.shrub + betas
[4,1]*yrpts$s.shrub + betas[5,1]*yrpts$t.wet + betas[6,1]*yrpts$s.wet + betas
[7,1]*yrpts$h.wet + betas[8,1]*yrpts$herb + betas[9,1]*yrpts$con.open + betas
[10,1]*yrpts$con.sp + betas[11,1]*yrpts$broad.d + betas[12,1]*yrpts$broad.o +
betas[13,1]*yrpts$mix.o + betas[14,1]*yrpts$mix.dens + betas[15,1]*yrpts$wate
r + betas[16,1]*yrpts$nonveg + betas[17,1]*yrpts$p_broad + betas[18,1]*yrpts$
p_consparse + betas[19,1]*yrpts$burn10low + betas[20,1]*yrpts$burn20low + bet
as[21,1]*yrpts$burn30low + betas[22,1]*yrpts$burn40low + betas[23,1]*yrpts$bu
rn60low + betas[24,1]*yrpts$burn10up.nt + betas[25,1]*yrpts$burn20up.nt + bet
as[26,1]*yrpts$burn30up.nt + betas[27,1]*yrpts$burn40up.nt + betas[28,1]*yrpt
s$burn60up.nt + betas[29,1]*yrpts$burn10up.con + betas[30,1]*yrpts$burn20up.c
on + betas[31,1]*yrpts$burn30up.con + betas[32,1]*yrpts$burn40up.con + betas[
33,1]*yrpts$burn60up.con + betas[34,1]*yrpts$burn10up.dec + betas[35,1]*yrpts
```

```
$burn20up.dec + betas[36,1]*yrpts$burn30up.dec + betas[37,1]*yrpts$burn40up.d
ec + betas[38,1]*yrpts$burn60up.dec + betas[39,1]*yrpts$ld1000 + betas[40,1]*
yrpts$exp.maj.rds + betas[41,1]*yrpts$exp.poly + betas[42,1]*yrpts$exp.settle
)

    yrpredN <- (yrpred - min(mapM))/(max(mapM)-min(mapM))

    #Classify predictions of range points
    binM <- ifelse(mapMN < eqM[[2]], 1, ifelse(mapMN < eqM[[3]], 2, ifelse(ma
pMN < eqM[[4]], 3, ifelse(mapMN < eqM[[5]], 4, ifelse(mapMN < eqM[[6]], 5, if
else(mapMN < eqM[[7]] , 6, ifelse(mapMN < eqM[[8]], 7, ifelse(mapMN < eqM[[9]
], 8, ifelse(mapMN < eqM[[10]], 9, 10)))))))))
    binM.all <- c(binM.all, binM)
    #Classify predictions of test points
    pts.useM <- ifelse(yrpredN < eqM[[2]], 1, ifelse(yrpredN < eqM[[3]], 2, i
felse(yrpredN < eqM[[4]], 3, ifelse(yrpredN < eqM[[5]], 4, ifelse(yrpredN < e
qM[[6]], 5, ifelse(yrpredN < eqM[[7]] , 6, ifelse(yrpredN < eqM[[8]], 7, ifel
se(yrpredN < eqM[[9]], 8, ifelse(yrpredN < eqM[[10]], 9, 10)))))))))
    pts.useM.all <- c(pts.useM.all, pts.useM)

    #Sum range predictions
    freq.aM2 <- c(sum(binM==1), sum(binM==2), sum(binM==3), sum(binM==4), sum
(binM==5), sum(binM==6), sum(binM==7), sum(binM==8), sum(binM==9), sum(binM==
10))
    #Sum test pt predictions
    freq.uM2 <- c(sum(pts.useM==1), sum(pts.useM==2), sum(pts.useM==3), sum(p
ts.useM==4), sum(pts.useM==5), sum(pts.useM==6), sum(pts.useM==7), sum(pts.us
eM==8), sum(pts.useM==9), sum(pts.useM==10))

    freq.aM <- freq.aM + freq.aM2
    freq.uM <- freq.uM + freq.uM2
  }
    #Selection ratios
    aM <- freq.aM/length(binM.all)
    uM <- freq.uM/length(pts.useM.all)
    srM <- uM/aM

    #Calculate r for area-adjusted frequency
    spearM <- cor.test(srM, 1:10, method='spearman')

    data.frame(Iteration = i, Spearman.Corr.Map = unname(spear[[4]]), p.value
.Map = spear[[3]], Spearman.Corr.Model = unname(spearM[[4]]), p.value.Model =
spearM[[3]])

}
stopCluster(myCluster)

#Collate results from list format to data frame
```

```r
kfold.df <- data.frame()
for(i in c(1:10)){
  df <- kfold.res[[i]]
  kfold.df <- rbind.data.frame(kfold.df, df)
}
#kfold.df ###NOT RUN
```

APPENDIX F: MODEL COEFFICIENTS FROM RESOURCE SELECTION FUNCTIONS

To assess seasonal habitat selection by boreal caribou in the Northwest Territories, resource selection functions (RSFs) were estimated at two separate scales (second- and third-order) and across seven distinct seasons within each scale. Here, model coefficients and their standard errors are shown for seasonal second-order RSFs (Table F 1), seasonal third-order RSFs (Table F 2), and all-year RSFs at both scales (Table F 3).

Table F 1: Model coefficients (β), their standard errors (SE) and *p*-values (*p*) from seasonal resource selection functions estimated at a second-order scale for boreal caribou in the Northwest Territories.

	Calving (*n* = 249 caribou [444 caribou-seasons])			Summer (*n* = 211 caribou [336 caribou-seasons])			Early Fall (*n* = 221 caribou [364 caribou-seasons])			Late Fall (*n* = 242 caribou [405 caribou-seasons])			Early Winter (*n* = 268 caribou [432 caribou-seasons])			Mid Winter (*n* = 340 caribou [623 caribou-seasons]			Late Winter (*n* = 350 caribou [659 caribou-seasons])		
Variable	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*
(Intercept)	-11.60	0.42	0.00	-13.92	0.59	0.00	-12.82	0.63	0.00	-11.27	0.54	0.00	-14.94	0.55	0.00	-6.29	0.28	0.00	-6.12	0.31	0.00
Bryoids	0.08	0.06	0.17	-0.19	0.09	0.03	0.25	0.13	0.05	1.30	0.08	0.00	1.93	0.05	0.00	1.41	0.05	0.00	0.61	0.11	0.00
Tall shrub	0.15	0.07	0.03	-0.03	0.08	0.65	0.27	0.15	0.07	0.44	0.13	0.00	1.15	0.06	0.00	0.93	0.06	0.00	0.36	0.11	0.00
Short shrub	-0.06	0.03	0.04	0.02	0.03	0.44	0.91	0.04	0.00	0.72	0.04	0.00	0.75	0.03	0.00	0.50	0.03	0.00	0.33	0.05	0.00
Treed wetland	0.30	0.02	0.00	0.22	0.02	0.00	0.95	0.03	0.00	1.24	0.03	0.00	1.40	0.02	0.00	1.24	0.02	0.00	0.95	0.03	0.00
Shrub wetland	0.27	0.02	0.00	0.12	0.03	0.00	0.99	0.03	0.00	1.35	0.03	0.00	1.34	0.02	0.00	1.23	0.02	0.00	0.87	0.03	0.00
Herb wetland	0.43	0.03	0.00	-0.10	0.04	0.02	1.00	0.05	0.00	1.56	0.04	0.00	1.45	0.03	0.00	1.21	0.03	0.00	0.55	0.05	0.00
Herb	0.34	0.07	0.00	0.08	0.08	0.28	0.50	0.11	0.00	-0.13	0.13	0.30	0.01	0.10	0.95	-1.45	0.19	0.00	-1.51	0.41	0.00
Conifer open	0.30	0.02	0.00	0.09	0.02	0.00	0.64	0.03	0.00	0.49	0.03	0.00	0.60	0.02	0.00	0.69	0.02	0.00	0.66	0.02	0.00
Conifer sparse	0.24	0.02	0.00	0.02	0.02	0.44	0.81	0.04	0.00	0.78	0.03	0.00	0.87	0.02	0.00	1.03	0.02	0.00	0.71	0.03	0.00
Broadleaf dense	-1.00	0.15	0.00	-1.08	0.15	0.00	-0.50	0.22	0.02	-0.99	0.27	0.00	-1.67	0.25	0.00	-1.70	0.21	0.00	-1.40	0.24	0.00
Broadleaf open	0.00	0.11	0.98	-0.76	0.15	0.00	-0.56	0.25	0.03	-0.21	0.18	0.25	0.00	0.13	1.00	-0.62	0.14	0.00	-0.79	0.26	0.00
Mixedwood open	-0.22	0.07	0.00	0.01	0.07	0.94	-0.19	0.14	0.16	-0.52	0.14	0.00	-0.19	0.10	0.05	0.69	0.05	0.00	1.04	0.06	0.00
Mixedwood dense	0.53	0.05	0.00	0.12	0.06	0.03	0.49	0.08	0.00	0.76	0.07	0.00	1.50	0.04	0.00	0.82	0.03	0.00	0.53	0.07	0.00
Water	-1.56	0.03	0.00	-1.85	0.03	0.00	-1.83	0.06	0.00	-1.39	0.04	0.00	-0.62	0.03	0.00	-1.06	0.03	0.00	-1.36	0.04	0.00
Non-vegetated	0.20	0.05	0.00	0.08	0.06	0.23	-0.06	0.12	0.64	-1.87	0.25	0.00	-1.55	0.16	0.00	-2.23	0.20	0.00	-3.22	0.58	0.00
Proportion of broadleaf (1-km radius)	-11.08	0.12	0.00	-10.01	0.13	0.00	-9.08	0.16	0.00	-10.46	0.16	0.00	-8.56	0.11	0.00	-6.11	0.08	0.00	-6.26	0.13	0.00
Proportion of conifer sparse (1-km radius)	-0.52	0.03	0.00	-0.48	0.04	0.00	-0.93	0.06	0.00	-0.83	0.05	0.00	-1.44	0.04	0.00	-1.21	0.03	0.00	-0.49	0.06	0.00
Burned lowlands (1-10 y.o.)	0.84	0.02	0.00	0.23	0.03	0.00	0.46	0.05	0.00	0.80	0.04	0.00	0.64	0.03	0.00	0.18	0.03	0.00	-0.49	0.06	0.00
																					(*cont'd*)
Burned lowlands (11-	-0.44	0.03	0.00	-1.02	0.05	0.00	-0.52	0.06	0.00	-0.54	0.06	0.00	-1.15	0.06	0.00	-2.27	0.09	0.00	-2.16	0.12	0.00

	Calving (*n* = 249 caribou [444 caribou-seasons])			Summer (*n* = 211 caribou [336 caribou-seasons])			Early Fall (*n* = 221 caribou [364 caribou-seasons])			Late Fall (*n* = 242 caribou [405 caribou-seasons])			Early Winter (*n* = 268 caribou [432 caribou-seasons])			Mid Winter (*n* = 340 caribou [623 caribou-seasons]			Late Winter (*n* = 350 caribou [659 caribou-seasons])		
Variable	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*
20 y.o.)																					
Burned lowlands (21-30 y.o.)	-0.33	0.03	0.00	-0.20	0.03	0.00	0.22	0.05	0.00	-0.16	0.05	0.00	-1.36	0.07	0.00	-1.83	0.07	0.00	-3.52	0.21	0.00
Burned lowlands (31-40 y.o.)	0.48	0.03	0.00	0.53	0.03	0.00	1.52	0.04	0.00	1.61	0.03	0.00	1.04	0.03	0.00	-0.67	0.04	0.00	-1.20	0.08	0.00
Burned lowlands (41-60 y.o.)	-1.06	0.08	0.00	0.03	0.05	0.54	0.47	0.07	0.00	0.87	0.05	0.00	0.98	0.04	0.00	0.47	0.04	0.00	0.24	0.06	0.00
Burned uplands non-treed (1-10 y.o.)	0.64	0.03	0.00	0.47	0.03	0.00	0.54	0.06	0.00	0.85	0.05	0.00	0.38	0.04	0.00	-0.50	0.06	0.00	-1.10	0.11	0.00
Burned uplands non-treed (11-20 y.o.)	-0.69	0.03	0.00	-0.88	0.04	0.00	-0.59	0.06	0.00	-0.92	0.07	0.00	-1.46	0.07	0.00	-2.87	0.12	0.00	-3.09	0.19	0.00
Burned uplands non-treed (21-30 y.o.)	-0.18	0.04	0.00	-0.05	0.03	0.11	0.53	0.05	0.00	-0.10	0.05	0.06	-1.72	0.08	0.00	-2.51	0.10	0.00	-4.77	0.45	0.00
Burned uplands non-treed (31-40 y.o.)	-0.47	0.07	0.00	-0.89	0.10	0.00	1.15	0.07	0.00	0.81	0.06	0.00	0.86	0.05	0.00	-1.67	0.13	0.00	-4.08	0.71	0.00
Burned uplands non-treed (41-60 y.o.)	-1.03	0.16	0.00	0.79	0.07	0.00	0.70	0.13	0.00	1.07	0.09	0.00	1.40	0.06	0.00	0.01	0.09	0.93	-0.49	0.18	0.01
Burned upland conifer (1-10 y.o.)	0.00	0.03	0.95	-0.79	0.04	0.00	-0.59	0.06	0.00	-0.51	0.06	0.00	-0.28	0.04	0.00	-0.49	0.04	0.00	-0.83	0.06	0.00
Burned upland conifer (11-20 y.o.)	0.20	0.06	0.00	-0.79	0.12	0.00	-0.29	0.15	0.05	-0.43	0.15	0.00	-1.26	0.16	0.00	-1.58	0.16	0.00	-1.55	0.25	0.00
Burned upland conifer (21-30 y.o.)	0.14	0.06	0.02	0.03	0.07	0.63	0.24	0.12	0.04	-0.30	0.14	0.02	-1.48	0.17	0.00	-2.03	0.18	0.00	-3.18	0.50	0.00
																					(*cont'd*)
Burned upland conifer (31-40	0.63	0.04	0.00	0.30	0.05	0.00	1.12	0.06	0.00	0.94	0.05	0.00	0.40	0.05	0.00	-0.44	0.06	0.00	-0.93	0.11	0.00

	Calving (*n* = 249 caribou [444 caribou-seasons])			Summer (*n* = 211 caribou [336 caribou-seasons])			Early Fall (*n* = 221 caribou [364 caribou-seasons])			Late Fall (*n* = 242 caribou [405 caribou-seasons])			Early Winter (*n* = 268 caribou [432 caribou-seasons])			Mid Winter (*n* = 340 caribou [623 caribou-seasons]			Late Winter (*n* = 350 caribou [659 caribou-seasons])		
Variable	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*
y.o.)																					
Burned upland conifer (41-60 y.o.)	-0.14	0.08	0.09	-1.00	0.09	0.00	0.51	0.09	0.00	0.76	0.08	0.00	0.97	0.06	0.00	0.77	0.04	0.00	1.03	0.06	0.00
Burned upland broadleaf (1-10 y.o.)	-0.09	0.11	0.45	0.41	0.09	0.00	-0.82	0.32	0.01	-0.54	0.28	0.05	-0.83	0.18	0.00	-0.81	0.16	0.00	-0.93	0.23	0.00
Burned upland broadleaf (11-20 y.o.)	-1.02	0.15	0.00	-2.35	0.36	0.00	-2.20	0.58	0.00	-1.08	0.36	0.00	-1.58	0.30	0.00	-3.33	0.58	0.00	-3.63	1.00	0.00
Burned upland broadleaf (21-30 y.o.)	-0.91	0.16	0.00	-0.83	0.16	0.00	-0.52	0.25	0.03	-1.33	0.45	0.00	-2.04	0.45	0.00	-3.09	0.45	0.00	-13.77	146.02	0.92
Burned upland broadleaf (31-40 y.o.)	0.48	0.07	0.00	0.10	0.08	0.23	0.53	0.13	0.00	0.93	0.11	0.00	0.62	0.09	0.00	-1.67	0.17	0.00	-3.55	0.71	0.00
Burned upland broadleaf (41-60 y.o.)	-2.01	0.38	0.00	-2.94	0.50	0.00	-1.60	0.45	0.00	-1.09	0.38	0.00	-0.49	0.25	0.05	-1.44	0.24	0.00	-2.19	0.58	0.00
Linear feature density (1-km radius)	-0.16	0.01	0.00	-0.15	0.01	0.00	-0.17	0.02	0.00	-0.23	0.01	0.00	-0.19	0.01	0.00	-0.13	0.01	0.00	0.02	0.01	0.16
Distance to major road	5.96	0.30	0.00	5.04	0.31	0.00	3.94	0.35	0.00	4.83	0.39	0.00	7.79	0.46	0.00	3.26	0.18	0.00	2.12	0.21	0.00
Distance to polygonal disturbance	5.43	0.30	0.00	7.70	0.46	0.00	6.03	0.49	0.00	2.18	0.26	0.00	4.35	0.28	0.00	1.54	0.12	0.00	1.07	0.16	0.00
Distance to settlement	-2.44	0.11	0.00	-1.64	0.13	0.00	-1.18	0.16	0.00	0.32	0.24	0.19	-0.57	0.14	0.00	-1.90	0.10	0.00	-1.51	0.13	0.00

Table F 2: Model coefficients (β), their standard errors (SE) and *p*-values (*p*) from seasonal resource selection functions estimated at a third-order scale for boreal caribou in the Northwest Territories.

	Calving (*n* = 194 caribou [298 caribou-seasons])			Summer (*n* = 170 caribou [258 caribou-seasons])			Early Fall (*n* = 196 caribou [308 caribou-seasons])			Late Fall (*n* = 210 caribou [349 caribou-seasons])			Early Winter (*n* = 226 caribou [343 caribou-seasons])			Mid Winter (*n* = 209 caribou [324 caribou-seasons])			Late Winter (*n* = 241 caribou [368 caribou-seasons])		
Variable	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*
(Intercept)	-18.19	0.65	0.00	-14.91	0.56	0.00	-15.68	0.66	0.00	-20.33	0.66	0.00	-19.29	0.63	0.00	-10.72	0.36	0.00	-9.65	0.43	0.00
Bryoids	0.31	0.07	0.00	-0.12	0.09	0.20	0.75	0.13	0.00	1.70	0.08	0.00	1.93	0.05	0.00	1.44	0.07	0.00	0.44	0.15	0.00
Tall shrub	0.28	0.08	0.00	0.20	0.09	0.03	0.58	0.17	0.00	0.76	0.14	0.00	1.06	0.08	0.00	1.06	0.08	0.00	0.55	0.14	0.00
Short shrub	0.21	0.03	0.00	0.26	0.03	0.00	1.33	0.05	0.00	1.07	0.04	0.00	1.00	0.03	0.00	0.59	0.04	0.00	0.33	0.06	0.00
Treed wetland	0.29	0.02	0.00	0.19	0.02	0.00	1.02	0.03	0.00	1.35	0.03	0.00	1.41	0.02	0.00	1.27	0.03	0.00	0.97	0.04	0.00
Shrub wetland	0.19	0.03	0.00	0.04	0.03	0.17	0.98	0.04	0.00	1.31	0.03	0.00	1.18	0.03	0.00	1.11	0.03	0.00	0.76	0.04	0.00
Herb wetland	0.24	0.04	0.00	-0.15	0.05	0.00	0.76	0.06	0.00	1.36	0.04	0.00	1.36	0.03	0.00	0.94	0.04	0.00	0.25	0.07	0.00
Herb	0.35	0.08	0.00	0.62	0.08	0.00	1.25	0.13	0.00	0.79	0.14	0.00	0.45	0.11	0.00	-1.12	0.26	0.00	-1.82	0.50	0.00
Conifer open	0.26	0.02	0.00	0.16	0.02	0.00	0.70	0.03	0.00	0.56	0.03	0.00	0.52	0.02	0.00	0.69	0.02	0.00	0.74	0.03	0.00
Conifer sparse	0.24	0.02	0.00	0.18	0.03	0.00	0.95	0.04	0.00	0.87	0.03	0.00	0.92	0.03	0.00	0.95	0.03	0.00	0.75	0.04	0.00
Broadleaf dense	-0.36	0.17	0.04	-0.39	0.16	0.02	0.19	0.23	0.39	-0.22	0.28	0.43	-0.85	0.27	0.00	-1.36	0.29	0.00	-1.10	0.34	0.00
Broadleaf open	0.00	0.13	0.97	-0.48	0.16	0.00	-0.23	0.25	0.36	0.30	0.19	0.11	0.37	0.13	0.00	-0.96	0.23	0.00	-1.94	0.50	0.00
Mixedwood open	-0.24	0.09	0.01	0.02	0.07	0.75	-0.21	0.14	0.14	-0.52	0.15	0.00	-0.55	0.11	0.00	-0.74	0.13	0.00	1.03	0.08	0.00
Mixedwood dense	0.15	0.06	0.01	-0.11	0.06	0.06	0.24	0.08	0.00	0.48	0.07	0.00	0.89	0.05	0.00	0.72	0.05	0.00	0.09	0.08	0.27
Water	-1.24	0.03	0.00	-1.57	0.04	0.00	-1.35	0.06	0.00	-0.86	0.05	0.00	-0.16	0.03	0.00	-0.59	0.04	0.00	-0.84	0.06	0.00
Non-vegetated	1.17	0.07	0.00	0.38	0.12	0.00	0.37	0.21	0.08	-0.57	0.27	0.04	-0.15	0.17	0.37	-1.94	0.50	0.00	-2.00	0.58	0.00
Proportion of broadleaf (1-km radius)	-9.10	0.15	0.00	-6.86	0.14	0.00	-6.75	0.18	0.00	-8.93	0.18	0.00	-6.78	0.13	0.00	-3.97	0.12	0.00	-3.18	0.17	0.00
Proportion of conifer sparse (1-km radius)	0.93	0.05	0.00	1.36	0.05	0.00	1.24	0.07	0.00	0.76	0.06	0.00	0.81	0.05	0.00	0.80	0.06	0.00	0.79	0.09	0.00
Burned lowlands (1-10 y.o.)	0.56	0.03	0.00	-0.05	0.03	0.09	0.21	0.05	0.00	0.49	0.04	0.00	0.13	0.04	0.00	-0.47	0.05	0.00	-1.32	0.09	0.00
																					(*cont'd*)
Burned lowlands (11-	0.26	0.04	0.00	-0.43	0.06	0.00	0.37	0.07	0.00	0.35	0.06	0.00	-0.68	0.07	0.00	-2.01	0.14	0.00	-1.95	0.21	0.00

	Calving (*n* = 194 caribou [298 caribou-seasons])			Summer (*n* = 170 caribou [258 caribou-seasons])			Early Fall (*n* = 196 caribou [308 caribou-seasons])			Late Fall (*n* = 210 caribou [349 caribou-seasons])			Early Winter (*n* = 226 caribou [343 caribou-seasons])			Mid Winter (*n* = 209 caribou [324 caribou-seasons])			Late Winter (*n* = 241 caribou [368 caribou-seasons])		
Variable	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*
20 y.o.)																					
Burned lowlands (21-30 y.o.)	0.10	0.04	0.01	0.27	0.04	0.00	0.84	0.05	0.00	0.27	0.06	0.00	-1.16	0.08	0.00	-1.33	0.10	0.00	-3.67	0.36	0.00
Burned lowlands (31-40 y.o.)	0.16	0.03	0.00	0.09	0.03	0.00	1.26	0.04	0.00	1.36	0.03	0.00	0.43	0.03	0.00	-1.31	0.06	0.00	-2.18	0.12	0.00
Burned lowlands (41-60 y.o.)	-1.07	0.09	0.00	0.12	0.05	0.02	0.71	0.07	0.00	1.15	0.06	0.00	1.44	0.04	0.00	-0.11	0.09	0.21	0.04	0.10	0.71
Burned uplands non-treed (1-10 y.o.)	-0.06	0.04	0.11	-0.47	0.04	0.00	-0.16	0.07	0.02	0.30	0.05	0.00	-0.14	0.05	0.00	-1.51	0.10	0.00	-1.90	0.15	0.00
Burned uplands non-treed (11-20 y.o.)	0.32	0.05	0.00	0.20	0.06	0.00	0.95	0.07	0.00	0.72	0.08	0.00	-0.58	0.08	0.00	-1.96	0.17	0.00	-3.03	0.45	0.00
Burned uplands non-treed (21-30 y.o.)	0.07	0.04	0.07	0.24	0.04	0.00	1.18	0.05	0.00	0.37	0.06	0.00	-1.33	0.09	0.00	-1.72	0.14	0.00	-4.26	0.50	0.00
Burned uplands non-treed (31-40 y.o.)	0.19	0.08	0.01	-0.42	0.10	0.00	1.68	0.07	0.00	1.70	0.07	0.00	1.04	0.06	0.00	-1.09	0.18	0.00	-3.23	0.71	0.00
Burned uplands non-treed (41-60 y.o.)	-0.91	0.16	0.00	0.68	0.08	0.00	1.20	0.13	0.00	1.46	0.10	0.00	1.77	0.07	0.00	-0.37	0.25	0.13	-1.04	0.34	0.00
Burned upland conifer (1-10 y.o.)	0.16	0.03	0.00	-0.58	0.04	0.00	-0.32	0.06	0.00	-0.32	0.06	0.00	-0.34	0.05	0.00	-0.66	0.06	0.00	-1.07	0.10	0.00
Burned upland conifer (11-20 y.o.)	0.46	0.08	0.00	-0.31	0.12	0.01	0.39	0.15	0.01	0.05	0.16	0.75	-0.88	0.17	0.00	-1.84	0.32	0.00	-3.37	1.00	0.00
Burned upland conifer (21-30 y.o.)	0.22	0.07	0.00	0.05	0.08	0.57	0.18	0.13	0.15	-0.34	0.16	0.03	-2.26	0.28	0.00	-1.53	0.22	0.00	-17.55	803.22	0.98
																					(*cont'd*)
Burned upland conifer (31-40	0.00	0.05	0.96	-0.42	0.05	0.00	0.42	0.06	0.00	0.58	0.05	0.00	-0.18	0.06	0.00	-1.09	0.08	0.00	-1.33	0.14	0.00

	Calving (*n* = 194 caribou [298 caribou-seasons])			Summer (*n* = 170 caribou [258 caribou-seasons])			Early Fall (*n* = 196 caribou [308 caribou-seasons])			Late Fall (*n* = 210 caribou [349 caribou-seasons])			Early Winter (*n* = 226 caribou [343 caribou-seasons])			Mid Winter (*n* = 209 caribou [324 caribou-seasons])			Late Winter (*n* = 241 caribou [368 caribou-seasons])		
Variable	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*
y.o.)																					
Burned upland conifer (41-60 y.o.)	-0.77	0.09	0.00	-1.10	0.09	0.00	0.19	0.09	0.04	0.46	0.08	0.00	0.53	0.06	0.00	0.67	0.07	0.00	0.38	0.10	0.00
Burned upland broadleaf (1-10 y.o.)	0.37	0.12	0.00	0.57	0.09	0.00	-0.94	0.34	0.01	-0.94	0.32	0.00	-0.58	0.19	0.00	-0.53	0.20	0.01	-1.21	0.36	0.00
Burned upland broadleaf (11-20 y.o.)	0.15	0.17	0.36	-1.47	0.41	0.00	-0.94	0.58	0.11	-0.11	0.36	0.75	-0.96	0.36	0.01	-14.31	305.61	0.96	-18.85	4113.68	1.00
Burned upland broadleaf (21-30 y.o.)	-0.70	0.22	0.00	-0.30	0.19	0.10	-0.01	0.26	0.97	-1.40	0.58	0.02	-2.03	0.50	0.00	-2.99	0.71	0.00	-18.74	2502.38	0.99
Burned upland broadleaf (31-40 y.o.)	0.41	0.08	0.00	-0.12	0.08	0.16	0.29	0.13	0.02	0.64	0.11	0.00	-0.03	0.10	0.75	-3.17	0.41	0.00	-17.29	669.91	0.98
Burned upland broadleaf (41-60 y.o.)	-1.47	0.45	0.00	-2.69	0.71	0.00	-0.92	0.58	0.11	-0.09	0.38	0.82	-0.04	0.26	0.89	-1.82	0.58	0.00	-2.34	1.00	0.02
Linear feature density (1-km radius)	-0.12	0.01	0.00	-0.12	0.01	0.00	-0.21	0.02	0.00	-0.15	0.02	0.00	-0.15	0.01	0.00	0.06	0.01	0.00	0.20	0.01	0.00
Distance to major road	8.07	0.43	0.00	6.59	0.36	0.00	5.52	0.42	0.00	8.03	0.51	0.00	11.61	0.58	0.00	4.51	0.24	0.00	3.78	0.30	0.00
Distance to polygonal disturbance	6.91	0.53	0.00	5.09	0.41	0.00	4.23	0.48	0.00	1.04	0.23	0.00	1.93	0.22	0.00	1.10	0.16	0.00	1.06	0.22	0.00
Distance to settlement	0.27	0.16	0.09	0.02	0.15	0.88	1.37	0.23	0.00	6.90	0.36	0.00	1.97	0.20	0.00	1.17	0.16	0.00	-0.02	0.20	0.91

Table F 3: Model coefficients (β), their standard errors (SE) and *p*-values (*p*) from resource selection functions (RSFs) estimated using data collected across the year from boreal caribou in the Northwest Territories. RSFs were estimated at second- and third-order scales.

	Scale					
	Second Order (*n* = 194 caribou [301 caribou-seasons])			Third Order (*n* = 194 caribou [301 caribou-seasons])		
Variable	β	SE	*p*	β	SE	*p*
(Intercept)	-8.36	0.28	0.00	-11.40	0.29	0.00
Bryoids	0.90	0.03	0.00	0.91	0.03	0.00
Tall shrub	0.79	0.04	0.00	0.66	0.04	0.00
Short shrub	0.35	0.02	0.00	0.51	0.02	0.00
Treed wetland	0.71	0.01	0.00	0.65	0.01	0.00
Shrub wetland	0.68	0.01	0.00	0.53	0.01	0.00
Herb wetland	0.85	0.02	0.00	0.55	0.02	0.00
Herb	0.06	0.05	0.17	0.45	0.05	0.00
Conifer open	0.38	0.01	0.00	0.37	0.01	0.00
Conifer sparse	0.38	0.01	0.00	0.49	0.01	0.00
Broadleaf dense	-0.94	0.07	0.00	-0.17	0.07	0.02
Broadleaf open	-0.02	0.06	0.72	0.14	0.06	0.02
Mixedwood open	0.05	0.04	0.17	0.01	0.04	0.80
Mixedwood dense	0.72	0.03	0.00	0.40	0.02	0.00
Water	-1.15	0.01	0.00	-0.77	0.01	0.00
Non-vegetated	-0.93	0.05	0.00	0.33	0.06	0.00
Proportion of broadleaf (1-km radius)	-8.80	0.06	0.00	-6.08	0.06	0.00
Proportion of conifer sparse (1-km radius)	-0.26	0.02	0.00	1.55	0.03	0.00
Burned lowlands (1-10 y.o.)	0.53	0.02	0.00	0.07	0.02	0.00
Burned lowlands (11-20 y.o.)	-0.91	0.02	0.00	-0.26	0.03	0.00
Burned lowlands (21-30 y.o.)	-0.51	0.02	0.00	-0.20	0.02	0.00
Burned lowlands (31-40 y.o.)	0.63	0.02	0.00	0.04	0.02	0.00
Burned lowlands (41-60 y.o.)	0.27	0.03	0.00	0.36	0.03	0.00
Burned uplands non-treed (1-10 y.o.)	0.49	0.02	0.00	-0.36	0.02	0.00

(*cont'd*)

	Scale					
	Second Order (*n* = 194 caribou [301 caribou-seasons])			Third Order (*n* = 194 caribou [301 caribou-seasons])		
Variable	β	SE	*p*	β	SE	*p*
Burned uplands non-treed (11-20 y.o.)	-1.00	0.02	0.00	0.10	0.03	0.00
Burned uplands non-treed (21-30 y.o.)	-0.44	0.02	0.00	-0.08	0.02	0.00
Burned uplands non-treed (31-40 y.o.)	-0.08	0.03	0.02	0.31	0.04	0.00
Burned uplands non-treed (41-60 y.o.)	0.49	0.04	0.00	0.54	0.05	0.00
Burned upland conifer (1-10 y.o.)	-0.39	0.02	0.00	-0.30	0.02	0.00
Burned upland conifer (11-20 y.o.)	-0.66	0.05	0.00	-0.16	0.05	0.00
Burned upland conifer (21-30 y.o.)	-0.51	0.05	0.00	-0.35	0.05	0.00
Burned upland conifer (31-40 y.o.)	0.32	0.03	0.00	-0.42	0.02	0.00
Burned upland conifer (41-60 y.o.)	0.16	0.03	0.00	-0.13	0.03	0.00
Burned upland broadleaf (1-10 y.o.)	-0.26	0.07	0.00	-0.16	0.07	0.02
Burned upland broadleaf (11-20 y.o.)	-1.49	0.12	0.00	-0.71	0.12	0.00
Burned upland broadleaf (21-30 y.o.)	-0.77	0.09	0.00	-0.49	0.09	0.00
Burned upland broadleaf (31-40 y.o.)	0.42	0.04	0.00	-0.32	0.04	0.00
Burned upland broadleaf (41-60 y.o.)	-1.39	0.15	0.00	-1.02	0.15	0.00
Linear feature density (1-km radius)	-0.14	0.01	0.00	-0.08	0.01	0.00
Distance to major road	4.56	0.13	0.00	5.72	0.14	0.00
Distance to polygonal disturbance	5.07	0.15	0.00	2.69	0.11	0.00
Distance to settlement	-2.72	0.07	0.00	1.16	0.08	0.00

APPENDIX G: RELATIVE CONTRIBUTION OF ENVIRONMENTAL VARIABLES TO MAPPED BINS OF SEASONAL RESOURCE SELECTION

We used outputs of seasonal resource selection functions (RSFs) to develop maps of predicted space use by boreal caribou in the Northwest Territories. Although RSFs generate a continuous surface of resource selection, we binned map pixels into 10 classes (1= weakest selection, 10 = strongest selection) to improve visual interpretation of predicted selection by caribou (Morris et al. 2016). In this appendix, we provide graphical representations of the proportional contribution of each resource covariate to each RSF bin for second-order RSF maps, beginning with categorical variables of local land-cover (Figs. G 1–8) followed by all continuous variables (Figs. G 9–14).

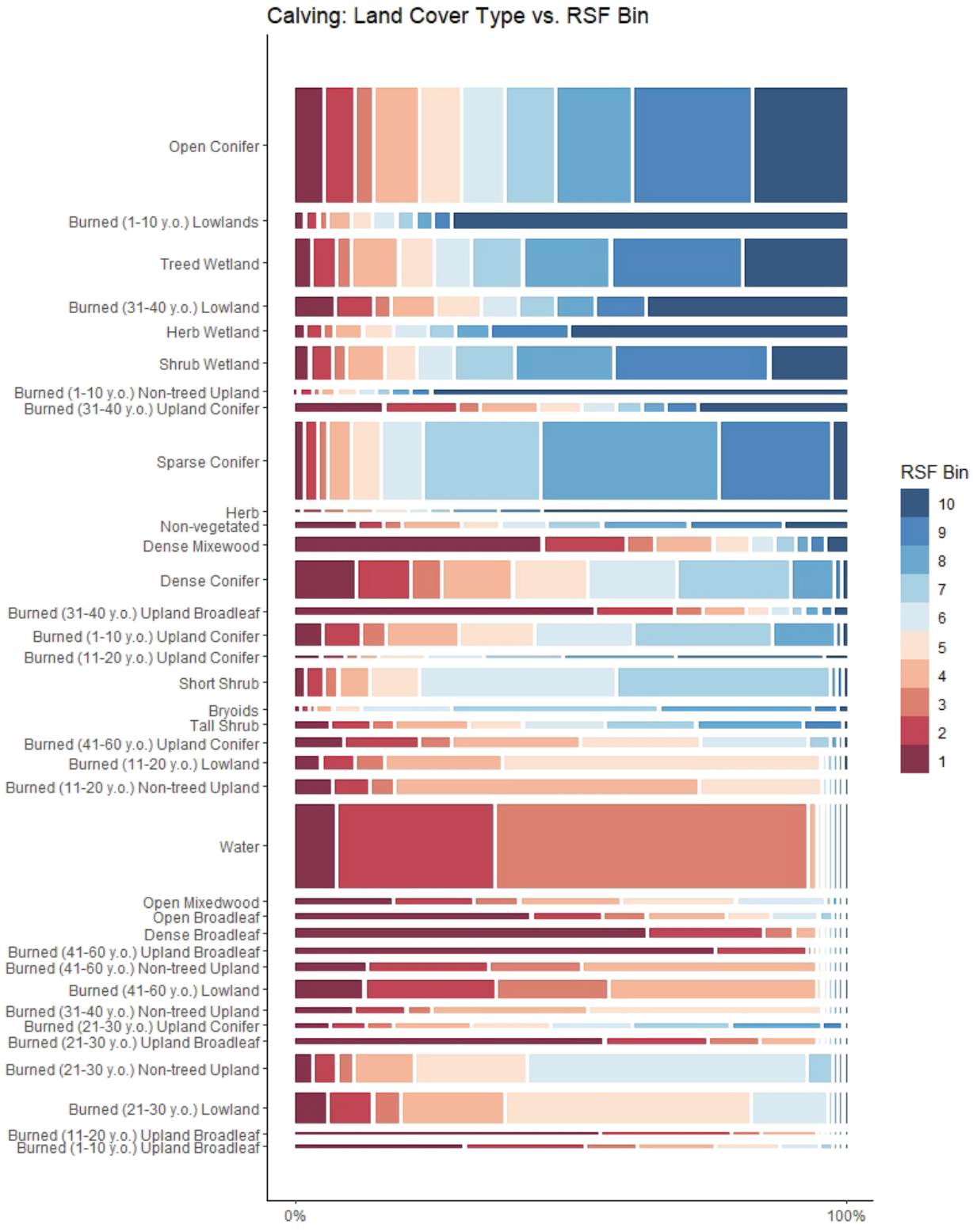


Figure G 1: The relative contribution of local land-cover variables to mapped bin values of resource selection during the calving season at a second-order scale by boreal caribou in the Northwest Territories. Bar width in the histogram is proportional to the area covered by each variable in the study area. Variables are ranked by their relative contribution to bin 10 (strongest selection).

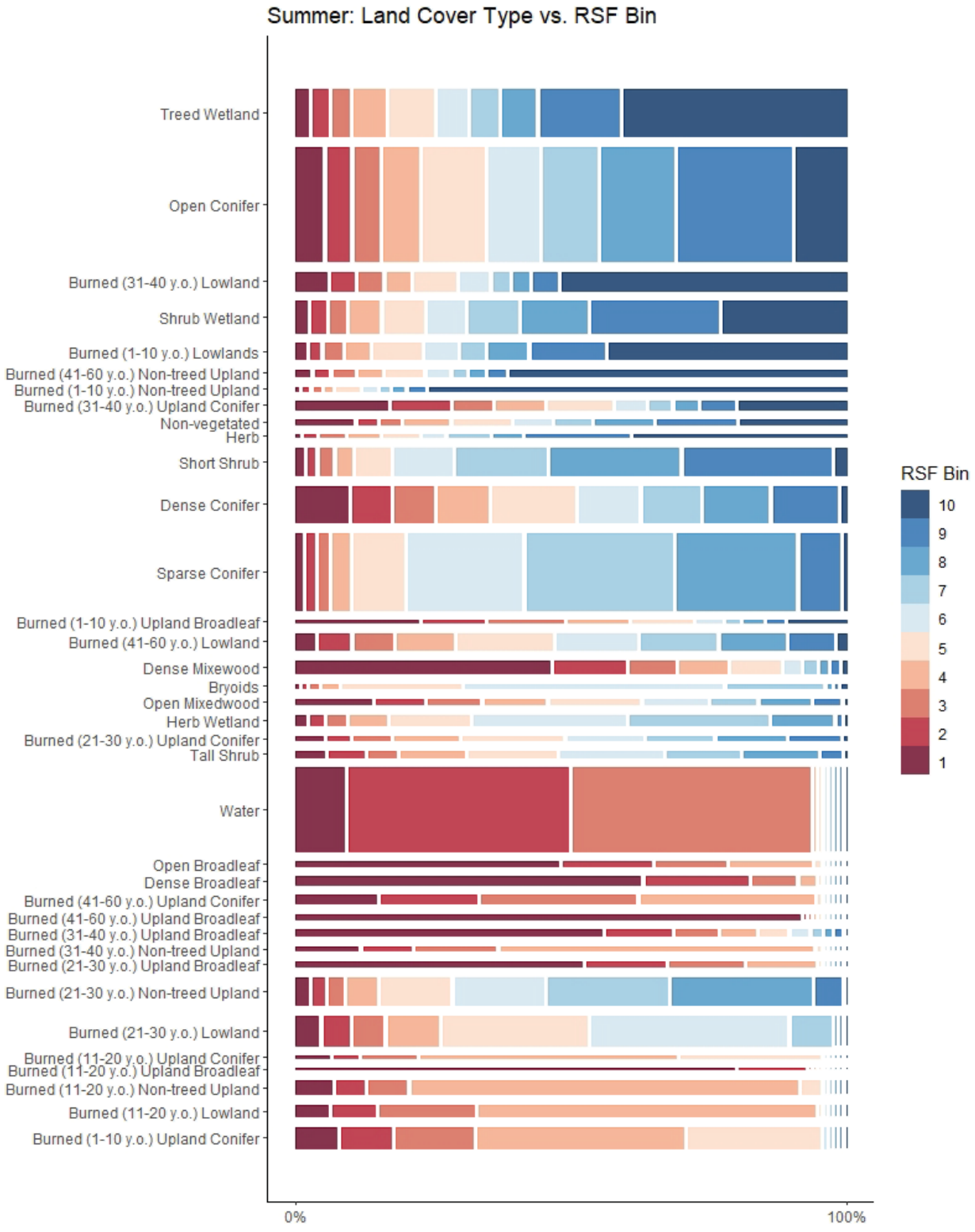


Figure G 2: The relative contribution of local land-cover variables to mapped bin values of resource selection at a second-order scale during the summer by boreal caribou in the Northwest Territories. Bar width in the histogram is proportional to the area covered by each variable in the study area. Variables are ranked by their relative contribution to bin 10 (strongest selection).

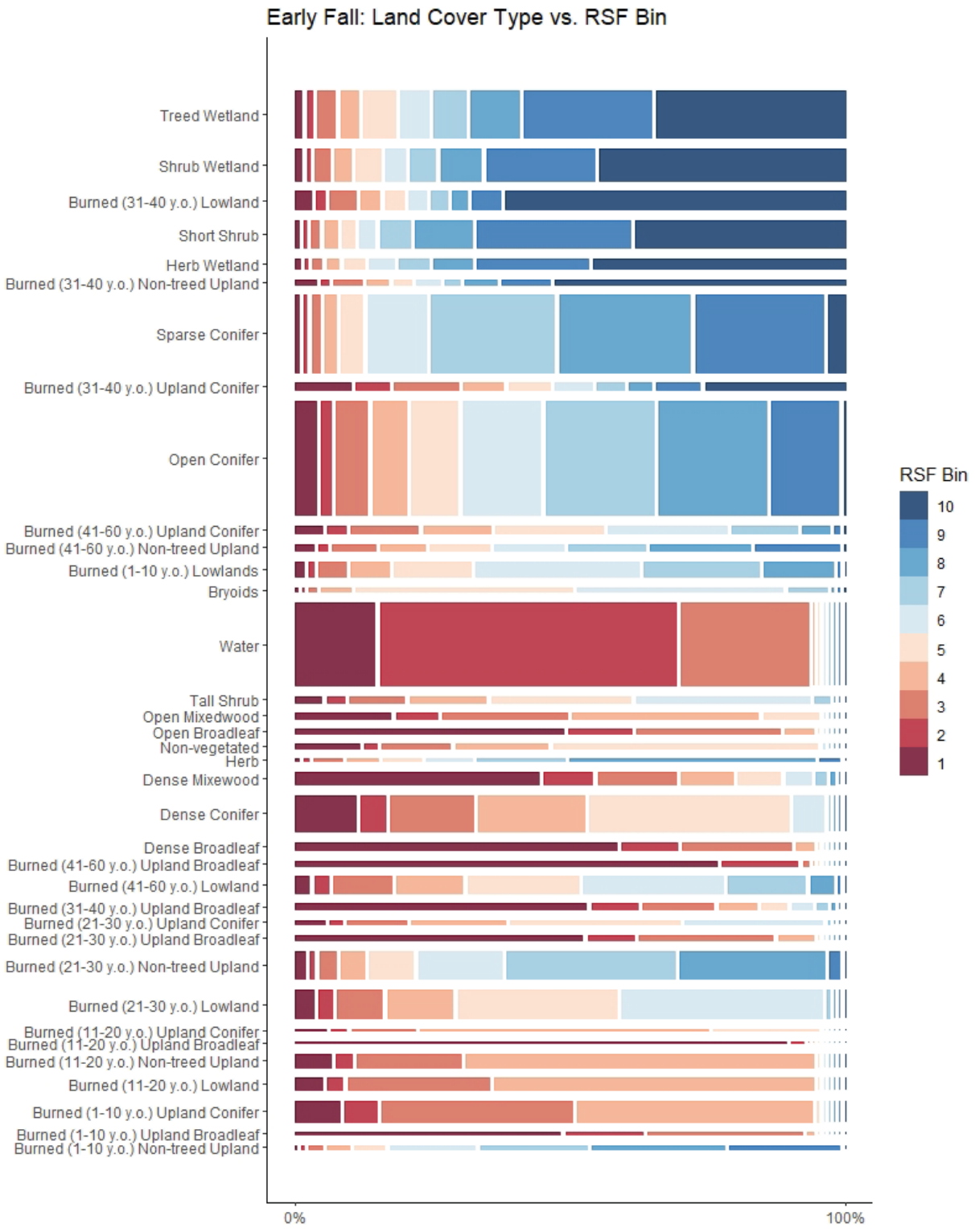


Figure G 3: The relative contribution of local land-cover variables to mapped bin values of resource selection at a second-order scale during the early fall by boreal caribou in the Northwest Territories. Bar width in the histogram is proportional to the area covered by each variable in the study area. Variables are ranked by their relative contribution to bin 10 (strongest selection).

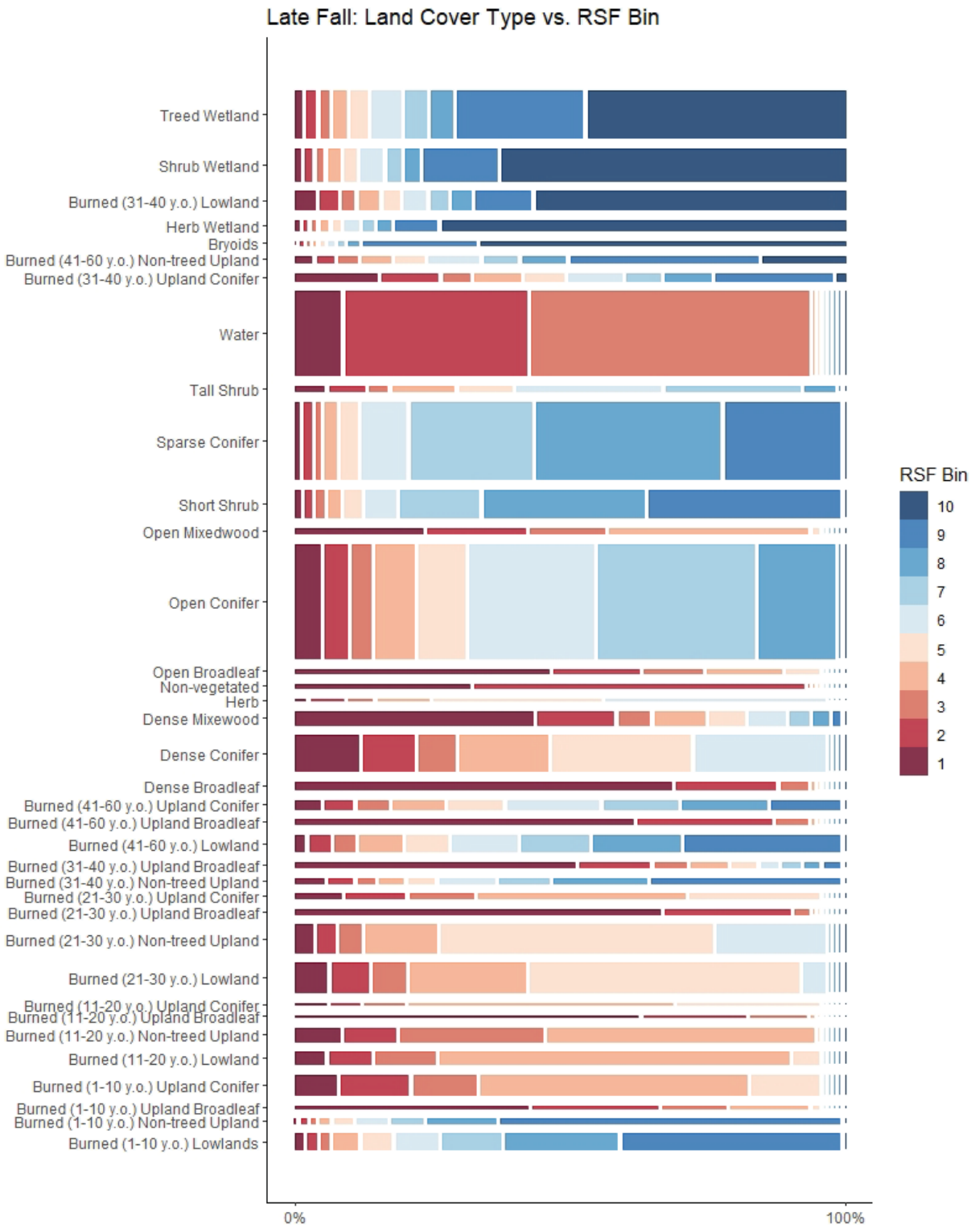


Figure G 4: The relative contribution of local land-cover variables to mapped bin values of resource selection at a second-order scale during the late fall by boreal caribou in the Northwest Territories. Bar width in the histogram is proportional to the area covered by each variable in the study area. Variables are ranked by their relative contribution to bin 10 (strongest selection).

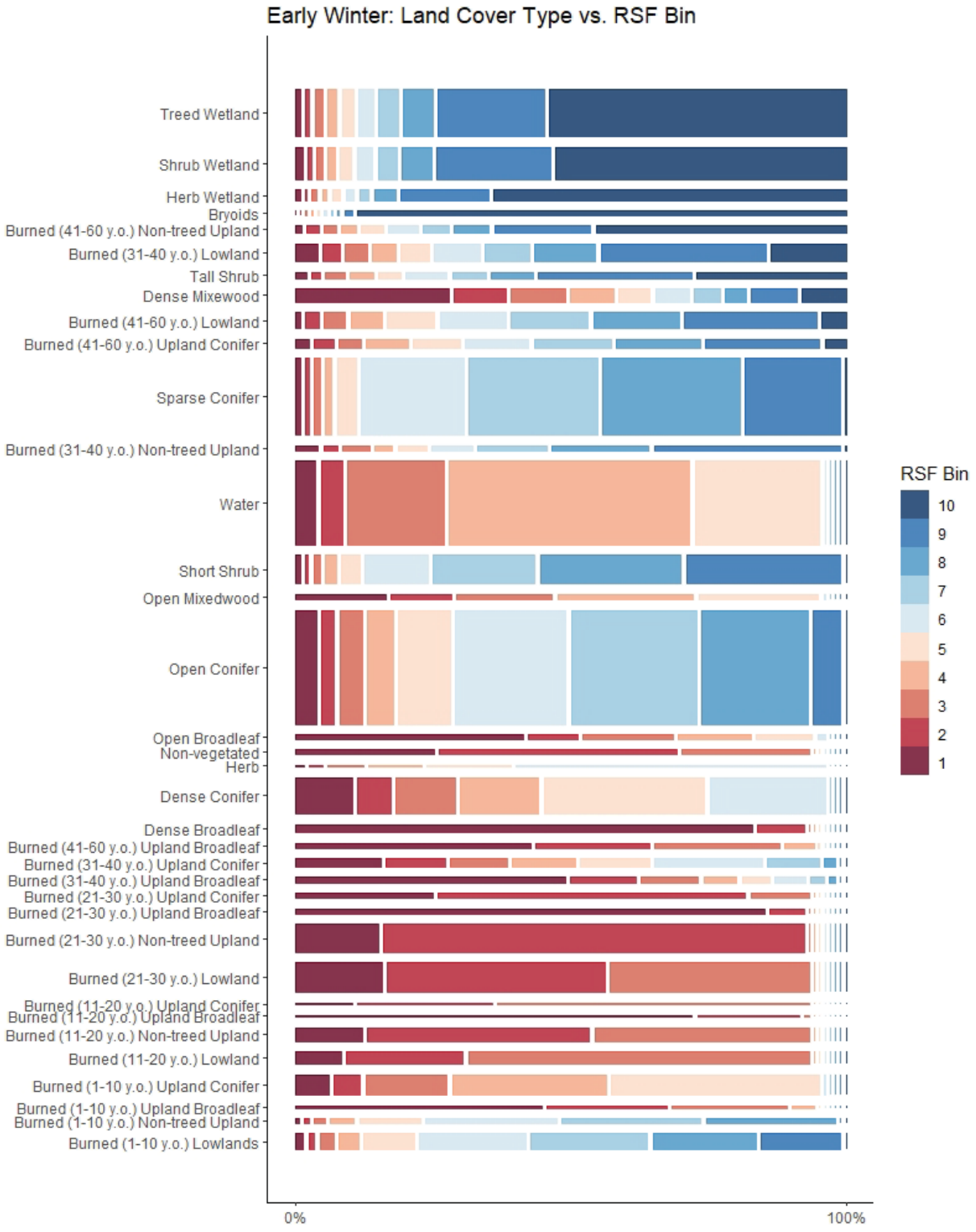


Figure G 5: The relative contribution of local land-cover variables to mapped bin values of resource selection at a second-order scale during the early winter by boreal caribou in the Northwest Territories. Bar width in the histogram is proportional to the area covered by each variable in the study area. Variables are ranked by their relative contribution to bin 10 (strongest selection).

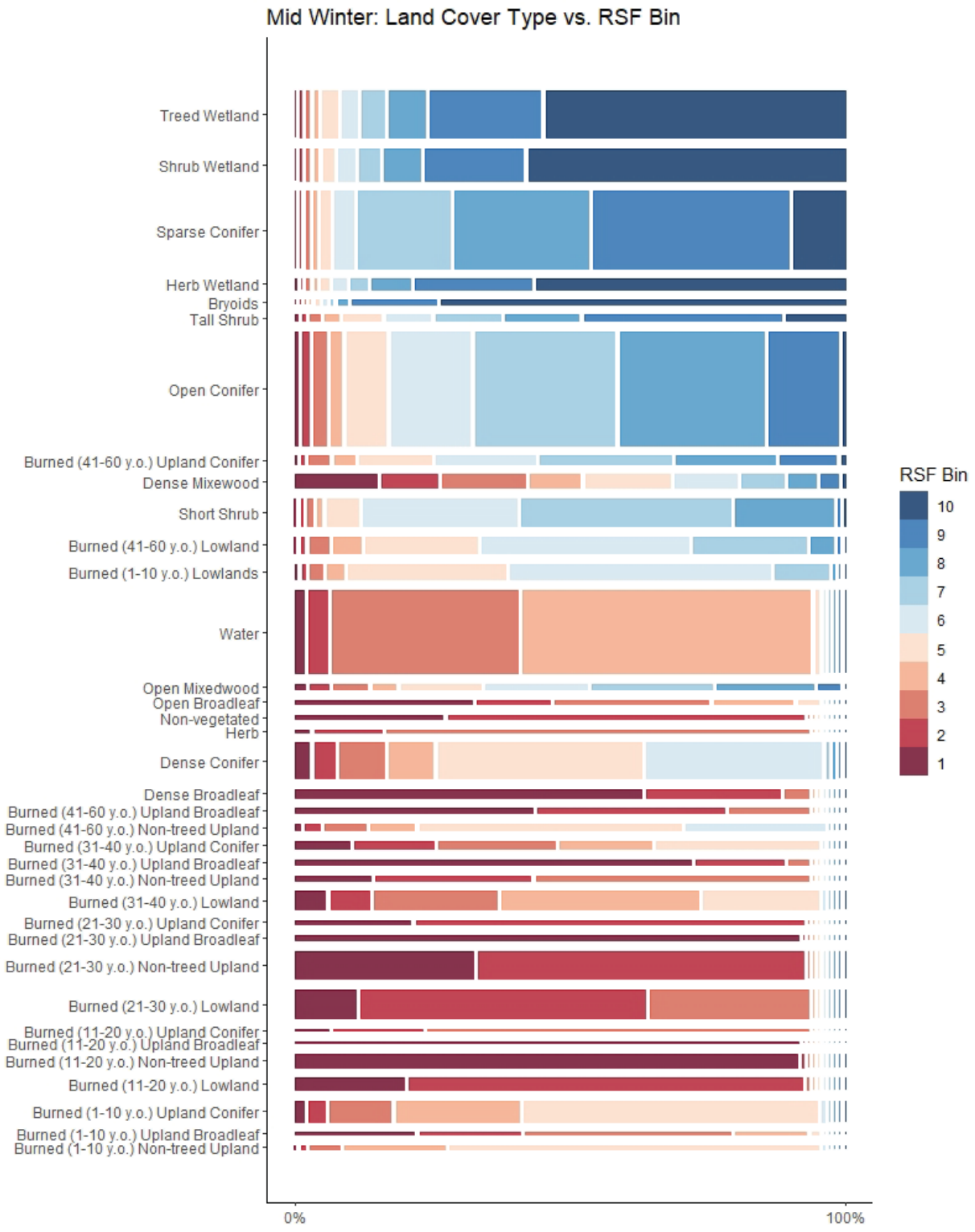


Figure G 6: The relative contribution of local land-cover variables to mapped bin values of resource selection at a second-order scale during the mid-winter by boreal caribou in the Northwest Territories. Bar width in the histogram is proportional to the area covered by each variable in the study area. Variables are ranked by their relative contribution to bin 10 (strongest selection).

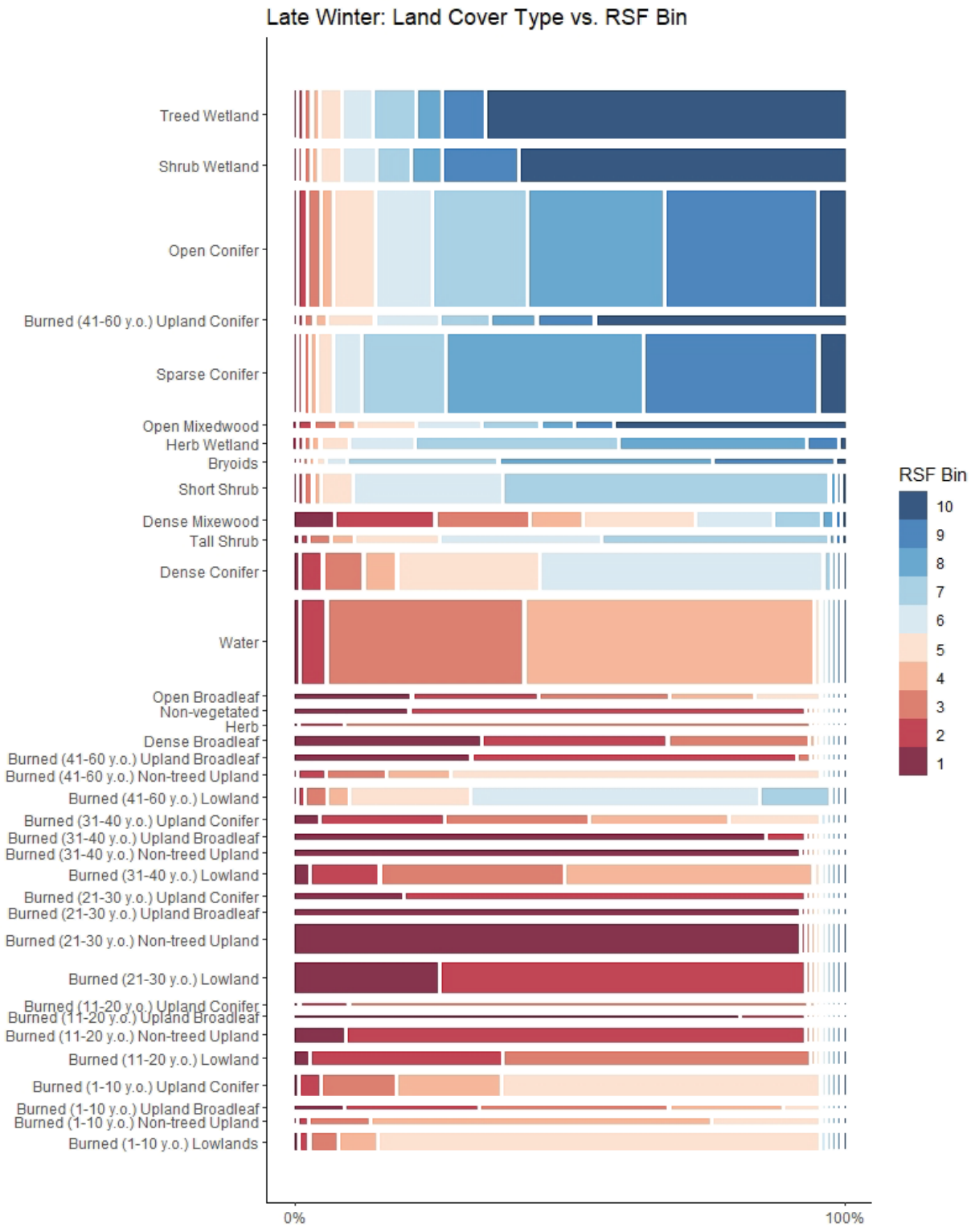


Figure G 7: The relative contribution of local land-cover variables to mapped bin values of resource selection at a second-order scale during the late winter by boreal caribou in the Northwest Territories. Bar width in the histogram is proportional to the area covered by each variable in the study area. Variables are ranked by their relative contribution to bin 10 (strongest selection).

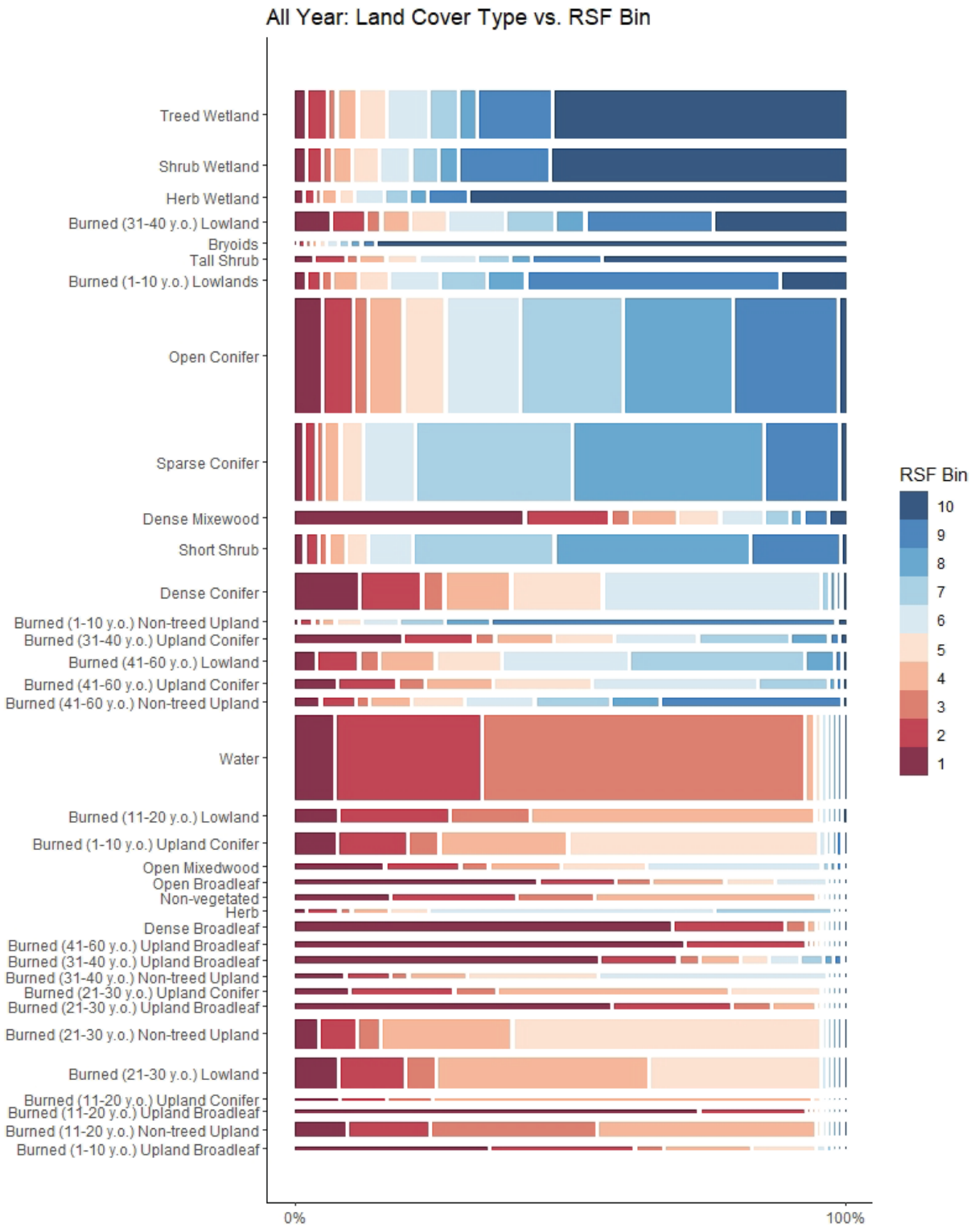


Figure G 8: The relative contribution of local land-cover variables to mapped bin values of resource selection at a second-order scale across the entire year by boreal caribou in the Northwest Territories. Bar width in the histogram is proportional to the area covered by each variable in the study area. Variables are ranked by their relative contribution to bin 10 (strongest selection).

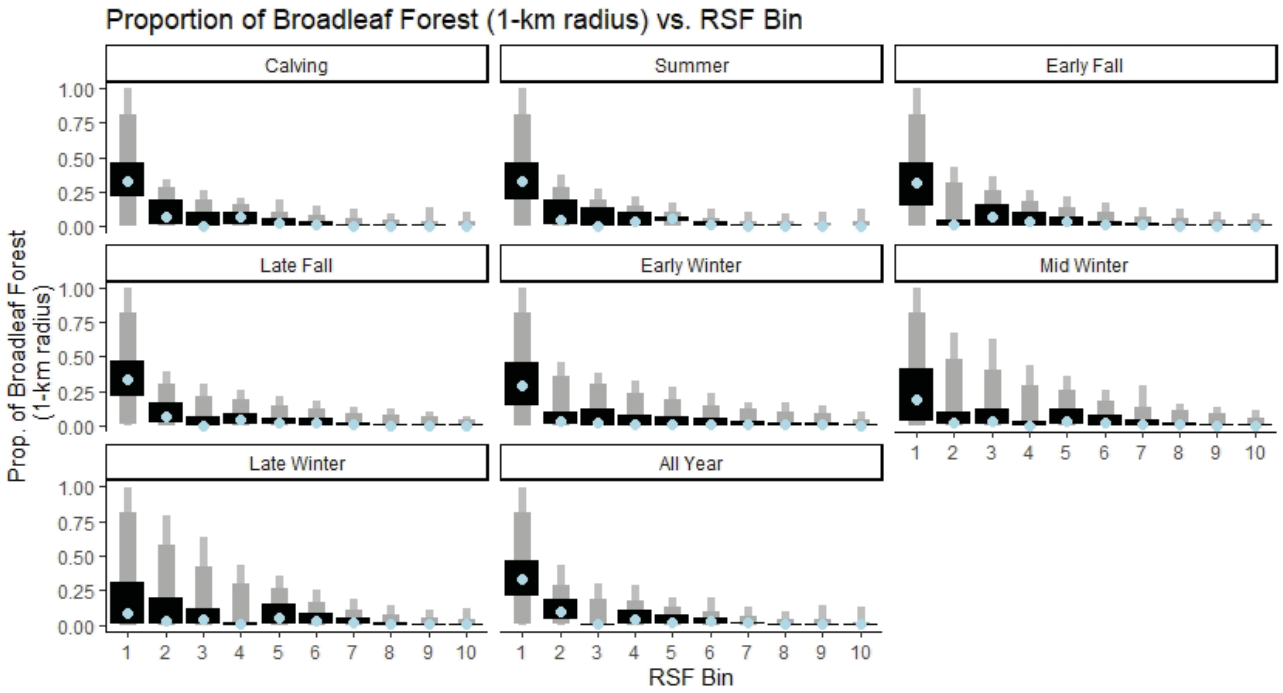


Figure G 9: The distribution of values measuring the proportion of broadleaf forest in a 1-km radius within mapped bin values of seasonal resource selection by boreal caribou in the Northwest Territories. Resource selection was estimated at a second-order scale. Blue points indicate the median value within a bin. Thin grey bars indicate the overall range of the data within a bin. Thick grey bars indicate values falling within the 95% quantile. Black bars indicate values falling within the inner 50% quantile.

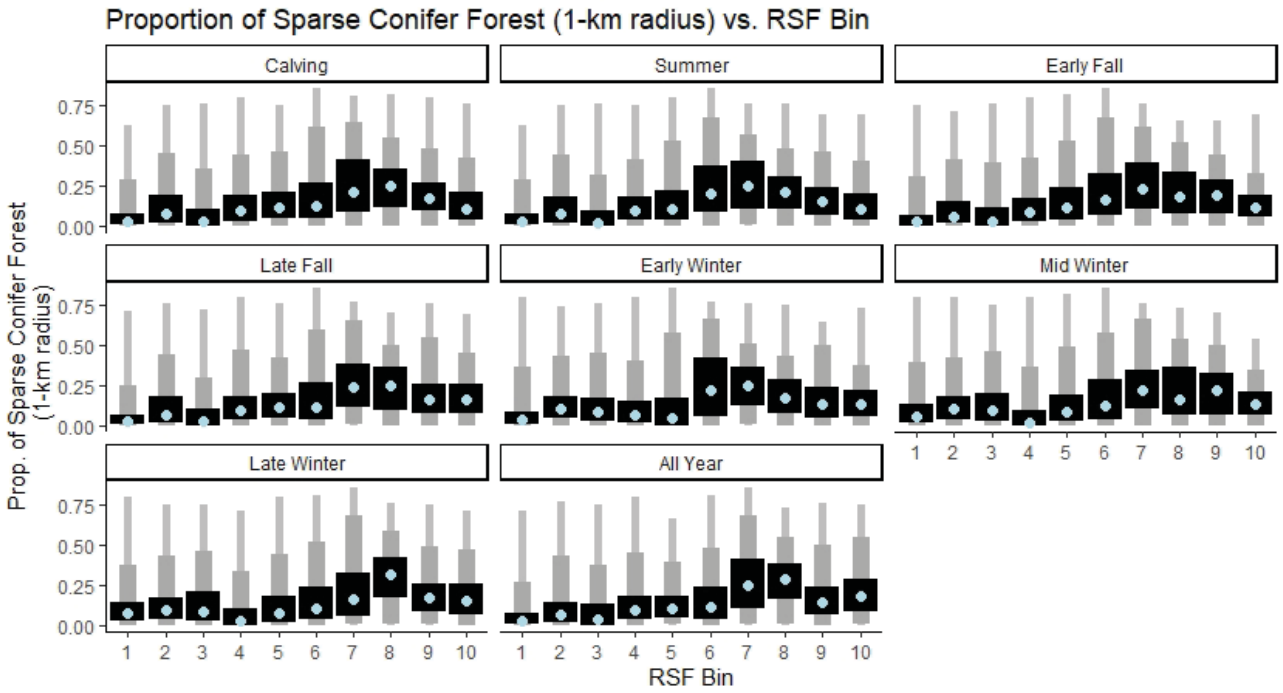


Figure G 10: The distribution of values measuring the proportion of sparse conifer forest in a 1-km radius within mapped bin values of seasonal resource selection by boreal caribou in the Northwest Territories. Resource selection was estimated at a second-order scale. Blue points indicate the median value within a bin. Thin grey bars indicate the overall range of the data within a bin. Thick grey bars indicate values falling within the 95% quantile. Black bars indicate values falling within the inner 50% quantile.

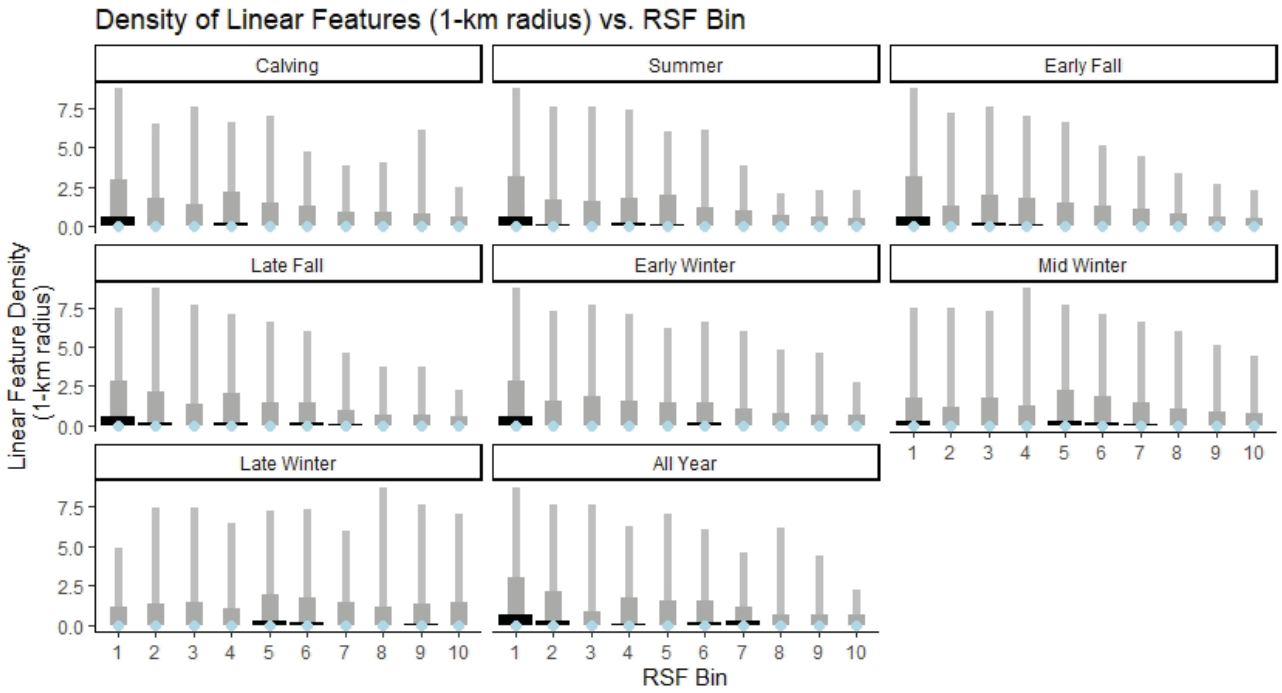


Figure G 11: The distribution of linear feature densities within mapped bin values of seasonal resource selection at a second-order scale by boreal caribou in the Northwest Territories. Blue points indicate the median value within a bin. Thin grey bars indicate the overall range of the data within a bin. Thick grey bars indicate values falling within the 95% quantile. Black bars indicate values falling within the inner 50% quantile.

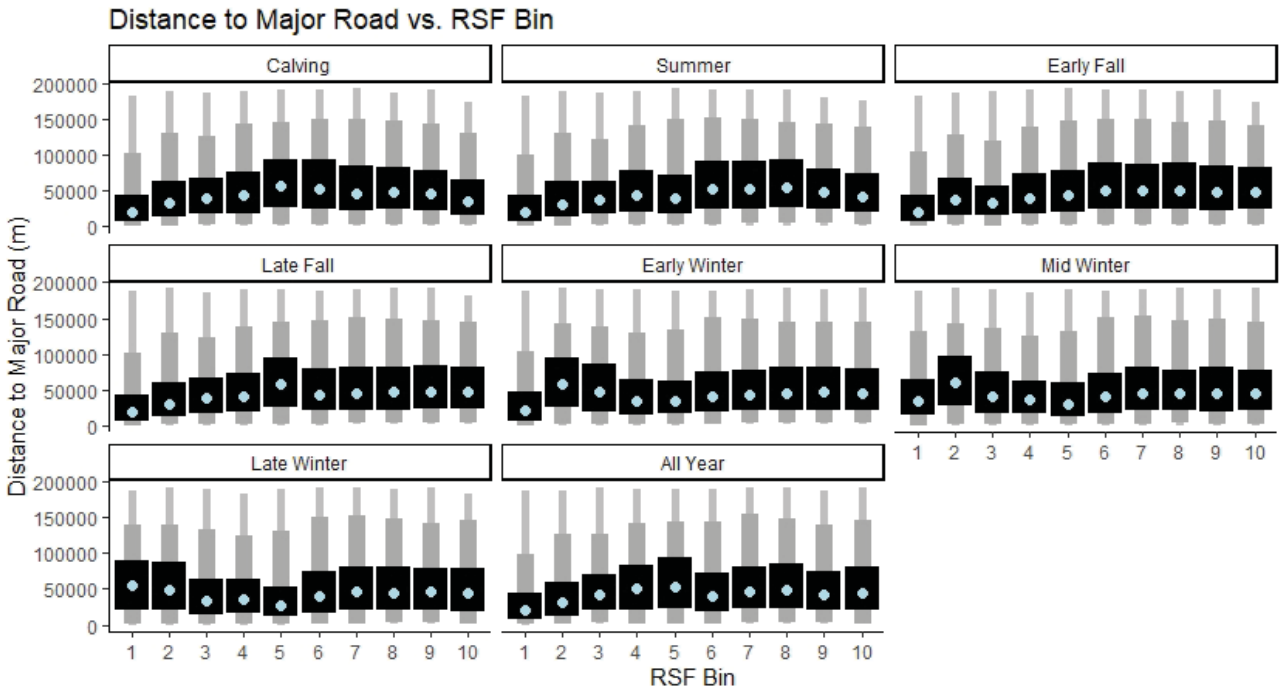


Figure G 12: The distribution of distances to the nearest major road within mapped bin values of seasonal resource selection by boreal caribou in the Northwest Territories. Resource selection was estimated at a second-order scale. Blue points indicate the median value within a bin. Thin grey bars indicate the overall range of the data within a bin. Thick grey bars indicate values falling within the 95% quantile. Black bars indicate values falling within the inner 50% quantile.

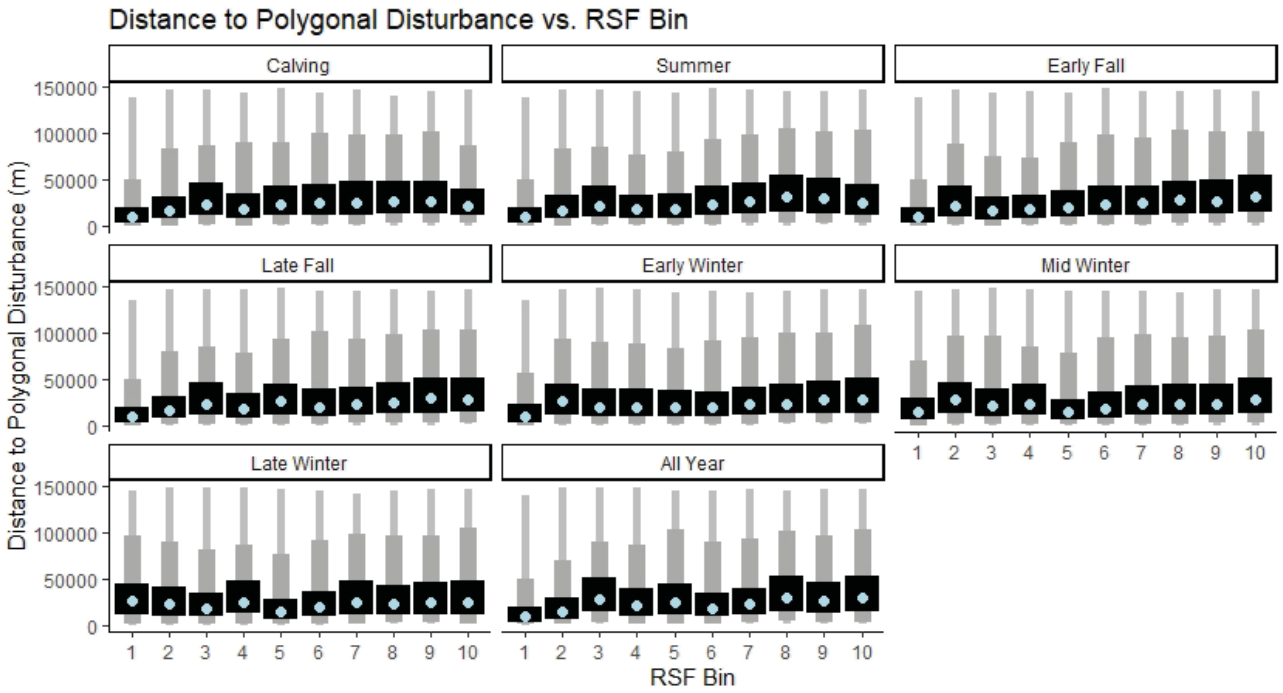


Figure G 13: The distribution of distances to the nearest polygonal disturbance (e.g. cut block or well pad) within mapped bin values of seasonal resource selection by boreal caribou in the Northwest Territories. Resource selection was estimated at a second-order scale. Blue points indicate the median value within a bin. Thin grey bars indicate the overall range of the data within a bin. Thick grey bars indicate values falling within the 95% quantile. Black bars indicate values falling within the inner 50% quantile.

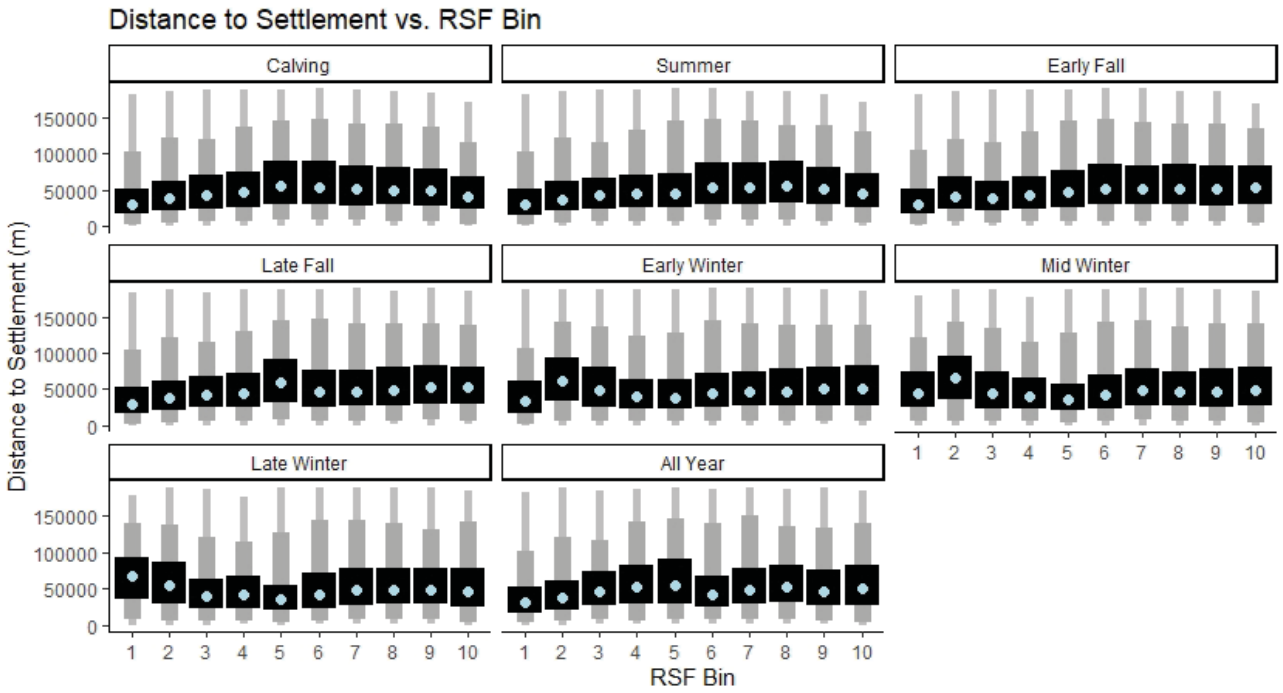


Figure G 14: The distribution of distances to the nearest settlement within mapped bin values of seasonal resource selection by boreal caribou in the Northwest Territories. Resource selection was estimated at a second-order scale. Blue points indicate the median value within a bin. Thin grey bars indicate the overall range of the data within a bin. Thick grey bars indicate values falling within the 95% quantile. Black bars indicate values falling within the inner 50% quantile.

Literature Cited

Morris, L. R., K. M. Proffitt, and J. K. Blackburn. 2016. Mapping resource selection functions in wildlife studies: Concerns and recommendations. Applied Geography 76:173–183.

APPENDIX H: COMPARISONS OF RESOURCE USE AND AVAILABILITY

Analyses of resource selection are used to assess how an organism's use of a particular resource (or environmental attribute; e.g., land-cover type) compares to how available the resource is in the spatial scale of interest. In the main report, results focused primarily on this "selection" ratio (use / availability), but inferences on selection can often be better informed by evaluating both the numerator and denominator of this ratio. In this appendix, we present graphs showing how resource use by caribou—as indexed by GPS locations from radio-collared females—compares to the availability of that resource at a second-order scale [note: third-order graphs are not provided as availability is unique to each caribou-year and providing matched comparisons of use versus availability is difficult to graph given the large sample sizes within each year]. Availability at the second-order scale was defined separately for caribou in the Northern group (Inuvik and Sahtu monitoring regions) and caribou in the Southern Group (Dehcho, North Slave and South Slave monitoring regions). For each group, we delineated availability by fitting a minimum convex polygon (MCP) around all GPS locations pooled from radio-collared caribou within the group then buffered each MCP by 15-km (approximately the maximum distance moved by caribou in a 24-hr period—see Appendix B) and clipped them to the boundaries of the study area. Note that the spatial scale of availability was therefore constant for all caribou within a group (Northern or Southern) but differed between groups. For each caribou-year (e.g., for caribou *i* with GPS locations recorded during year *j*), we sampled availability by generating 5000 random points within the MCP of the individual's group. Caribou GPS locations and random locations were then matched to year-specific explanatory variables (e.g., GPS and caribou locations in 2012 were matched to land-cover, fire, and human disturbance data estimated for 2012).

For each graph, we compared caribou use to availability within each regional monitoring area (Inuvik, Sahtu, Dehcho, North Slave, and South Slave). Because of the sampling framework outlined above, availability is relatively constant between Inuvik and Sahtu (the Northern group) and among Dehcho, North Slave, and South Slave (the Southern group), though small variations will occur for some resources among monitoring areas within a group (see below). For land-cover resources, which were categorical variables, proportional use (the number of GPS locations in a given land-cover / the total number of GPS locations) is compared to proportional availability (the number of random locations in a given land-cover / the total number of random locations). For continuous variables (e.g. distance to nearest major road), the mean value of the GPS locations is compared to the mean value of the random locations. In all instances, proportions and mean values are first calculated for each caribou-year, then averaged across caribou-years to derive population-level estimates, which are accompanied by 95% confidence intervals that represent an estimate of the variation among individual caribou-years. Note that because the entire data set of caribou GPS locations spanned 2002–2017 and random locations were matched to year-specific explanatory variables, the mean values for random locations will vary across years.

Order of graphs:

- Unburned land-covers: (Figs. H1-8)
- Burned lowlands and upland conifer (Figs. H9-16)
- Burned broadleaf forest and non-treed uplands (Figs. H17-24)
- Landscape context (Figs. H25-32)

- Distance-to variables (Figs. H33-40)
- Linear feature density (Figs. H41-48)

Within each section, the sequence of graphs is calving, summer, early fall, late fall, early winter, mid-winter, late winter, and all year.

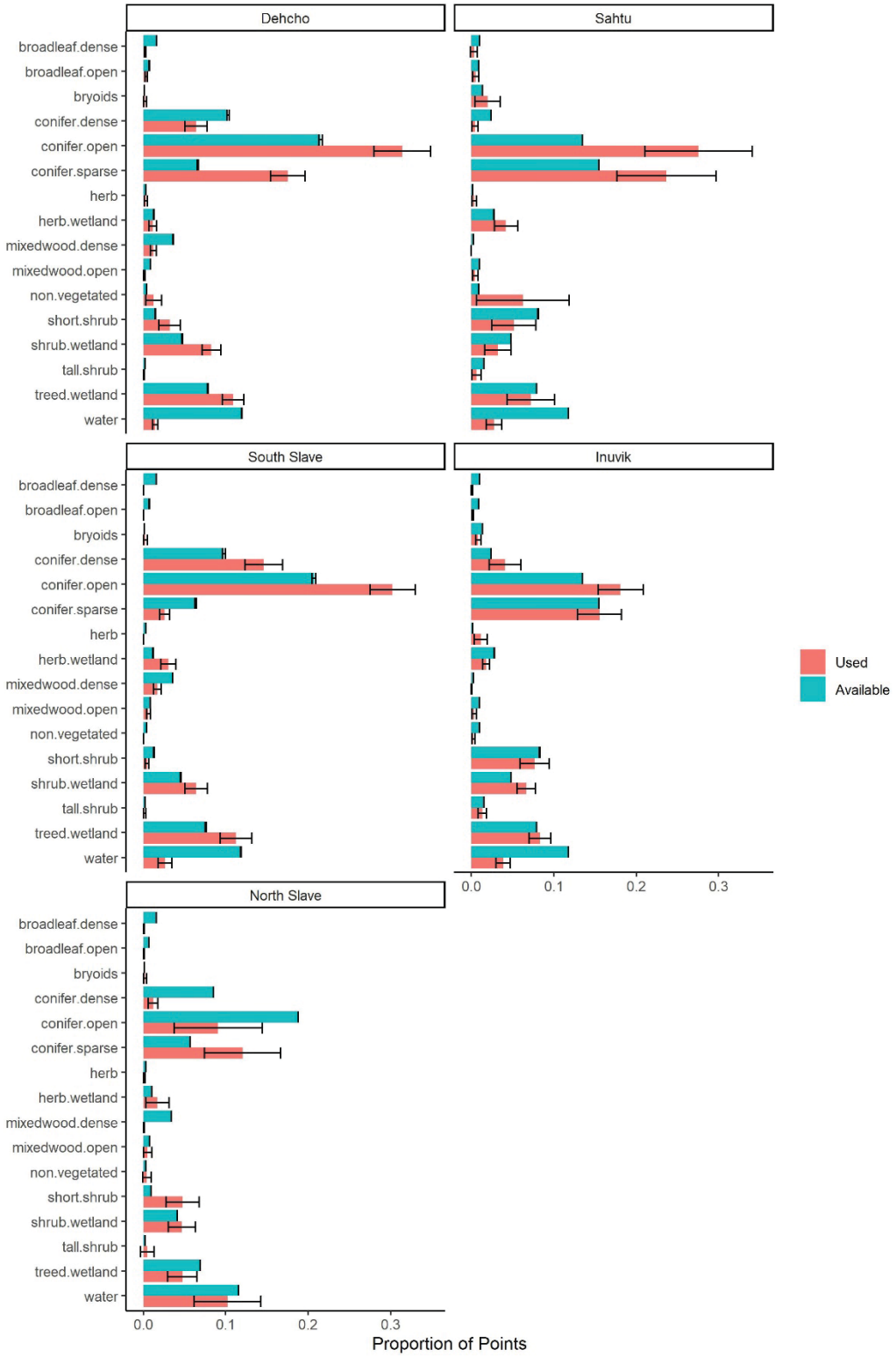


Figure H 1: The proportion of used (GPS) locations and available (or random) locations falling within various unburned land-cover types among the five regional monitoring areas during **calving**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

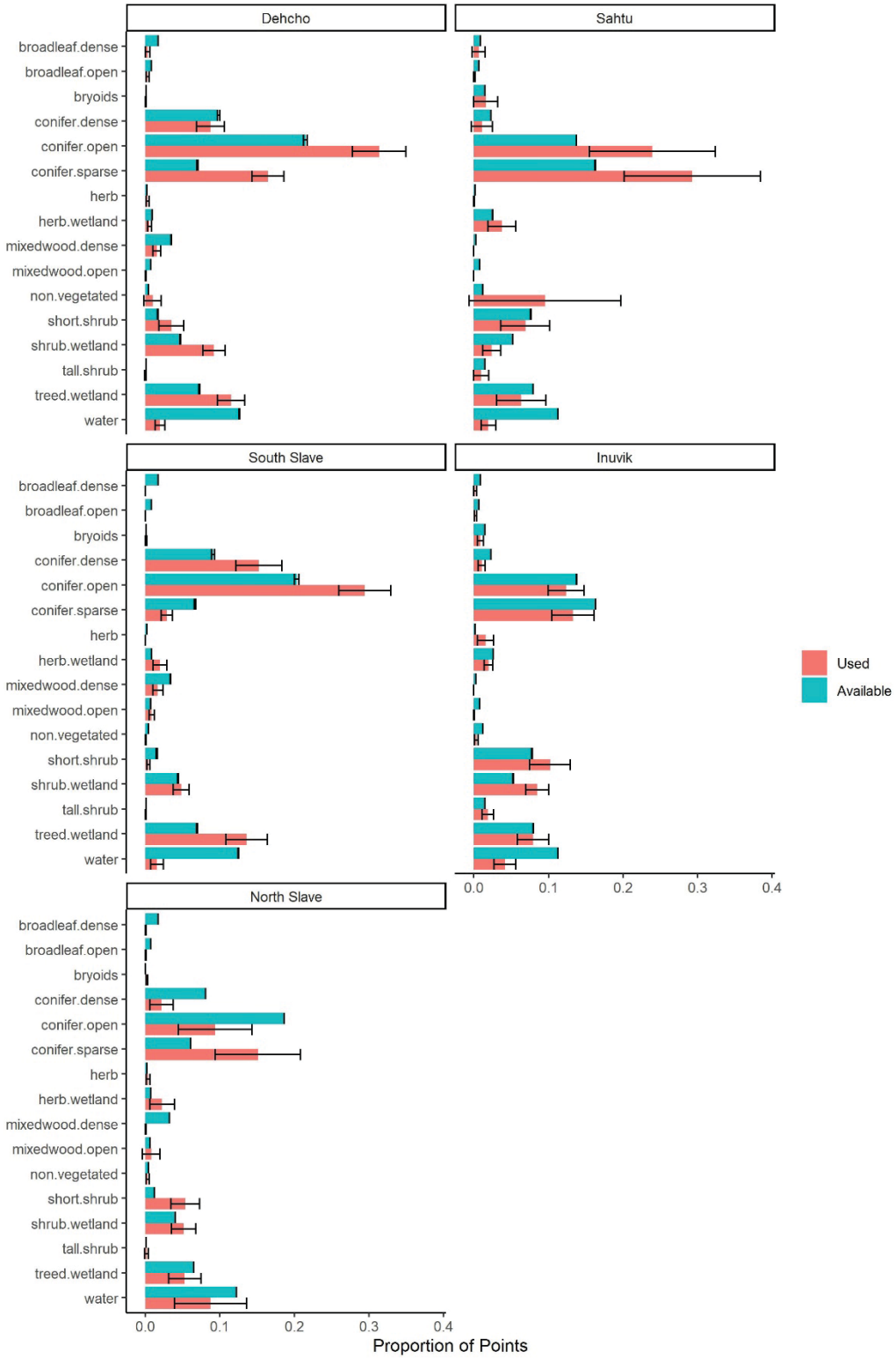


Figure H 2: The proportion of used (GPS) locations and available (or random) locations falling within various unburned land-cover types among the five regional monitoring areas during **summer**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

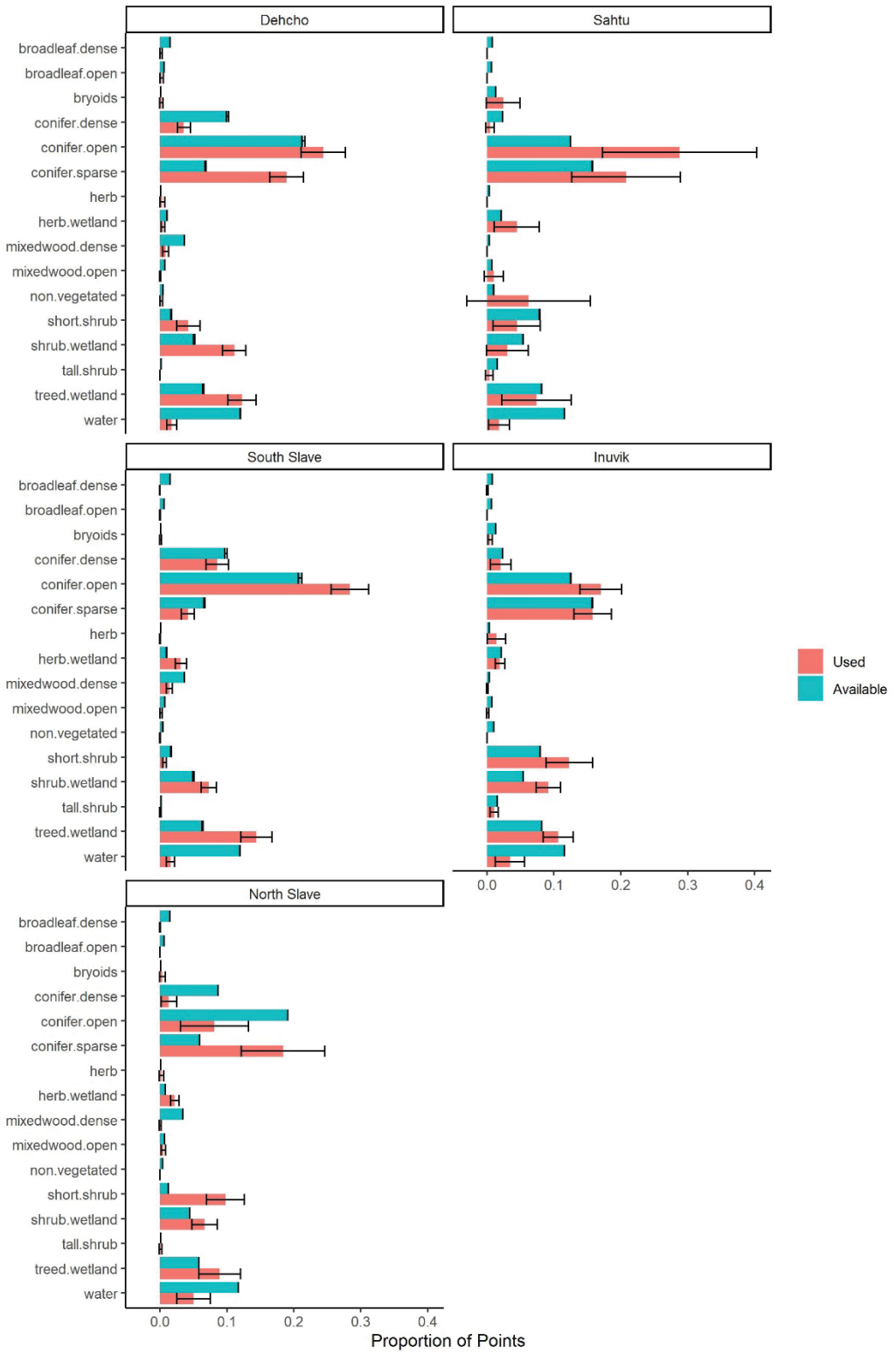


Figure H 3: The proportion of used (GPS) locations and available (or random) locations falling within various unburned land-cover types among the five regional monitoring areas during **early fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

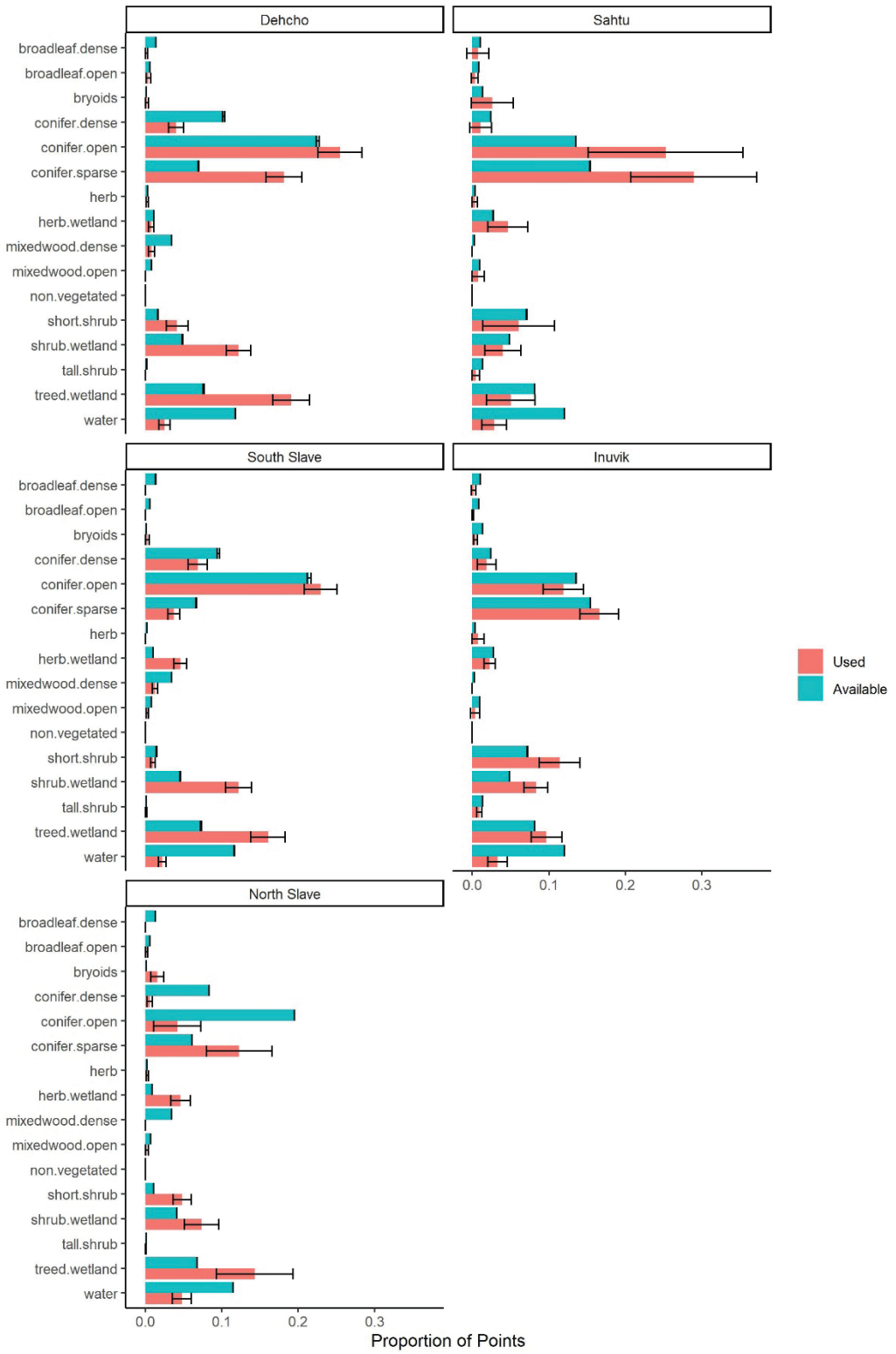


Figure H 4: The proportion of used (GPS) locations and available (or random) locations falling within various unburned land-cover types among the five regional monitoring areas during **late fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

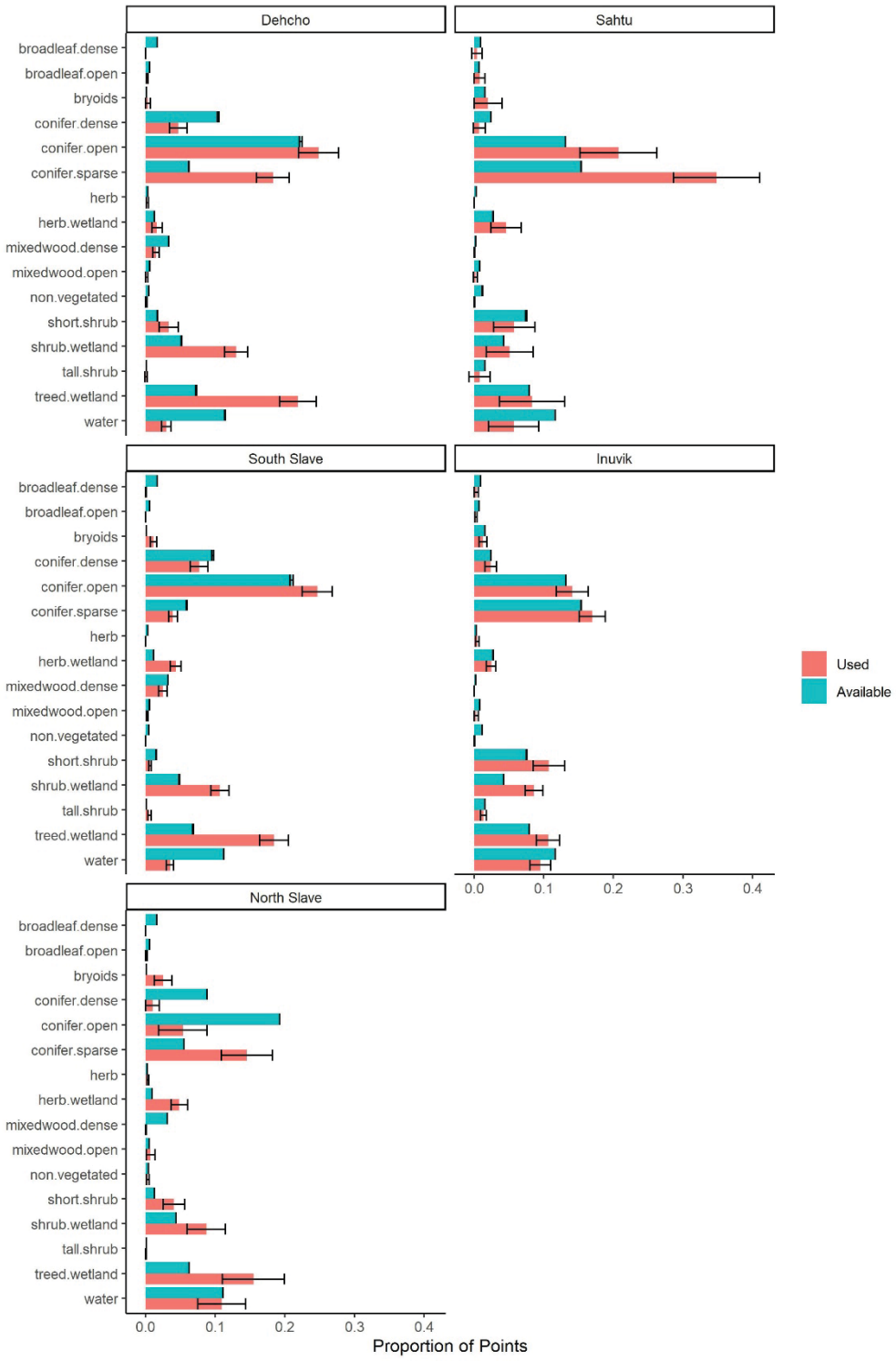


Figure H 5: The proportion of used (GPS) locations and available (or random) locations falling within various unburned land-cover types among the five regional monitoring areas during **early winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

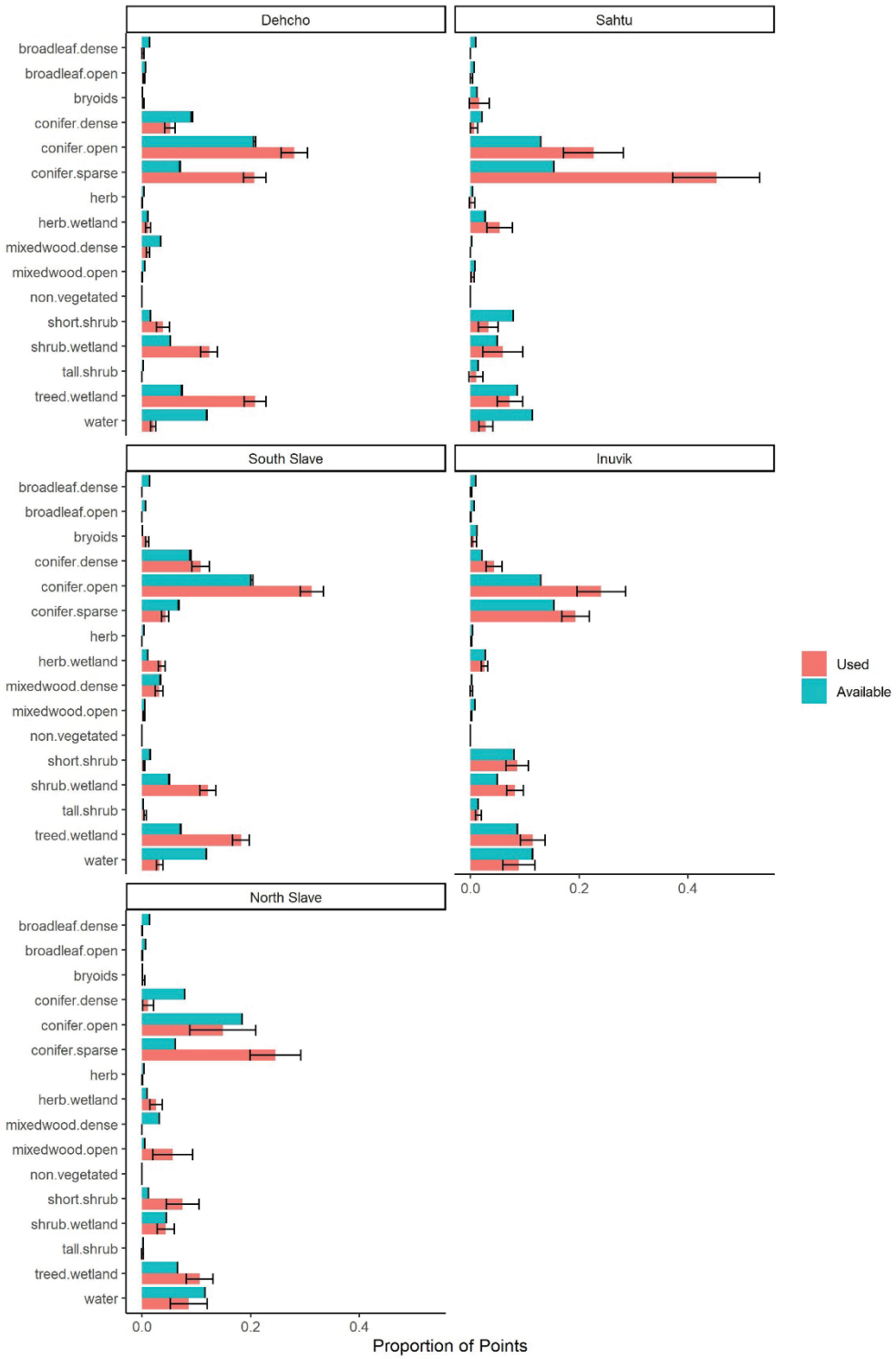


Figure H 6: The proportion of used (GPS) locations and available (or random) locations falling within various unburned land-cover types among the five regional monitoring areas during **mid-winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

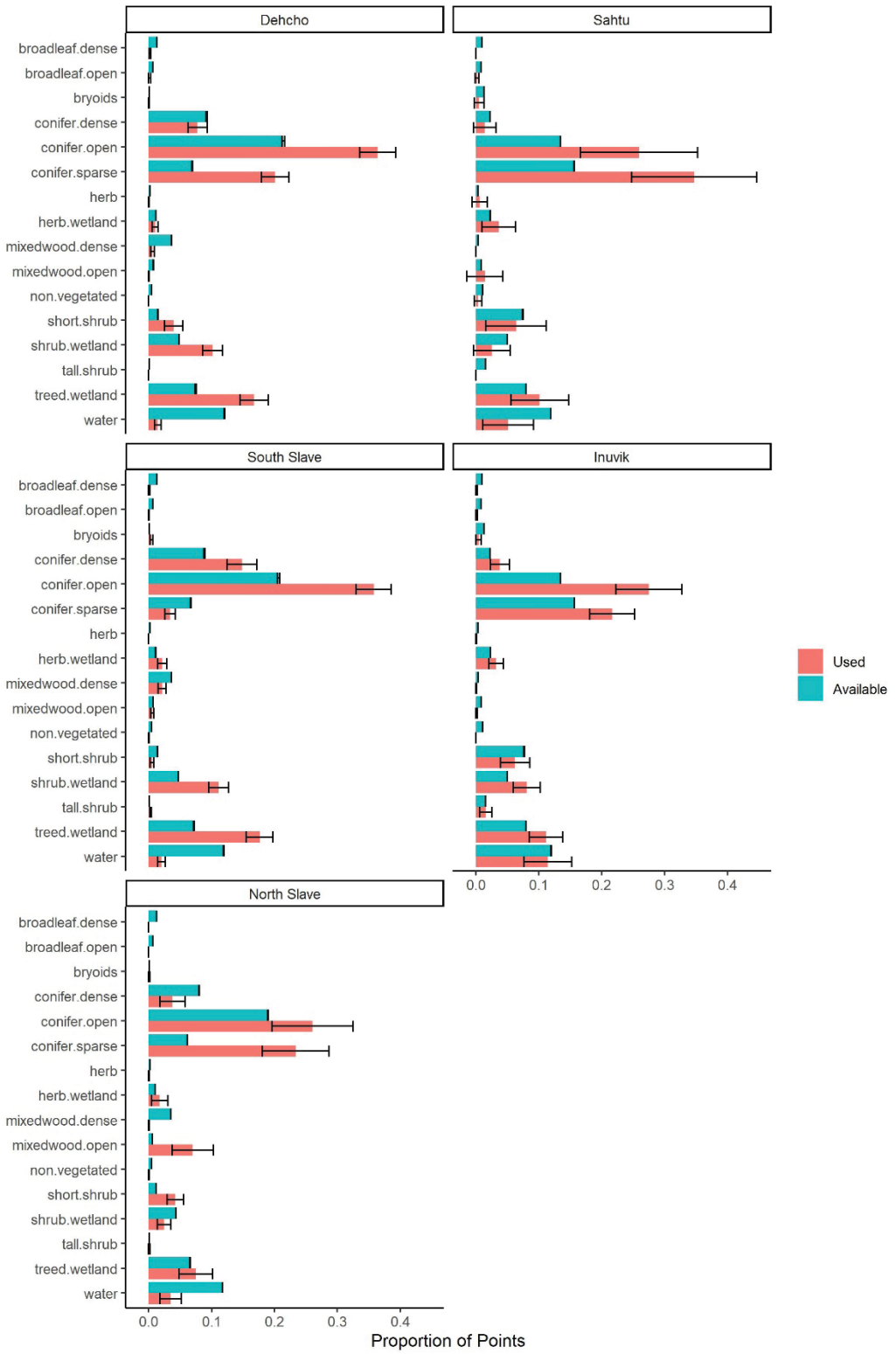


Figure H 7: The proportion of used (GPS) locations and available (or random) locations falling within various unburned land-cover types among the five regional monitoring areas during **late winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars

represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

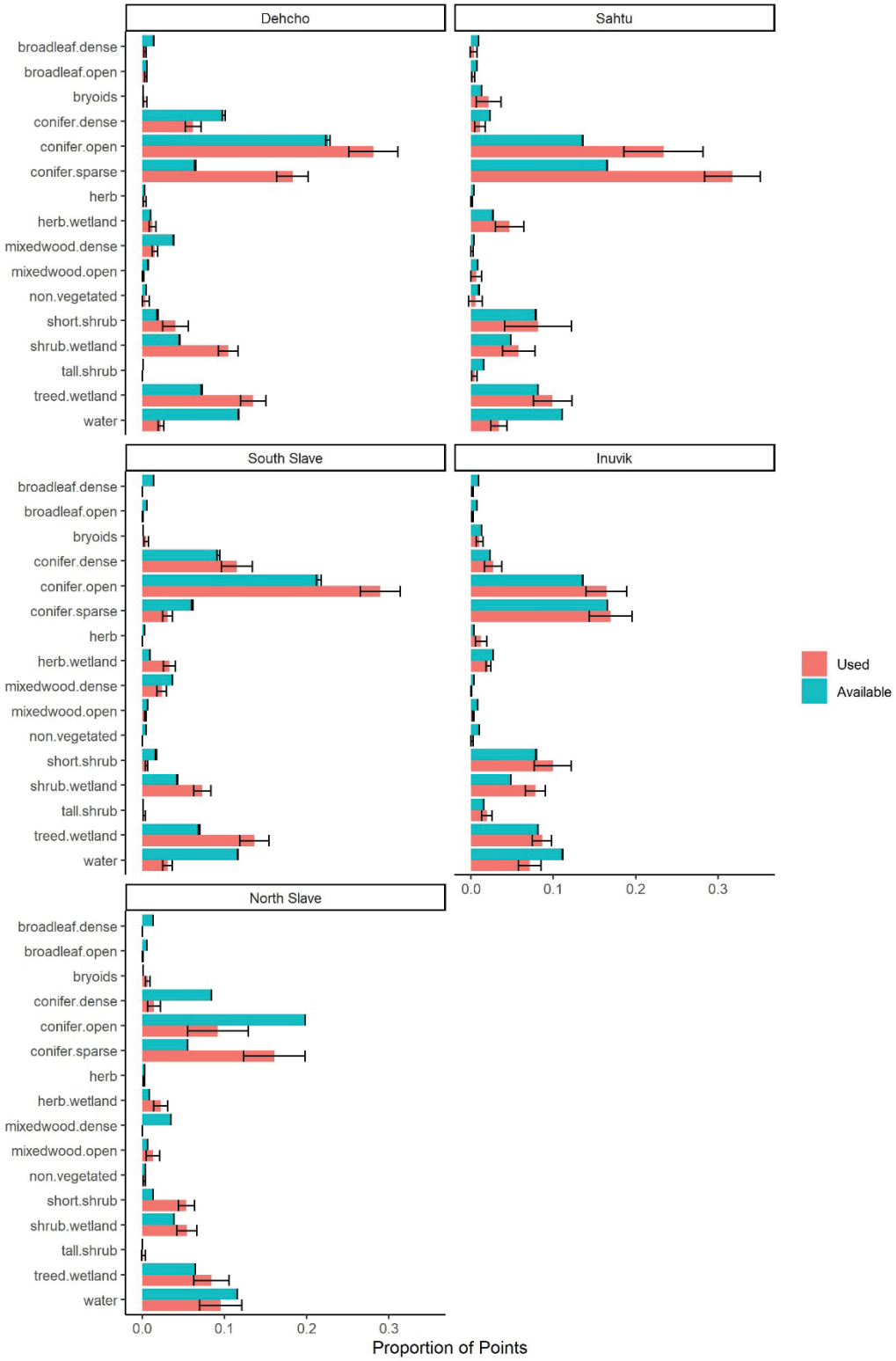


Figure H 8: The proportion of used (GPS) locations and available (or random) locations falling within various unburned land-cover types among the five regional monitoring areas on a **yearly** basis. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

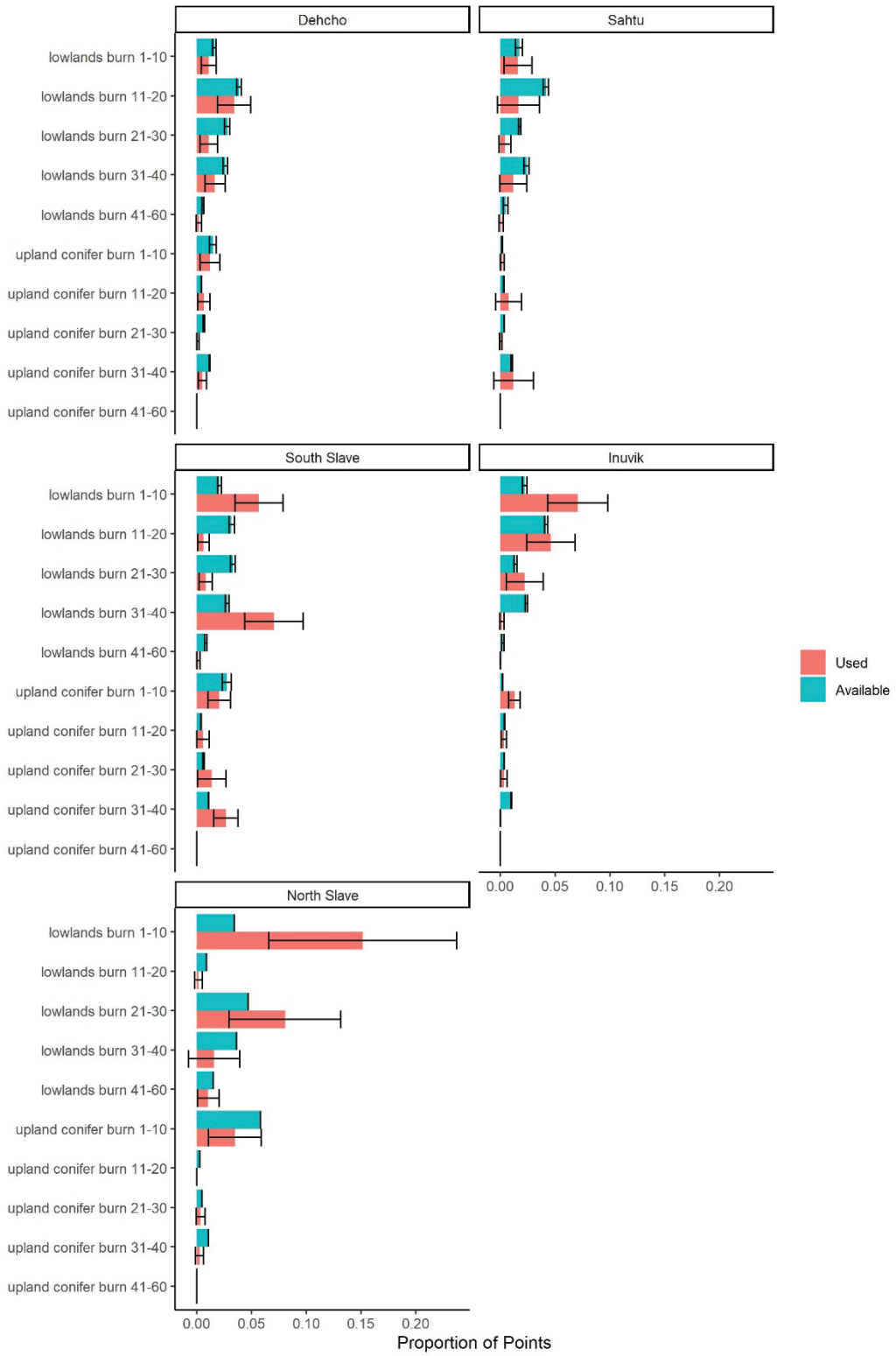


Figure H 9: The proportion of used (GPS) locations and available (or random) locations falling within burned lowlands and upland conifer among the five regional monitoring areas during **calving**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

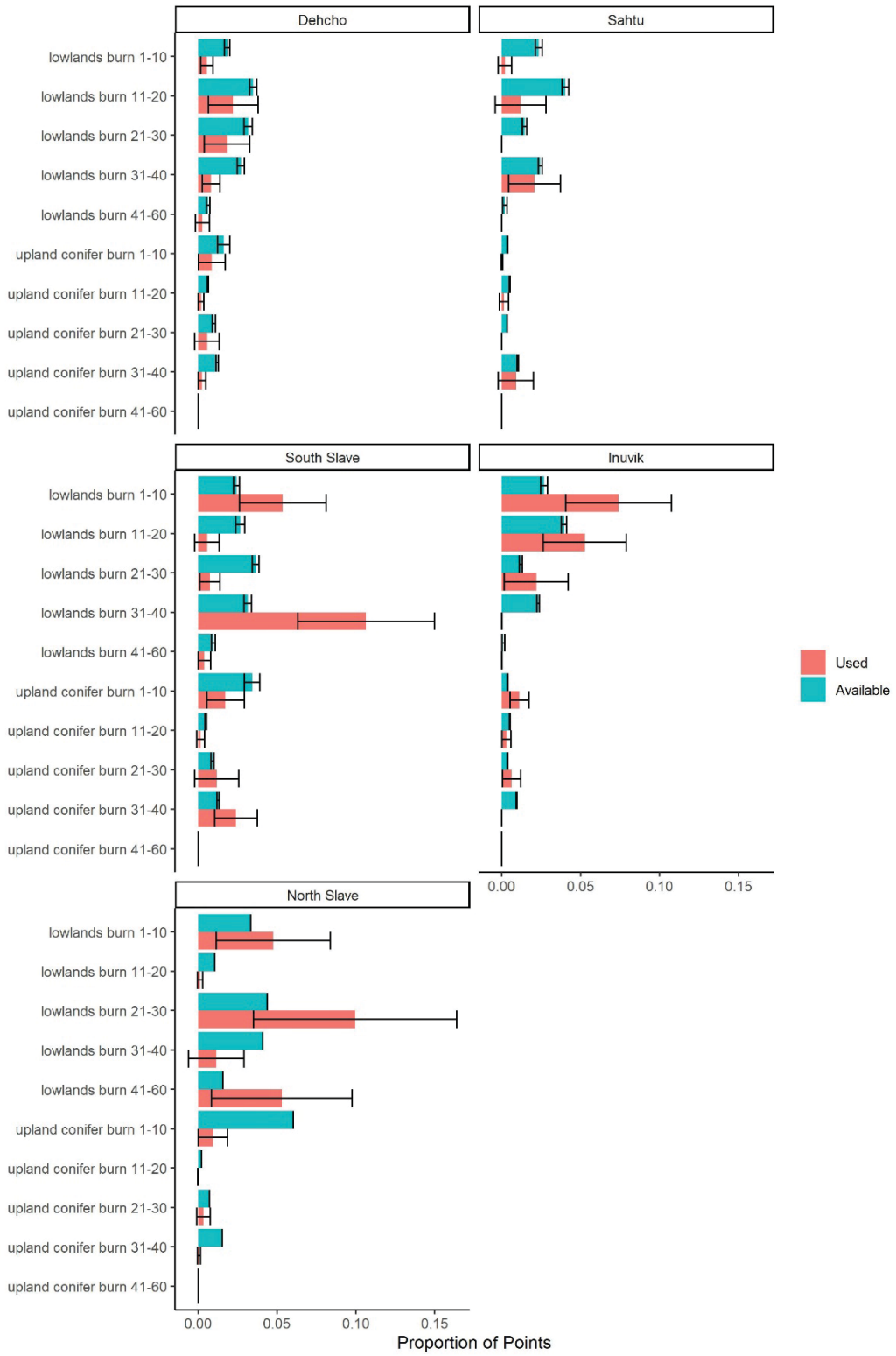


Figure H 10: The proportion of used (GPS) locations and available (or random) locations falling within burned lowlands and upland conifer among the five regional monitoring areas during **summer**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

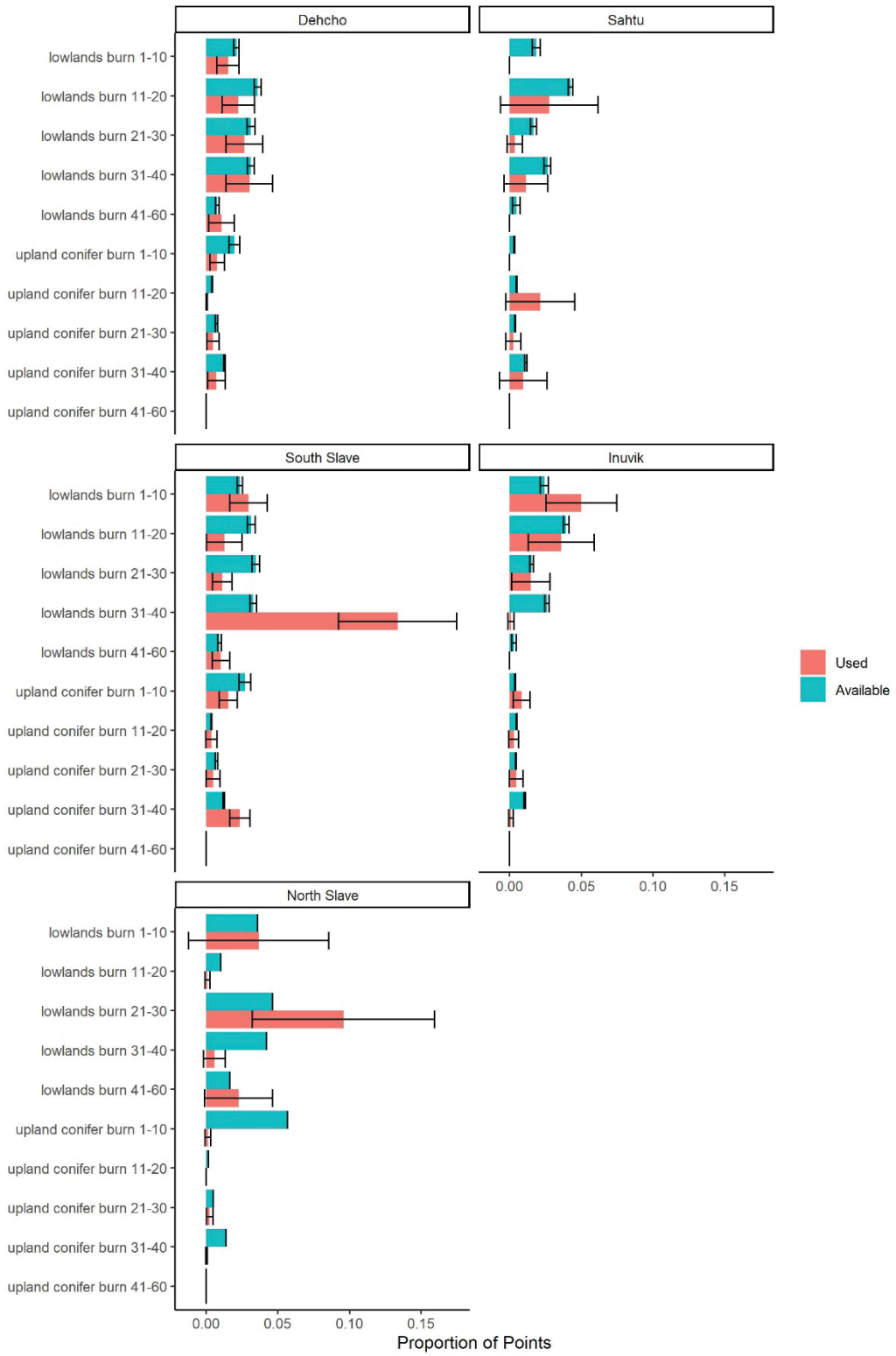


Figure H 11: The proportion of used (GPS) locations and available (or random) locations falling within burned lowlands and upland conifer among the five regional monitoring areas during **early fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

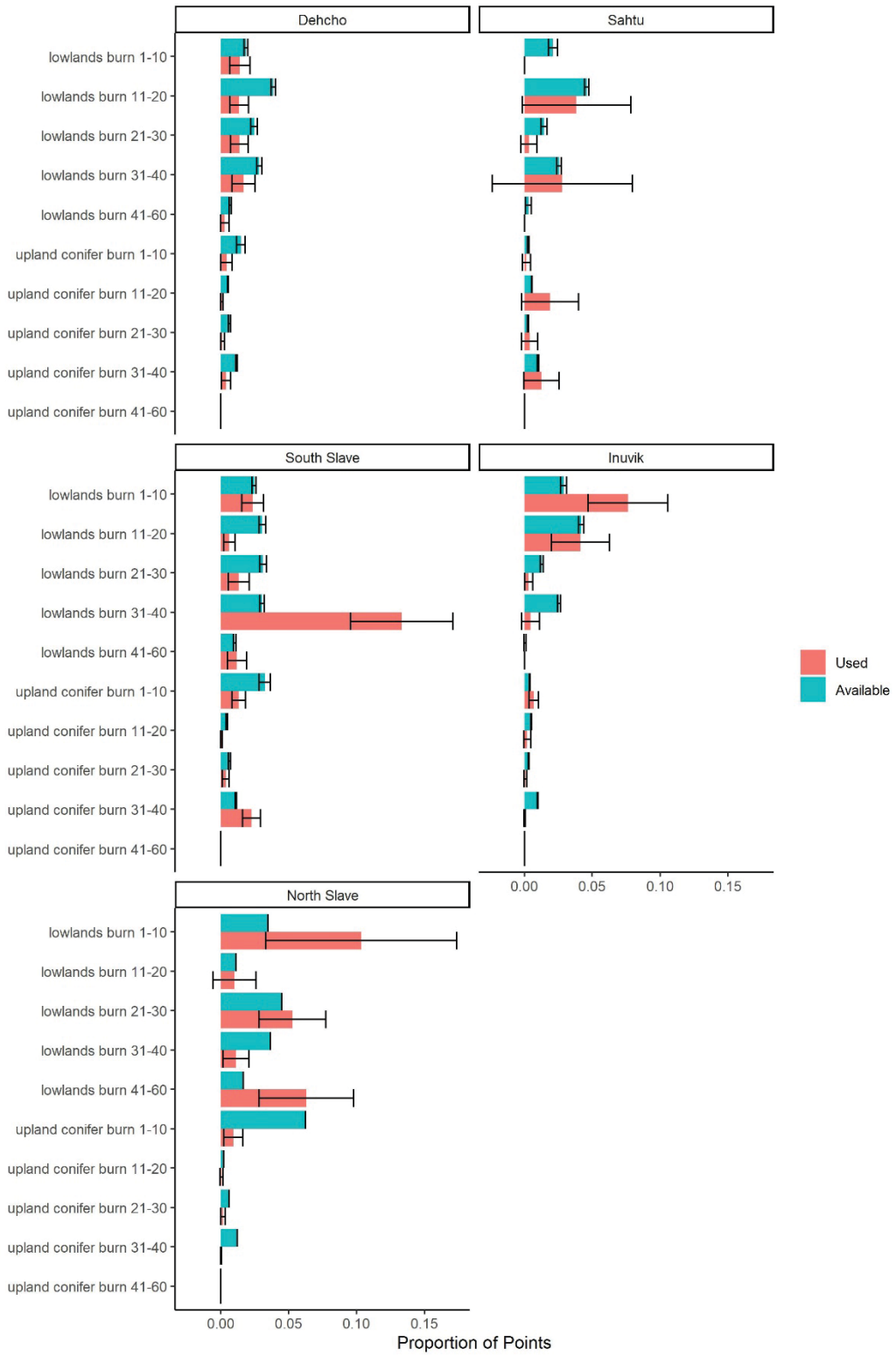


Figure H 12: The proportion of used (GPS) locations and available (or random) locations falling within burned lowlands and upland conifer among the five regional monitoring areas during **late fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

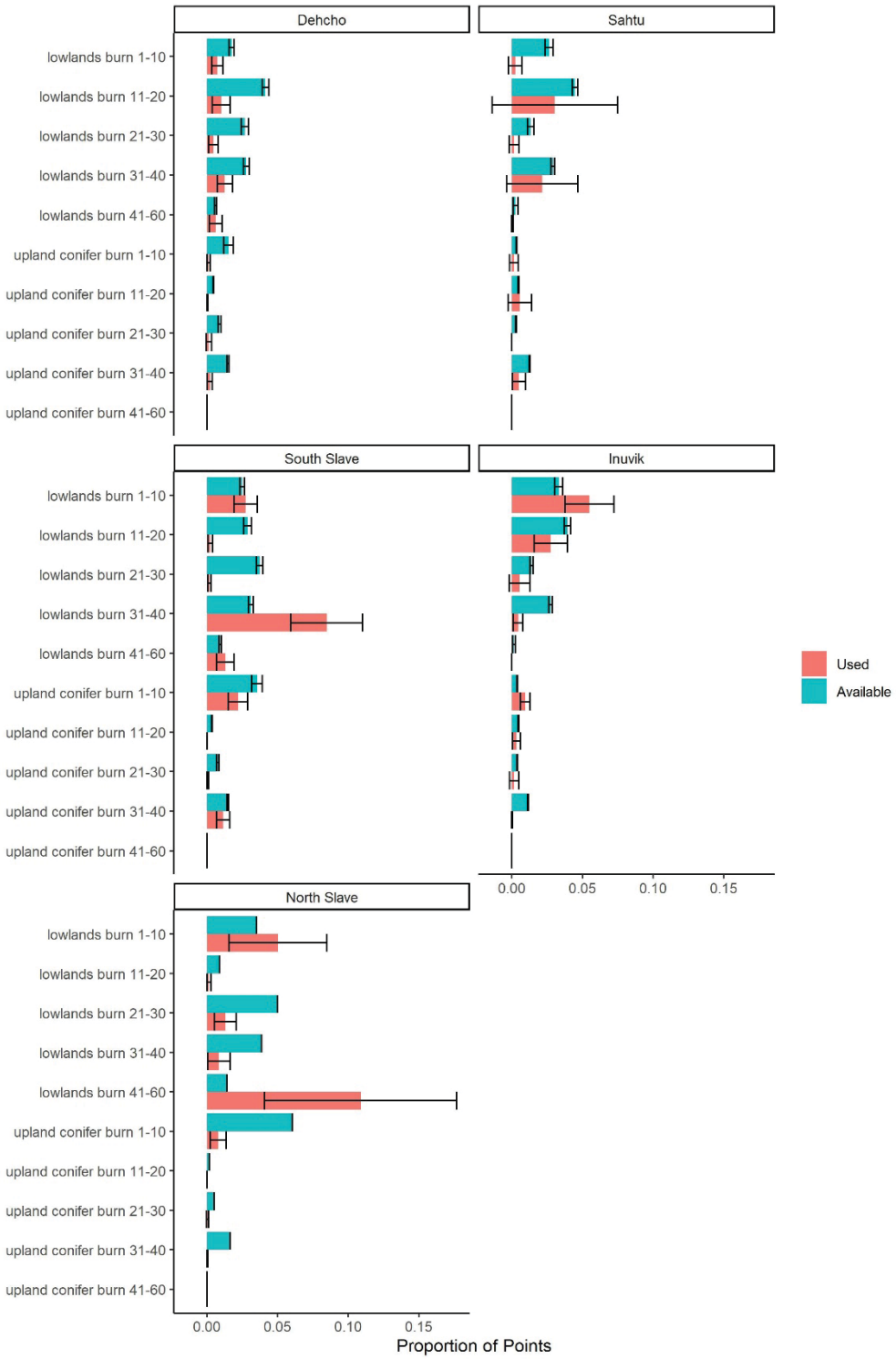


Figure H 13: The proportion of used (GPS) locations and available (or random) locations falling within burned lowlands and upland conifer among the five regional monitoring areas during **early winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

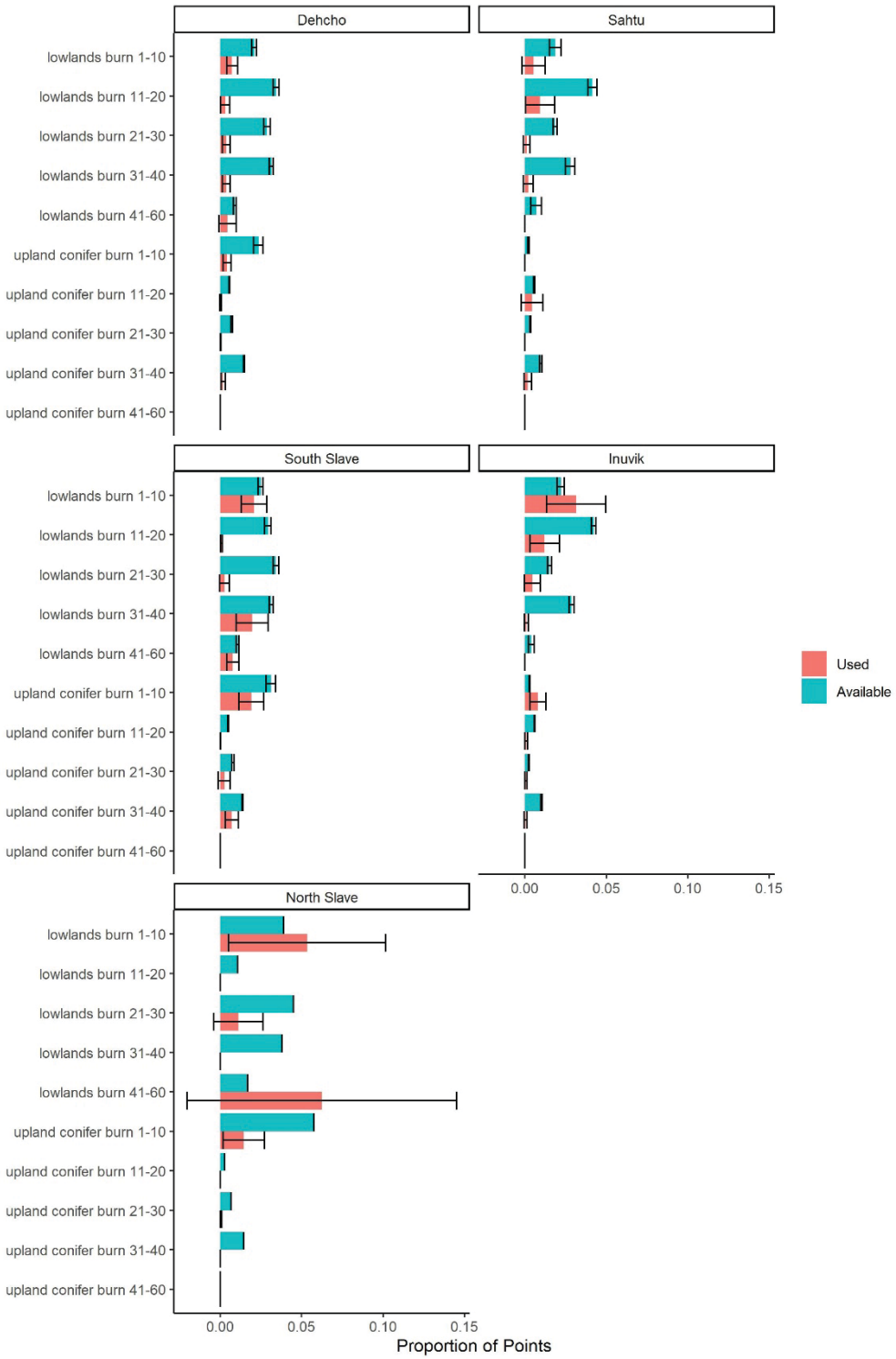


Figure H 14: The proportion of used (GPS) locations and available (or random) locations falling within burned lowlands and upland conifer among the five regional monitoring areas during **mid-winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

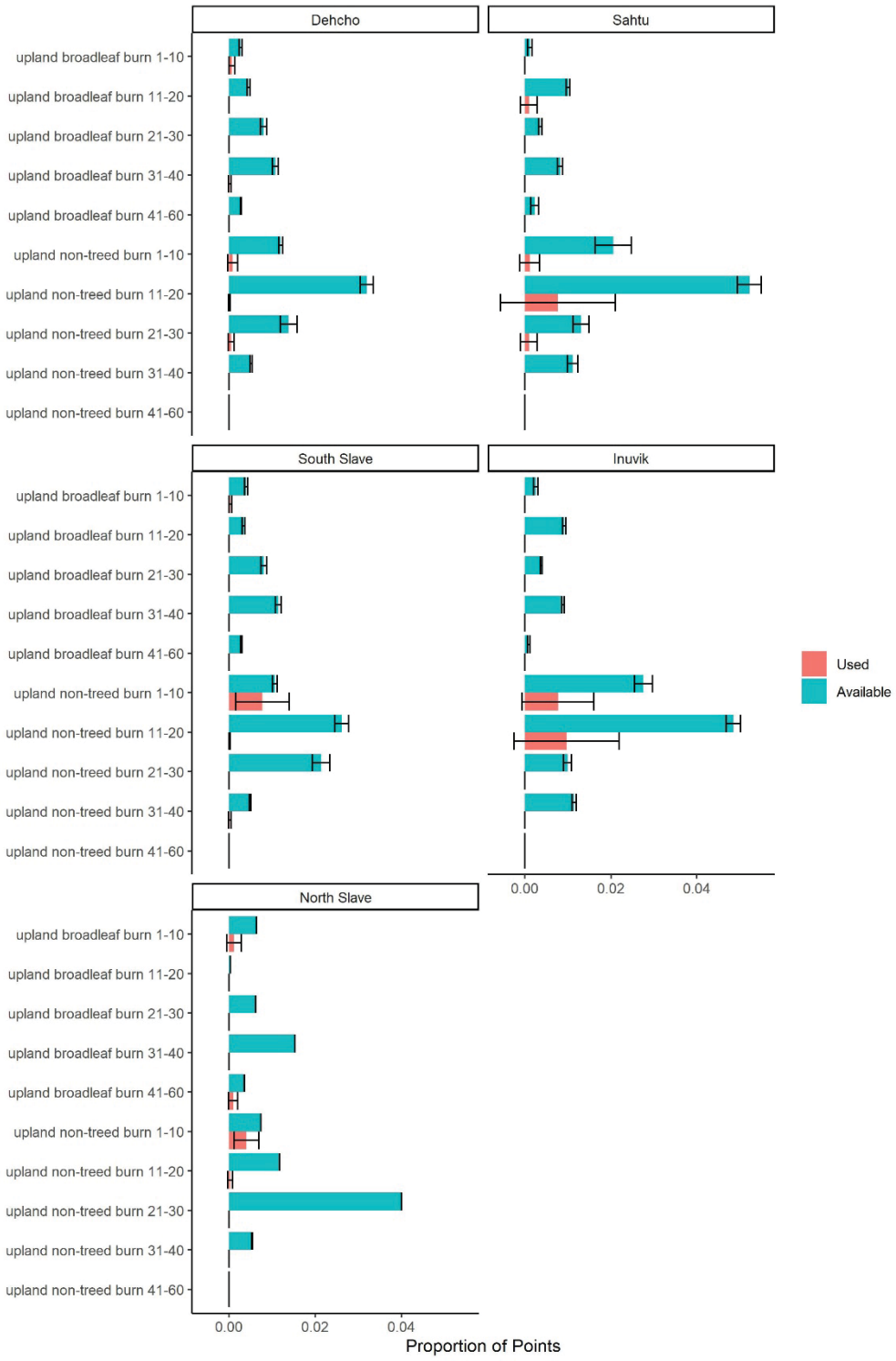


Figure H 15: The proportion of used (GPS) locations and available (or random) locations falling within burned lowlands and upland conifer among the five regional monitoring areas during **late winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

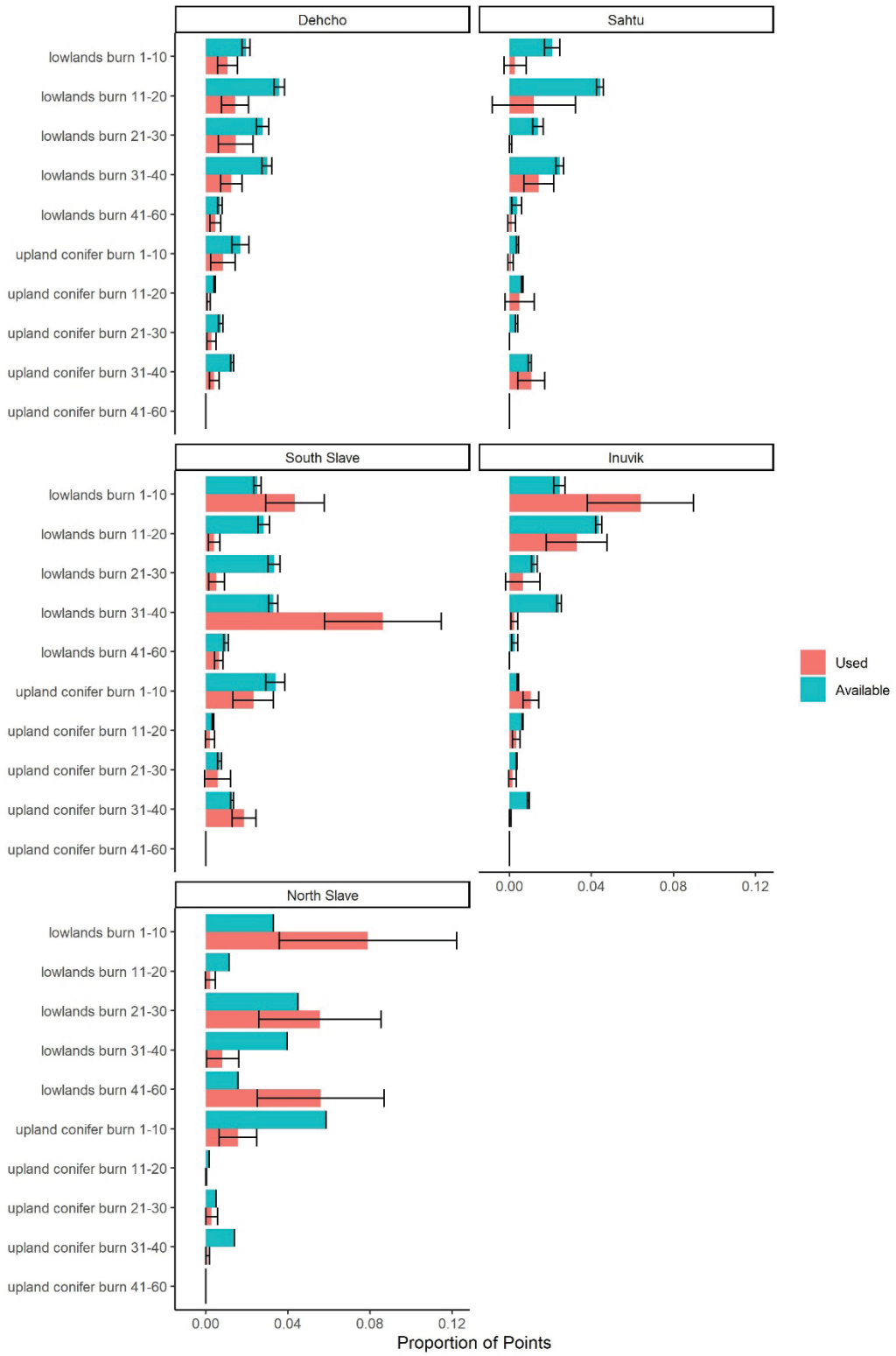


Figure H 16: The proportion of used (GPS) locations and available (or random) locations falling within burned lowlands and upland conifer among the five regional monitoring areas on a **yearly** basis. Random locations were sampled within the available area defined at a second-order scale. Error bars

represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

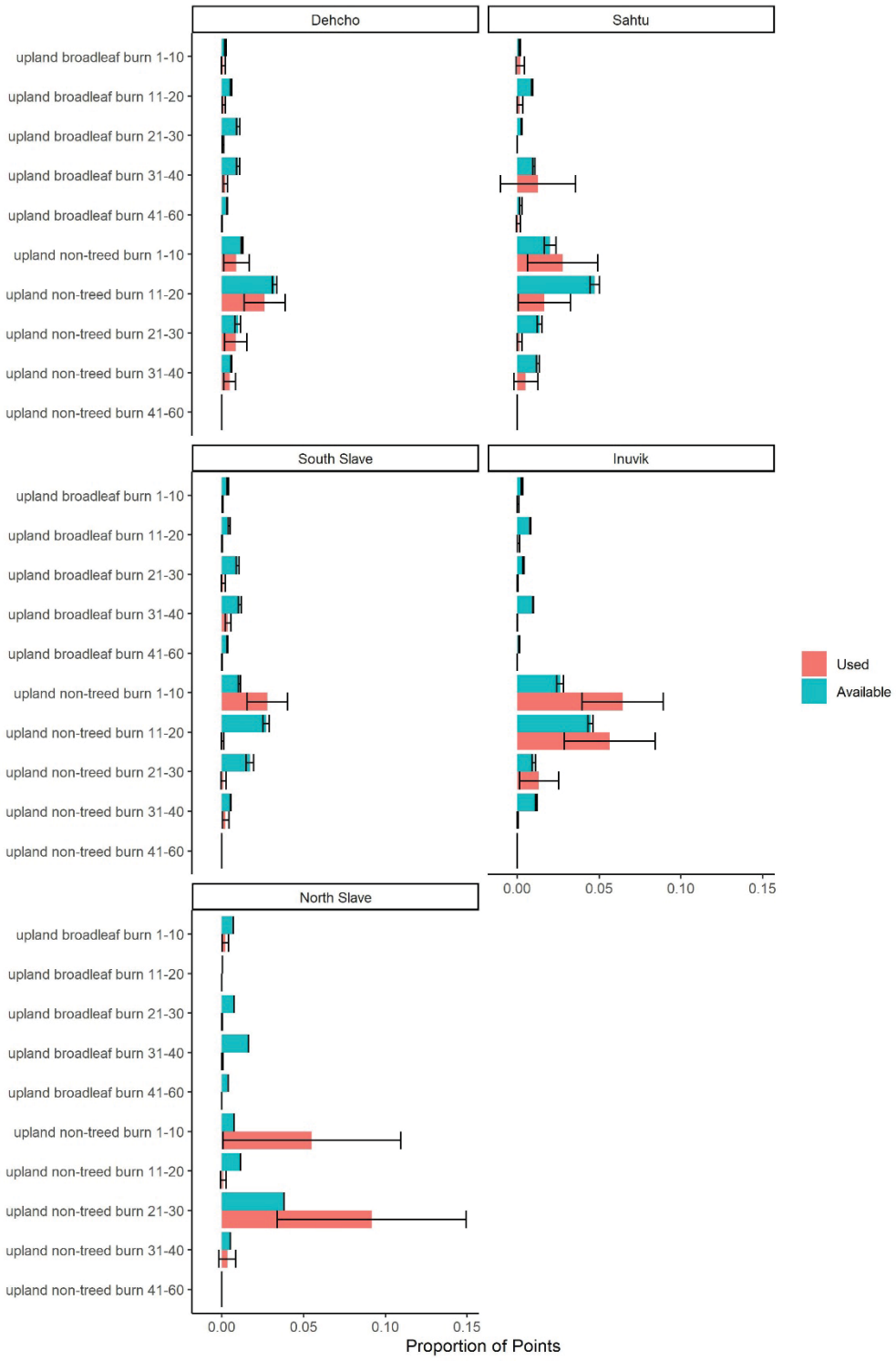


Figure H 17: The proportion of used (GPS) locations and available (or random) locations falling within burned upland broadleaf forest and non-treed uplands among the five regional monitoring areas during **calving**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

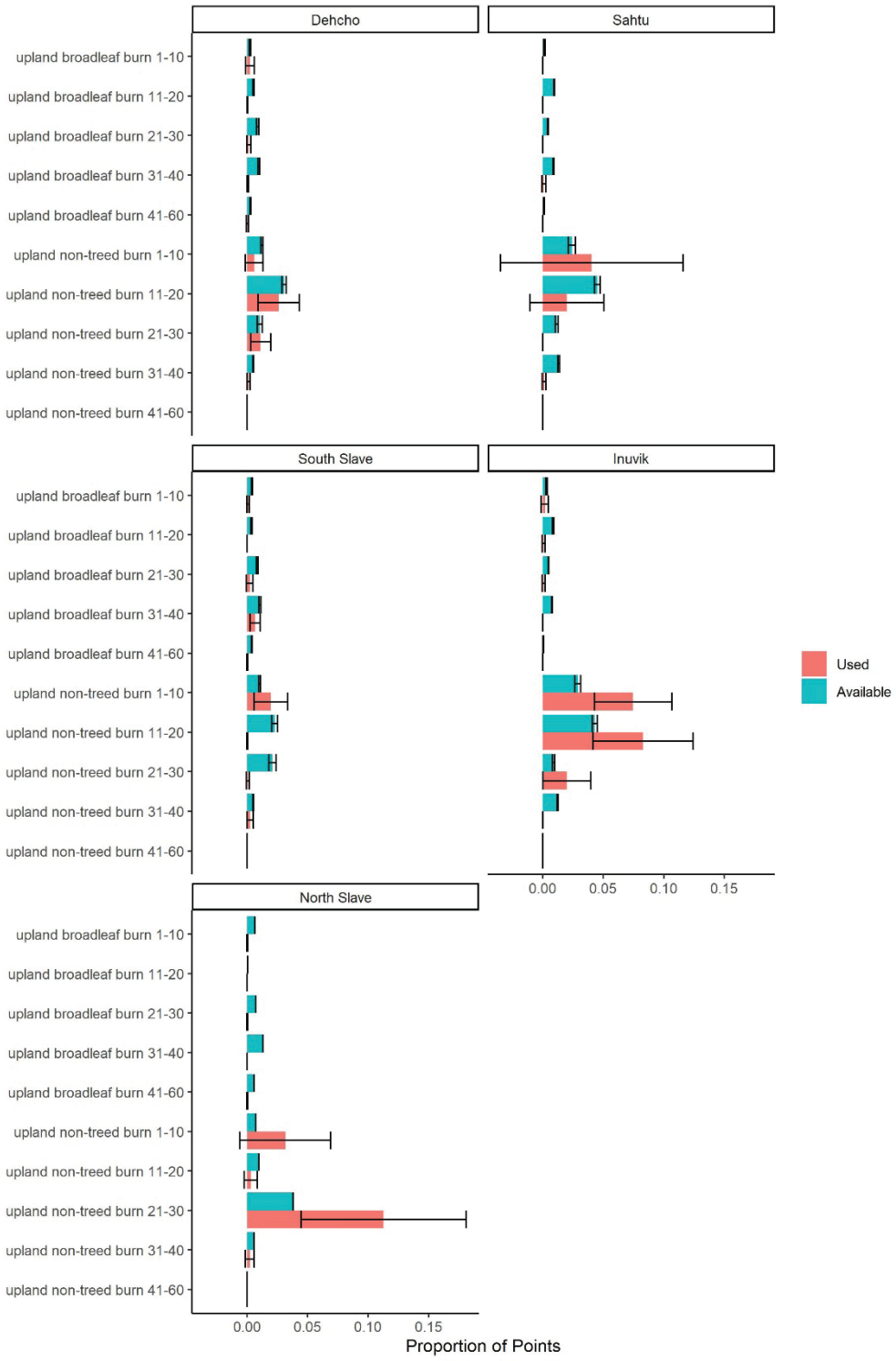


Figure H 18: The proportion of used (GPS) locations and available (or random) locations falling within burned upland broadleaf forest and non-treed uplands among the five regional monitoring areas during **summer**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

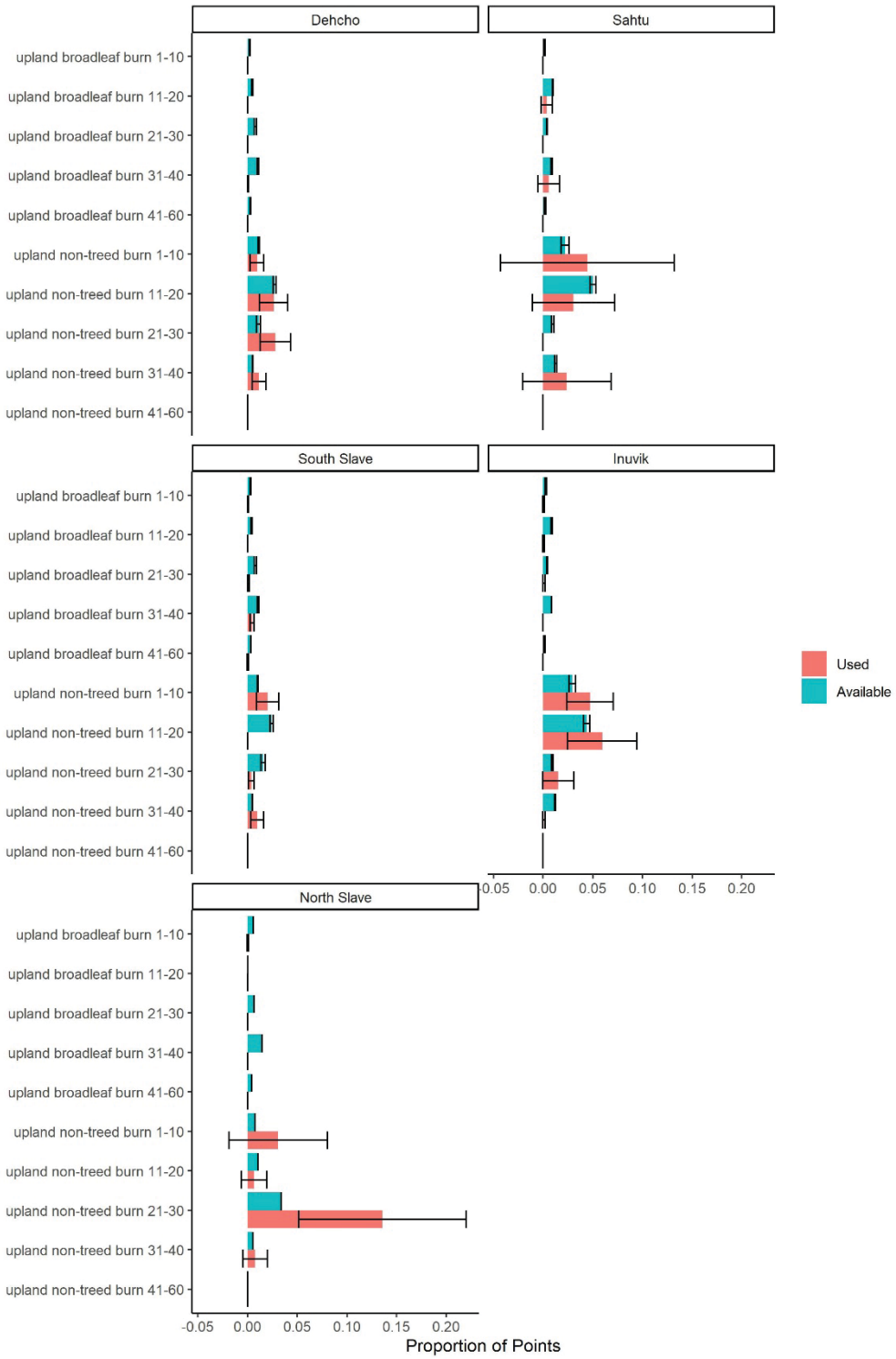


Figure H 19: The proportion of used (GPS) locations and available (or random) locations falling within burned upland broadleaf forest and non-treed uplands among the five regional monitoring areas during **early fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

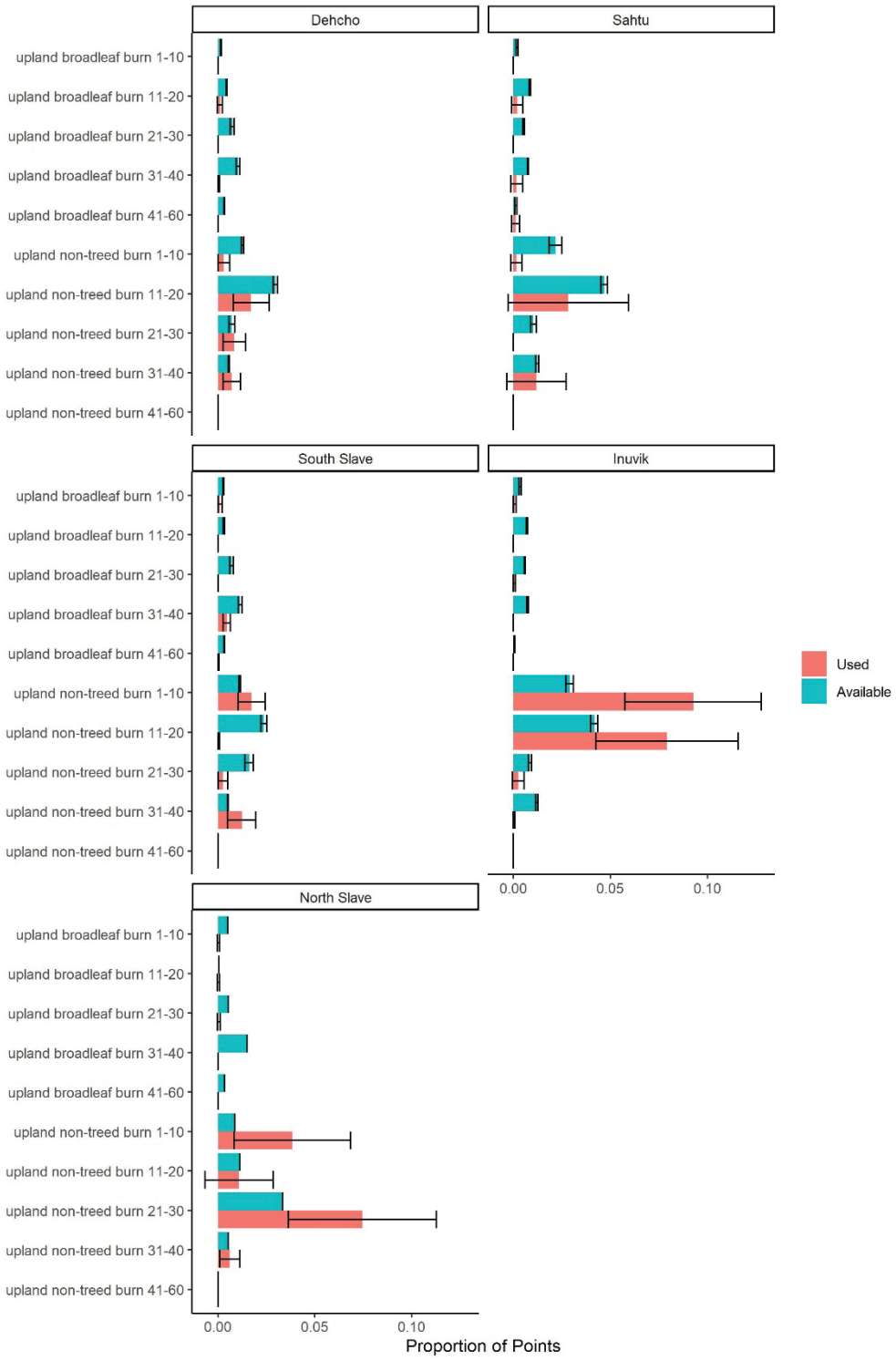


Figure H 20: The proportion of used (GPS) locations and available (or random) locations falling within burned upland broadleaf forest and non-treed uplands among the five regional monitoring areas during **late fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

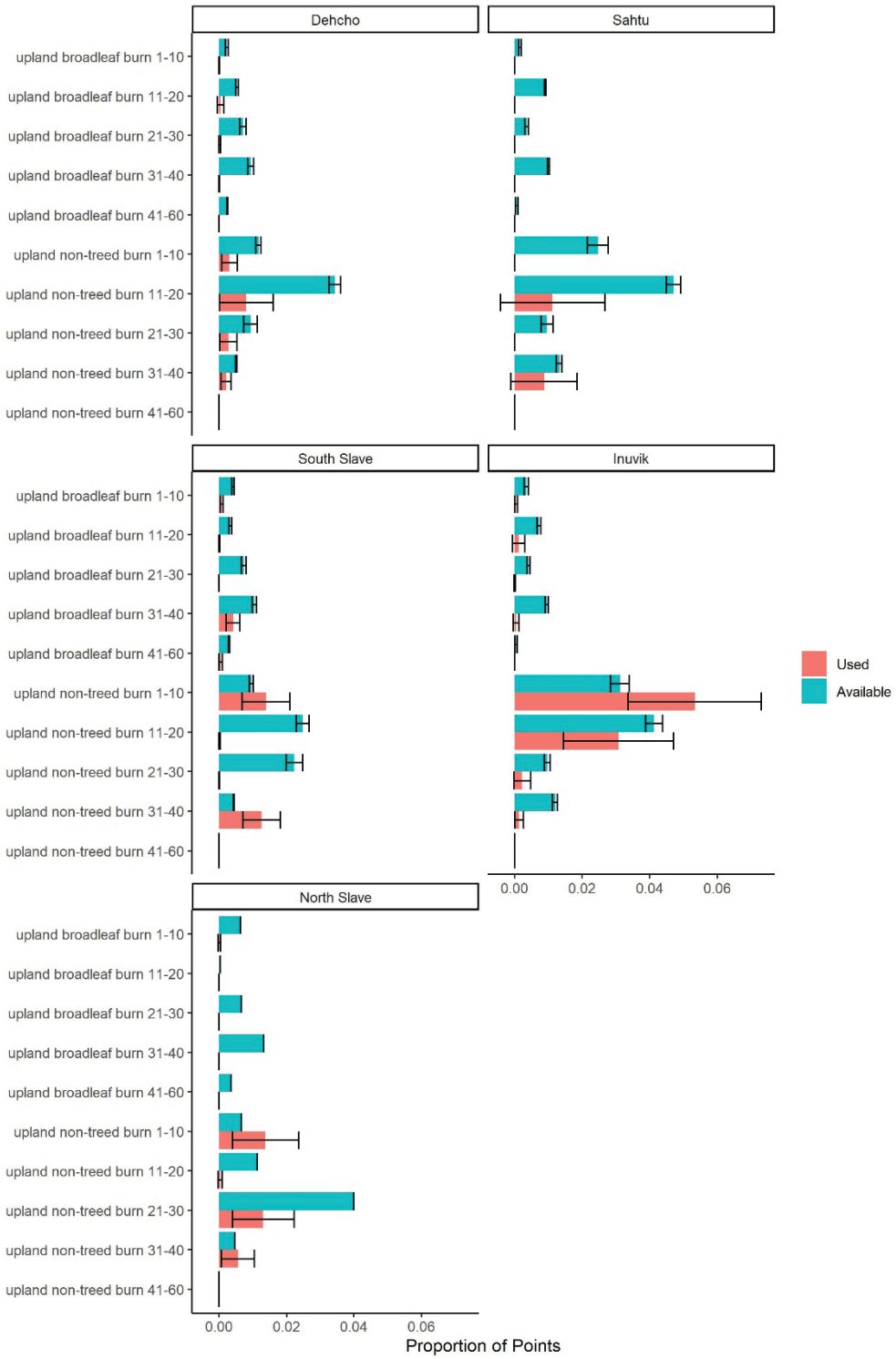


Figure H 21: The proportion of used (GPS) locations and available (or random) locations falling within burned upland broadleaf forest and non-treed uplands among the five regional monitoring areas during **early winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

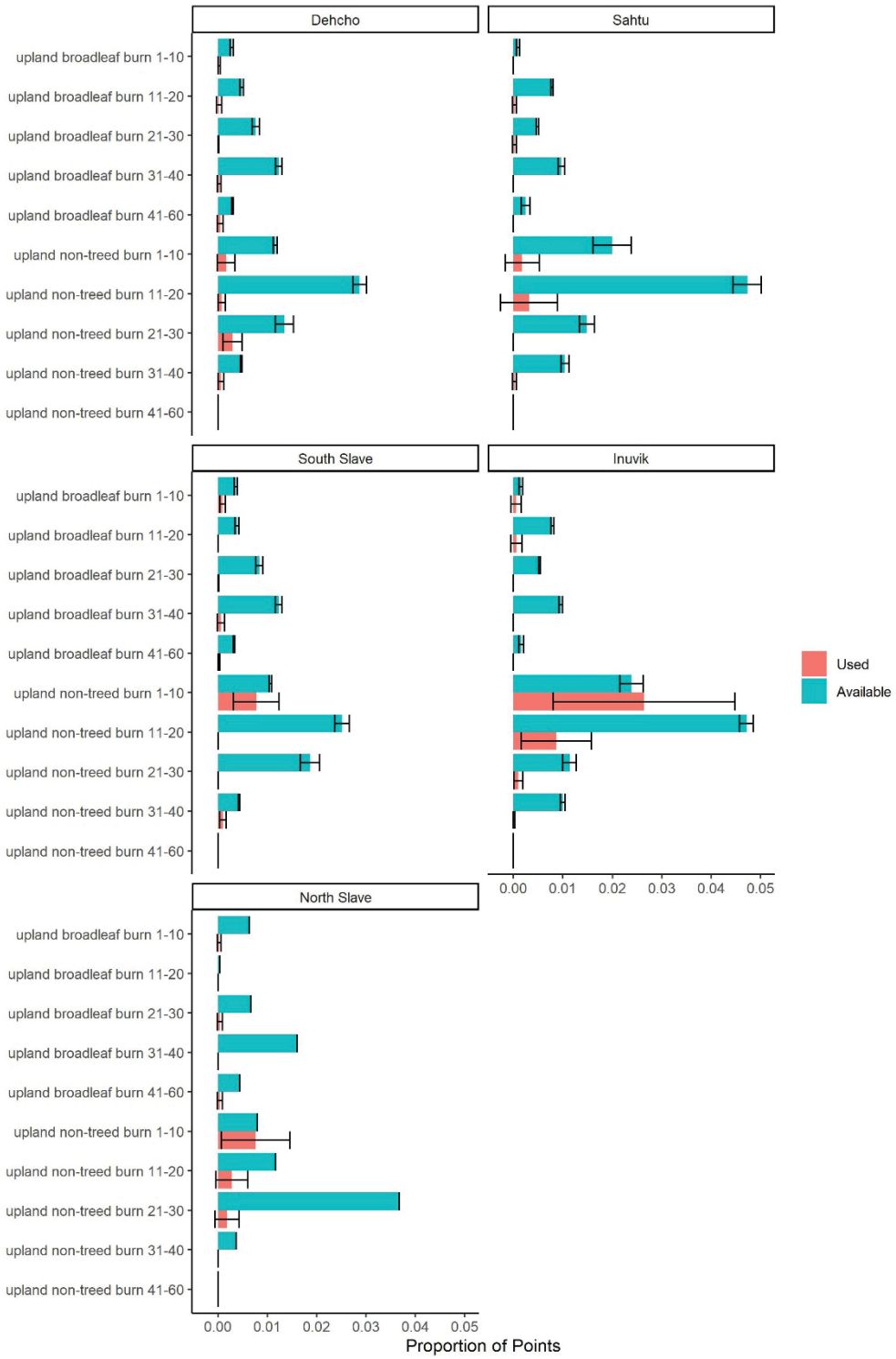


Figure H 22: The proportion of used (GPS) locations and available (or random) locations falling within burned upland broadleaf forest and non-treed uplands among the five regional monitoring areas during **mid-winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

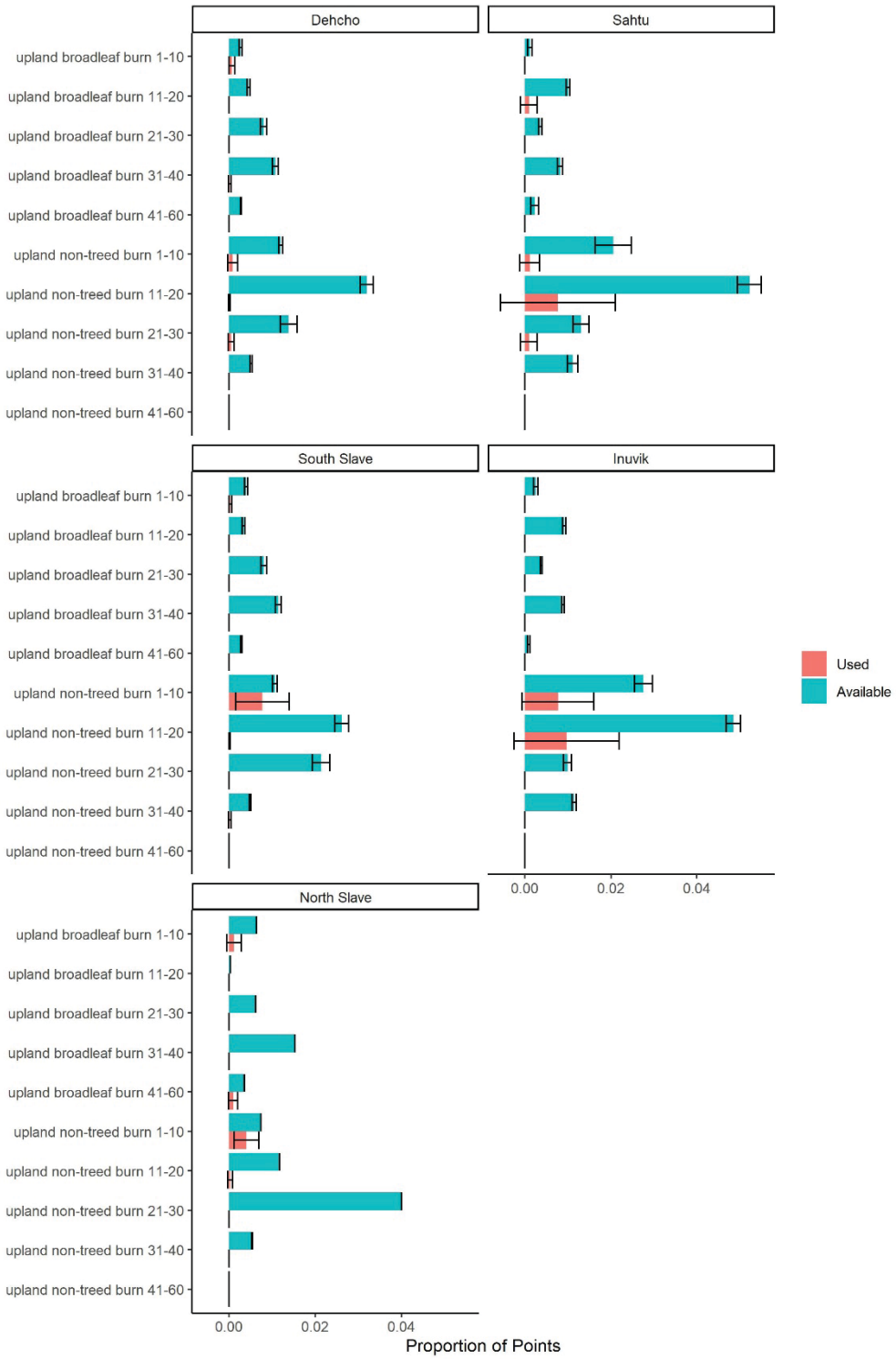


Figure H 23: The proportion of used (GPS) locations and available (or random) locations falling within burned upland broadleaf forest and non-treed uplands among the five regional monitoring areas during **late winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

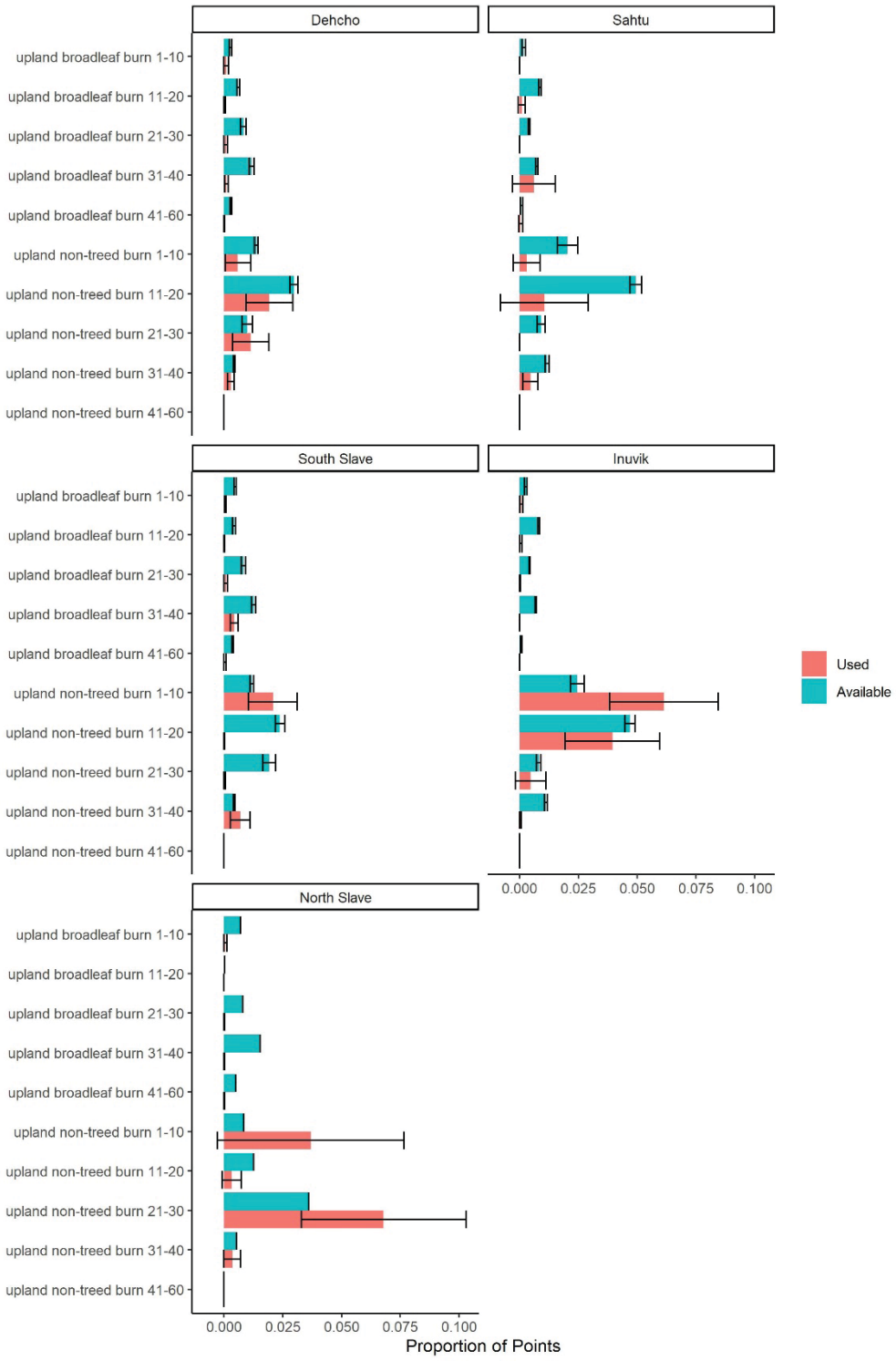


Figure H 24: The proportion of used (GPS) locations and available (or random) locations falling within burned upland broadleaf forest and non-treed uplands among the five regional monitoring areas on a **yearly** basis. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

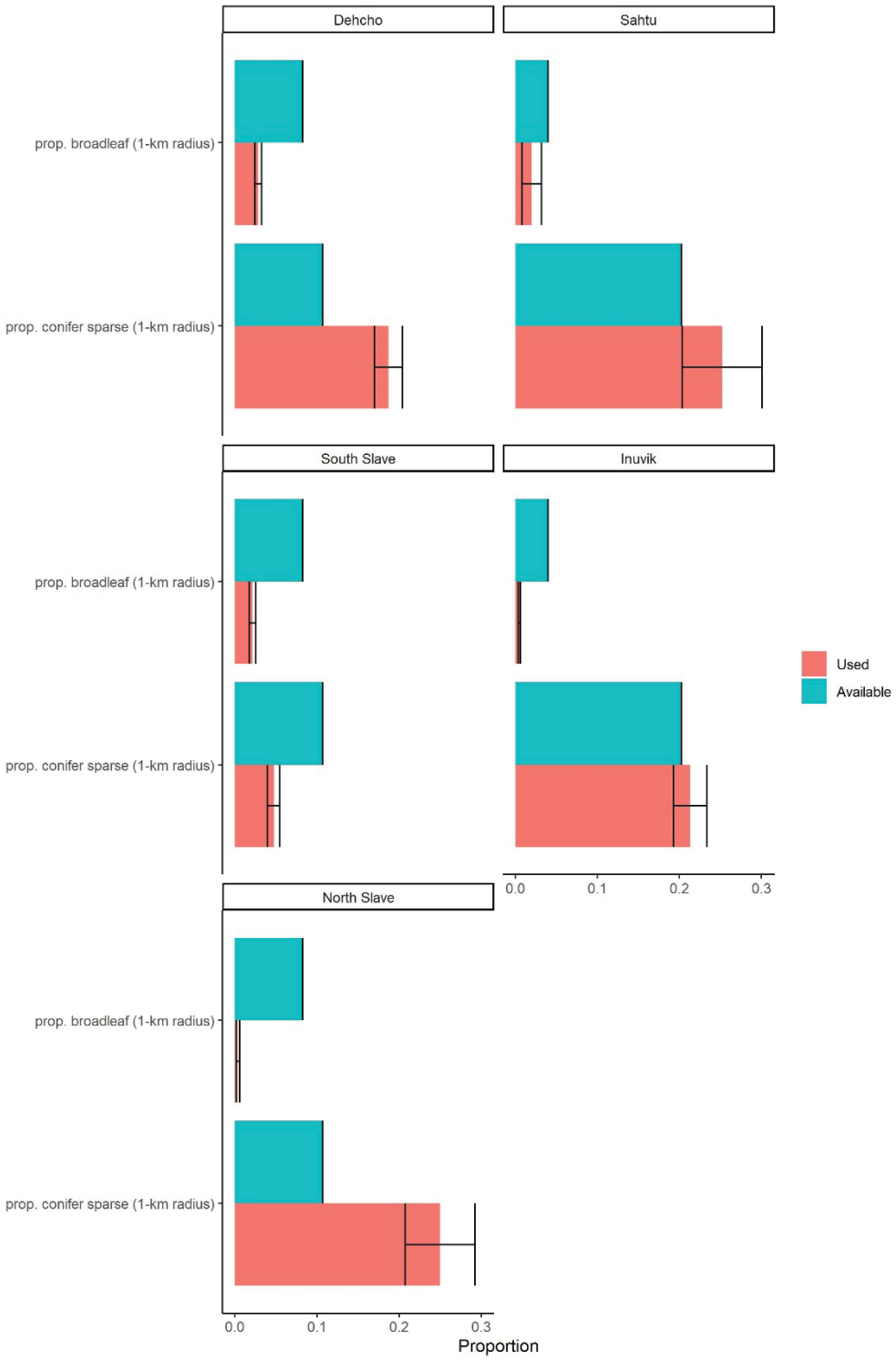


Figure H 25: The mean proportions of broadleaf forest and sparse conifer forest in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **calving**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

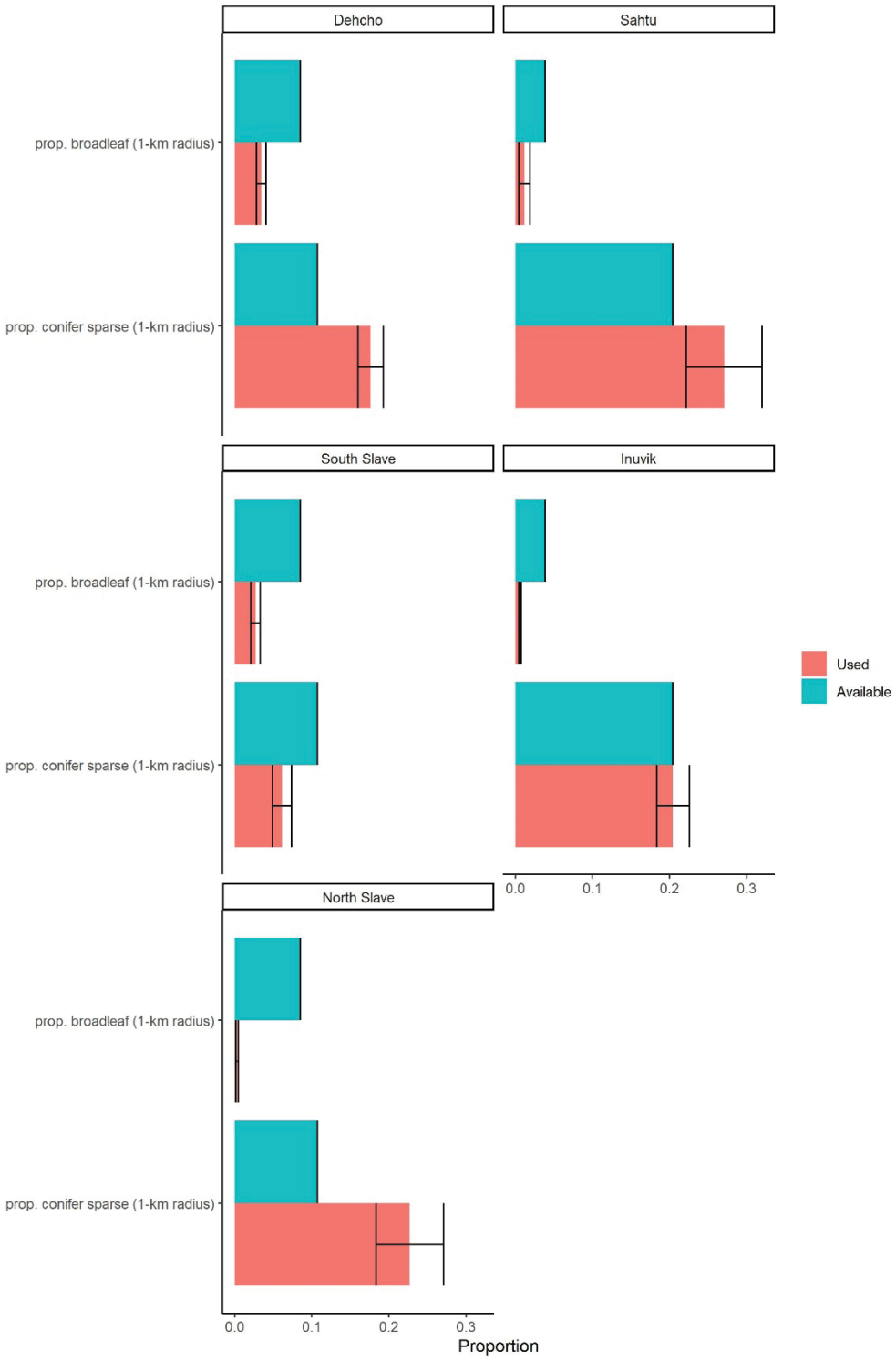


Figure H 26: The mean proportions of broadleaf forest and sparse conifer forest in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **summer**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

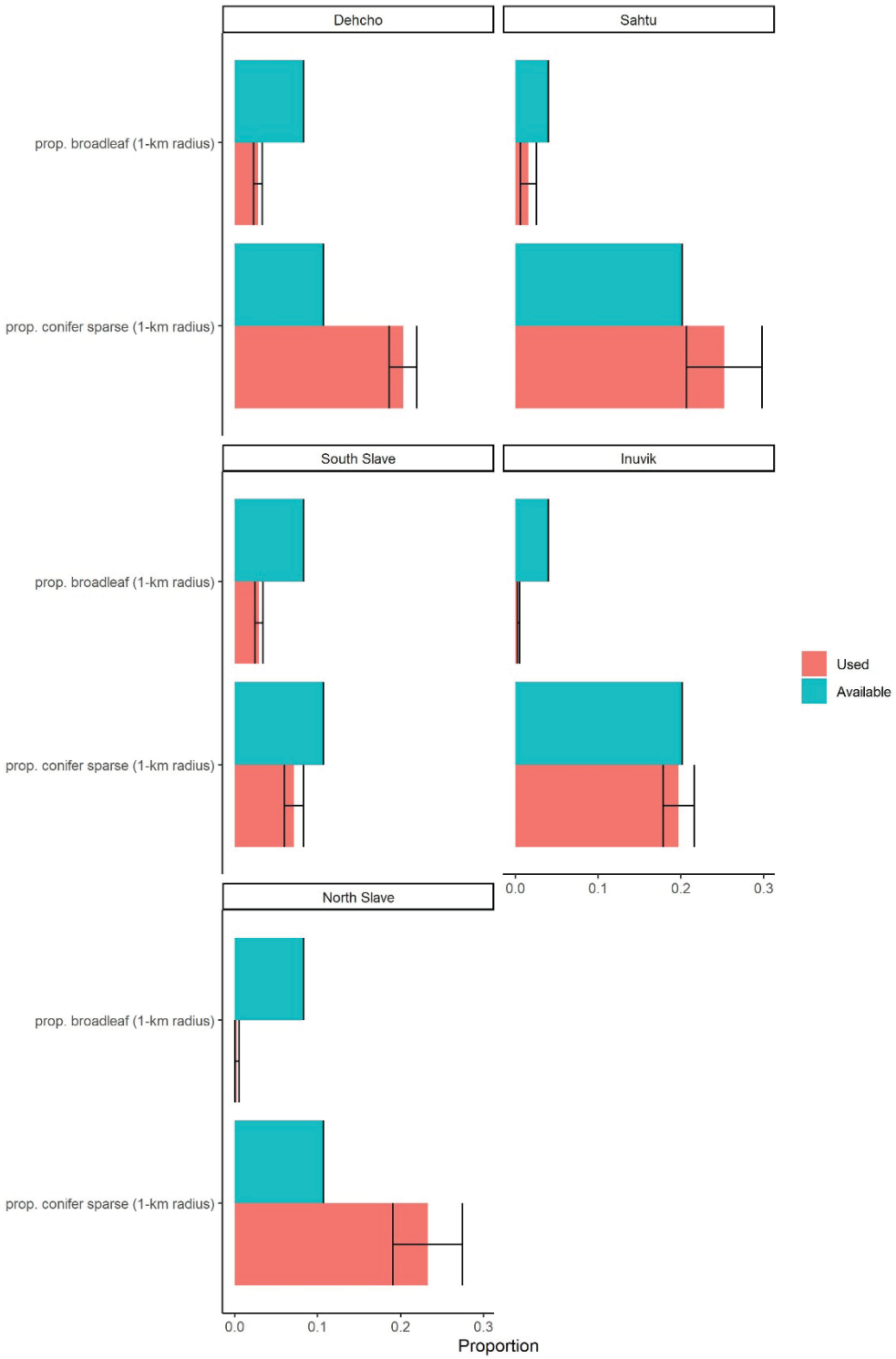


Figure H 27: The mean proportions of broadleaf forest and sparse conifer forest in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **early fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

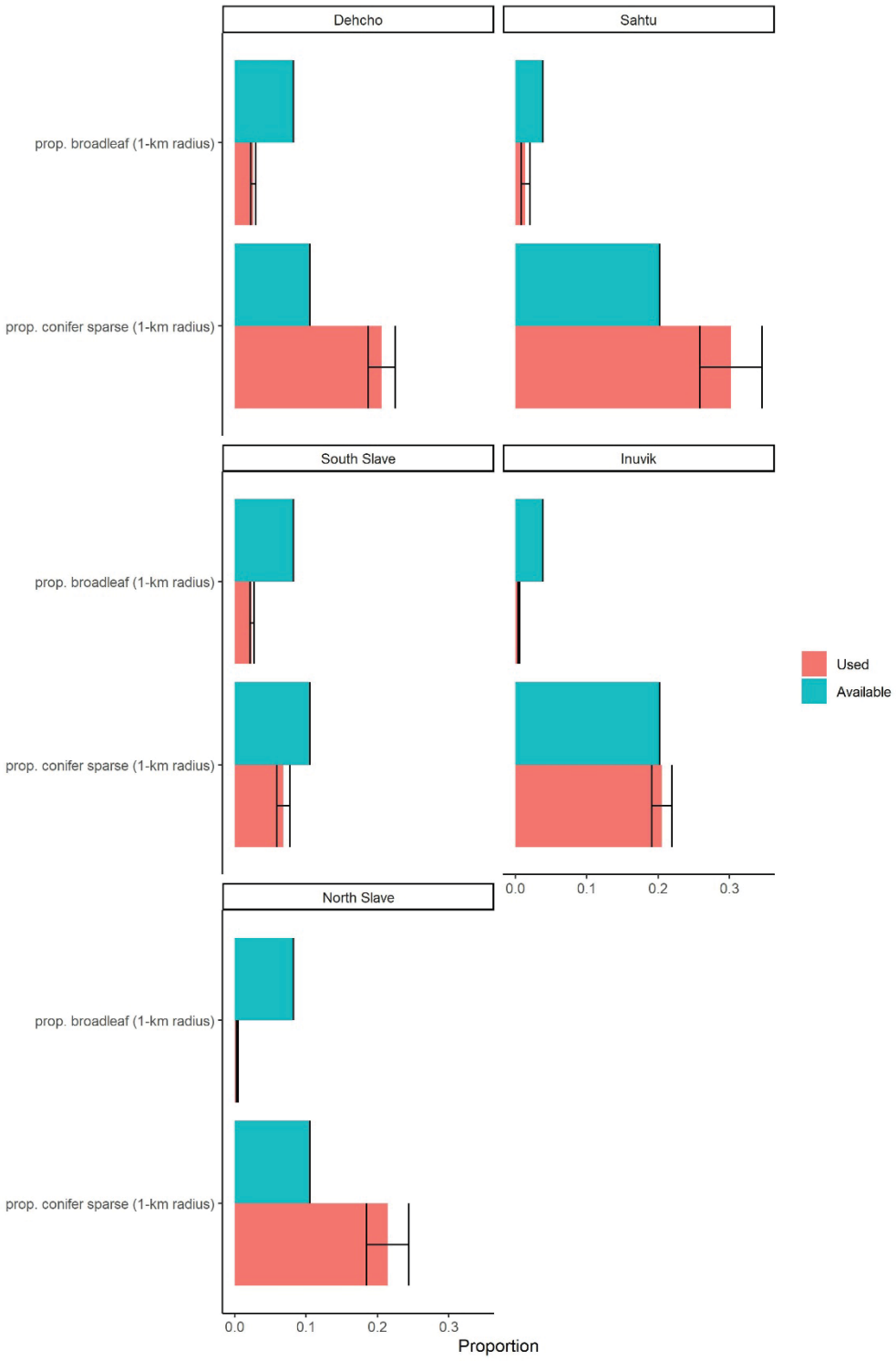


Figure H 28: The mean proportions of broadleaf forest and sparse conifer forest in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **late fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

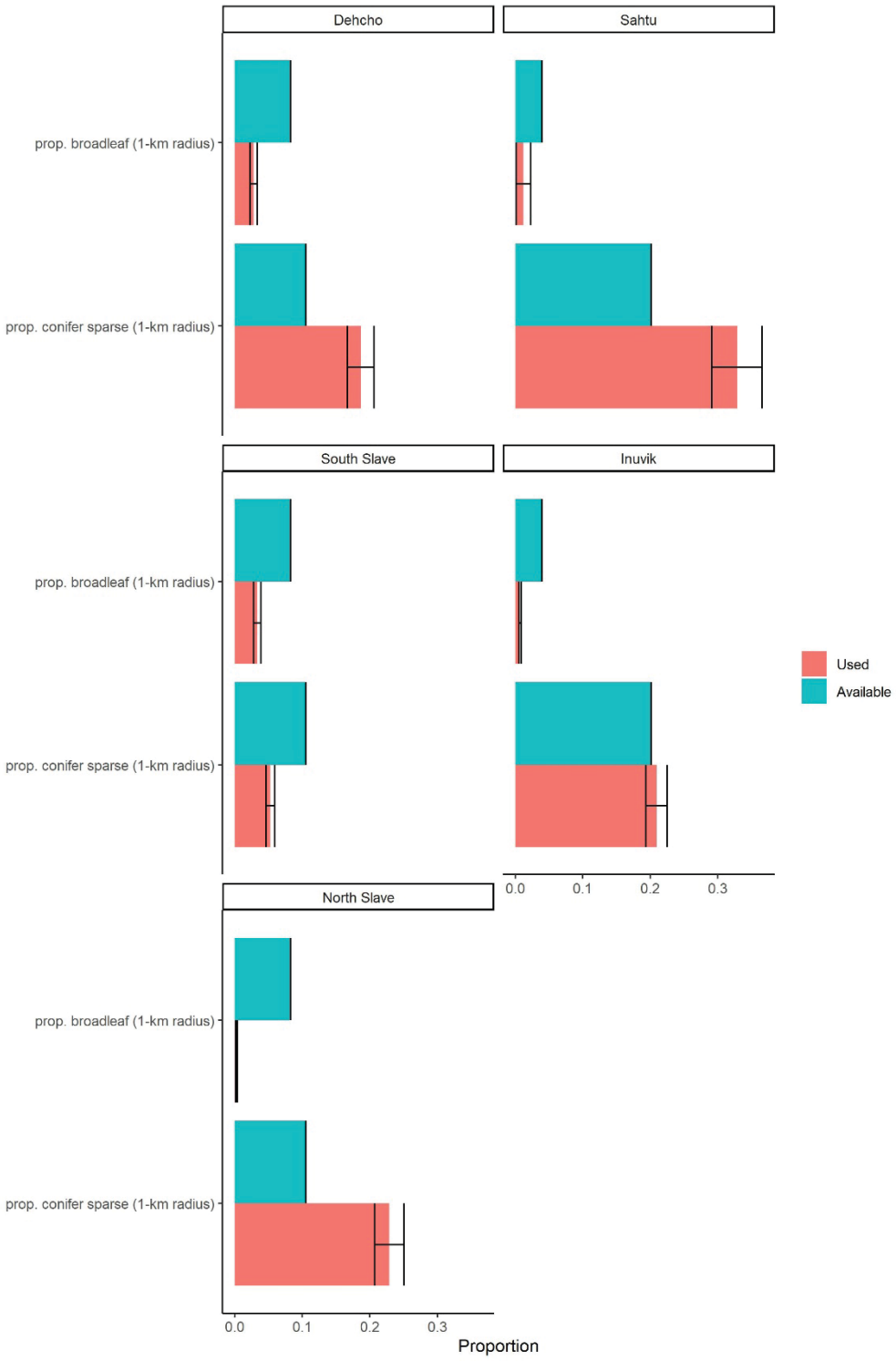


Figure H 29: The mean proportions of broadleaf forest and sparse conifer forest in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **early winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

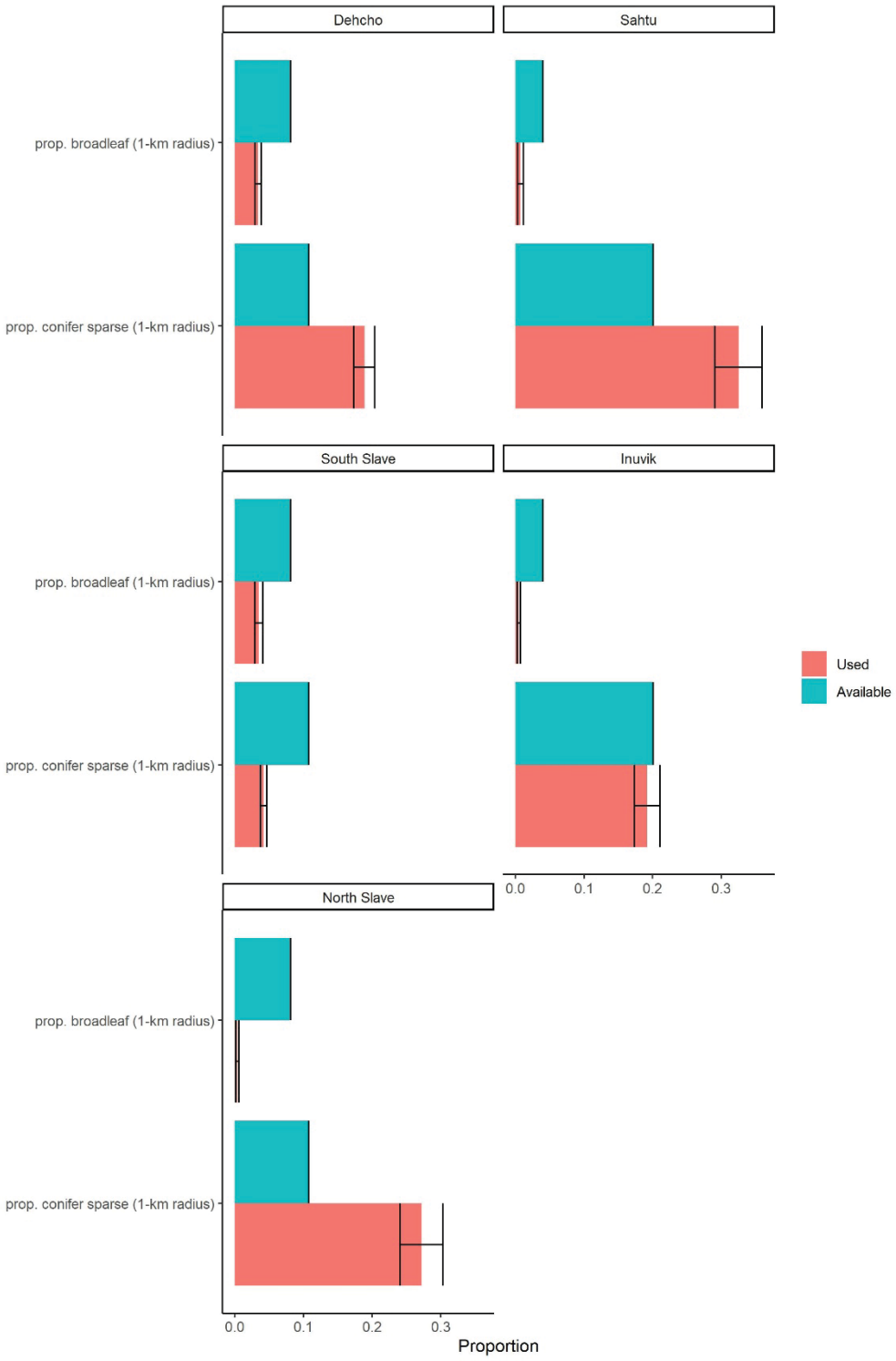


Figure H 30: The mean proportions of broadleaf forest and sparse conifer forest in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **mid-winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

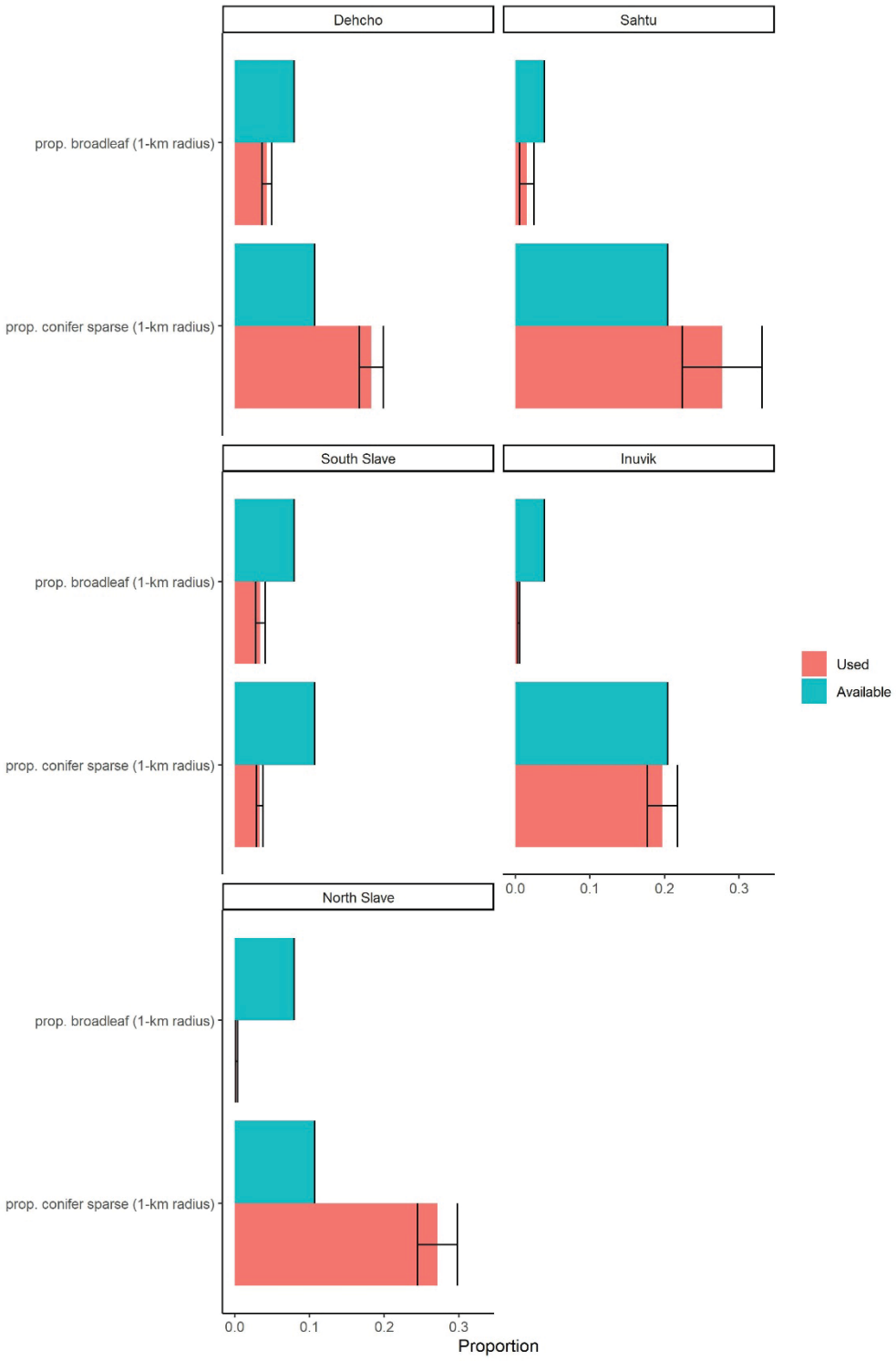


Figure H 31: The mean proportions of broadleaf forest and sparse conifer forest in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **late winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

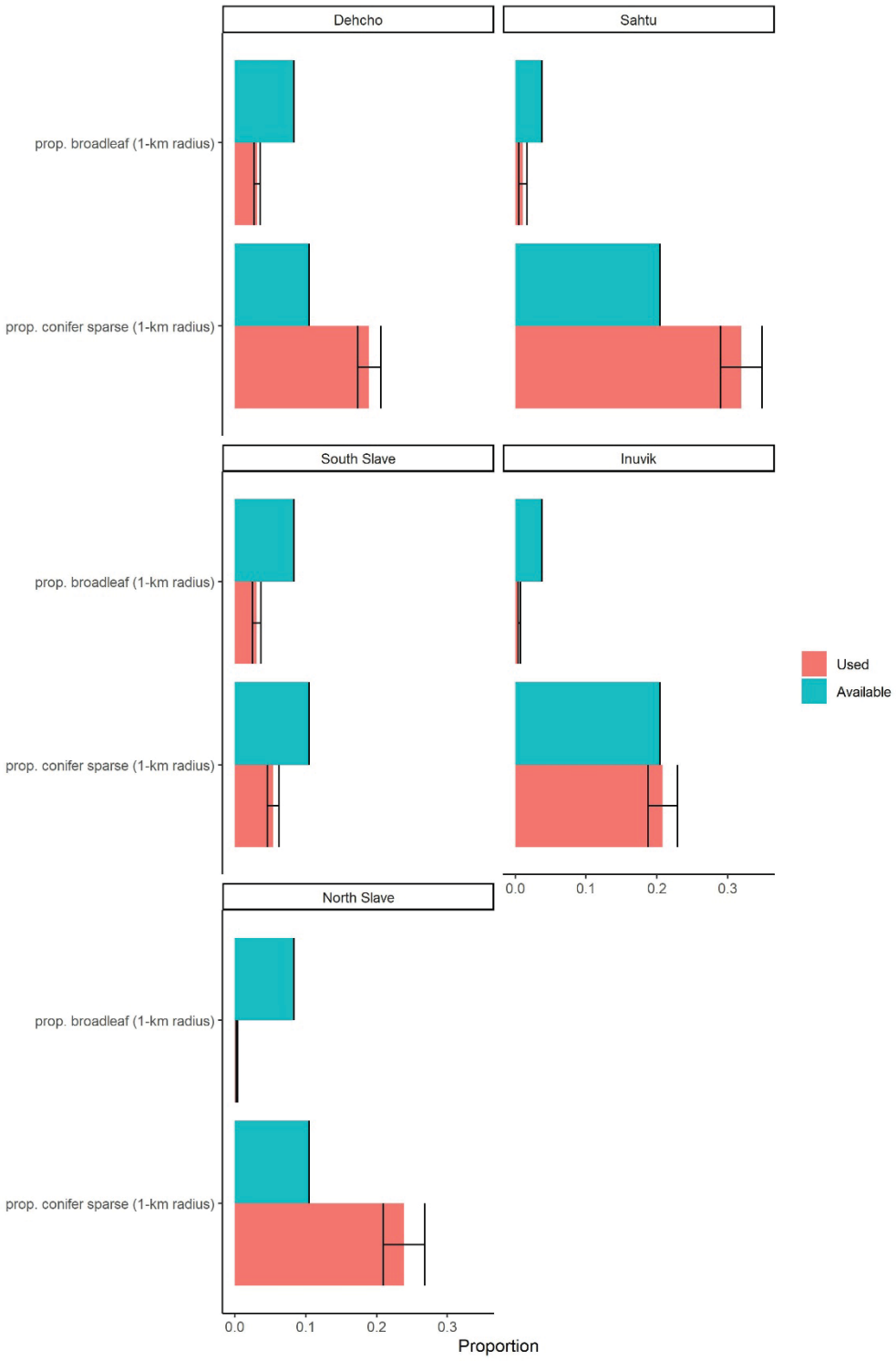


Figure H 32: The mean proportions of broadleaf forest and sparse conifer forest in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas on a **yearly** basis. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean proportion calculated across individual caribou-years.

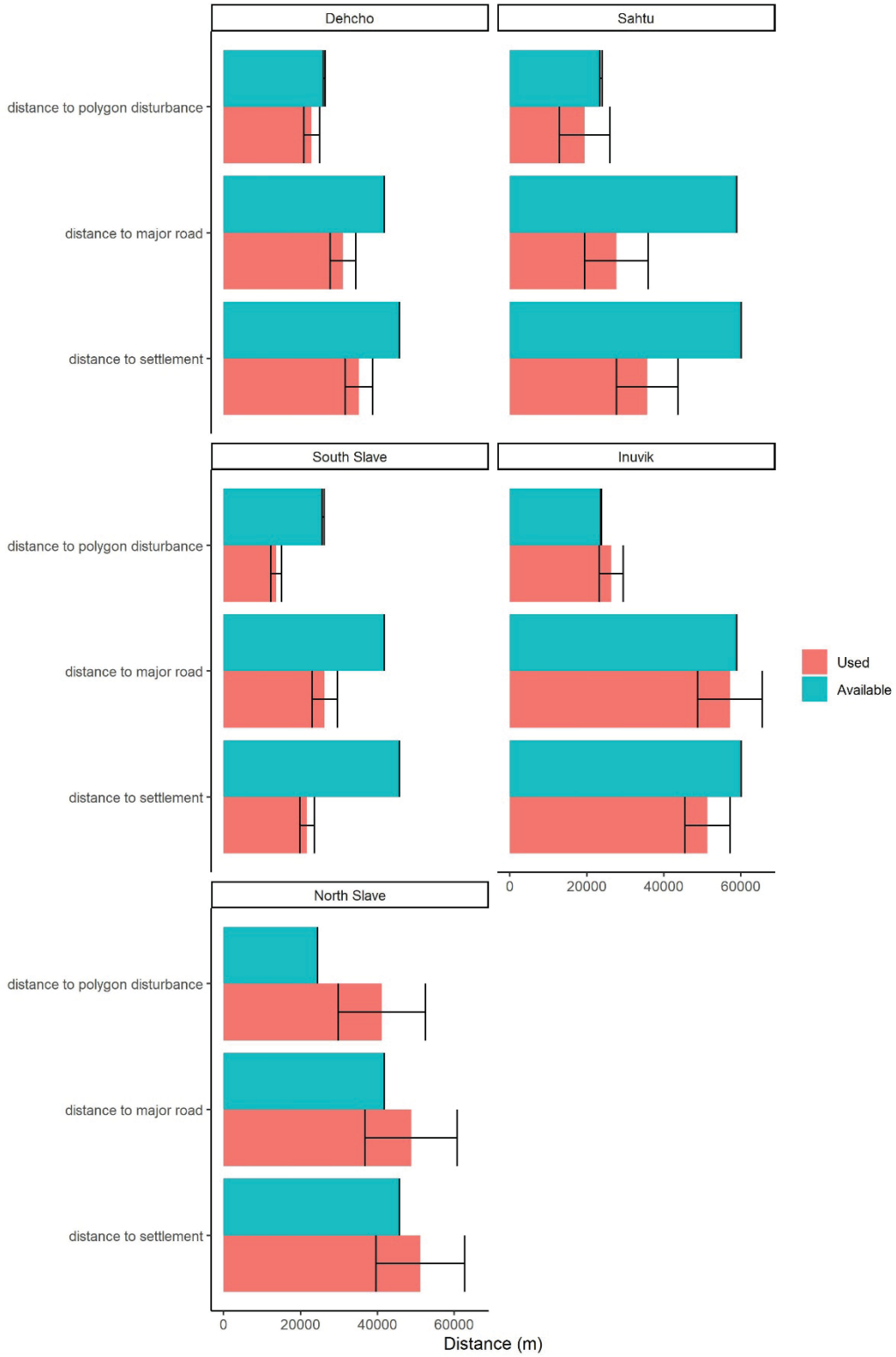


Figure H 33: The mean distances to various anthropogenic disturbances for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **calving**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean distance calculated across individual caribou-years.

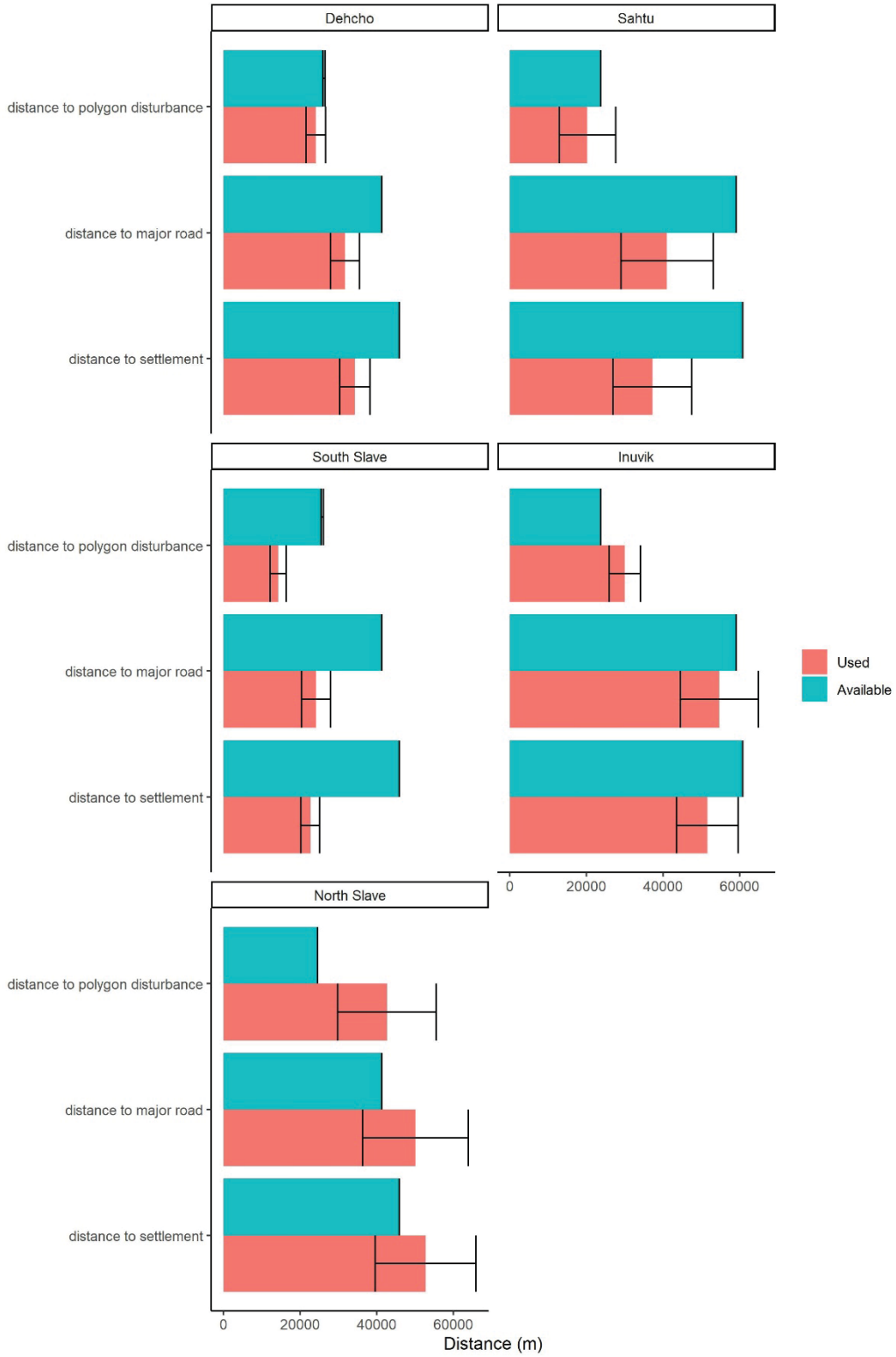


Figure H 34: The mean distances to various anthropogenic disturbances for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **summer**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean distance calculated across individual caribou-years.

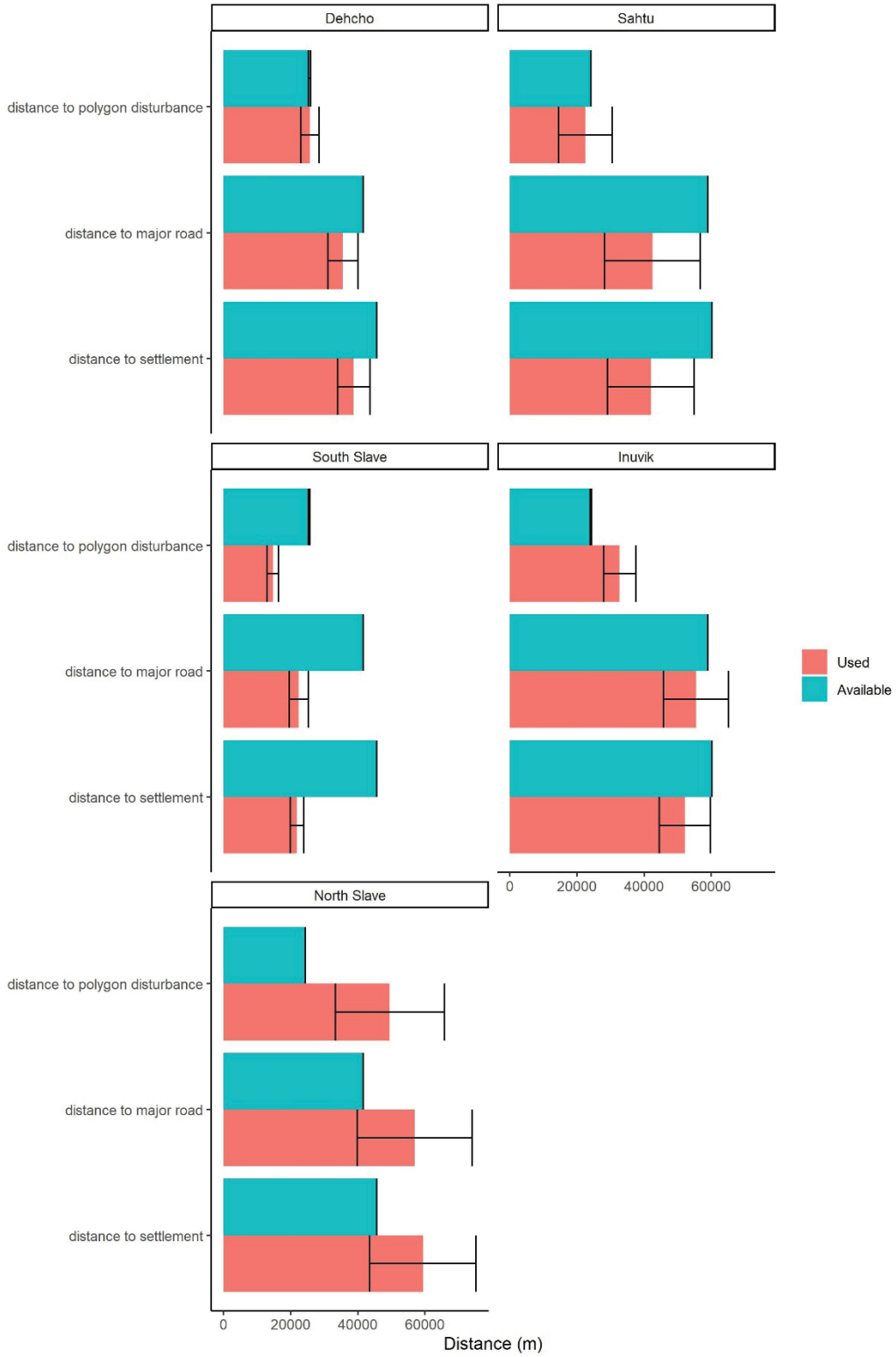


Figure H 35: The mean distances to various anthropogenic disturbances for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **early fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean distance calculated across individual caribou-years.

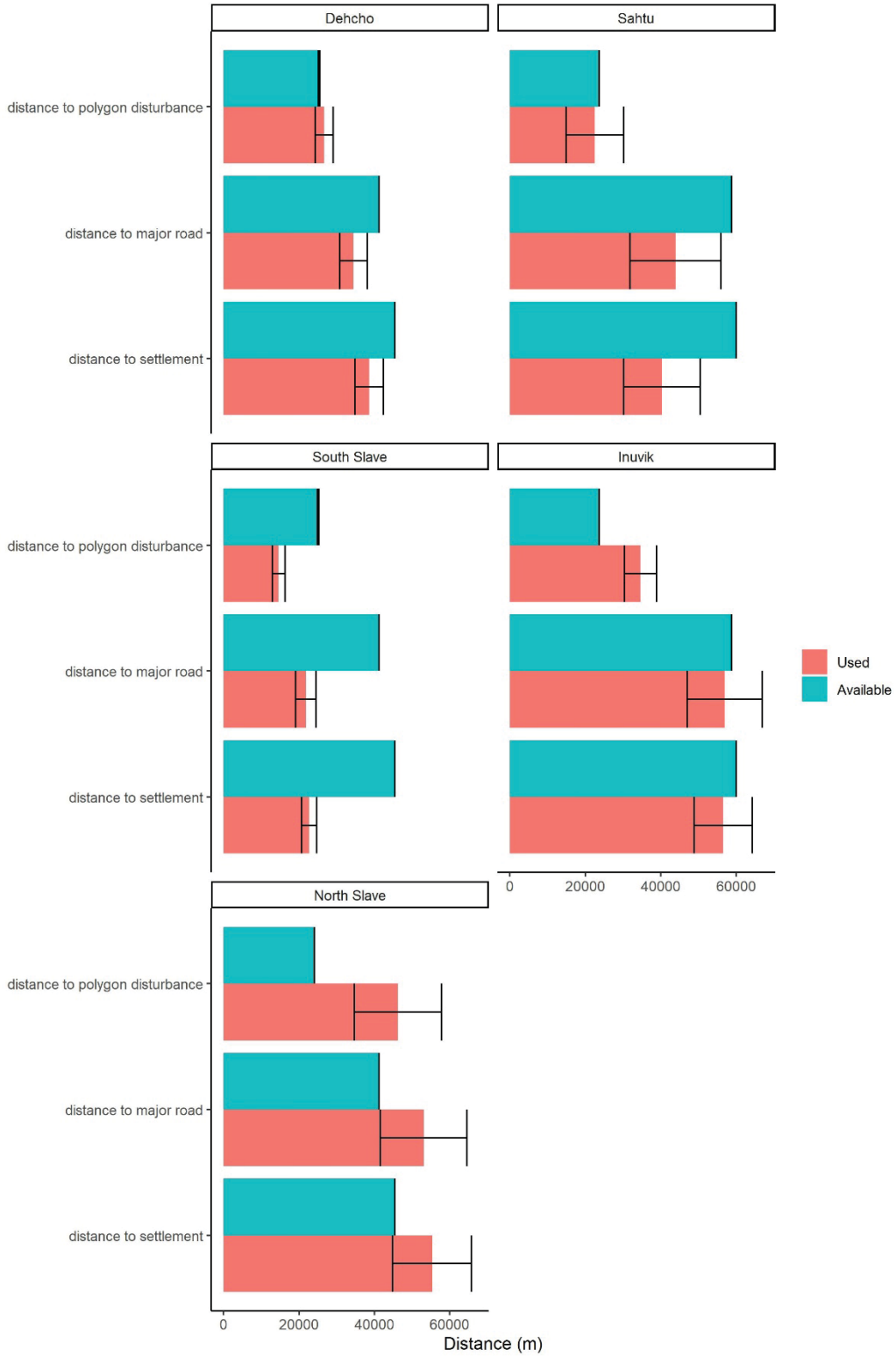


Figure H 36: The mean distances to various anthropogenic disturbances for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **late fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean distance calculated across individual caribou-years.

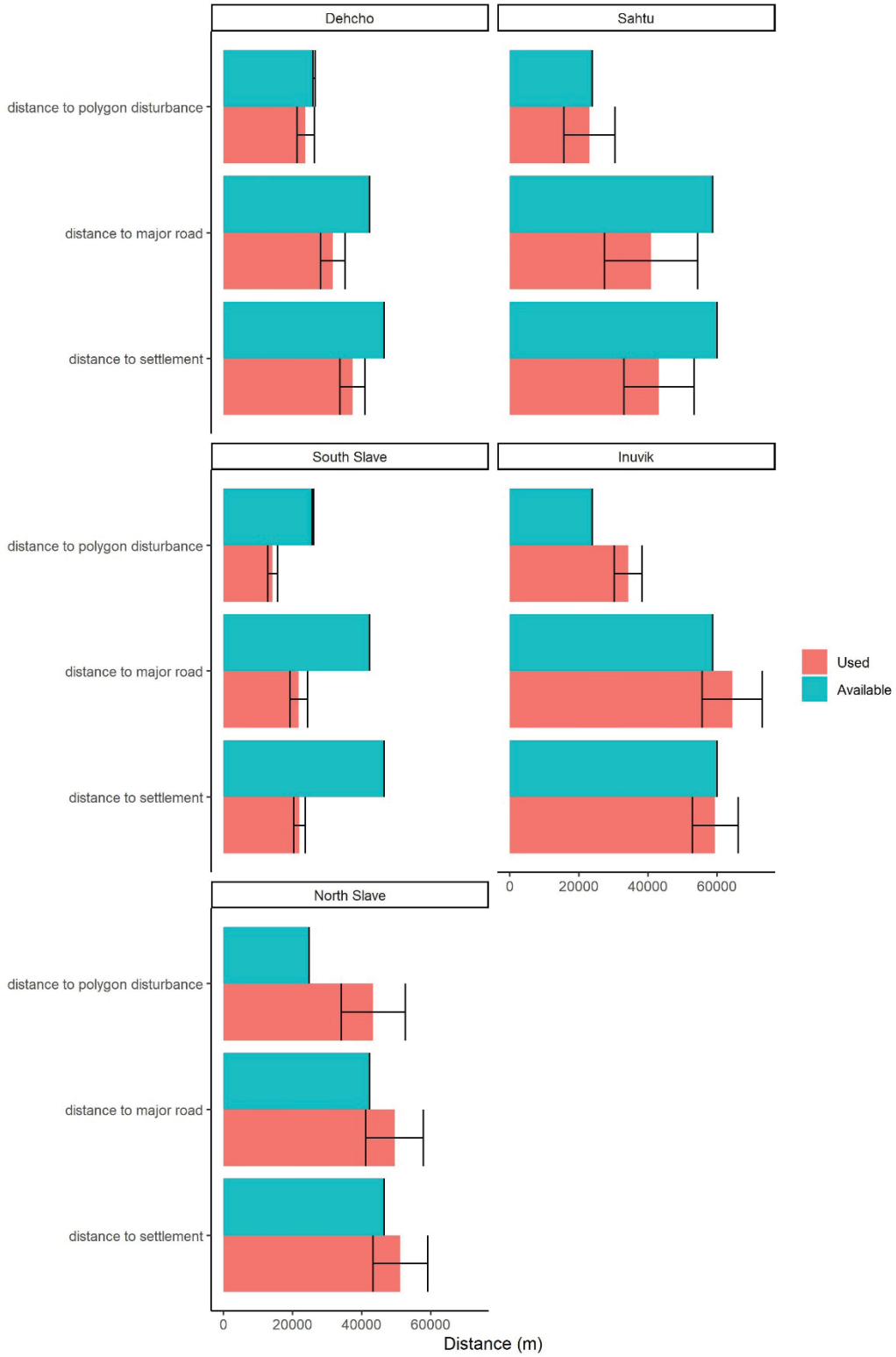


Figure H 37: The mean distances to various anthropogenic disturbances for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **early winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean distance calculated across individual caribou-years.

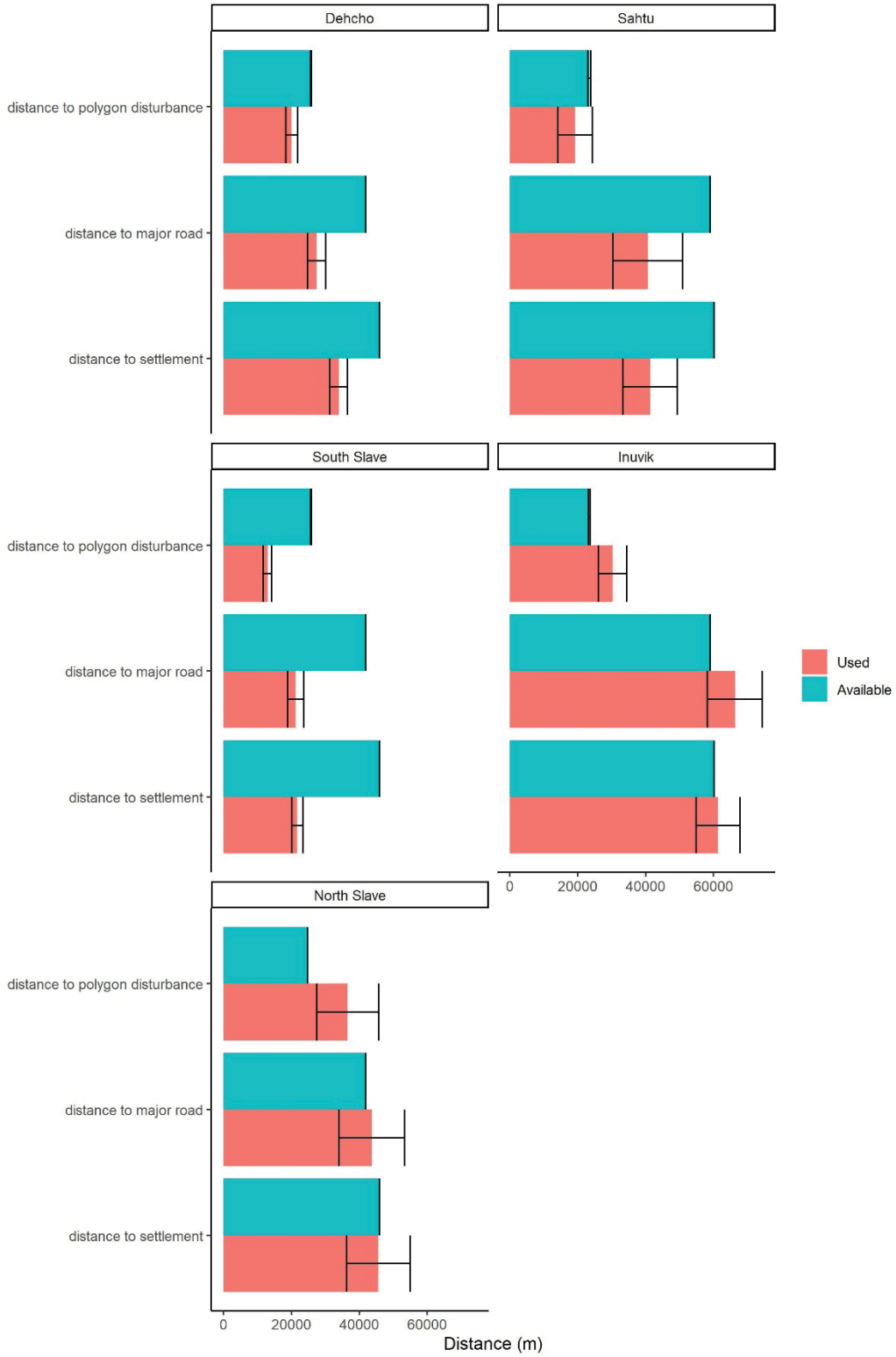


Figure H 38: The mean distances to various anthropogenic disturbances for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **mid-winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean distance calculated across individual caribou-years.

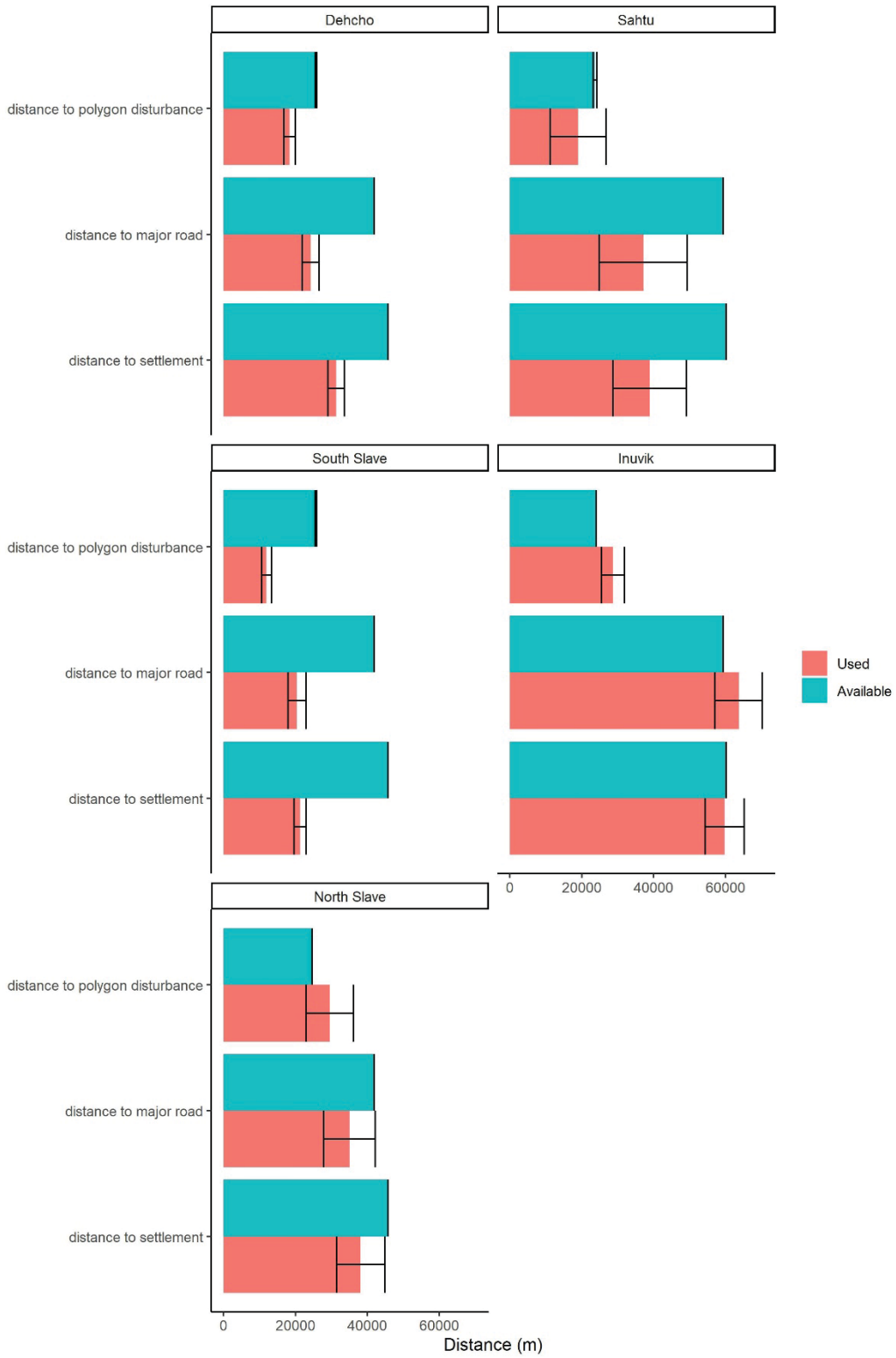


Figure H 39: The mean distances to various anthropogenic disturbances for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **late winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean distance calculated across individual caribou-years.

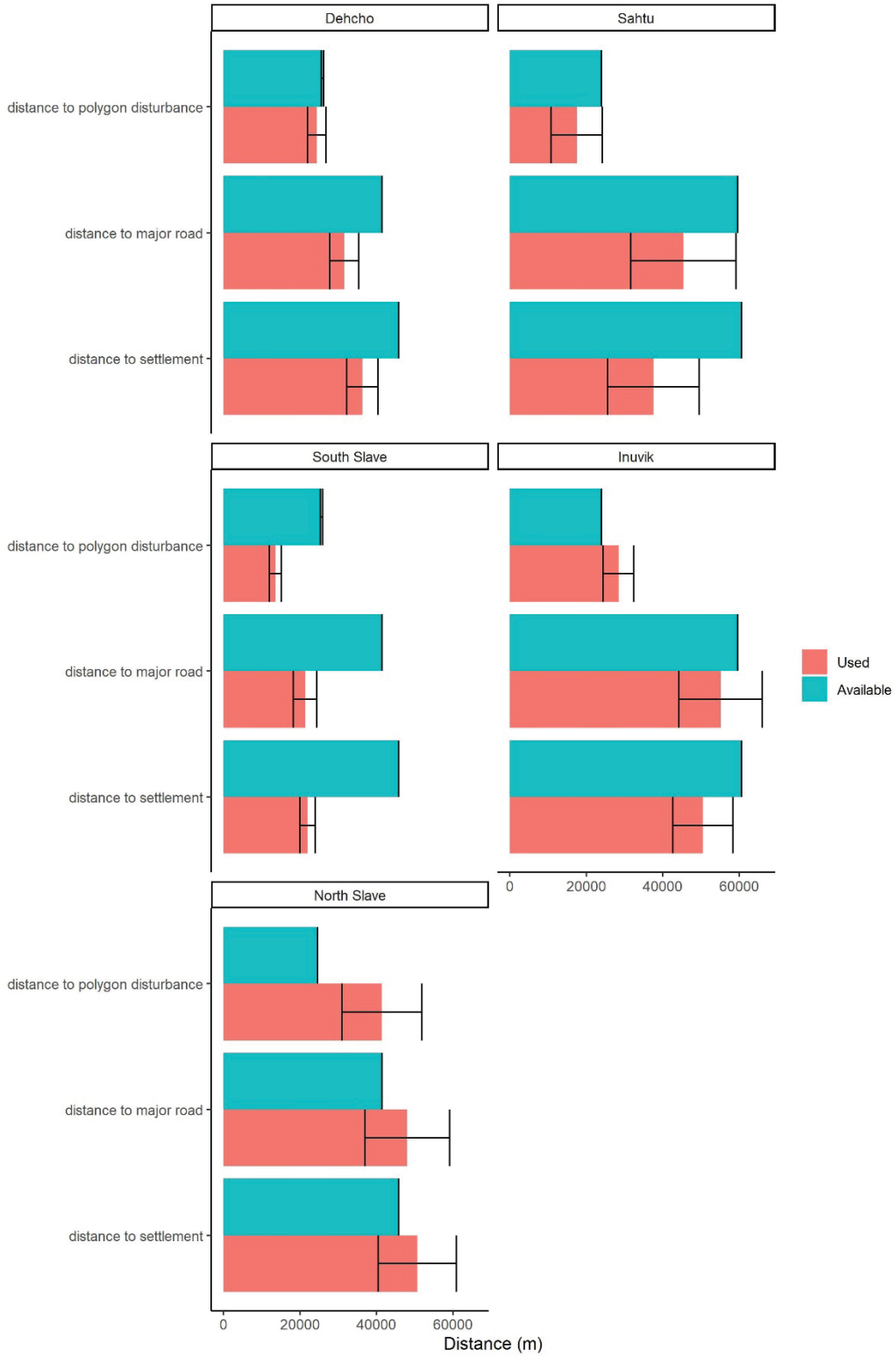


Figure H 40: The mean distances to various anthropogenic disturbances for used (GPS) locations and available (or random) locations among the five regional monitoring areas on a **yearly** basis. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean distance calculated across individual caribou-years.

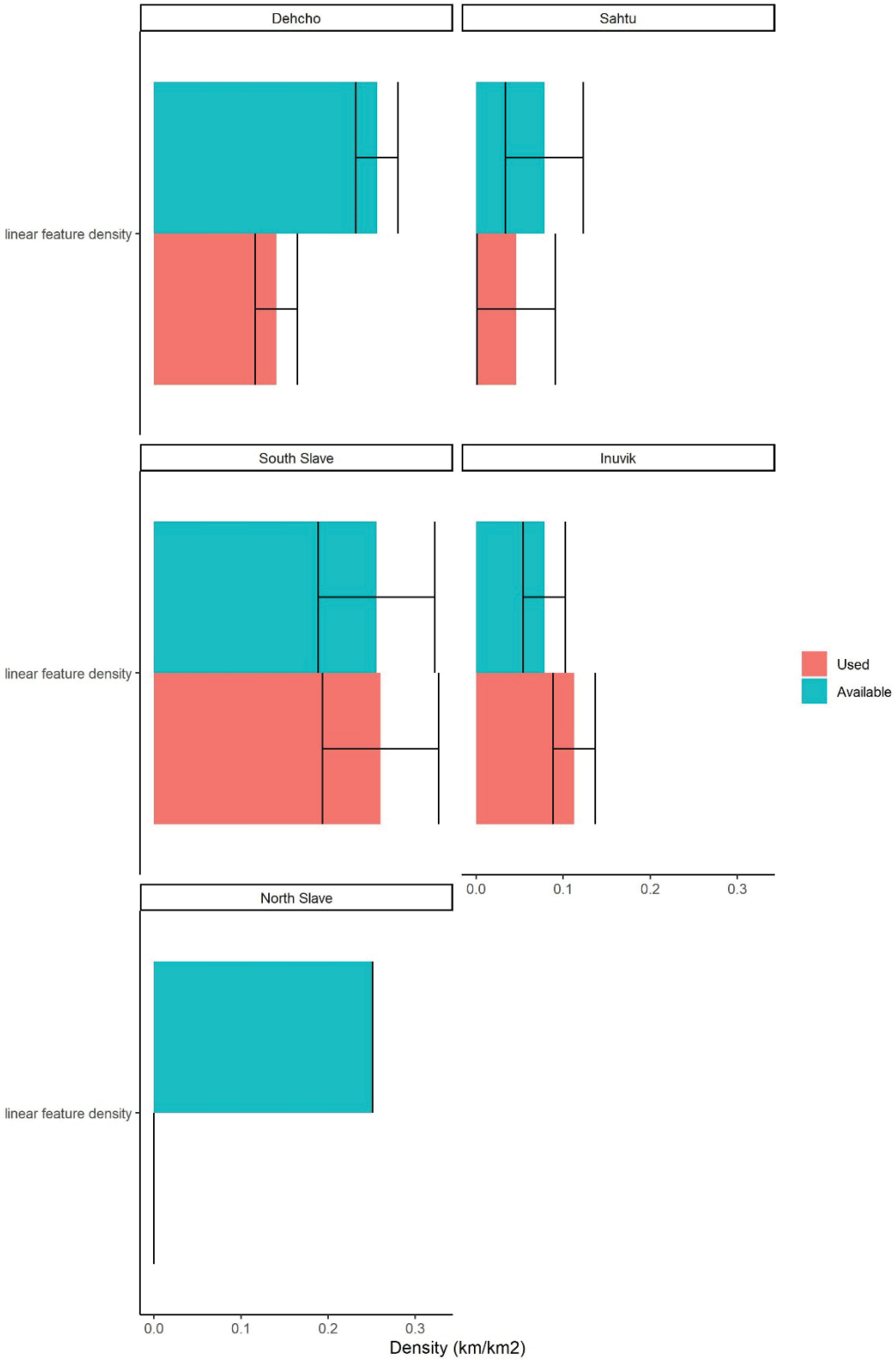


Figure H 41: The mean densities of linear features in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **calving**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean densities calculated across individual caribou-years.

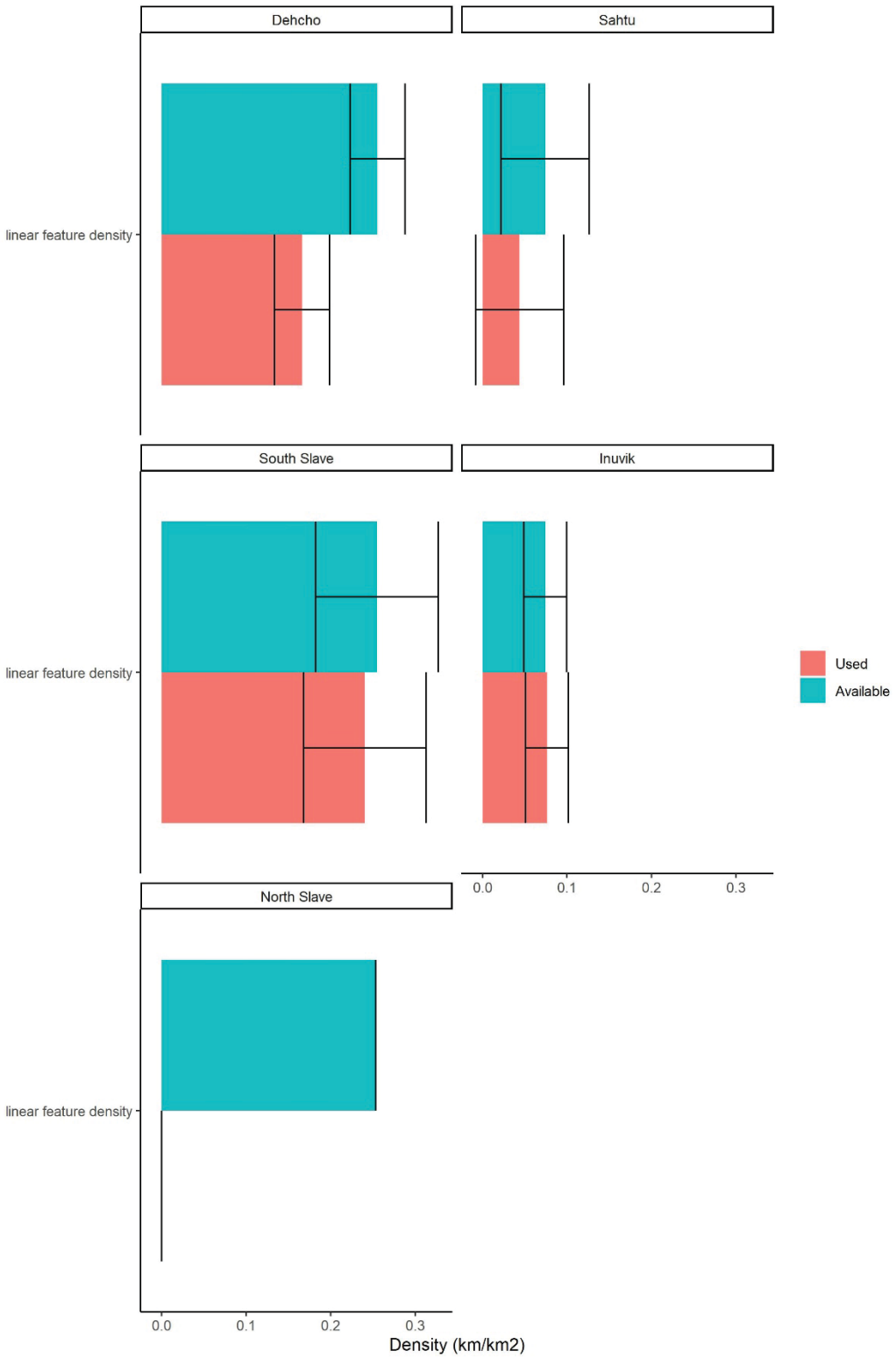


Figure H 42: The mean densities of linear features in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **summer**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean densities calculated across individual caribou-years.

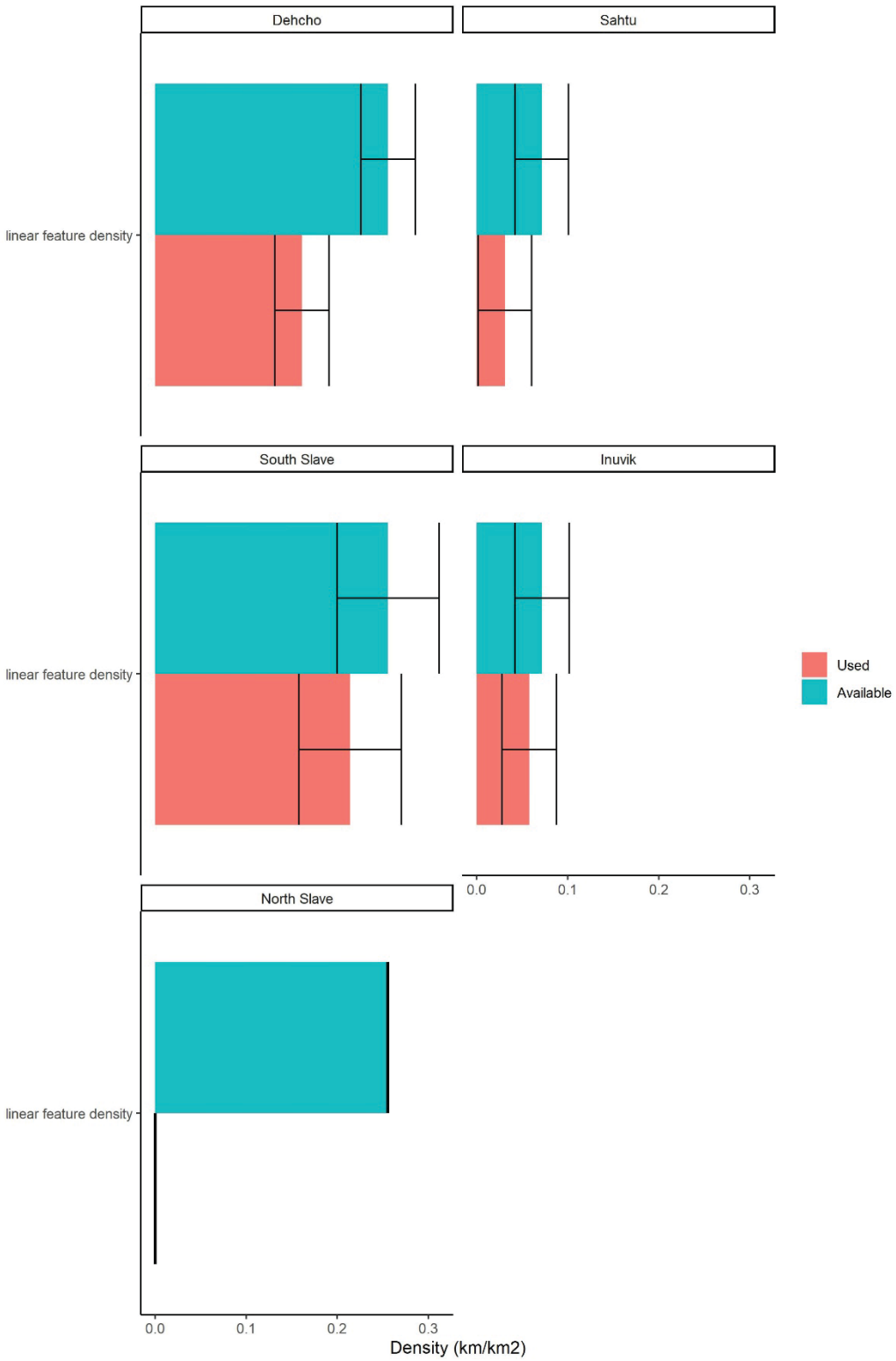


Figure H 43: The mean densities of linear features in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **early fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean densities calculated across individual caribou-years.

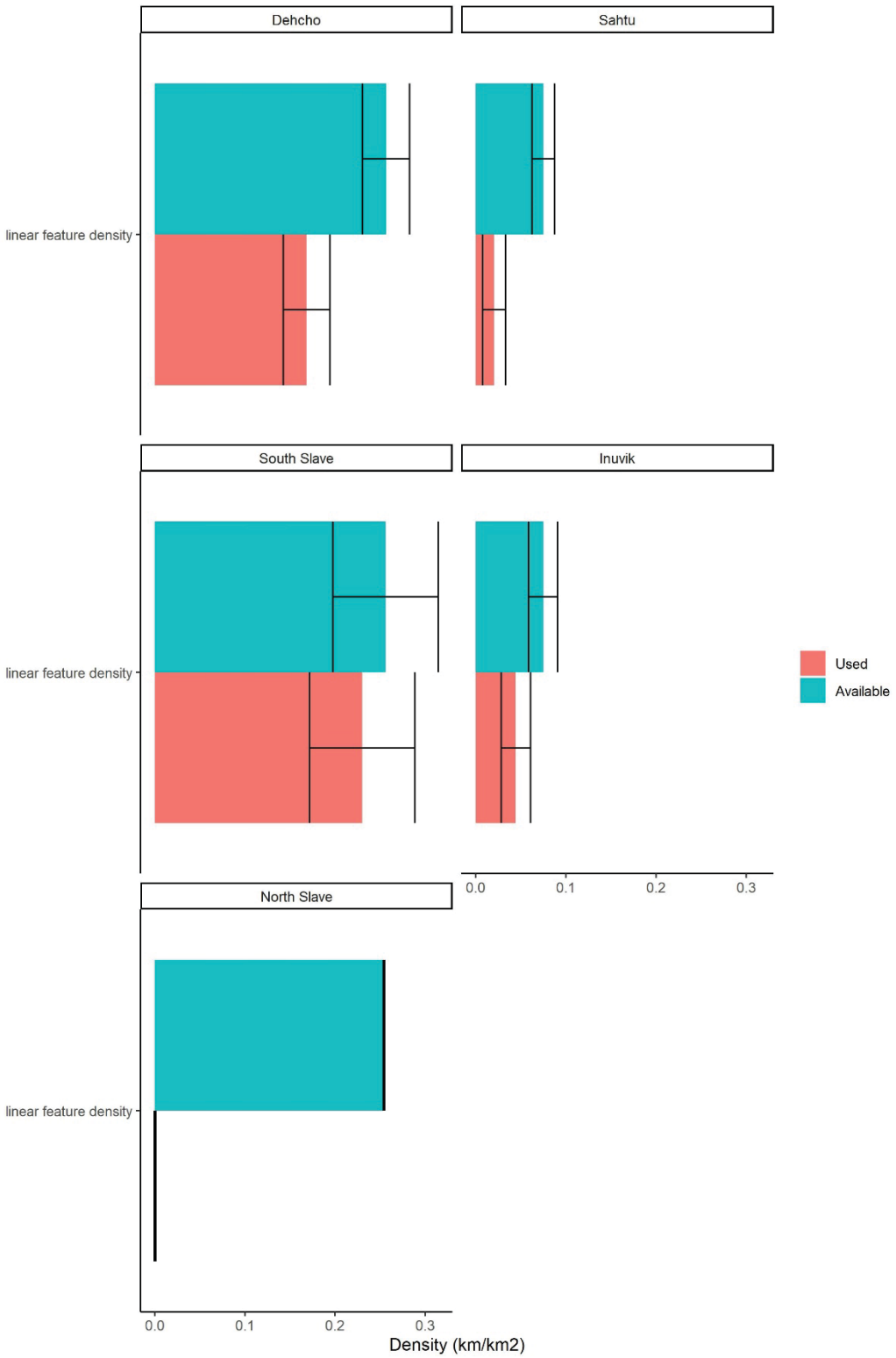


Figure H 44: The mean densities of linear features in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **late fall**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean densities calculated across individual caribou-years.

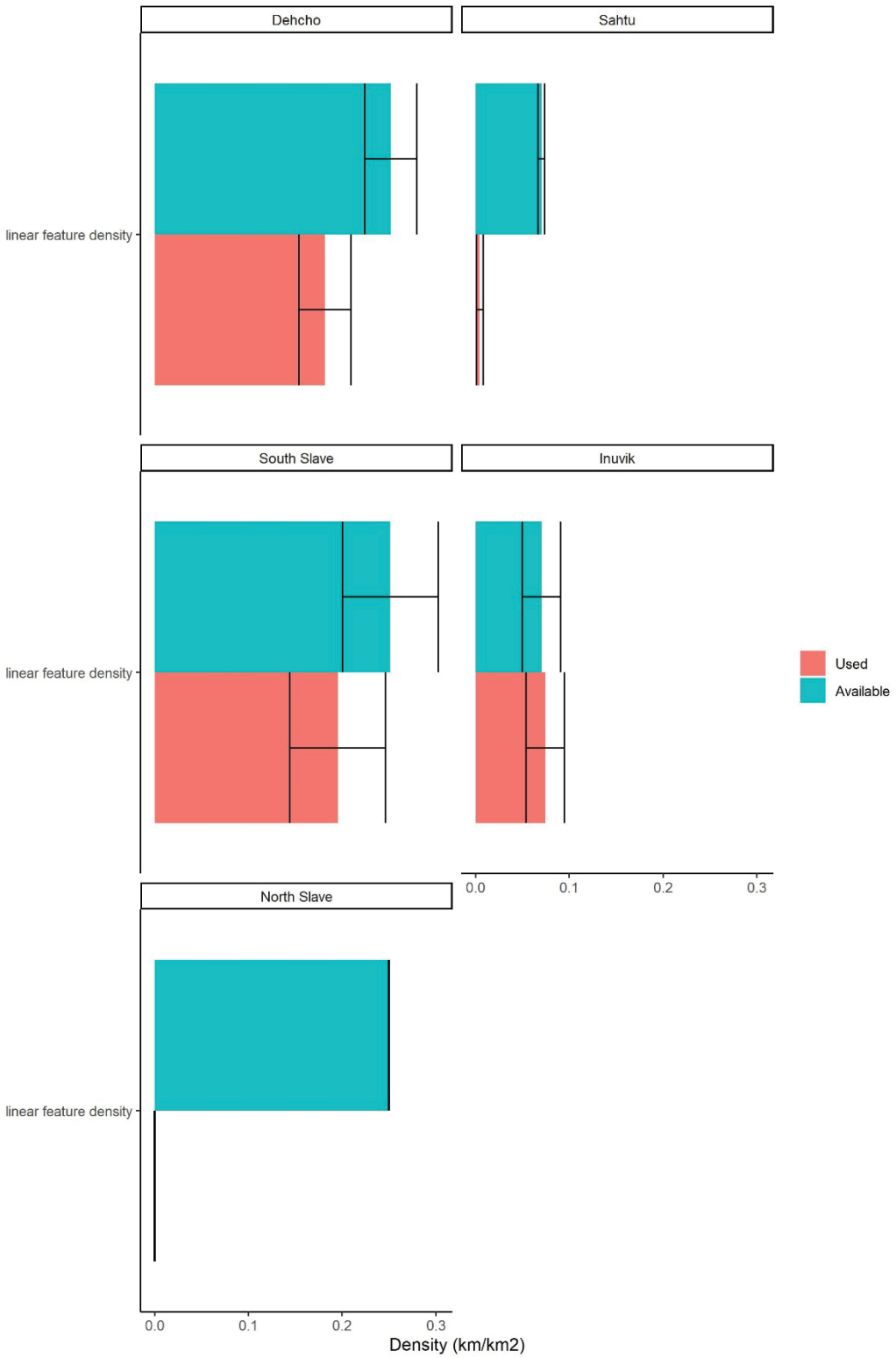


Figure H 45: The mean densities of linear features in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **early winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean densities calculated across individual caribou-years.

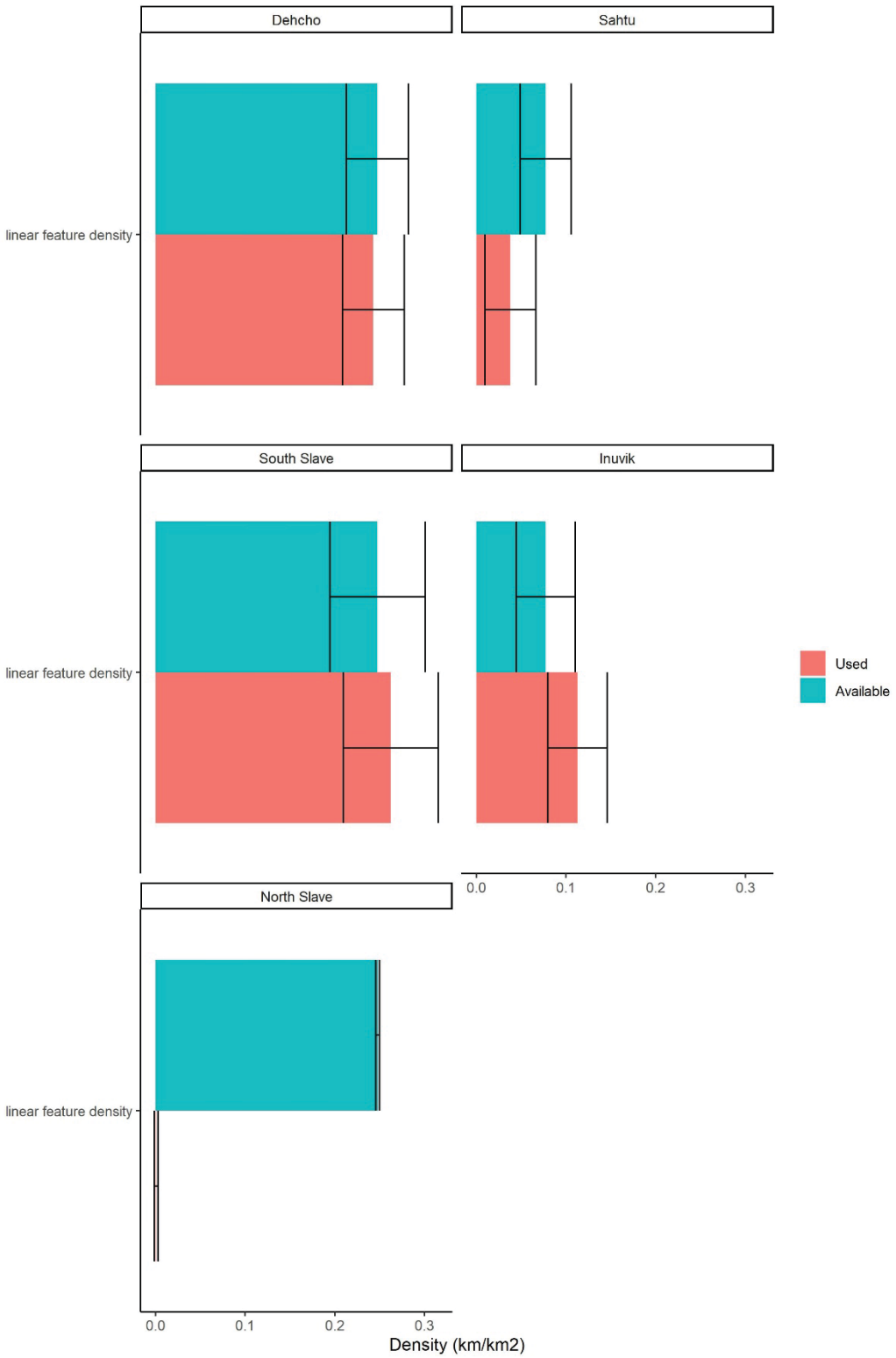


Figure H 46: The mean densities of linear features in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **mid-winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean densities calculated across individual caribou-years.

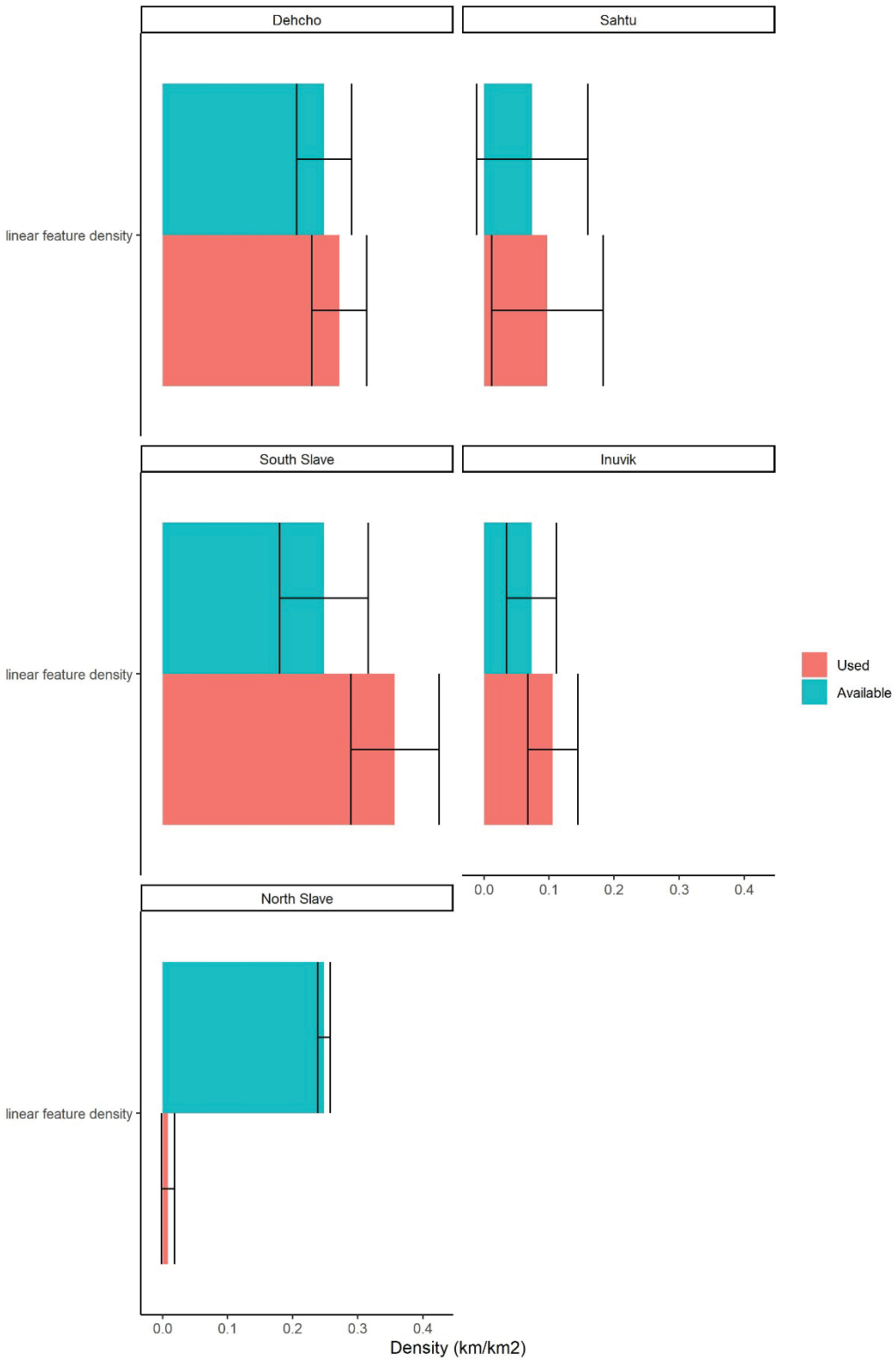


Figure H 47: The mean densities of linear features in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas during **late winter**. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean densities calculated across individual caribou-years.

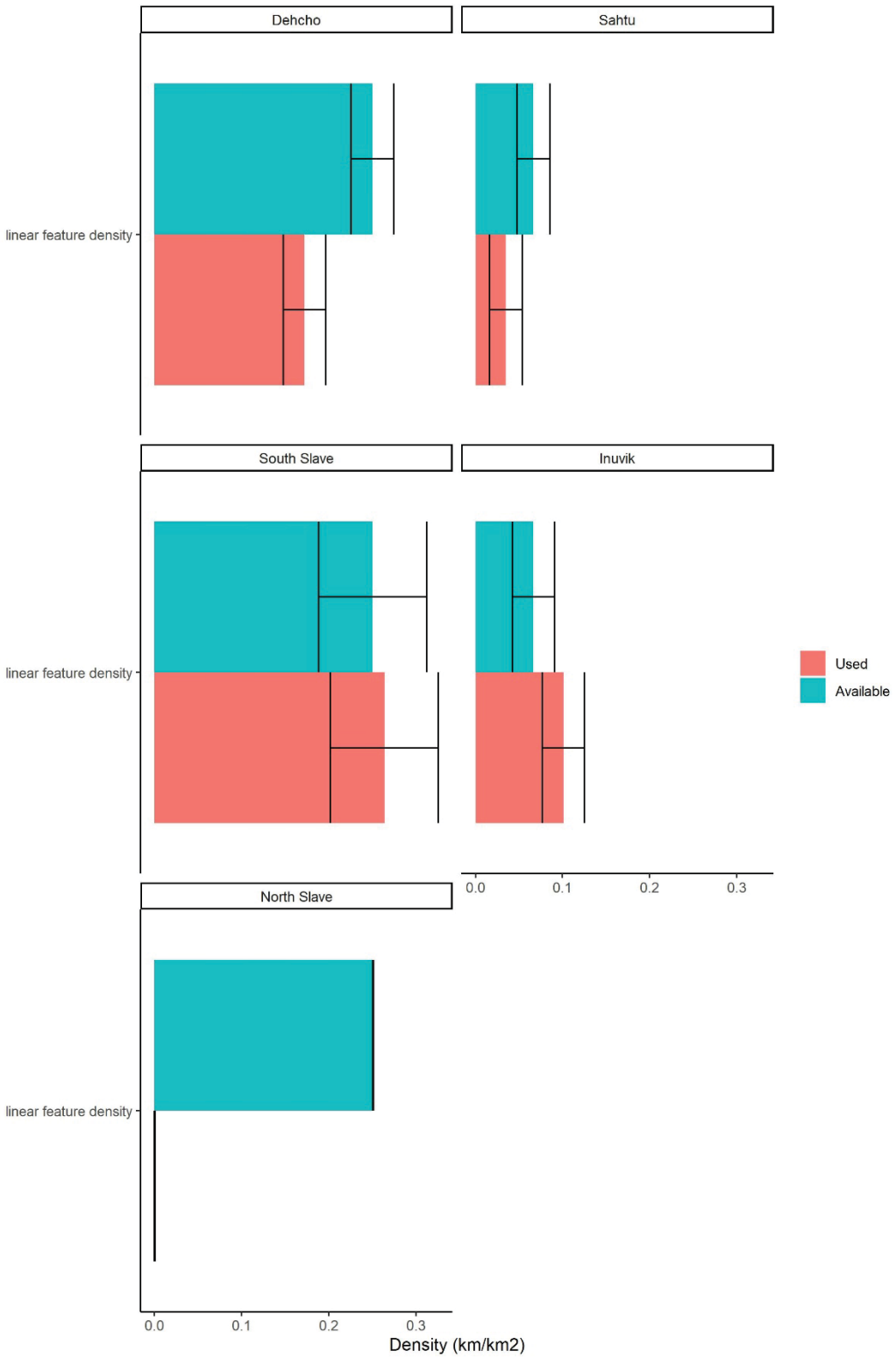


Figure H 48: The mean densities of linear features in a 1-km radius for used (GPS) locations and available (or random) locations among the five regional monitoring areas on a **yearly** basis. Random locations were sampled within the available area defined at a second-order scale. Error bars represent the 95% confidence intervals of the mean densities calculated across individual caribou-years.

APPENDIX I: PREDICTIVE SEASONAL AND ALL-YEAR RESOURCE SELECTION FUNCTION MAPS

The fixed-effect (or population-level) coefficients from each of the 2nd order sand 3rd order seasonal and all-year resource selection function (RSF) models were used to generate predictive maps of habitat selection within the project's study area. The maps represent the predicted relative likelihood of habitat selection based on landscape conditions current to 2017 (i.e. including fires occurring up to 2017). For each map, we partitioned the predicted RSF values for pixels (30-m resolution) into 10 bins to improve visual interpretation of seasonal resource selection by caribou. Cut points between bins were delineated using the same approach as for k-fold cross validation. Specifically, coefficients from a given RSF model were used to predict values for the random locations (n = 40,000) sampled within the combined North and South MCPs used in 2nd order RSF models, and the predicted values for these locations were partitioned into decile bins (i.e., 10 bins with each bin having an equal number of points, which equates to an equal-area binning approach). Note that extrapolating the RSF model to the full study area and binning RSF values based on the above approach causes some inequality in the number of map pixels contained in each category. Bin 1 (dark red) represents the most strongly avoided habitat and Bin 10 (dark blue) represents the most highly selected habitat. Each map includes the outlines for the North and South minimum convex polygons (buffered by 15-km), which were used to define availability for 2nd order RSF models. Any areas outside of these two polygons represent areas where RSF model predictions have been extrapolated beyond the extent of the collar data and inferences about habitat selection in these areas should be treated with greater caution. The NT1 range boundary is included on each of the maps to illustrate where they RSF model has been extrapolated beyond the NT1 range. Inferences about habitat suitability beyond the NT1 range boundary (with the exception of areas south of the NWT/AB/BC border) should similarly be treated with caution as there is less certainty about whether boreal caribou occur in these areas.

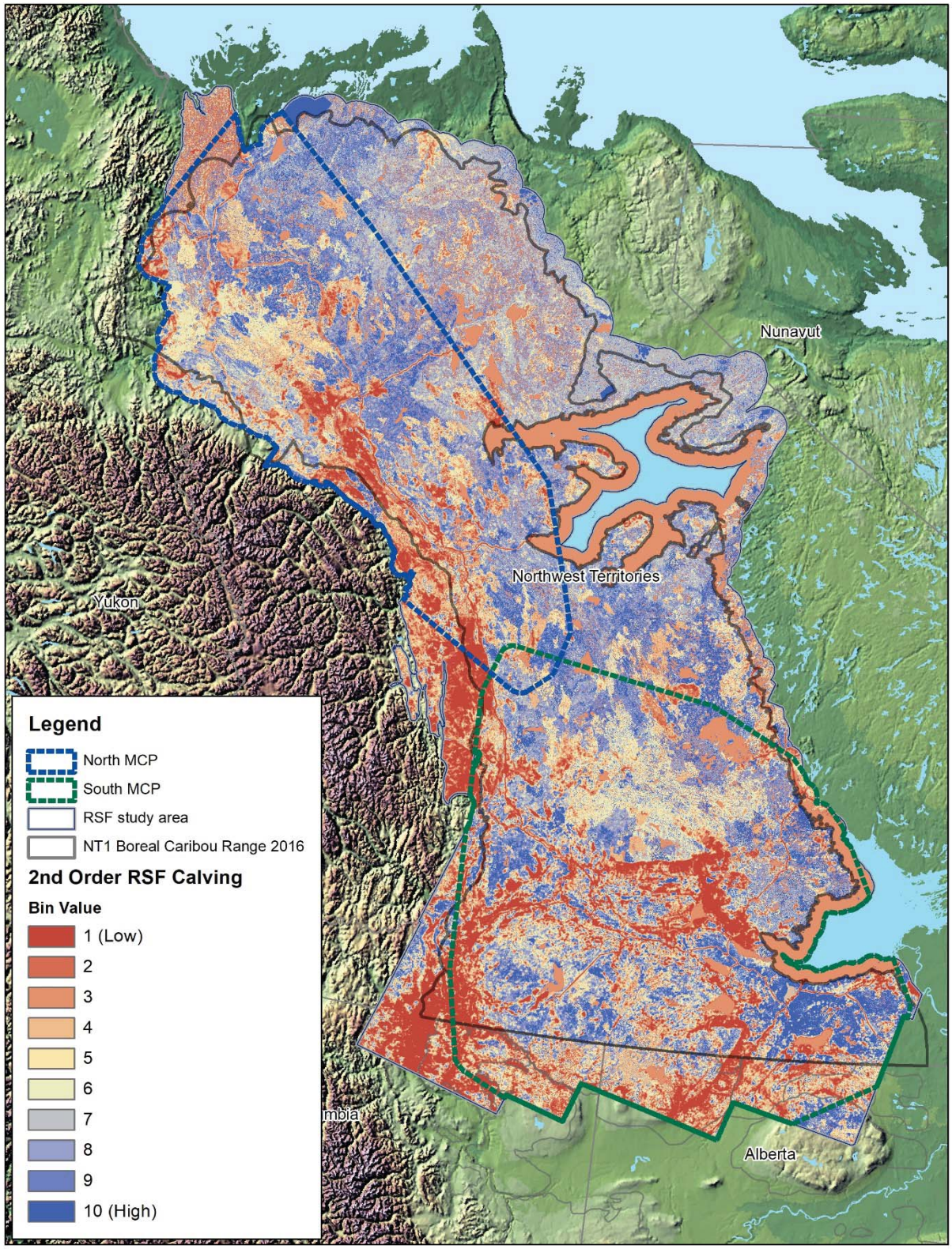


Figure I 1: Map of predicted RSF values at the 2nd order scale during the **Calving** season partitioned into 10 equal area bins.

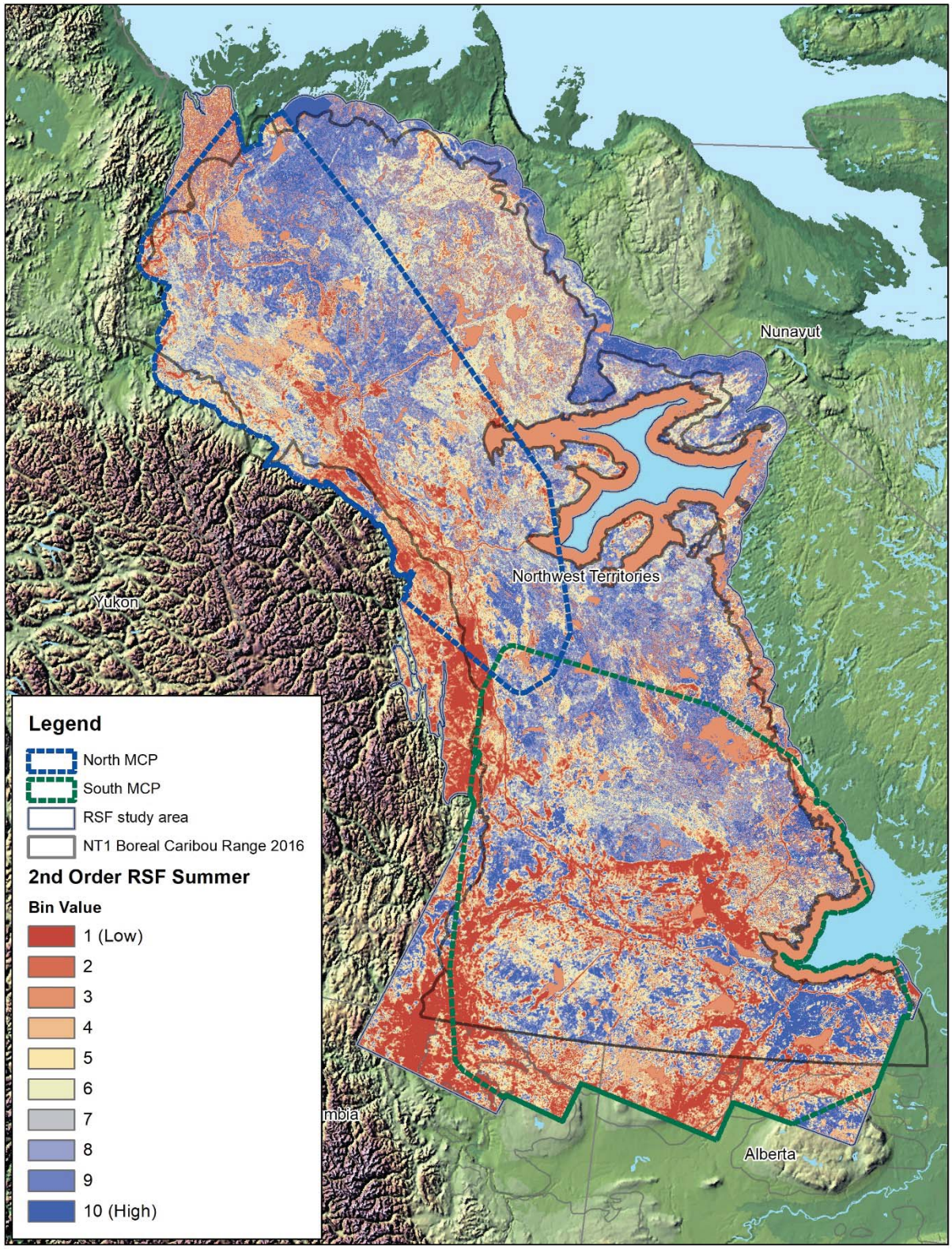


Figure I 2: Map of predicted RSF values at the 2nd order scale during the **Summer** season partitioned into 10 equal area bins.

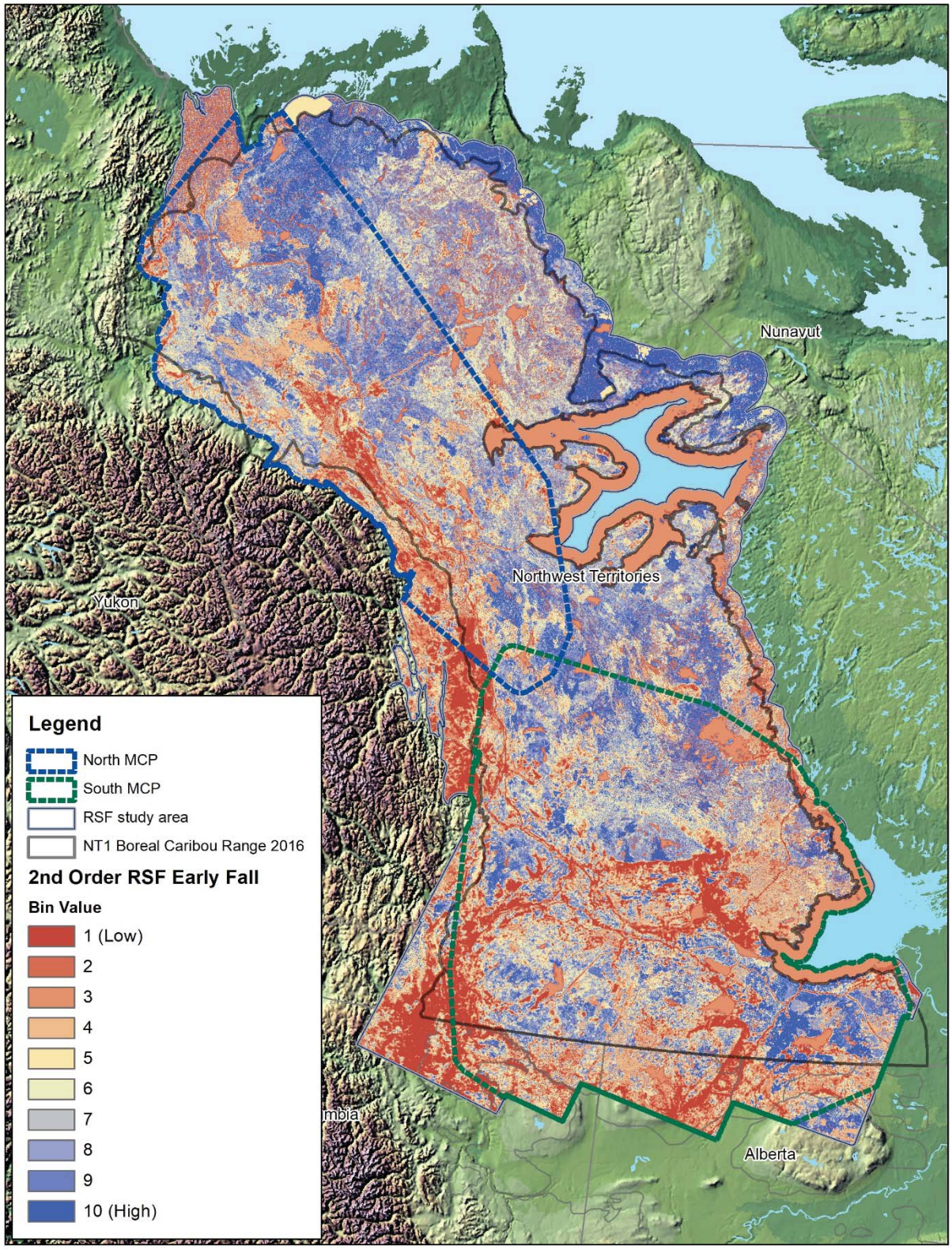


Figure I 3: Map of predicted RSF values at the 2nd order scale during the **Early Fall** season partitioned into 10 equal area bins.

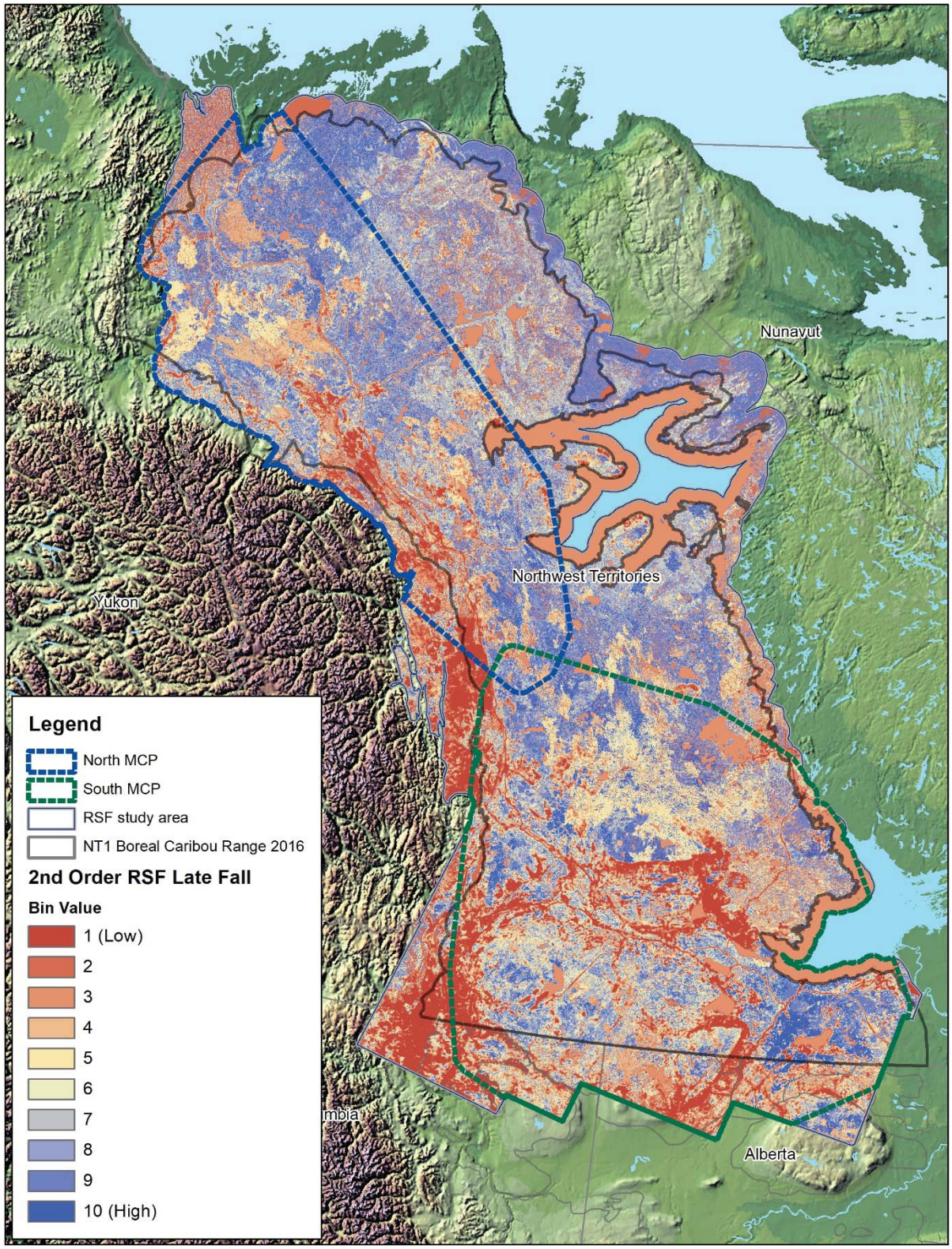


Figure I 4: Map of predicted RSF values at the 2nd order scale during the **Late Fall** season partitioned into 10 equal area bins.

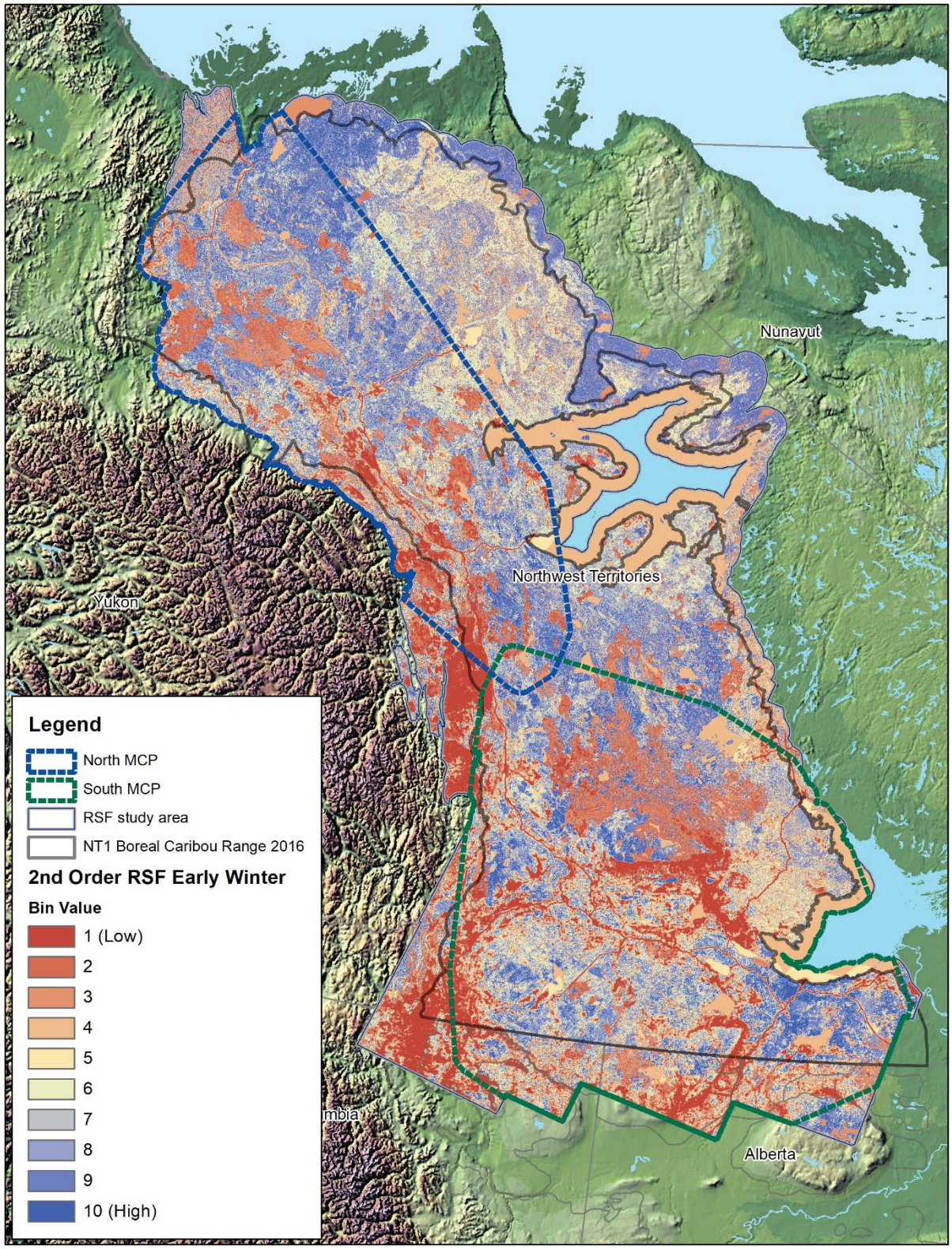


Figure I 5: Map of predicted RSF values at the 2nd order scale during the **Early Winter** season partitioned into 10 equal area bins.

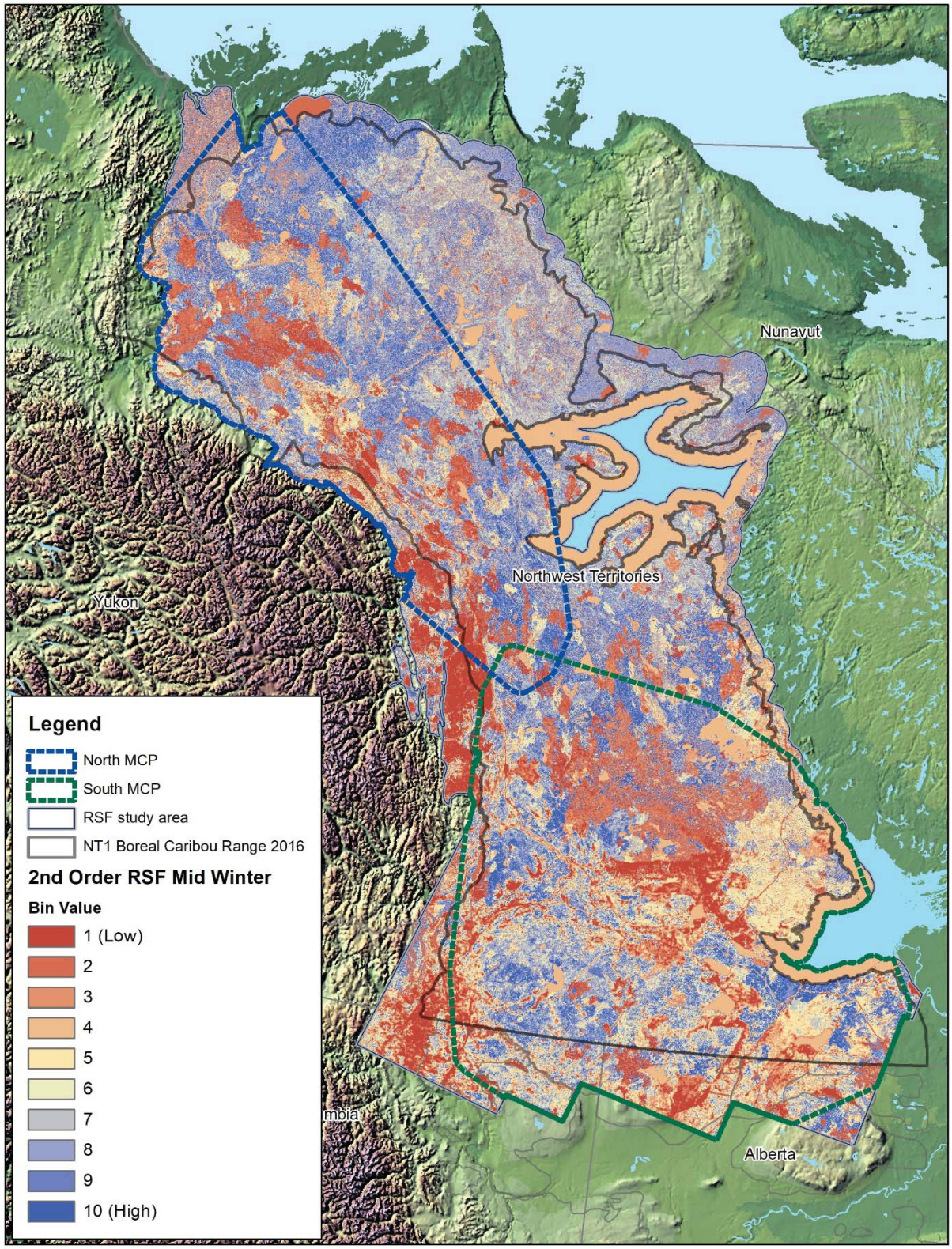


Figure I 6: Map of predicted RSF values at the 2nd order scale during the **Mid Winter** season partitioned into 10 equal area bins.

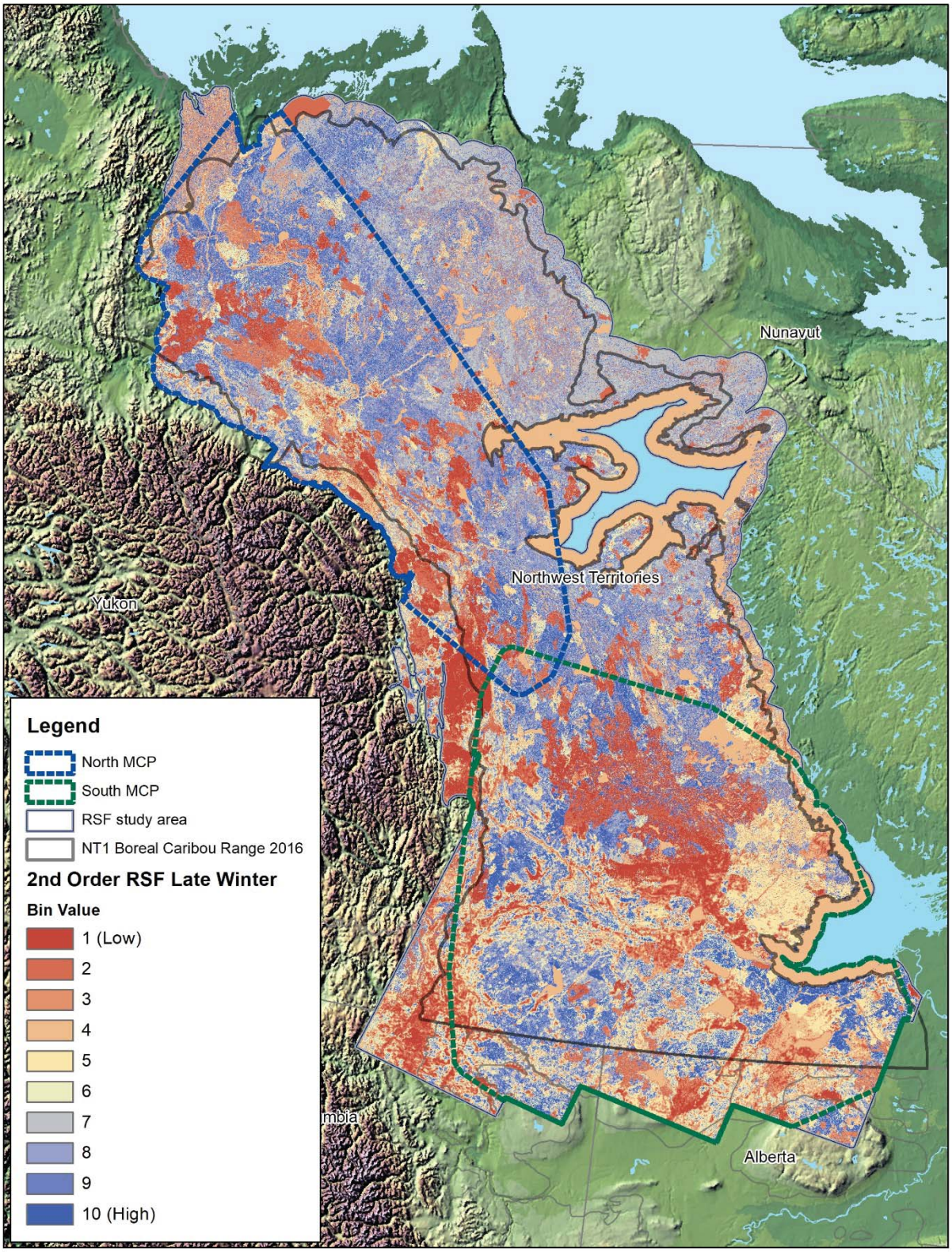


Figure I 7: Map of predicted RSF values at the 2nd order scale during the **Late Winter** season partitioned into 10 equal area bins.

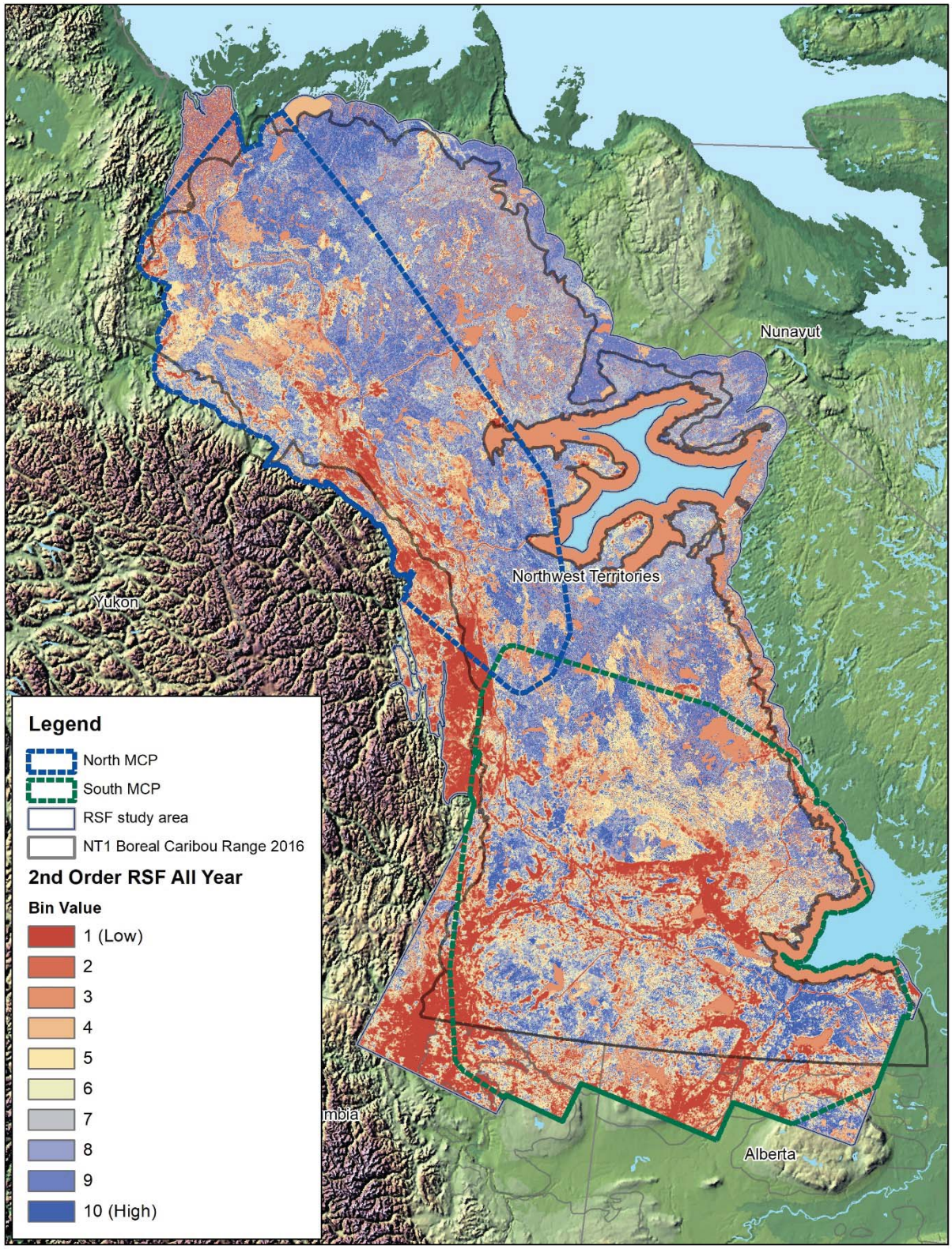


Figure I 8: Map of predicted RSF values at the 2nd order scale from the **All Year** model partitioned into 10 equal area bins.

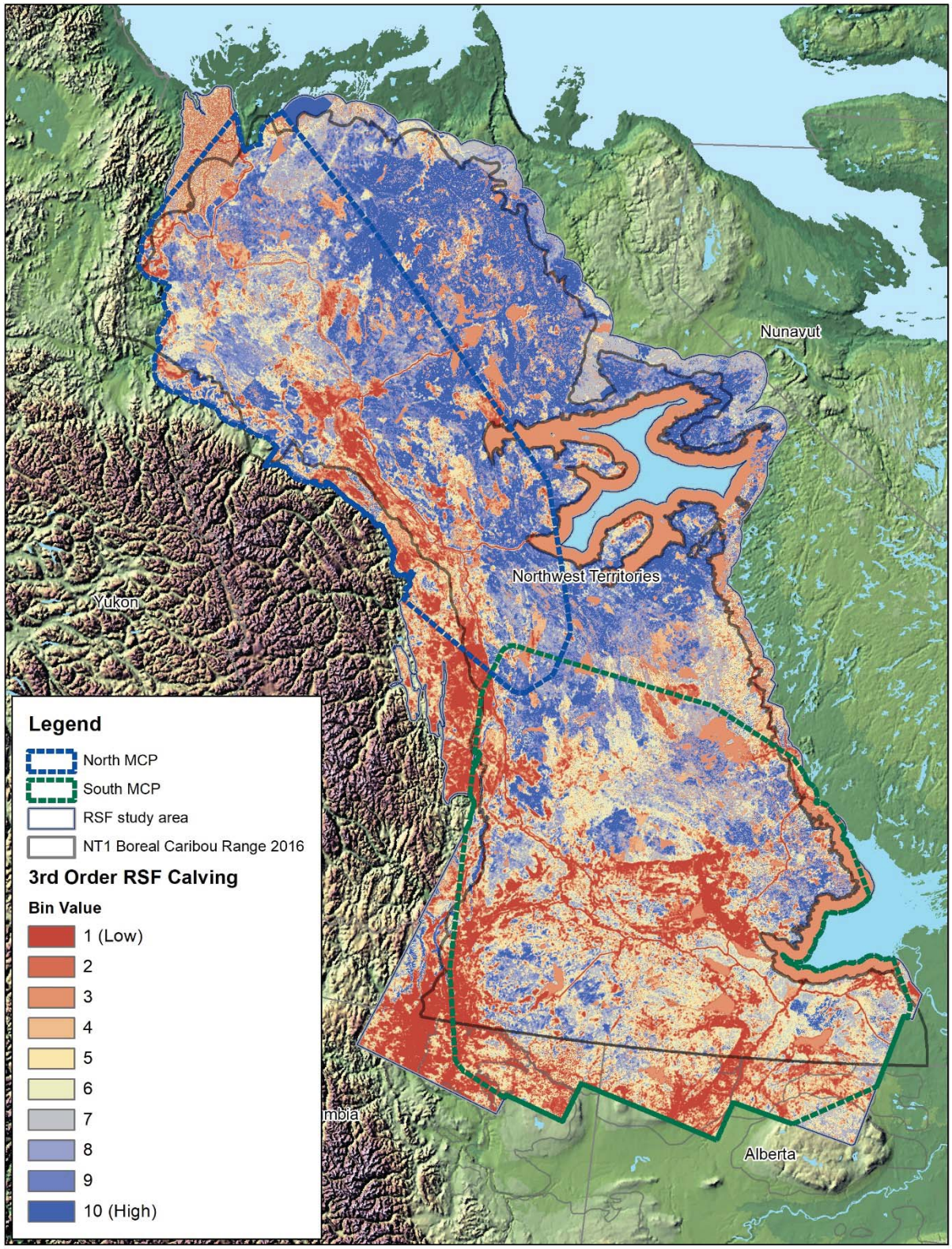


Figure I 9: Map of predicted RSF values at the 3rd order scale during the **Calving** season partitioned into 10 equal area bins.

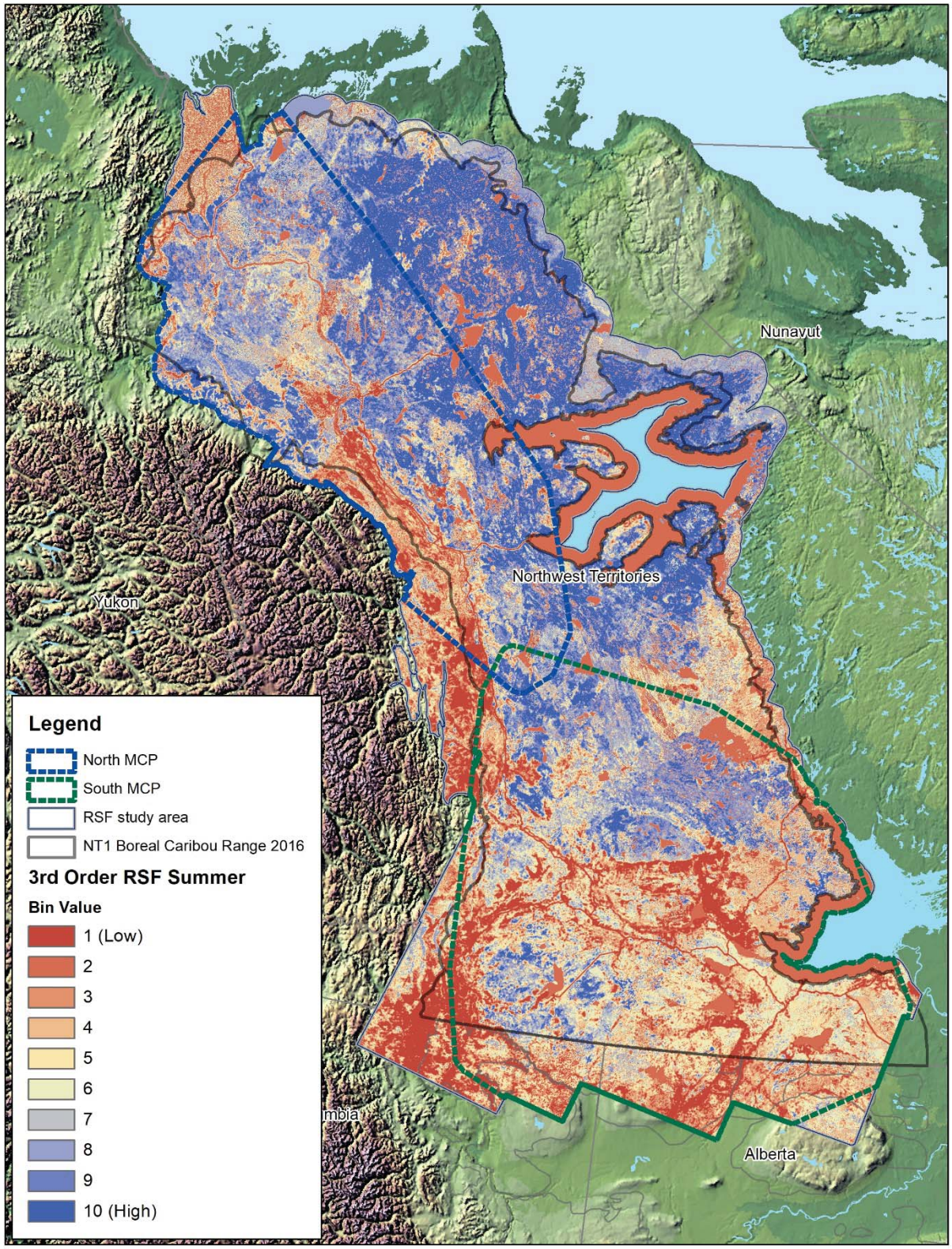


Figure I 10: Map of predicted RSF values at the 3rd order scale during the **Summer** season partitioned into 10 equal area bins.

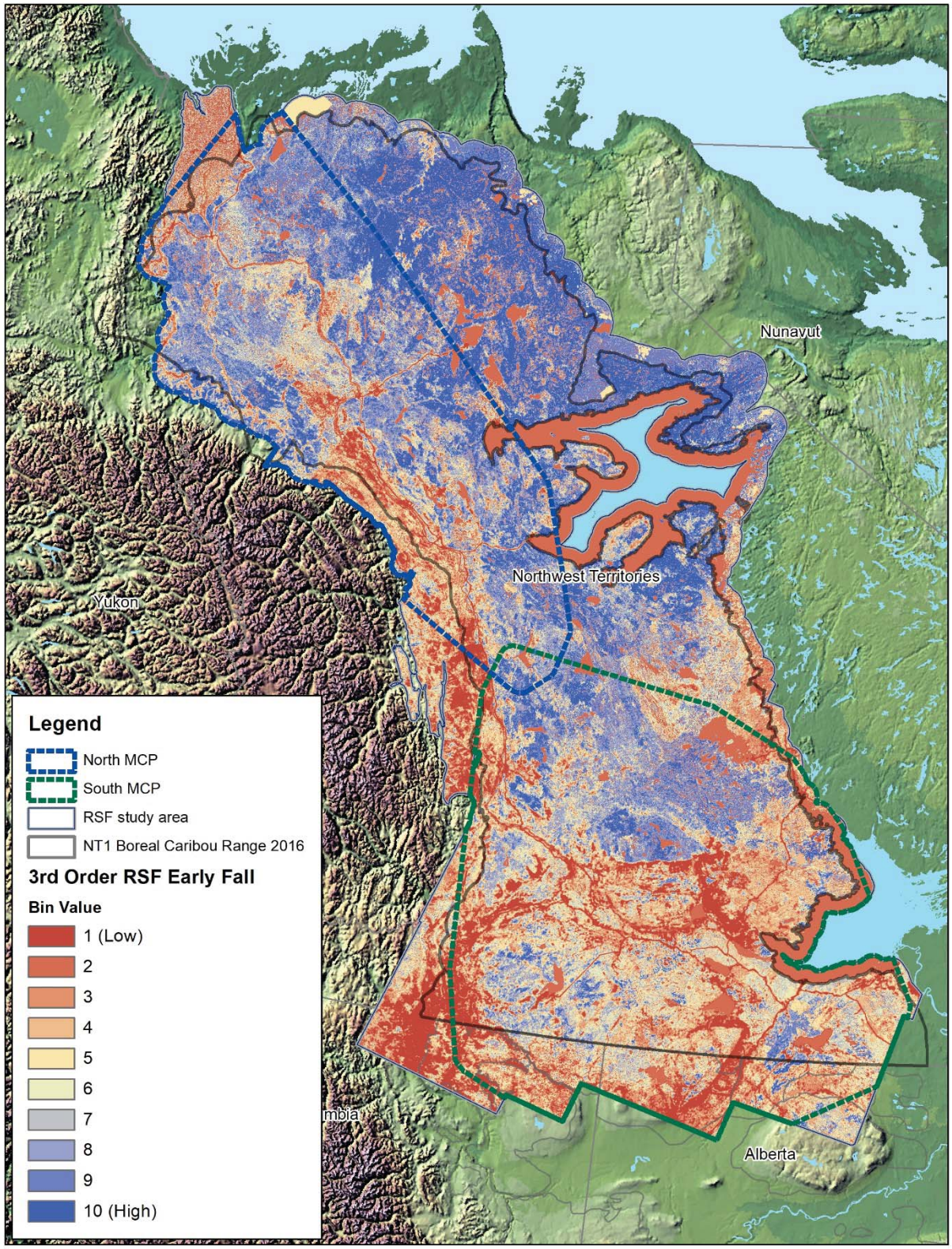


Figure I 11: Map of predicted RSF values at the 3rd order scale during the **Early Fall** season partitioned into 10 equal area bins.

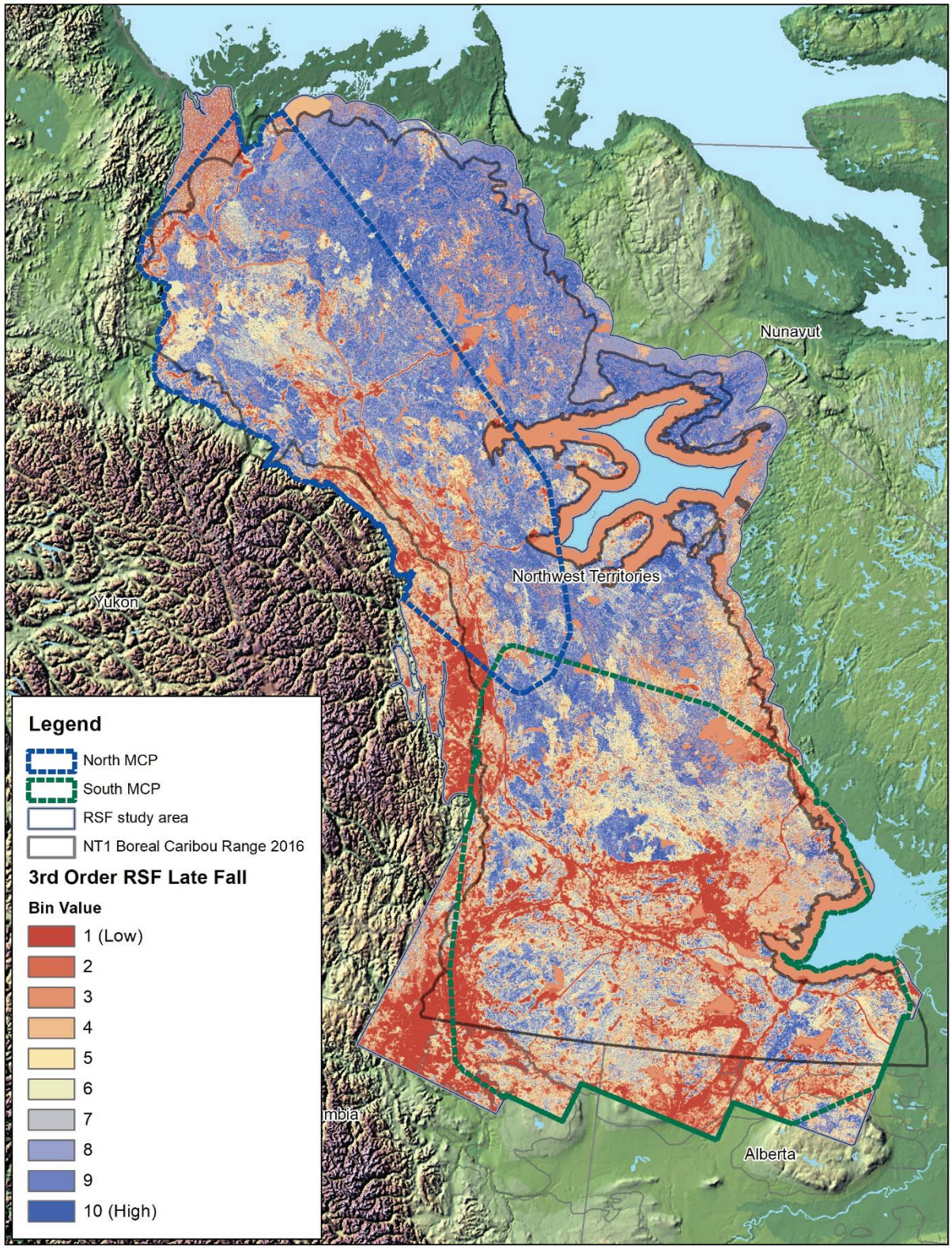


Figure I 12: Map of predicted RSF values at the 3rd order scale during the **Late Fall** season partitioned into 10 equal area bins.

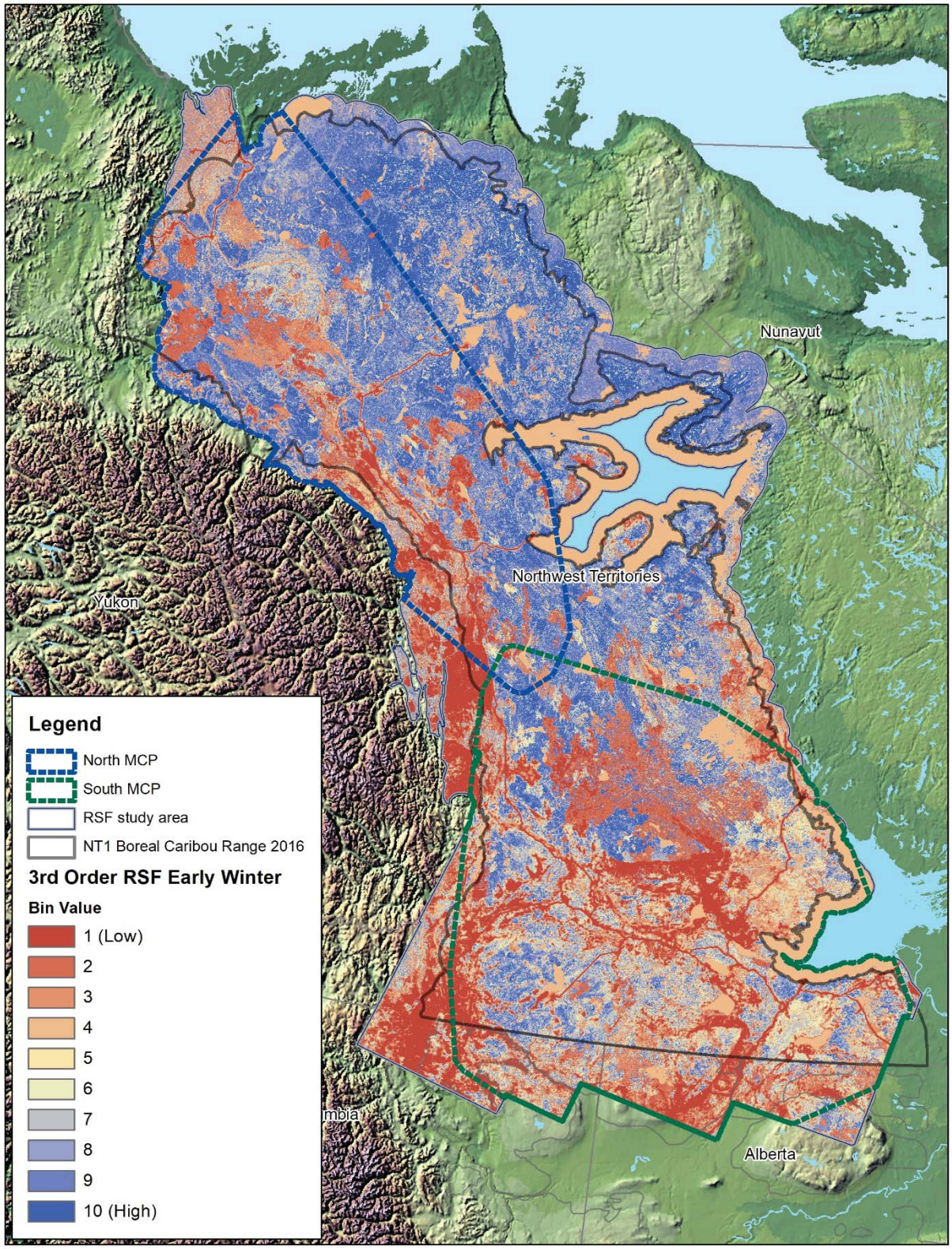


Figure I 13: Map of predicted RSF values at the 3rd order scale during the **Early Winter** season partitioned into 10 equal area bins.

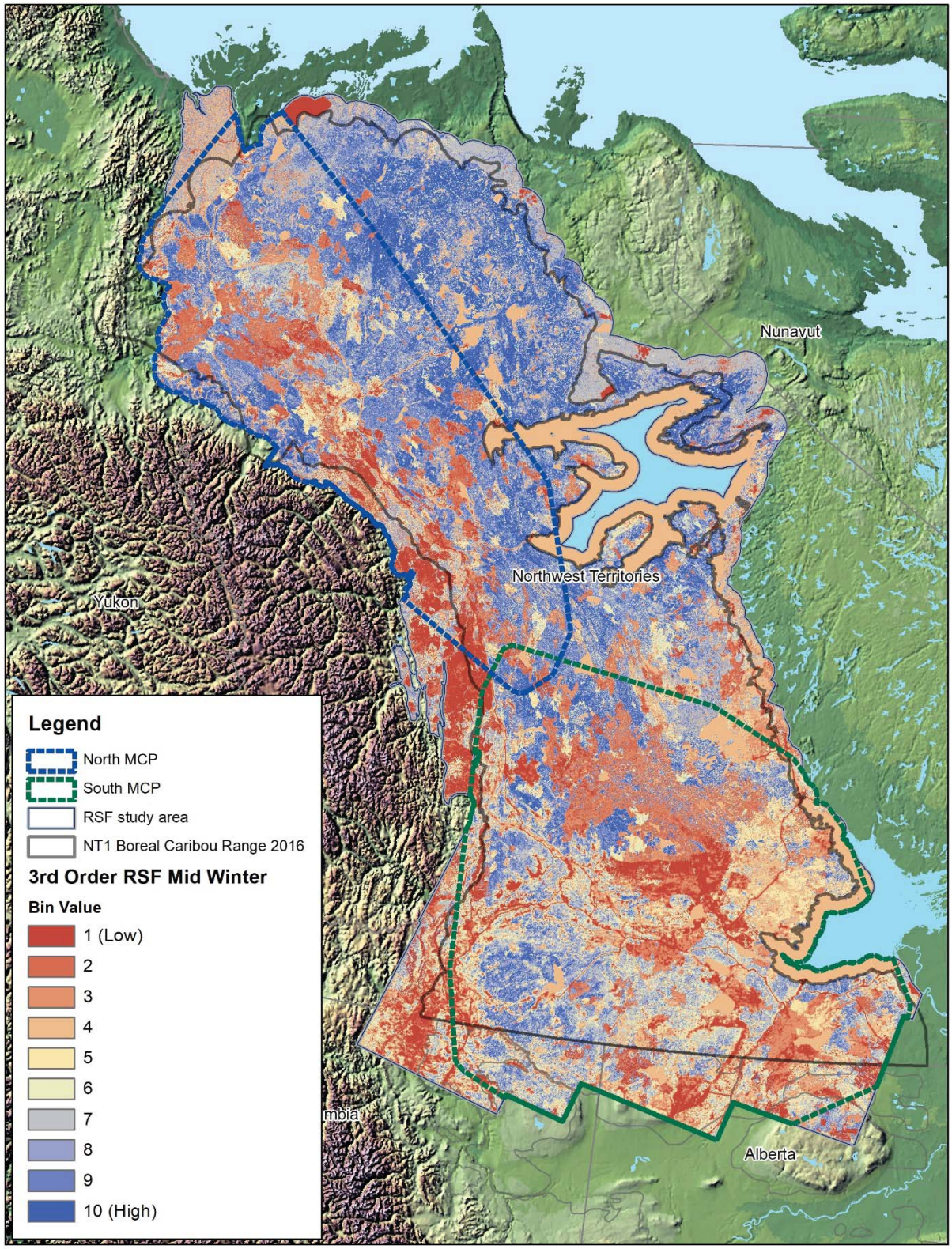


Figure I 14: Map of predicted RSF values at the 3rd order scale during the **Mid Winter** season partitioned into 10 equal area bins.

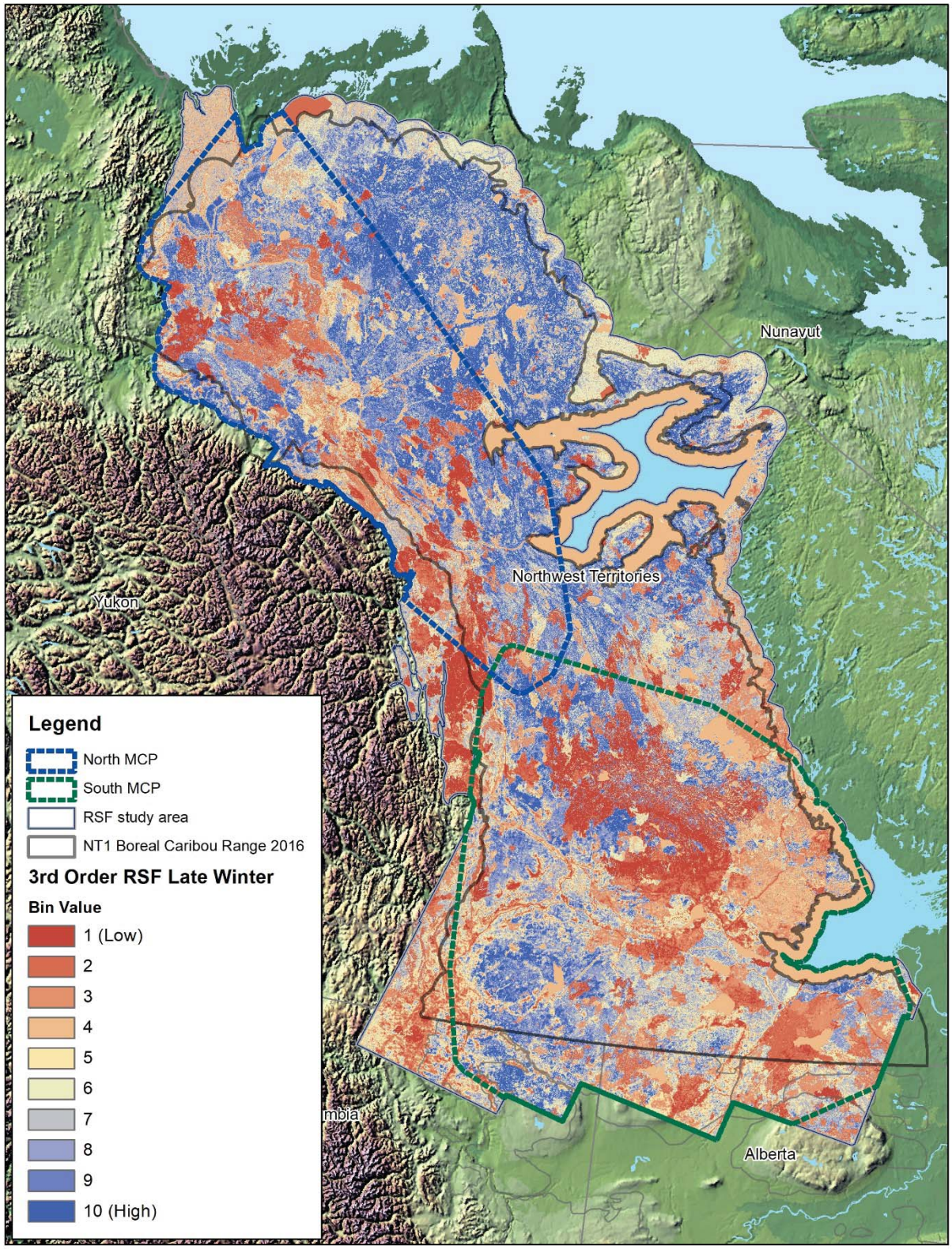


Figure I 15: Map of predicted RSF values at the 3rd order scale during the **Late Winter** season partitioned into 10 equal area bins.

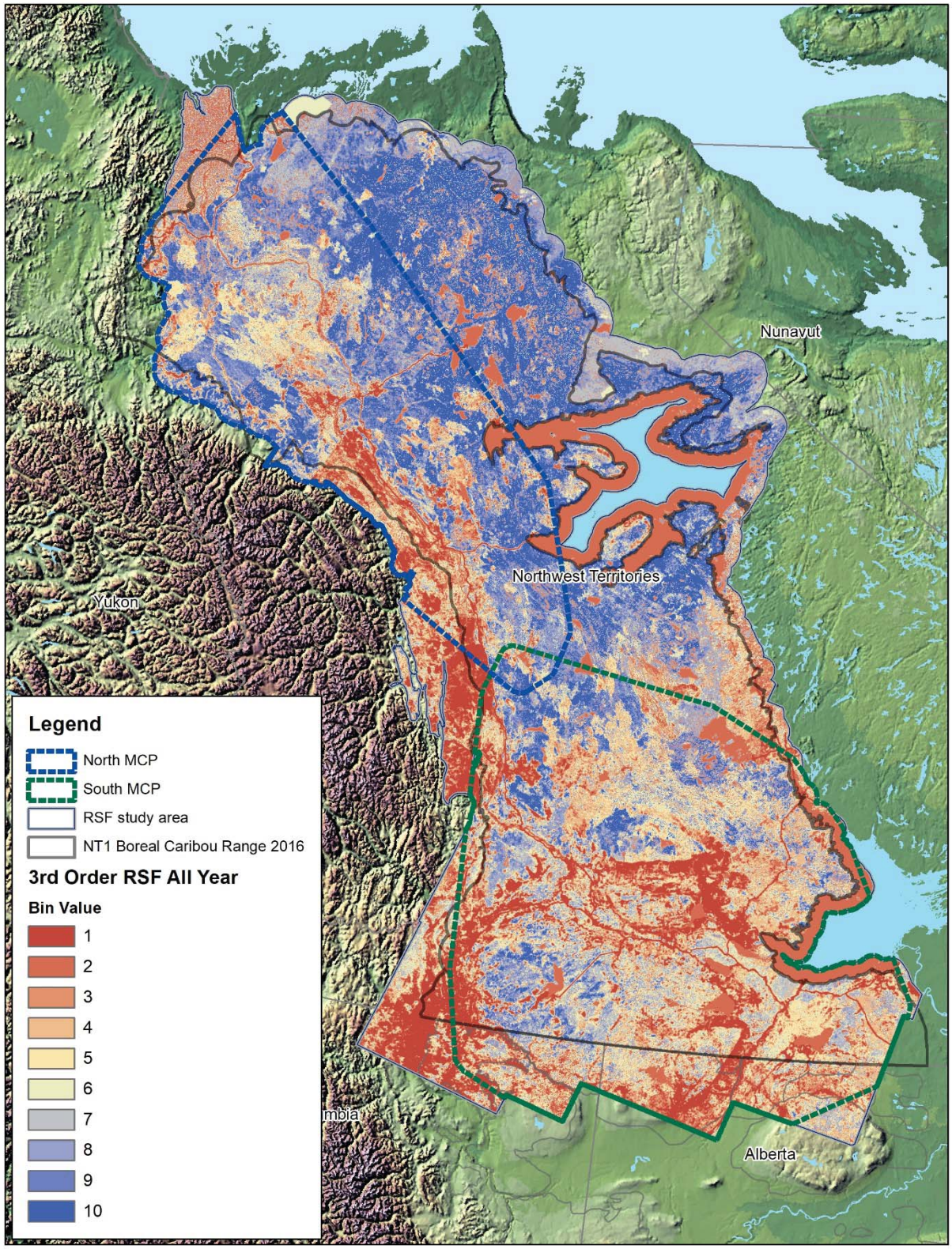


Figure I 16: Map of predicted RSF values at the 3rd order scale from the **All Year** model partitioned into 10 equal area bins.

Environment Canada Environnement Canada



Operational Framework for Use of Conservation Allowances

Canada

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Operational Framework for Use of Conservation Allowances

This framework sets the parameters, based on existing legislated authorities, practice and policy, for how and when conservation allowances should be used or recommended by Environment Canada. Conservation allowances are the third step of the mitigation hierarchy, a three-step approach that first examines options to avoid and minimize environmental impacts. The framework applies where Environment Canada has a role related to the review or approval of proposed land- or resource-use activities, including those that occur on federal lands or waters, projects, or activities that are subject to federal legislation, actions that would affect Aboriginal and/or treaty rights, or when Environment Canada has environmental protection or conservation objectives that would be affected by the proposed activity.

The use of conservation allowances by Environment Canada under this framework will be monitored and the results, including both demonstrated ecological success and other indicators (e.g. percent of proponents who successfully meet all the provisions of their allowance agreement) will be tracked. These allowances will be reviewed in the context of periodic evaluations of departmental programs and initiatives that employ them.

To support the framework, Environment Canada will develop implementation guidance for Environment Canada practitioners on the use of conservation allowances. This guidance would address the specific goals and objectives of legislation and policy, as well as specific issues related to the nature of the biological element (e.g. wetlands versus species at risk).

1. Background

Conservation allowances (also referred to as conservation offsets) provide measurable conservation outcomes through implementation of project-based actions. Conservation allowances provide a balancing effect by establishing new environmental features (such as habitat or ecosystem types) to compensate for those that have been impacted. Conservation allowances address the “residual impacts” that remain after measures to avoid and minimize are adopted.

The goal of conservation allowances is to achieve environmentally responsible development by replacing ecosystem functions that would be lost as a result of proposed land- or resource-use activities. When used effectively, conservation allowances help to conserve and protect important environmental resources. For example, a conservation allowance could entail securing and preserving high-quality replacement habitat to compensate for the loss of species’ habitat due to a land- or resource-use activity.

2. Current Practice Internationally and in Canada

Conservation allowances have long been used in Canada and internationally to achieve conservation objectives for wetlands, biodiversity, endangered species and other valued ecosystem components.

Most Government of Canada experience with conservation allowances has been gained through two policies:

- The Policy for the Management of Fish Habitat, which was developed and administered by the Department of Fisheries and Oceans, and supported the former habitat protection provisions of the *Fisheries Act*;
- Canada's Federal Policy on Wetland Conservation (FPWC), which provides a framework for undertaking measures such as conservation allowances to address impacts on wetlands in relation to the federal environmental assessment process.

In addition to federal government experience, a number of provinces, including British Columbia, Alberta, Nova Scotia, New Brunswick and Prince Edward Island, also have experience with or are developing approaches to the use of measures such as allowances.

Internationally, the U.S. Wetland Mitigation program is one of the longest-standing programs for conservation allowances (referred to in their policy and legislation as offsets). As described in section 404 of the U.S. *Clean Water Act*, adverse impacts on wetlands, streams and other aquatic resources must be avoided and minimized to the extent practicable. For impacts that cannot be avoided, compensatory mitigation is required to replace the loss of wetland and resource functions within the watershed. Also in the U.S., conservation banking for endangered species was first undertaken in the early 1990s and is enabled by the U.S. *Endangered Species Act*, which requires federal agencies to ensure that their actions do not jeopardize listed species.

Australia, New Zealand and the EU also have experience in the use of measures such as conservation allowances.

3. Environment Canada's Authorities Related to Conservation Allowances

Opportunities for the consideration of conservation allowances may arise through processes administered under the *Migratory Birds Convention Act, 1994* (MBCA), the *Species at Risk Act* (SARA), the *Canadian Wildlife Act* (CWA) and *Canadian Environmental Assessment Act, 2012* (CEAA 2012) that could allow Environment Canada to consider a proposal for conservation allowances as a means of mitigating residual environmental effects. However, each case will have to be determined on its own set of facts to see whether the proposal is consistent with the purposes of the Act in question and effectively addresses the environmental effect.

Under CEAA 2012, the Minister of the Environment, the National Energy Board and the Canadian Nuclear Safety Commission may consider in the environmental assessment process any mitigation measures that the decision maker considers appropriate for the "elimination, reduction or control of the adverse environmental effects of a designated project", including "restitution for any damage to the environment caused by those effects through replacement, restoration, compensation or any other means." Such mitigation measures may include a range of possible actions, including conservation allowances.

When used in relation to authorities provided by MBCA or CWA, conservation allowances could involve de-listing an identified portion of a sanctuary or wildlife area and, at the same time, adding a new portion of land (the allowance area) to the listed area. This provides Environment Canada with a means of dealing with allowance proposals involving federal lands or, in the case of the CWA, public lands as defined under the Act, where appropriate. The decision to list or de-list a migratory bird sanctuary or a wildlife area will be subject to the discretion of the Governor in Council upon recommendation of the Minister and will require clear justification for why it should be adopted. For example, if a third-party proponent requests the ability to conduct activities on an area within an existing National Wildlife Area, the boundaries could be amended to exclude the area proposed for impact and to include a new area that has been deemed an acceptable replacement. Once the new allowance area is added to a listed protected area, it would be subject to the enforcement provisions either for migratory bird sanctuaries under MBCA or wildlife areas under CWA.

In limited cases, allowance proposals can be considered under SARA, provided the permitting requirements under section 73 are met and the allowance helps meet the goals of the Act. Section 73 of SARA enables the government to enter into an agreement or to issue a permit authorizing a person to engage in an activity affecting a listed wildlife species, any part of its critical habitat or the residences of its individuals provided that all reasonable alternatives have been considered and the best solution adopted, all feasible measures will be taken to minimize the impact of the activity on the species or its critical habitat or the residences of its individuals, and the activity will not jeopardize the survival or recovery of the species. In cases where an allowance activity is aligned with SARA's goals, Environment Canada could include an allowance as part of permit conditions to further protect the species in order to make that proposed impact acceptable.

The use of conservation allowances could also be established through agreements under the *Department of Environment Act* (DOE Act). Under the DOE Act, the Minister of Environment has authority to enter into agreements (which could include conservation allowances) for issues concerning the mandate of the Department, as long as the agreement is not contrary to or inconsistent with the purposes of other statutes falling within the Minister's mandate.

Lastly, the FPWC, established in 1991, provides a framework for mitigating proposed impacts to wetlands that are connected to federal actions and provides Environment Canada with some of its earliest ongoing experience in the application of conservation allowances. The FPWC commits all federal departments to the overall goal of no net loss of wetland functions (1) on federal lands and waters, (2) in areas affected by the implementation of federal programs where the continuing loss or degradation of wetlands has reached critical levels, and (3) where federal activities affect wetlands designated as ecologically or socio-ecologically important to a region.

4. Key Participants

***Environment Canada*:** As administrator of the framework, Environment Canada's role includes evaluation of the appropriate application of conservation allowances within the mitigation hierarchy, review of proposed allowances, entry into allowance agreements or approval of permits, providing advice to other federal departments or provincial authorities, review of monitoring reports and compliance promotion activities.

***Allowance proponent*:** The allowance proponent is the entity responsible for the undertaking of a land- or resource-use activity expected to have adverse impacts on the environment. In most cases, the proponent will also be responsible for the development of the conservation allowances, including developing and submitting a proposal to Environment Canada or the responsible authority. Allowance proponents may work with third-party organizations to undertake any part of the allowance proposal or development, implementation or monitoring.

***Other government departments*:** The Framework is an Environment Canada document, but partnering with other government departments will be necessary in many cases. For example, partnering with Aboriginal Affairs and Northern Development Canada will be sought for some activities located in the North. Where impact avoidance is not possible, the Framework's approach to determining the appropriate design and use of conservation allowances could be used to contribute to increased consistency in consultation and accommodation for impacts on s.35 or treaty rights.

Similarly, collaboration with the Department of Fisheries and Oceans will be sought for conservation allowances and activities with impacts related to the mandates of both departments. In cases where other federal departments are involved, Environment Canada would provide advice to and work with the regulatory authority, as required.

***Other levels of government*:** While other levels of government are not bound by this framework, their partnership will be essential in areas of shared or overlapping jurisdiction. The most frequent partnering is expected with provincial governments for activities being undertaken on provincial Crown lands or privately owned lands not under federal jurisdiction. Where there is overlap in federal and provincial conservation allowance programs, a single conservation allowance may suffice if it meets the criteria of both jurisdictions.

Environment Canada will consult and work with Aboriginal governments when conservation allowances are contemplated for impacts from proposed land- and resource-use activities that would affect Aboriginal and/or treaty rights or lands and when a proposal is made for an allowance activity to be situated on Aboriginal lands.

5. Determining whether to use conservation allowances

Conservation allowances are the last step of the mitigation hierarchy, a conceptual framework that, in its basic form, has three steps:

- Avoid proposed impacts;
- Minimize proposed impacts; and
- Address any residual environmental effects that cannot be avoided or sufficiently minimized with the use of conservation allowances.

For each of these steps, all alternatives should be considered, with the "best practicable option(s)" being applied in each case. The best practicable option means the best method for preventing or minimizing the proposed adverse effects of a land- or resource-use activity on the environment having regard, among other things, to:

- The nature of the proposed impact and the sensitivity of the receiving environment to adverse effects;
- The financial implications, and the effects on the environment, of that option when compared with other options;
- The current state of technical knowledge and the likelihood that the option can be successfully applied; and
- The ability to successfully mitigate the effects, for example, by replacing the affected habitat with a new area performing similar ecological functions to those that were lost.

The options considered should include the possibility of not proceeding with the land- or resource-use activity.

Consideration of whether to use conservation allowances should be undertaken as early as possible for a planned land- or resource-use activity when it is apparent that there will be residual effects after all practicable avoidance and minimization measures have been adopted. The analysis of alternatives should be documented, and the level of effort devoted to the analysis should be commensurate with the risks associated with the proposed land- or resource-use activity.

Applying the mitigation hierarchy

- ***Identify all potential adverse impacts*** *– including direct, indirect and cumulative.* Include not only physical impacts but also other effects on species, individuals or functional habitat such as increases in noise or predators.
- ***Determine whether potential impacts can be avoided.*** The viability of avoidance and mitigation options should be examined with respect to ecological risk, whether ecological features are replaceable, economic viability, land ownership, technological feasibility and logistics in light of the overall project. A relatively high cost of an alternative may not necessarily make it "impracticable."
- ***Determine whether potential impacts can be minimized.*** This should consider modifications such as changes to engineering designs, alternative construction techniques, contingency planning, timing considerations and location considerations.

- ***Determine whether residual effects may still be expected.*** After all avoidance and minimization options have been fully considered, determine whether conservation allowances would be an appropriate means to address residual environmental effects.

Other considerations regarding the appropriate use of conservation allowances
Once the avoidance and minimization steps of the mitigation hierarchy have been applied, the decision on whether to implement a conservation allowance will also be influenced by a number of other factors:

- The proposed plan for providing allowances must meet the legislative authorities of any relevant Act and, in certain circumstances, informed by the conservation objectives of Environment Canada. Conservation allowances will not be automatically required for every residual impact.
- The proposed conservation allowance must have a high probability of ecological success.
- Where the proponent is not able to secure full ownership of an ecologically and geographically appropriate tract of land, it should be ascertained whether the proponent has sufficient capacity to deliver allowances that will provide for the desired conservation benefits, or whether another approach to mitigation is needed.
- Another jurisdiction may have established a conservation or land-use plan that adequately addresses the proposed impact. The measures put in place by the other jurisdiction would need to be reviewed carefully to ensure that Environment Canada's allowance criteria are addressed. For example, a provincial or regional land-use plan may contemplate expected land- or resource-use activities and set aside protected areas ahead of time in anticipation of the adverse environmental impacts associated with these expected activities. In this case, the protected area could function as a "habitat bank" from which future allowances could be obtained.

6. Allowance Design Elements

The following allowance design elements reflect international best practices for conservation allowances and are to be used as the starting point in the development of a conservation allowance. The design elements should be applied case-by-case based on the legislative framework under which the allowance is being applied, potential environmental impacts of the proposed land- or resource-use activity and desired socio-ecological outcomes as well as consideration of Canada's unique conservation goals and needs.

The allowance design elements are:

Equivalency: ***Conservation allowance projects should compensate for adverse impacts by protecting, enhancing or restoring equivalent ecological function at another site.***
Ecological functions are processes (such as nutrient cycling or seed dispersal) that are carried out or enabled by an ecosystem and that are necessary for the self-maintenance of that ecosystem. Analysis of equivalency should consider both quality (provision of similar or dissimilar ecological function) and quantity of ecological functions in the context of conservation priorities. Provision of similar habitat types or ecosystem functions provide a starting point for the design of a conservation allowance.

In some cases, a conservation allowance may be designed to provide greater than equivalent ecological functions in order to account for identified risks, such as that the allowance will not be fully successful. Whatever the unit of measurement, the ratio of the conservation allowance habitat area to impacted habitat should be greater than 1:1 in all cases, and normally at least 2:1. There will be instances where much higher ratios are appropriate; for example, experience in other jurisdictions in North America shows use of ratios ranging from 3:1 to 40:1. The choice of ratio for each allowance will be case-specific, based on an assessment of a number of factors (e.g. impact type, severity and duration, site characteristics, existing regional mitigation ratios, uncertainties).

Additionality: ***Conservation allowances should provide ecological protection beyond what would be provided under a business-as-usual scenario.*** "Additionality" ensures that the new ecological feature(s) provided by the conservation allowance replace what has been lost through land or resource development, providing an overall balance between what is lost and what is gained. The following criteria should be assessed in order to establish whether an allowance is additional:

- *Does the allowance result in incremental conservation benefits?* (E.g. actions to create, enhance, restore or rehabilitate habitat, or measures to preserve existing habitat that is under threat.)
- For allowances that propose to preserve existing habitat*, is that existing habitat under identified threat and does the proposed allowance extend effective legal protection that responds to that threat?* This may be achieved, for example, through land trust ownership and management.
- *Can proponents demonstrate that the proposed allowance is additional to existing legislation, regulations, programs, land-use plans and funding?* If the allowance action has already received funding, been incentivized or is required, does it build upon the existing actions in a clearly identified way?
    - If no legislative or funding commitment has been put in place to implement an existing conservation program or land-use plan, an allowance designed to implement some aspect of that plan may still be considered additional if it meets federal conservation allowance criteria.
    - Where there is overlap in the allowance requirements of two jurisdictions, a single allowance may suffice in some cases. However, the measures put in place by another level of government or federal department would need to be reviewed carefully.
    - In addition, a single allowance may be proposed to meet the conservation allowance requirements related to more than one federal act or policy. For example, an environmental assessment may consider a proposed impact to a migratory bird sanctuary on federal lands, and the allowance design could account for both CEAA objectives and MBCA objectives.

Location: ***The location of a conservation allowance should have comparable ecosystem values, such as species composition and habitat structure, and should be determined based on an assessment of the relevant species and habitat/ecosystem context.*** Where information to make the above assessments is unavailable, the default location of a conservation allowance should be as close to the original site of impact as possible.

However, in some cases it may be most ecologically appropriate to undertake an allowance at a site that is distant from the site of impact. For example, a more distant allowance site may be appropriate if it is able to provide greater ecological benefit to the affected species.

Timing: ***The preference is for conservation allowances that can be implemented before the adverse impacts of proposed development occur.*** In cases where implementing compensatory measures prior to impact is not feasible, the next best solution would be to implement the compensatory measures at the same time as the land- or resource-use activity. Establishing the conservation allowance agreement after the land- and resource-use activity has commenced is not considered appropriate.

Duration: ***The positive effects of the conservation allowance should last an appropriate amount of time to compensate for the duration of the ecological loss resulting from the project.*** A conservation allowance should be actively maintained until it is self-sustaining or it has met predetermined performance standards. While conservation outcomes should ideally be guaranteed until the adverse impacts of a land- or resource-use activity cease to exist, the duration of allowance activities may be limited by the legislative authority, including the ability to enforce the provisions of a supporting agreement. Conservation allowances that are maintained only as long as the land- or resource-use activity's adverse impacts endure are appropriate where the impacts of the activity are short-term and reversible.

Accountability: ***Conservation allowances should be formalized through written documentation, such as an agreement between Environment Canada and the allowance proponent (and, where appropriate, other partners, such as provincial or Aboriginal governments), or, where possible, formalized through permitting or other conditions***. The form of the documentation (referred to in this document generically as an "agreement") could take many forms.

It could be in the form of a letter of agreement, a memorandum of understanding, or other formal agreement such as an agreement under the DOE Act (described in more detail in Section 3 above).

Alternatively, it could also be a condition within a Decision Statement issued under CEAA 2012. Likewise, in certain circumstances, it may be possible to include elements of an allowance agreement in the terms and conditions of a permit or agreement under section 73 or through a section 11 conservation agreement under SARA. Each proposal would need to be examined on a case-by-case basis to see whether it respects the purposes of SARA. If the full details of the conservation allowance are not covered by the permit or conservation agreement, there may still be a need for an allowance agreement.

There may also be cases where it is appropriate to undertake a conservation allowance through an approach such as the transfer of title or by applying land-use restrictions to relevant land. The terms of the allowance could also be included in provincial permits or authorizations where those permits or authorizations are able to account for off-site measures.

An allowance agreement should include key elements such as the amount and nature of the allowance, timing, duration, monitoring procedures, milestones and consequences for non-performance. The content and detail of an allowance plan will be greater for land- or resource-use projects of greater scale or complexity, such as those identified as designated projects under CEAA 2012.

The enforceability of allowance agreements depends on the nature of the instrument through which they are implemented. For example, if a conservation agreement was included as a condition in a Decision Statement issued under CEAA 2012, that condition would become subject to enforcement provisions contained within the Act. Allowance requirements contained in the terms and conditions of a section 73 SARA permit could also be subject to enforcement conditions, including permit withdrawal.

Where allowances are provided under an agreement, then the agreement should include clauses that set out the consequences if there is failure by the proponent to complete the conservation allowance appropriately. These clauses could include:

- Payment of damages equivalent to the harm caused by the failure to complete the conservation allowance;
- Payout of a letter of credit;
- Provisions, including written agreement by a third-party landowner where necessary, to allow the Minister or a third party access to the site to complete the conservation allowance, if it is not satisfactorily completed by the proponent; and/or
- The commitment of a province to undertake regulatory action, for example environmental protection orders.

Other Design Considerations: Some jurisdictions have established conservation areas called “banks” from which developers can purchase “credits” representing a particular species or ecosystem type. In Canada, a proactive, proponent-led approach might be possible where one or more proponents or a third party would acquire and set aside an area of land that they would be able to draw upon to mitigate future impacts. The conserved area would be established prior to approval of any land- or resource-use activities. The conserved area would have to be administered in a transparent manner that would ensure that no portion of the conserved area would be used more than once for a conservation allowance. It would be determined on a case-by-case basis whether the conserved area (or some portion of it) would qualify as an allowance for a specific impact, and whether the provision of the allowance could constitute compliance with particular legislative or other obligations.

7. Conclusion

This framework allows for flexibility, so that each conservation allowance can be tailored according to the different types and scales of land- and resource-use activities and their potential impacts. Each allowance must be developed in consideration of the facts of the specific case and the purpose of the relevant legislative authority. The aim is to ensure that all allowances are supported by formal written agreements or other documentation such as permitting conditions, which will allow for better enforceability, monitoring and tracking of results.

Annex A

Environment Canada Experience with Conservation Allowances

In Canada, conservation allowances are currently being used at the federal and provincial levels to achieve statutory and policy objectives. This annex provides a description of Environment Canada's experience to date with conservation allowances. This experience reflects a range of approaches, based on the different contexts within which the allowance activities have been applied.

Conservation allowances under the Federal Policy on Wetland Conservation

In accordance with the FPWC, Environment Canada has provided recommendations for measures such as conservation allowances in environmental assessment processes. For example, allowances were recommended to help compensate for 4 ha of wetlands that were displaced during construction of the Canadian Museum of Nature's Aylmer Consolidation Facility. Prior to construction, an initial environmental screening report completed under the *Canadian Environmental Assessment Act* in November 1995 found that 15 ha of the 17 ha building site were wetlands. The report recommended that the construction project still go ahead because it was expected that the project would stimulate the local and regional economy and that the functions of the wetland did not have a significant role either in the ecosystem or in the economy. It was determined that "targeted mitigation measures" including stewardship conservation of wetland not impacted by construction and the transfer of additional land to the Canadian Museum of Nature for ongoing stewardship would be sufficient to compensate for the expected impacts to the wetland.

Subsequent to the start of construction at the site, in February 1996 the Minister of Canadian Heritage called for an independent panel to review the environmental screening report. The independent panel determined that the suggested mitigation measures were not sufficient compensation for the loss of 4 ha of wetland, since all areas slated for conservation stewardship as part of the mitigation measures were already wetlands and already federal lands subject to the FPWC and thus already protected by the policy for the long term. In order to strengthen the mitigation measures and fully comply with the "no net loss" provision of the FPWC, it was recommended that the federal government either restore former wetlands or construct new wetlands on federal lands near the construction site, with a replacement ratio of at least 2:1. Environment Canada advised that site selection should emphasize the ability of the allowance site to replace specific wetland functions lost on the 4 ha of impacted wetland rather than simply aiming to replace the lost area acre-for-acre.[1]

Wetland conservation allowances can also be undertaken in accordance with the FPWC by allowing a third party to arrange for an offsite allowance for an approved impact on a wetland. An example of the application of this approach to mitigation is provided by the

[1] Example adapted from: Lynch-Stewart, Pauline. "Canadian Museum of Nature Aylmer Consolidation Facility: Important Lessons About Applying the *Federal Policy on Wetland Conservation*". In Cox, K,W,, Grose, A. (eds.) (2000) Wetland Mitigation in Canada: a framework for application. Sustaining Wetlands Issues Paper 2000-1. North American Wetlands Conservation Council (Canada), Ottawa.

compensation undertaken for impacts on wetlands during the construction of a new bus terminal at Lewis Estates in the City of Edmonton. The proposed wetland impact required approval from Environment Canada. Ducks Unlimited Canada (DUC) was the third party that received funds from the City of Edmonton to undertake this activity. In order to meet Environment Canada's expectations, DUC committed to restoring an existing wetland rather than creating a new one, since restored wetlands tend to be more successful than those that are created. DUC agreed to secure a restoration site within an agreed-upon area in order to ensure the allowance site would be relatively close to the site of impact. The terminal construction impacted a total of 1.31 ha of wetland, thus requiring 3.93 ha of restored wetland to replace it, based on the agreed 3:1 allowance ratio. The funds provided by the City of Edmonton for this conservation allowance enabled partial restoration of an 11.32-ha wetland basin. Other compensation approvals funded the outstanding restoration needs, and the construction required to complete the restoration of this wetland basin is now complete.

Environment Canada has also sought conservation allowances for impacts on wetlands in cooperation with other federal departments. A good example of this is provided by the Vancouver Airport expansion in the early 1990s, which resulted in impacts to 350 ha of wetland and upland habitat. Avoidance and minimization options were considered during the 1989 Environmental Assessment Review Process for the proposed project; however, compensation was deemed necessary for residual effects to 350 ha of habitat. Environment Canada took the lead in developing a Compensation Strategy that would compensate for these residual effects. Compensation included transfer from Transport Canada to Environment Canada of 171 ha of ecologically important land for protection as well as monetary compensation of $9 million to pay for the outstanding 178 ha of impacted land. The dollar value of monetary compensation provided was calculated based on a 1:1 ratio and "fair market value" for non-commercial upland delta lands. Environment Canada manages the transferred parcels of land as the Sea Island Conservation Area and as part of the Alaksen National Wildlife Area. The $9 million has been used to secure new protected lands, enhance habitat quality on existing protected lands and provide an endowment to implement a private land-stewardship program.

Other examples of the application of conservation allowances for wetlands include the CP Edmonton Intermodal Facility and the Anthony Henday South East Extension ring road, also in Edmonton. Both projects replaced impacted wetlands at a 3:1 compensation ratio.

Conservation allowances as part of *Species At Risk Act* section 73 permits

Environment Canada has experience issuing permits that require the use of habitat compensation measures such as conservation allowances under SARA. For example, Environment Canada recently issued a permit for the cutting of 9 Butternut trees for the construction of a highway in Quebec. Prior to issuing the permit, all feasible measures were considered to avoid and minimize the impact of the project on the Butternut trees, but none were found. Since the project will not jeopardize the survival or recovery of the Butternut tree, whose populations have been mostly impacted by disease, the use of measures such as a conservation allowance was accepted as an appropriate approach to compensate for

the impact. A 2:1 ratio was required for the allowance (18 trees will be planted in place of the 9 cut). The exact location of the replacement plantation will be determined according to expert recommendations, and a five-year monitoring program will be implemented to monitor the health status of the planted trees. Adaptive management requires replacement of any trees that die.

Conservation allowances as amendments to boundaries of existing National Wildlife Areas and Migratory Bird Sanctuaries

Past management of the Cape Jourimain National Wildlife Area (NWA) provides an example of the application of conservation allowances in an NWA. The road approaching the bridge linking New Brunswick and Prince Edward Island runs through the Cape Jourimain NWA. The opening of the bridge in 1997 resulted in increased traffic congestion along an upgraded road right-of-way (originally built in the 1960s) located in the NWA. Significant safety concerns arose as a result of the increase in traffic and the New Brunswick Department of Transportation requested release and use of 3.7 ha of the NWA in order to construct off-ramps that would address these safety concerns. An adjacent 1.2 ha parcel of land was also proposed for de-listing in order to accommodate future plans to build a parking lot for the proposed Cape Jourimain Nature Centre. The total 4.9 ha proposed for de-listing had no uncommon biological communities, being comprised of second-growth mixed woods and old pasture land. In exchange, 75.8 ha of biologically significant lands were added to the NWA as follows:

- The Department of Public Works and Government Services Canada transferred 11.8 ha of biologically important land adjacent to the NWA from its land holdings to Environment Canada. This strip of land was identified as providing an important songbird migration corridor and valuable riparian habitat.
- Strait Crossing Development Incorporated purchased and transferred into Environment Canada's inventory 64 ha of privately held wetland and associated upland adjacent to the NWA.

These changes to the boundaries of the Cape Jourimain NWA required an amendment of the CWA's *Wildlife Area Regulations*, which provide detailed boundaries for each listed NWA, by the Governor in Council. The regulatory amendment was final on May 26, 1999.[2] Decisions regarding the quality and quantity of the required allowance were based on the professional judgment of Environment Canada staff, who negotiated the required quantity of conservation allowances with the project proponent.[3]

Similar to the Cape Jourimain NWA example, Environment Canada has also recommended the use of terrestrial conservation allowances for proposed impacts to Migratory Bird Sanctuaries during the environmental assessment (EA) process. For example, during the EA for the Mackenzie Gas Project (MGP) in the Northwest Territories, allowances were recommended for the predicted flooding to the Kendall Island Bird Sanctuary that would result from MGP activities. While a final decision on whether the MGP will go ahead has

[2] Description of this allowance is based on the *Regulations Amending the Wildlife Area Regulations* published in the *Canada Gazette*, Part II, Vol. 133, No. 11, 26/5/99.

[3] Terriplan Consultants (2011). Habitat Offsets as Compensation and Mitigation for Habitat Loss Due to Industrial Activities. Prepared for Environment Canada – Canadian Wildlife Service, Yellowknife (18-19).

not yet been made, it does provide a good example of how allowances may be applied through the EA process. In this case, since flooding associated with a gas extraction project was determined to be unavoidable, conservation allowances were deemed to be a suitable mitigation approach. The proposed allowance project was to establish replacement bird habitat outside of the existing sanctuary area. The area of replacement habitat was to be provided at a 5:1 ratio, meaning that the allowance area would have been five times the size of the flooded area. Environment Canada would have worked to determine the exact location of the allowance activity by engaging the Inuvialuit, Gwich'in, other governments, other government departments and stakeholders (including environmental non-governmental organizations and industry).

Conservation allowances as agreements as part of environmental assessment process

Environment Canada has experience in the development of voluntary allowances undertaken to promote responsible resource development. For example, Environment Canada entered into an agreement for a conservation allowance with Total E&P Canada Ltd. (TOTAL) for their Joslyn North Mine Project in Alberta.

The joint federal-provincial review panel established to oversee the EA of the project recommended mitigation, such as off-site offsets, be identified in addition to the on-site mitigation and avoidance measures to mitigate impacts on valued wildlife, species at risk and migratory birds, and reduce the overall cumulative effects on wildlife in general.

TOTAL responded by offering lands on a neighbouring oil-sands lease as replacement wildlife habitat while reclamation on the Joslyn North Mine Project proceeds. This was formalized with an agreement with Environment Canada that included monitoring to gauge the effectiveness of the reclamation in re-establishing wildlife habitat.

Additional Resources:

For additional information on the use of conservation allowances and other mitigation measures, please visit the following links:

Fisheries and Oceans Canada
www.dfo-mpo.gc.ca/habitat/role/141/1415/14154-eng.htm

Environmental Mitigation Policy for British Columbia
www.env.gov.bc.ca/emop

Alberta's Provincial Wetland Restoration and Compensation Guide
www.waterforlife.alberta.ca/01533.html

Alberta Land-Use Framework
https://landuse.alberta.ca/ConservationStewardship/ConservationStewardshipTools/ConservationOffsets/Pages/default.aspx

Nova Scotia Wetland Conservation Policy
www.gov.ns.ca/nse/wetland/conservation.policy.asp

Prince Edward Island Wetland Conservation Policy
www.gov.pe.ca/forestry/index.php3?number=1015685

www.ec.gc.ca

Additional information can be obtained at:

Environment Canada
Inquiry Centre
10 Wellington Street, 23rd Floor
Gatineau QC K1A 0H3
Telephone: 1-800-668-6767 (in Canada only) or 819-997-2800
Fax: 819-994-1412
TTY: 819-994-0736
Email: enviroinfo@ec.gc.ca

August 14, 2024

JoAnne Deneron
Chair
Mackenzie Valley Environmental Impact Review Board
Yellowknife, NT

Via: Online Review System

Government of Canada's Information Requests for the proposed Mackenzie Valley Highway Project (EA1213-02)

Dear Ms. Deneron,

To support the Review Board's environmental assessment process, and in accordance with the Review Board's Rules of Procedure, the Government of Canada is submitting information requests (attached) for the Government of the Northwest Territories (GNWT) Department of Infrastructure's (INF) proposed Mackenzie Valley Highway (MVH) Project.

As provided in the Online Review System's information request (first round) public review, it is understood that this information request process allows for detailed questioning to help parties better understand the MVH Project, its potential impacts on the environment and people, and how to mitigate those impacts. In response, the Northern Projects Management Office (NPMO) is submitting the attached information requests on behalf of Heath Canada (HC), Natural Resources Canada (NRCan), Fisheries and Oceans Canada (DFO), and Environment and Climate Change Canada (ECCC). Transport Canada and Crown-Indigenous Relations and Northern Affairs Canada have reviewed materials available on the Review Board's public registry but do not have any information requests at this time.

It is understood that there will continue to be opportunities to provide comments and recommendations on the proposed MVH Project as the environmental assessment continues. The Government of Canada appreciates the opportunity to submit these information requests.

If you have any questions related to this correspondence, please contact Shannon Allerston at Shannon.allerston@cannor.gc.ca or 867-445-7230.

Sincerely,

Paradis, Adrian

Digitally signed by Paradis, Adrian
Date: 2024.08.14 15:09:51 -06'00'

Adrian Paradis
Projects Director
Northern Projects Management Office
Canadian Northern Economic Development Agency

NORTHWEST TERRITORIES

Traditional Knowledge Assessment of Boreal Caribou (Mbedzih) in the Dehcho Region



Prepared by Dehcho First Nations

January 2011

The document is a non-confidential summary of the Dehcho report. The maps and community appendices referred to in the document have been deemed confidential and are not included in the report.

Traditional Knowledge Assessment of Boreal Caribou (Mbedzih) in the Dehcho Region

Prepared by Dehcho First Nations
For the Canadian Wildlife Service

January 2011

Funded by the Government of Canada

Published by the Dehcho First Nations
Fort Simpson, Northwest Territories

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Cover photo: Boreal caribou swimming across Beaver Lake; Peter Redvers

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Terminology

In English, the term 'woodland caribou' refers to both 'boreal caribou' (those woodland caribou that do not normally reside in mountain areas) and to southern and northern species of 'mountain caribou'. In Dene Zhatie/Yati (the Dene language of the Dehcho area), the term 'mbedzih' refers to woodland caribou as distinct from barren-ground caribou (nódi) and generally refers to both boreal and mountain species of the animal, although distinctions between these groups of animals are acknowledged[1]. Given that this assessment focuses only on 'boreal caribou' and does not include 'mountain caribou', the term 'boreal caribou' is used as the primary term.

Introduction

Environment Canada, through the Canadian Wildlife Service (CWS), is currently mandated to develop a National Recovery Strategy and Action Plan to preserve and enhance declining boreal caribou populations across Canada and protect and maintain populations that are currently stable. Environment Canada determined that Aboriginal Traditional Knowledge (ATK, or TK) respecting boreal caribou should help guide and inform the development of this Recovery Strategy and Action Plan.

In the fall of 2010, Environment Canada entered into a contribution agreement with Dehcho First Nations (DFN) whereby Environment Canada would fund a series of harvester meetings in each of the Dehcho communities to gather TK information on boreal caribou in the Dehcho, review this information in relation to TK already documented by Dehcho communities, and prepare a summary report. DFN retained Crosscurrent Associates Ltd. of Yellowknife to coordinate this work and facilitate or co-facilitate harvester meetings in each of the Dehcho communities. This work was governed by the Dehcho First Nations' Traditional Knowledge Research Protocol (2004). Environment Canada provided Crosscurrent Associates Ltd. with an outline of the type of information required, a set of topographical maps (in hard copy and digital formats) to use for the meetings, and summaries of previous community meetings undertaken by CWS over the past year.

Prior to the harvester meetings, Crosscurrent Associates Ltd. gathered, reviewed, and summarized existing TK information regarding boreal caribou by community. This process helped identify information gaps that could be addressed through the harvester sessions. A group interview guide was developed (see Appendix 10), based on information needs provided by CWS. Then meetings were arranged through the respective First Nation councils or local resource management agencies and harvesters, co-facilitators/interpreters[2], and note takers were identified. The harvester meetings took place between October 16th and November 17th, 2010. Although West Point First Nation did not participate in these meetings, some data and information from previous TK work in this community has been presented in Appendix 9. Fort Liard, although still in the Dehcho Region, has withdrawn from the Dehcho First Nations' government and therefore did not participate in this assessment.

A total of forty-nine (49) harvesters participated in the community meetings, including a mix of elders and adult harvesters. Other community members -- such as youth observers, interpreters, co-facilitators, and/or resource managers – were also involved in varying degrees.

Based on notes taken at the sessions, information documented on topographical maps, and the previous TK information compiled, community summaries were prepared (see Appendices 1 through 9). These

[1] Mountain caribou are generally larger and in some instances have slightly darker shading.
[2] Some communities chose to use interpreters only while other had co-facilitator/interpreters.

appendices were circulated to their respective communities for review and feedback, and the regional summary was then prepared based on the information in these appendices.

A key item of consideration was the amount of detail to include on maps, given that locations of seasonal migratory paths, mineral licks (or wallows), calving areas, and rich lichen habitat are considered sensitive. Given that this level of detail is likely not required for the development of a National Recovery Strategy and Action Plan, information about these types of locations is presented in narrative form only rather than detailed in map form. The detailed information can be brought forward by communities and DFN during subsequent range-level planning activities in the Dehcho. Instead, the attached maps for each of the communities provide topographical names for narrative reference and, with the exception of Fort Providence[3], a generalized representation of active harvesting areas, and, therefore known habitat areas, based on Dehcho First Nation traditional land use data gathered in 1997 and 1998. This representation helps to scope out the general distribution of boreal caribou throughout the Dehcho region from a harvesting perspective. A more detailed explanation of the attached maps is provided below.

For the purposes of this report (to guide national Recovery Strategy and Action Plan development) English place names have been used, except where Dene place names make specific reference to boreal caribou (mbedzih). However, all of the geographic locations mentioned in the report, along with many other geographic features, have Dene place names and these names can and should be used for subsequent range-level planning activities in the Dehcho.

Description of Attached Maps

A regional map and a series of community area maps are attached to this assessment in the appendices for geo-referencing and to provide a form of visual representation of boreal caribou range within the Dehcho region. More detailed traditional knowledge (TK) map data regarding boreal caribou has been gathered by the individual Dehcho communities (including the locations of movement and migration routes, calving areas, mineral licks and wallows, and rich lichen patches), but publishing this information in map format in a public forum is considered sensitive. Furthermore, some of this data is more appropriate for community-based range management planning and not deemed essential by DFN at this time for the development of the National Recovery Strategy and Action Plan. For this reason, rather than publishing this data in this assessment report, it is referred to in more general terms in narrative form.

The attached maps provide an overview of boreal caribou harvesting areas based on historical kill-site data gathered by Dehcho First Nations as a component of a traditional land use study conducted in 1997-1998. This kill-site data does not include all active DFN harvesters, is for a limited time frame (ie. is within the memory of the informants as of 1997-1998), and likely under-represents actual harvesting activity and range because harvesters can forget specific hunts and also tend to underreport harvesting for cultural reasons. However, the data provides a reasonable representation of the geographical extent of Dehcho boreal caribou harvesting activities and therefore known boreal caribou habitat areas.

The attached maps were created by carrying out a density analysis of all kill sites documented in the 1997-1998 land use study, using ArcView GIS, based on the relative number of boreal caribou harvested per square kilometer, and broken into three gradients to better identify higher use areas. The total number of kill sites documented in the Dehcho was 2247 and the number of sites varied by community.

[3] The Fort Providence big game harvesting data was not broken down by species, so woodland caribou harvesting could not be isolated for density mapping purposes.

Although based on quantitative data, the polygons are representational only and the designations of low harvest, moderate harvest, and high harvest are as much qualitative as quantitative. In essence, what is being represented is a relative depiction of the pattern of woodland caribou harvesting over a fixed period of time among a time-limited sample of Dehcho harvesters based on memory. The sample size of 2247 is likely enough to conclude that the pattern is a reasonable representation of active harvesting areas. If this pattern is reasonable, then the areas in which more caribou are harvested likely represent better habitat areas. However, good boreal caribou habitat is likely under-represented on these maps given that most of the DFN harvesting occurs in the fall and winter, so spring and early summer habitat may not be fully represented. Furthermore, the maps only depict areas which are readily accessible to and are utilized by harvesters, so more remote or difficulty terrain, while harboring boreal caribou, may not be actively harvested. The data does show that boreal caribou are harvested throughout the entire Dehcho land use area, which highlights the extensive land base on which boreal caribou rely and the importance of boreal caribou conservation initiatives from a harvester and habitat protection standpoint.

It must be noted that the kill data for the Fort Providence area was not broken out by species (moose, boreal caribou, etc.) so no analysis was done for this land use area. Also, the data that extends into the Mackenzie Mountains likely illustrates 'mountain caribou' rather than boreal caribou harvesting areas, although there is some overlap in the foothills as discussed later in this assessment.

Dehcho Traditional Knowledge Assessment Summary

The categories used below for the analysis and presentation of the information gathered were provided by the Canadian Wildlife Service for the purposes of National Recovery Strategy and Action Plan preparation. Summaries for each category are drawn from the individual community information presented in the appendices.

Populations

Boreal caribou are common throughout the Dehcho region, although some areas tend to have higher concentrations of individuals. To some degree, population densities and trends can be inferred by traditional observations of average group sizes as well as by community harvesting levels. From this perspective, the boreal caribou population in the Dehcho is relatively stable in most areas, with a tendency toward a slow decline in others, particularly in those areas impacted by forest fires, introduction of bison, and/or high levels of sensory, hunting, and/or developmental pressures.



Boreal caribou feeding area northeast of Cameron Hills; Peter Redvers

Traditional knowledge information about boreal caribou recruitment activities (calving) is not extensive, likely given that boreal caribou spread out over large areas and generally stay in wetlands and burned areas that are difficult to access during the spring calving season. By the fact that populations are generally stable and that group sightings in fall and winter generally include a mix of adult and younger animals (with adults being the majority of the group), it is inferred that recruitment is stable.

In the Nahanni Butte area (Map A1), the population of boreal caribou along the Liard River valley and to the immediate west of the valley (between the river and mountains) is generally low but stable. Group sizes observed are generally in the range of 1 to 3 animals, but in late winter a group as large as 20 animals has been seen. The population of boreal caribou to the east of the Liard River, between the Liard River and Trout Lake (Sambaa K'e), particularly in and south of the Arrowhead Lake area, particularly, is considered high and stable.

It should be noted that, because of the possibility of some interaction between the boreal caribou to the west of the Liard River and the mountain caribou in the Mackenzie Mountains, the mountain caribou population (most of which are in Nahanni National Park Reserve) is considered strong, with up to 50 animals being seen in a single group.

In the Trout Lake area (Map A2), the population of boreal caribou is moderate to high throughout the entire area and is considered stable. Common group sizes range from 2-3 animals to 7-8 animals, with groups as large as 40 animals observed northeast of the community in late March.

In the Wrigley area (Map A3), the population of boreal caribou is moderate to high throughout most of the area and is considered stable in most areas, with some decline in the corridor between the Mackenzie River (Dehcho) and the Franklin Mountains. The strongest population is to the east of the Franklin Mountains. Group sizes of 6-7 animals are common in the fall through early winter with groups as large as 30-40 animals not uncommon in late winter, particularly east of the Franklin Mountains.

In the Fort Simpson area (Map A4), the population of boreal caribou is generally moderate and stable throughout the area, with certain areas, such as the Horn Plateau (Edehzhie) and the lowlands and foothills around Sibbeston Lake, harboring relatively strong populations. Groups sizes of 5-7 animals are not uncommon with groups of up to 17-19 animals observed during the mid to late winter months.

In the Jean Marie River area (Map A5), boreal caribou are common but not abundant, and the population appears to be in slow decline. The most common group size in recent years has been 2-3 animals, but group sizes of 5-7 animals are not uncommon and groups as large as 15 animals have been seen in late winter. Harvesters note that group sizes were larger in the past.

In the Fort Providence area (Map A6), the population of boreal caribou appears to be generally and slowly declining over the past number of years, likely due to pressures from forest fires, the expansion of the imported wood bison herd, and increased sensory disturbance. The population on the Horn Plateau (Edehzhie) remains the strongest, with a greater portion of the decline occurring south and southeast of that area, to the north of the Mackenzie River and in and around the Mackenzie Wood Bison Sanctuary. Group sizes are most commonly 2-3 animals and larger groups are less common today, although more common in the past.

In the Kakisa area (A7), the population of boreal caribou remains relatively high throughout the Tathlina Lake and Kakisa Lake areas, particularly in the area between and to the west of those lakes, but the population on the Cameron Hills plateau has clearly declined due to development pressures. Group sizes of 10-15 animals in the area northwest of Tathlina Lake during the mid winter months are not uncommon, while groups of 5-7 animals are occasionally sighted inland from the south shore of Beaver Lake.

In the Hay Rıver area (Map A8), the population of boreal caribou is generally considered stable with some recent decline noted in the area southwest of Buffalo Lake and the area to west of the community of Hay River[4]. Hay River harvesters also note a decline in the population inhabiting the Cameron Hills plateau. Group sizes of 2-3 animals, and up to 5-8 animals, are most common throughout the Hay River area, while groups as large as 40 animals have been observed in the past southwest of Buffalo Lake during late winter. Those areas showing some decline in population appear to be subject to increased access by skidoo, hunting pressure from both Aboriginal and non-Aboriginal hunters (see 'Overharvesting' below), and, in the case of the Cameron Hills plateau, oil and gas development.

Range Boundaries and Patterns

Specific information regarding range and movement for each Dehcho First Nation community is presented in the appendices, so this section of the assessment focuses on broader range boundary and pattern matters.



Boreal caribou tracks crossing muskeg prairie east of Sambaa K'e; Troy Marsh

It appears that the entire Dehcho region could be referred to as boreal caribou range, in that boreal caribou populations, in varying levels (likely dependent on habitat availability and habitat pressures), are found throughout the entire region. Although the Mackenzie Mountains are generally identified as mountain caribou range, there is also evidence from Nahanni Butte and Wrigley that there is some interaction between mountain caribou and the boreal caribou that inhabit the foothills and river valleys along the eastern edge of the Mackenzie Mountains, which means that the boreal caribou range in the Dehcho extends to some degree into the Mackenzie Mountains.

From a traditional knowledge perspective, the degree to which individual boreal caribou move throughout the entire Dehcho range and therefore interact is not known, but it is known that many groups of boreal caribou have relatively significant 'linear' seasonal movement or migration patterns while others remain for the most part in large multi-habitat areas and simply shift the pattern of use of those areas based on seasonal habitat preferences.

Significant 'linear' movements appear to occur in the Wrigley area (groups of boreal caribou cross the Mackenzie River south and north of the community on the ice from east to west in the late winter / early spring and return during the late summer / early fall); in the Fort Simpson area (groups of boreal caribou cross the Mackenzie River from the northeast to the southwest in early spring between Ebbutt Hills and Sibbeston Lake and return during the late summer and fall); in the Kakisa area (groups of boreal caribou cross the upper Kakisa River area from the western foothills of the Cameron Hills to the area northwest of Tathlina Lake in the fall / early winter and return in the early spring); and in the Hay River area (groups

[4] A decline in the area west of Hay River was also noted in previous documents by West Point First Nation.

of boreal caribou spend spring and summer in the Caribou Hills in Northern Alberta and return to the area north and northwest of Buffalo Lake in the fall).

In the Fort Providence area, groups of boreal caribou used to move between Beaver Lake and the base of the Horn Plateau (Edehzhie) in the late summer / early fall and then back to the Beaver Lake lowlands in the early spring, but this seasonal movement has diminished, possibly due to expansion of the bison population in that area.

The boreal caribou population on the Horn Plateau (Edehzhie) appears to remain on the Plateau year round, but shifts habitat use by season, although some interaction with neighboring populations likely occurs. On the Plateau, boreal caribou tracks are embedded in the moss from ongoing use. Boreal caribou also appear to remain year round in the area below the east and northeast edge of the Cameron Hills. This area contains a wide variety of habitat from rolling forested hills along the base of the Hills to open muskeg / mixed forest lowlands between the Hills and the Hay River. A similar pattern appears to exist north of Nahanni Butte along the east side of the Nahanni Range, with boreal caribou moving between the foothills of the Range and the wetlands / mixed forest landscape between the Range and the Liard River. Boreal caribou using the habitat surrounding the Jean Marie River essentially remain in the area to the south of the community but shift east-west and north-south (including across the Mackenzie Highway) seasonally, depending on habitat preferences. In the Trout Lake area, boreal caribou appear to move freely throughout the area, including around the lake, particularly to the north of the lake, but shift habitat preference by season.

The only definitive separation of populations occurs in the southern portion of the Hay River area, where boreal caribou on the west side of the Hay River and Mackenzie Highway (between the highway and the Cameron Hills) do not cross over to the east side of the Hay River where there is a concentrated population of boreal caribou north and north east of Swan Lake – and vice versa. These populations, although separated by only a few kilometers (along with a river and a highway), do not appear to mix.

In one area of the Dehcho, the Wrigley area east of the Franklin Mountains, there is considerable overlap between boreal caribou range and barren-ground caribou range in the mid-winter months. Groups of boreal caribou have been observed walking and feeding among large herds of barren-ground caribou, particularly around the Fish Lake area. The barren-ground caribou, which come down from the Sahtu so are part of what is referred to as the Bluenose West herd, only recently returned to this area after being away for approximately fifty years.

Overall, range and movement patterns appear to differ somewhat within the region (significant 'linear' movement versus less obvious 'rotational' movement), with varying degrees of overlap between community land use areas, such that it would be difficult to clearly identify separate populations (sub-populations) within the region, with the exception of the southern Hay River area and to some degree the Horn Plateau. The consistent factor is that all population groups move throughout the year in response to common seasonal habitat preferences, as summarized below.

Habitat

The general seasonal habitat trend is for boreal caribou to spread out throughout marsh and wetlands during the spring calving period; to stay close to and in areas with greater amounts of muskeg terrain throughout summer; to move more freely in fall and early winter throughout a range of habitats, while gathering into larger groups; and to overwinter in larger groups in areas that have higher amounts of thicker brush (both black spruce and pine) while remaining close to muskeg and 'willow prairie' areas that harbor ground lichens and sedge grasses. The Dehcho region generally appears to provide the wide

and diverse range of habitat types that woodland caribou use throughout the year along with ready access, in most areas, to both hanging and ground lichens and other foraging vegetation.

From a broad perspective, boreal caribou rely on ground and hanging lichens as well as sedge grasses for feed and remain close to habitat where this type of food is accessible. Areas with 'white muskeg' are known to be good habitat as well as areas with rich 'hanging moss'. Open 'bog' areas (a few large bogs are located in the Dehcho, particularly between Fort Simpson and Jean Marie River) are avoided. Boreal caribou generally do not congregate in the same areas as moose due to habitat preference and well as predator avoidance. There appears to be a correlation between boreal caribou presence and pine forested areas. There are a large number of 'endaa' (wallows or licks) throughout the Dehcho, but the location of these sites are kept confidential unless there is a specific threat from development . Communities may be willing to share this information for community-level management planning.



Boreal caribou feeding site northeast of Cameron Hills; Peter Redvers

For the most part, with the exception of the Cameron Hills and the Mackenzie Bison Sanctuary, there has been minimal change to boreal caribou habitat since oil and gas exploration was halted in the early 1970s. The Dehcho landscape, now that many seismic lines have grown in, remains relatively pristine habitat.

Spring (late March through May): Once the snow crust softens, boreal caribou move from their over-wintering habitat in relatively large groups and begin to travel to and spread out over calving areas, which are generally in wetlands, marshlands, or even burn areas that are difficult for predators to access. The largest concentrations of boreal caribou are generally seen in late winter / early spring, just before they disperse to calving areas.

Summer (June through early August): Throughout the summer, boreal caribou primarily utilize muskeg areas or areas with access to muskeg. They lay in heavy moss that has permafrost under it in order to stay cool. They appear to move around less frequently during the mid summer months but begin to move more in late summer / early fall.

Fall / Early Winter (late August through November): Fall is a transitional period, in that boreal caribou begin to move around over a wider and more diverse habitat area during the rutting and post rutting period. This is the time of year when boreal caribou are often seen along or crossing water bodies. Their primary habitat is 'open' country and they still spend considerable time in muskeg areas that harbor ground lichens as well as sedge grasses.

Winter (November through March): As winter progresses, boreal caribou tend to spend less time in open and muskeg areas and concentrate in larger groups on higher ground in thicker brush areas, where there is still access to open areas that harbor ground lichens. As the snow gets deeper and crusts (generally January through mid March), they remain more often in areas of dense pine or thickly wooded black spruce (referred to as 'dedłını' in Trout Lake) where snow is softer, where there is hanging lichen, and where there remains access to open, mixed vegetation for ground foraging. This particular mix of habitat, which supports larger groups in smaller habitat use areas, appears critical for over-wintering survival.

Harvesting



Boreal caribou hunt east of Sambaa K'e; Troy Marsh

Throughout the Dehcho, there appears to be a decline in the harvesting of boreal caribou by Dehcho First Nation members, although boreal caribou continue to be harvested. This decline is likely due to a few factors. First, harvesters do not spend as much time on the land today as previous generations did, which means that incidental contact with boreal caribou, and the opportunity to harvest them, is less frequent. Second, given that boreal caribou are shy animals and sensitive to sensory disturbance, the use of skidoos rather than dog teams decreases incidental contact. Decreased use of dog teams means that the need for harvested meat for dogs has also decreased. Third, the use of boreal caribou hides for snowshoe lacing and dog harnesses has diminished so there is less need for the special characteristics of this hide (it stretches less than moose hide). Fourth, most harvesters prefer moose to boreal caribou (moose provide more meat and are a preferred taste) so boreal caribou are mostly harvested on an opportunistic basis while doing other land use activities, such as trapping or moose hunting. Finally, some harvesters are aware that boreal caribou are at risk, having heard of significant drops in boreal caribou populations in southern Canada, and therefore have cut back on their harvesting of the animals.

Consistent with past practice, harvesting of boreal caribou generally takes place in the fall and winter months, when the animals are moving around more (fall / early winter) or are in larger groups in more concentrated areas (mid to late winter/early spring).

Dehcho harvesters are aware that non-Dene harvesting of boreal caribou appears to be steady or rising slightly, due to increased knowledge by non-Dene hunters of key winter caribou habitat areas and recent restrictions on the hunting of barren-ground caribou (forcing non-Dene hunters to hunt in less restrictive areas), but non-Dene harvesting numbers are not known. (This matter is addressed in more detail in the 'Overharvesting' section below.)

Estimating actual Dehcho First Nation harvest numbers is speculative at best, given that harvest information is not necessarily openly shared and is often under-represented (for both personal and cultural

reasons), but, based on harvester estimates, an estimate of 100-150 boreal caribou per year at the current time is not unreasonable. This does not include mountain caribou, which are commonly harvested in the fall time up the rivers flowing out of the Mackenzie Mountains.

Relationship / Values

> *Before we got out to the lake there... Bonıface paıd the water. We made a fıre there, made tea, we cooked out and he fed the fıre and he fed the lake too, tobacco and matches and some tea. He paıd the water and prayed that the weather stayed good as long as we remaıned huntıng ın the area. Man ıt was a beautıful tıme I remember back then because the lake was just calm, really calm, just looked lıke a glass. You could see way out on the lake, ducks movıng around, I see those lıttle rıpples, that's how I see the water. As long as we camped there, hunted around the area no wınds or storm came around. But we had a great hunt at that tıme, we got some carıbou, some moose, we shot three moose and a couple bıg carıbou. (Dehcho Elder)*
>
> *That's where ıt was saıd a talkıng carıbou used to lıve. People saıd a carıbou that talked lıke a human lıved there long ago... They saıd ıt would clımb trees and talked a lot about thıngs. He would sıt up there and look around but nobody would go close to ıt. People saıd that carıbou would talk to ıtself say thıngs lıke "I see smoke, there are people lıvıng there" and thıngs lıke that. The carıbou would clımb trees... That's why they call ıt Mbedzı̨ı̨ Gotsele. There ıs a place they call Mbedzı̨ı̨ Gotsele and Mbdzı̨ı̨ Gochoo. Mbedzı̨ı̨ Gochoo ıs besıde the bıg lake.(Dehcho Elder)*

Although boreal caribou are currently an 'incidental species' from a harvesting perspective -- and are not actively harvested in the same way as moose or even mountain sheep -- boreal caribou, mbedzih, are highly respected and valued by Dehcho harvesters.

The meat is valued for human consumption and the hide is valued for making specialized craft products such as snowshoe lacing, dog harnesses, and drums, because it doesn't stretch as much as moosehide. Traditionally, the hide, because it was thin and strong, was stretched across window openings in cabins to keep out cold but allow light through. In one community, the stomach contents of boreal caribou, given its high lichen content, was used for making a nutritional soup.

On a deeper level, Dehcho Dene have a spiritual relationship with mbedzih that carries with it certain obligations not to unduly harm or disrespect the animals. For this reason, most elders and many harvesters are very uncomfortable with the collaring that has been carried out for research purposes. They feel that collaring harms individual animals, affects the animal's relationship with other boreal caribou, and is simply not respectful toward the integrity of the animal. This disrespect will result in the Creator 'taking the animals away'.

Respect is shown ceremonially by making tobacco or other offerings before hunting in a particular area or, in the past, holding ceremonies at seasonal gatherings to thank the Creator for animals harvested over the past year. Taboos relating to the use of mbedzih hair and antlers are still followed in some communities today. In at least one Dehcho area, place names associated with mbedzih are still used, including place names associated with the cultural story of a talking caribou.

Harvesters feel that it is our behavior toward boreal caribou (and other animals) that is affecting their well-being and that we therefore have to be conscious of our behavior toward these animals if they are going to be sustained. Decisions affecting boreal caribou need to be made from a relationship-based, land-based perspective and not on the basis of paper research and reports.

Factors Affecting Sustainability

Calf Survival

As noted above, detailed information about calving is not well known given that boreal caribou tend to calve in isolation in inaccessible locations, but, based on harvesters' knowledge, factors affecting calf survival include the following:

- Minimizing disturbance to boreal caribou cows during the mid to late winter when energy conservation is important and relocation is difficult due to snow conditions;
- Protecting known and likely calving habitat and minimizing disturbances in wetland / marsh / and burn areas during late April through early June;
- Controlling known calf predator populations (wolves and bears).

Habitat Changes

Although, for the most part, boreal caribou habitat in the Dehcho is relatively pristine, extensive, and productive, the major habitat changes that have occurred in the Dehcho have been due to oil and gas development, introduction of bison, and forest fires. Changes in the use of productive habitat have also resulted from sensory disturbance. And new changes to habitat from climate change are beginning to be noticed. These matters are addressed in the sections below.

Forest Fires

Forest fires are known to damage boreal caribou habitat, particularly deep burning fires that destroy lichen cover. Once a fire has damaged a habitat area, boreal caribou generally do not go back into the area for foraging purposes and it can take decades for the land to recover. However, there is also evidence that boreal caribou use burned areas as travel corridors and that some foraging on fresh growth does occur. Boreal caribou do not frequent burned areas in the mid to late winter, even as travel corridors.



Forest fire in boreal caribou habitat east of Sambaa K'e; Peter Redvers

In the Dehcho, a few boreal caribou habitat areas have been impacted by forest fire, including the area south of Bulmer Lake, the area between Mills Lake and the base of the Horn Plateau (Edehzhie), and an area immediately to the southeast of Beaver Lake. Fires generally damage a portion of a habitat area but do not cause as much damage to open muskeg areas, which continue to host lichen cover.

Other areas in the Dehcho have been relatively fire free and habitat remains in good shape. This includes the rich habitat area east of the Franklin Mountains in the Wrigley area; much of the Jean Marie River area, particularly old growth forests to the immediate south of the community and northeast between the

Mackenzie River and Horn Plateau (Edehzhie); the area surrounding Kakisa and Tathlina Lakes; and the area around the Hay River Dene Reserve and surrounding the north and west sides of Buffalo Lake.

As noted in the management section below, particularly rich habitat areas, known to harbor quality lichen cover, need to be documented and listed under the GNWT's 'values at risk' protocol for fire protection decision-making purposes.

<u>Industry and Development</u>
Based on their collective experience of the major oil and gas exploration activities that took place in the Dehcho during the late 1950s through to the early 1970s, harvesters are particularly concerned about the immediate and cumulative impacts of development in the region. Seismic lines, sensory disturbance from oil and gas exploration activities, oil and contaminant spills, and use of seismic wire all resulted in immediate impacts to boreal caribou. Animals were driven away from development activities and did not return to these areas for many years; some animals became entangled in seismic wire and died; and elders expressed concerns about animals become contaminated through exposure to oil and other contaminants left on or under the ground.



Old cutlines southwest of Sambaa K'e; Dennis Deneron

Once this development stopped though, and once many of the seismic lines grew back in, boreal caribou appear to have re-adapted to the landscape and the re-grown lines do not appear to be a deterrent to use. It should be noted, though, that the level of seismic activity in the Dehcho remained for the most part at the preliminary level (ie. seismic lines were generally spread out) and that intensive 3D seismic was only carried out in a few areas of the Dehcho. Some elders have commented that since this extensive development, boreal caribou have become more wary and do not linger as long in open areas as they did prior to these disturbances.

The construction of the Norman Wells pipeline caused boreal caribou to leave the corridor area for a number of years before eventually returning. As well, in Wrigley, elders noted that boreal caribou that were harvested close to the corridor had the taste associated with stress (see Disease and Parasites section below).

Current and new developments remain a concern. Both Kakisa and Hay River Dene Reserve harvesters have noted that boreal caribou numbers have decreased on the Cameron Hills plateau due to extensive oil and gas development and production. Nahanni Butte is concerned about the impacts of a winter haul road to the Prairie Creek Mine on over-wintering boreal caribou to the east of the Nahanni Range and the community has proposed a road realignment to help mitigate impacts. Sambaa K'e and Jean Marie River have expressed ongoing concern about the impact of the proposed Mackenzie Gas pipeline on over-wintering boreal caribou along the corridor. Sambaa K'e and Nahanni Butte have ongoing concerns about expanded oil and gas development and production in the Arrowhead Lake area. Dehcho First Nations collectively are concerned about opening the Horn Plateau (Edehzhie) to potential mineral or

oil/gas development and have launched a court action to reinstall interim land protection in the area to protect the ecosystem, with a particular focus on the watershed and boreal caribou habitat. Jean Marie River harvesters noted that logging of old growth areas, which has been done selectively in the Jean Marie River area for a number of years, needs to be reviewed.

At this time, with the exception of the Cameron Hills, there is minimal resource development activity occurring in the Dehcho, although a few major projects are pending. Dehcho First Nations has strategically chosen to use this lull in activity (due in large part to Dehcho Process negotiations) to establish and implement a Dehcho Land Use Plan and establish a Dehcho Resource Management Authority to properly regulate new development, but negotiations with Canada and the GNWT have been proceeding very slowly. As noted in the management section below, the land use plan and resource management authority are seen as being the most effective tools for ensuring sustainability of existing boreal caribou populations.



Cutlines on Cameron Hills; Peter Redvers

In the interim, the establishment of a Dehcho Boreal Caribou Working Group to carry out range management activities is embedded in two existing regulatory licences -- the Cameron Hills expansion project licence (2004) and the National Energy Board certificate for the Mackenzie Gas Project (2010). However, this group is still in the process of being established.

<u>Predation</u>

Wolf populations throughout the Dehcho appear to be increasing, due in part to the fact that fewer of these animals are trapped or hunted today than in the past, for both cultural and socio-economic reasons. However, with the exception of the Fort Providence area, wolf pack sizes are considered to be normal for the area (generally 4-7 animals in a pack) and there is no evidence of increased killing of boreal caribou by wolves. The large packs seen in the Fort Providence area (in one case, 70 animals) appear to be due to the increase in the bison population and it is not known to what extent these large packs have impacted boreal caribou, although Fort Providence appears to have seen the most decline in boreal caribou in the Dehcho region and wolf predation may be a factor (disturbance to boreal caribou habitat by bison and forest fires have also been identified as reasons for this decline).



Wolf following boreal caribou tracks NE of Cameron Hills; Peter Redvers

Harvesters know that seismic and other lineal disturbances open corridors for wolves and can lead to an increase in predation of boreal caribou and other game animals and are concerned about this impact.

There has also been an increase in the bear population throughout the Dehcho. This past summer, it was not uncommon to see a sow bear with three cubs, which would normally be considered quite unusual. It is known that bears will kill boreal caribou calves in the spring time. The increase in bears is largely due to the fact that the harvesting of bears for meat and fur has declined considerably, as harvesters are uncomfortable harvesting and eating bears that may have been foraging in dumps or other contaminated sites.

Cougars have been increasingly seen (directly or through tracks) throughout the Dehcho region over the past decade and are suspected of harvesting boreal caribou, although there is no direct evidence to date of this occurring. This increase in cougars appears to be associated with a concurrent increase in whitetail deer (jumping deer) in the area and extensive oil and gas exploration activity occurring in northern Alberta and British Columbia (perhaps pushing cougars northward).

Increased predation of boreal caribou by wolves, bears, and cougars may be offset by the fact that other prey species are available. Moose populations remain high throughout the Dehcho, there has been a large increase in bison populations in the Fort Providence and Nahanni Butte areas, whitetail deer populations appear to be gradually increasing, and, in the past few years, signs of elk have appeared in the Mackenzie Mountains west of Wrigley and around Trout Lake. Beaver populations have also been increasing due to less trapping activity, and it is known that wolves and bear prey on beaver.



Wolf along Simpson Hwy; Peter Redvers

As noted in the management section below, ongoing monitoring of predator and prey species needs to be carried out, with a focus on boreal caribou predation rates. Measures to increase harvesting to more historical and traditional levels also need to be considered.

<u>Parasites and Disease</u>

Overall, boreal caribou in the Dehcho appear to be in good health. There are no reported incidents of unusual internal parasites or evidence of disease and animals are generally fat when harvested in the fall and winter. The only two health issues that harvesters express concern about are the handling and collaring of boreal caribou for research purposes and the appearance of two apparently stressed and unusually thin animals in the Trout Lake area.

Collaring remains a controversial issue. In spite of concerns by elders, most communities agreed to collaring in order to get baseline data for management purposes. Now that adequate data has been gathered, and given ongoing concerns about the negative impacts of collaring, the general consensus is that collaring should not continue. There are two main concerns: 1) that netting, handling, and collaring

of animals causes physical injury and weakening of collared animals, and 2) that netting, handling, and collaring of animals is culturally inappropriate and disrespectful. Harvesters have seen collared animals with open sores on their necks and at least one collared animal appears to have died either through starvation or disease because its remains were not scavenged. Elders are increasingly uncomfortable about the need to chase, net, and handle animals for collaring; about the weight and size of the collars around the animals' necks; and about the impact of begin disrespectful to the animals on the long term sustainability of the population. Other means of carrying out research, using less intrusive methods, need to be developed.

Harvesters know that boreal caribou (and other big game) that are highly stressed from sensory or other disturbances taste differently. In the Trout Lake area, two animals were killed within the past year that exhibited signs of stress and were also unusually thin. Aside from the taste being bad and having limited fat, the animals did not show signs of illness. There is no local explanation for this phenomenon, so it needs to be monitored.

Sensory Disturbance

As noted in the section on Industry and Development above, boreal caribou are particularly sensitive to sensory disturbance and have been affected by sensory disturbance from oil and gas exploration in the past (and currently in the Cameron Hills). The potential impact of pending and future development remains a major concern.

Harvesters also note that boreal caribou are sensitive to other localized disturbances, including increased use of skidoos, increased use of motorized boats, heavy truck traffic, and low flying aircraft. Finding means to reduce sensory disturbances would therefore benefit boreal caribou populations, especially reducing sensory disturbances at critical periods, such as during calving and over-wintering periods, needs to be a priority.

Over-Harvesting

Over-harvesting is of moderate concern at this time, with most concerns being expressed about the following areas: to the southwest of Buffalo Lake, to the west of the community of Hay River, along the river systems around Fort Providence, and around the Fish Lake and Willowlake River areas near Wrigley. Over-harvesting by Dehcho harvesters is not the issue, because traditional harvesting has clearly declined over the past few decades for a number of reasons (see Harvesting above), but there has been a slow increase in non-Dehcho and non-Dene hunters coming into a few reasonably accessible habitat areas in the Dehcho during the fall and winter months. It is not known how many animals these hunters are taking so this situation needs to be more closely monitored.

Closure / limiting of the barren-ground caribou harvest north of Yellowknife and increased access to rivers systems in the fall using jet boats has added to overharvesting concerns. Also, as favored boreal caribou habitat becomes more widely known over time, particularly winter habitat, these areas become more heavily targeted.

Harvesters in Jean Marie River are concerned about harvesting of 'mbedzihcho', the larger boreal caribou bulls, because these are considered the best breeders and they would like to see both voluntary and imposed restriction on the harvesting of large bulls. [A number of communities raised concerns about the harvesting of mature mountain caribou bulls as well, particularly by outfitters, and feel that this practice weakens population health.]

Harvesters support monitoring and, perhaps, changes to the non-Dene boreal caribou harvesting season to better protect over-wintering boreal caribou populations.

Vehicle Collisions
Even though there are a number of all season and winter roads crisscrossing the Dehcho region, and a reasonable number of boreal caribou sightings along these roads, there are no known incidences of boreal caribou been struck by vehicles. Sensory disturbance from large trucks, particularly on winter roads, is more of a concern.

Climate Change
The Dehcho region is clearly getting warmer and wetter overall, with more rainfall in August and September and even into October. This change is creating more incidences of ice crusting along the ground which may make it more difficult for boreal caribou to forage for ground lichens. Sudden thaws and melting during winter months also create crusts on the snow that make it difficult for boreal caribou to move around and escape predators. In some instances, frost heaves that harbor lichens are diminishing or melting entirely which reduces availability of this particularly rich habitat site. Wetter summers and falls are resulting in higher water levels on smaller rivers and streams, increasing boat access (particularly jet boat access) into boreal caribou habitat areas previously difficult to access at these times of year.

Climate change does not yet appear to be affecting ground or hanging lichens, although some monitoring of future changes to lichen due to climate change should be undertaken.

Dehcho Boreal Caribou Protection Recommendations

During this assessment, along with soliciting traditional knowledge information from Dehcho harvesters regarding boreal caribou, DFN asked harvesters to provide direction on management recommendations that would help guide protection and recovery planning and implementation activities. The community-specific recommendations brought forward and discussed by harvesters are listed in the community appendices.

The following regional recommendations are derived from these community-based recommendations and need to be considered by Canadian Wildlife Service in its development of a National Recovery Strategy and Action Plan. DFN also expects to be actively involved in the implementation of these plans in the Dehcho region, initially through CWS and the GNWT, but ultimately through the Dehcho Resource Management Authority. On an interim basis, these recommendations, along with the specific community-based recommendations and the other information provided in this assessment, can also guide the deliberations of the Dehcho Boreal Caribou Working Group once it is fully established.

1. Finalize and approve the Dehcho Land Use Plan and formally establish the Dehcho Resource Management Authority to implement the land use plan and other wildlife and resource management activities as they relate to boreal caribou.
2. Finalize the establishment of current Candidate Protected Areas in the Dehcho, with full surface and sub-surface protection from industrial development, in order to preserve large undisturbed boreal caribou habitat areas.
3. Restrict and monitor industrial development generally during critical boreal caribou calving and over-wintering periods.
4. Halt new boreal caribou collaring research and work with harvesters to develop alternative research and population monitoring methods, including greater use of community-based monitoring, aerial surveys, and less intrusive technical monitoring devices.
5. Restrict further expansion of imported bison populations into boreal caribou habitat areas by opening these areas to bison harvesting.

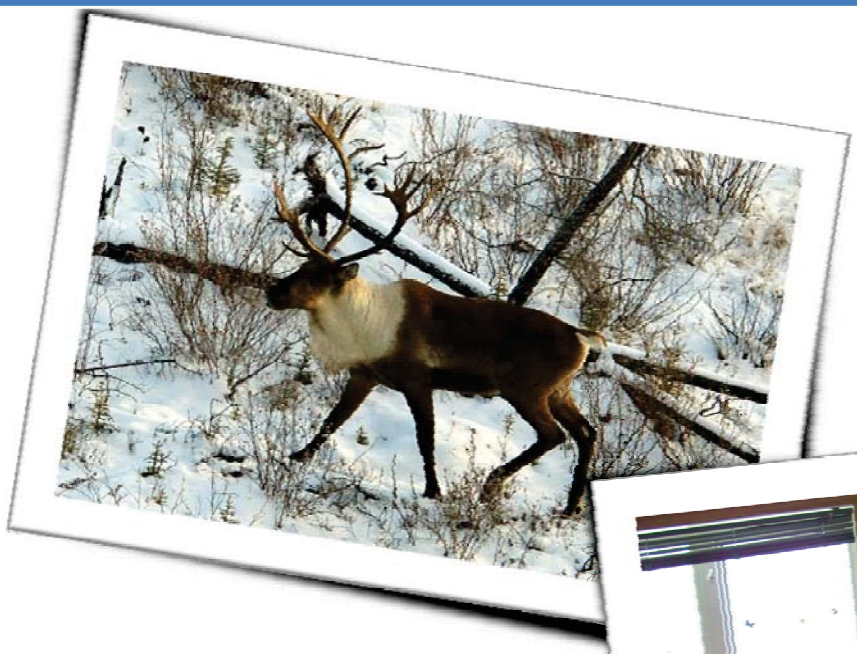
6. Carry out more detailed analyses of critical habitat characteristics, with a particular focus on calving and over-wintering habitat as well as lichen availability, quality, density, and vulnerability (from development, airborne pollution, and climate change).
7. Verify special habitat sites / areas – such as wallows/licks, rich lichen areas, old growth forest areas, calving areas, etc. – and locate these sites / areas on GNWT 'values at risk' maps to guide forest fire management decisions.
8. Restrict non-Dene hunting for boreal caribou during the overwintering period and in locations where overhunting appears to be impacting populations (ie. shorten current season, review hunting zones, and protect mature bulls).
9. Identify and implement measures to encourage increased traditional harvesting of wolf and bear in order to limit population growth, while monitoring predator populations.
10. Ensure that Dehcho harvesters respect critical habitat periods and voluntarily maintain current harvesting levels rather than expanding or increasing harvest levels.



Fort Providence elders and harvesters meeting regarding boreal caribou; Peter Redvers

The appendices and maps for each community are confidential and have not been included in this report.

Gwich'in Traditional Knowledge: Woodland Caribou, Boreal Population





Boreal woodland caribou. Photo: John Nagy, ENR

Billie Lennie interviews Mary Teya in Fort McPherson. Photo: GRRB

Kristi Benson
Gwich'in Social and Cultural Institute
January 14, 2011

Acknowledgements

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Executive Summary

The GSCI and GRRB conducted a study to gather and present Gwich'in Traditional Knowledge on Woodland Caribou – Boreal population (woodland caribou). There is a stable population of woodland caribou in the Gwich'in Settlement Area and surrounding regions which are harvested by Gwich'in living in Inuvik, Aklavik, Fort McPherson, and Tsiigehtchic. However, the Canadian population is classified as threatened under the federal *Species at Risk Act*. Environment Canada supported the project in order to integrate Gwich'in Traditional Knowledge in the recovery planning process for woodland caribou. The study involved searching the digital archives of GSCI for relevant primary and secondary data, and conducting 20 interviews with Gwich'in hunters and Elders. Study results are presented in the following report.

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1. Introduction

1.1. Description of project

Woodland caribou, boreal population occur throughout a large portion of the Gwich'in Settlement Area (see Figure 1, below). They are larger than the barren-ground caribou and Porcupine caribou more often harvested by the Gwich'in. Although not harvested as often as other types of caribou they still form an important food source and are recognized as a culturally valuable species by the Gwich'in.

Woodland caribou are listed as a threatened species under the federal *Species at Risk Act* and Environment Canada is preparing a national recovery strategy and action plan. Gwich'in traditional knowledge (TK) will be integrated into the recovery planning process as appropriate. The purpose of this study was to gather and collate Gwich'in traditional knowledge for use in the recovery planning process. The GSCI and the GRRB used previously recorded Gwich'in traditional knowledge, and conducted interviews with holders of Gwich'in traditional knowledge to obtain TK about general observations, special significance, physical description, distribution, habitat, population size and trend, limiting factors and threats, and health of the woodland caribou.

1.1. Previous traditional knowledge work on boreal caribou in the region

A table showing previous traditional knowledge work on caribou in the Gwich'in area can be found as Appendix 3. When interview information from other studies is used in this report, a full citation can be found in this appendix.

2. Methodology

The GRRB and GSCI worked together to carry out this project, with assistance from Environment Canada to ensure the project met their requirements for recovery planning. A total of 20 semi-structured interviews were carried out by GSCI and GRRB, in all four NWT Gwich'in communities (Aklavik, Fort McPherson, Inuvik, and Tsiigehtchic). Eighteen interviews were recorded using a digital sound recorder, and two interviewees declined to be recorded. A (NAME OF RECORDER) was used to store the sounds in MP3 format files, which were later transcribed to GSCI standards. Information was drawn using Sharpie markers on a set of maps provided by Environment Canada. The mapped information was later digitized by Environment Canada into a Geodatabase. All data is held by GSCI and GRRB, and original research materials are in storage at the GSCI's storage area in the NWT Archives. Environment Canada also has a copy of the digital data with the exception of data from one interviewee who wished to remain confidential. Maps were scanned and saved in digital format as well. Interviewees were given the option of receiving a copy of the sound recording or typed transcript. An informed consent statement (Appendix 1) was read to the interviewees which governs the use of the information. A questionnaire was used by interviewers to guide the interviews (Appendix 2).

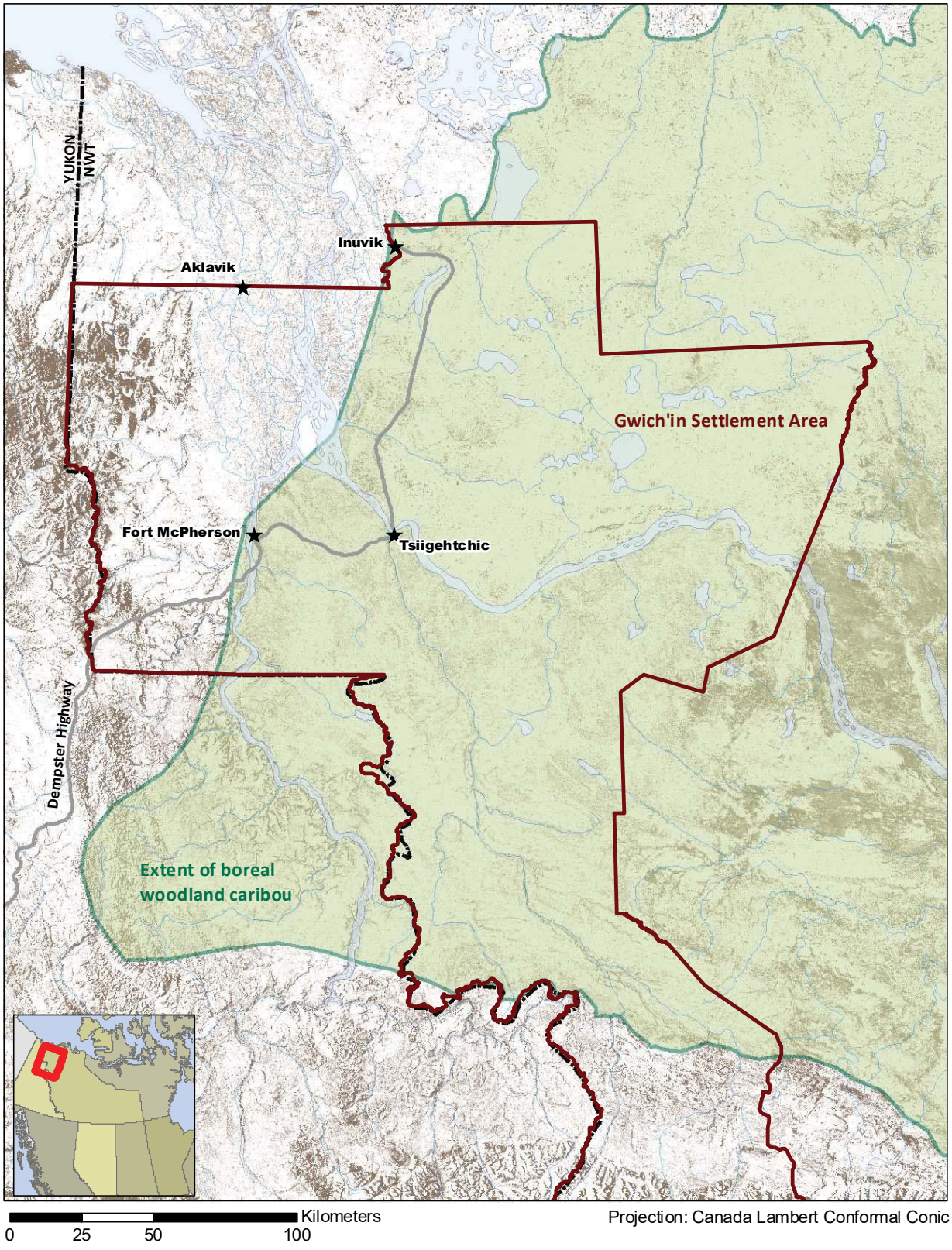


Figure 1: Map of Gwich'in Settlement Area showing extent of Boreal Woodland Caribou

3. Gwich'in Traditional Knowledge: Boreal woodland caribou

Gwich'in hunters and Elders have extensive experience on the land, and a remarkable ability to recall and categorize information about wildlife and other biophysical and cultural phenomena. In interviews, they provide information willingly and demonstrate a strong desire to preserve their way of life and share information for future generations. They generally state if information is from their own experience, and indicate if the information they are imparting is from a single occurrence or if it's a life-long pattern they have observed. They also clarify if they have heard it from another person. Often the name of the 'source' and their community is provided to contextualize any second-hand information. They constantly revise their information and share with other hunters judiciously, including updates on health and population trends. Many interviewees have worked with government caribou biologists and this information is woven deftly into their understanding of wildlife, and shared with other hunters.

Places mentioned in the text of this report are shown in Figure 2, below.

3.1. Special significance of woodland caribou

Like all animals harvested by the Gwich'in, woodland caribou are important because they are a food source (Mary Teya Oct 14, 2010). A common sentiment was that if a woodland caribou is seen while hunting or otherwise out on the land, it will be shot for food. The differences in behaviour (i.e. not migrating in large herds) and population (i.e. relatively small population over a large area) are implicated as the reasons why woodland caribou are generally not specifically sought when hunting.

Woodland caribou were noted by interviewees as being useful as a starvation food "according to say my dad, who died 15 years ago, like they'd look after all that too. It's [for an] emergency" (Ernest Vittrekwa Oct 15 2010). For example, for several years in the 1970s, Richard Ross travelled to Inuvik to hunt woodland caribou when there was no Porcupine caribou near Aklavik, "well that's all there was … so we went and hunted" (Oct 28 2010). Robert Alexie Sr. indicated that woodland caribou are important to his community as a back up when the harvest of Porcupine caribou is not sufficient, "well it's good...it's very important because if there's no caribou [and people are] hardly getting meat, people see it out there; they'll go for it" (Oct 13 2010). Emma Kay mentioned they'll take woodland caribou, "if we don't see our own caribou. Woodland caribou comes in handy to us because it's good eating too. My son shot about a couple one year and I didn't even know the difference. I just said…big caribou! He just laugh. He never told me it was woodland. [They were] out here on Deepwater Lake" (Oct 13 2010). An Inuvik interviewee indicated that there is also a spiritual aspect to hunting caribou for him – he feels his survival is connected to the animals' survival and taking care of the caribou is a part of this connection.

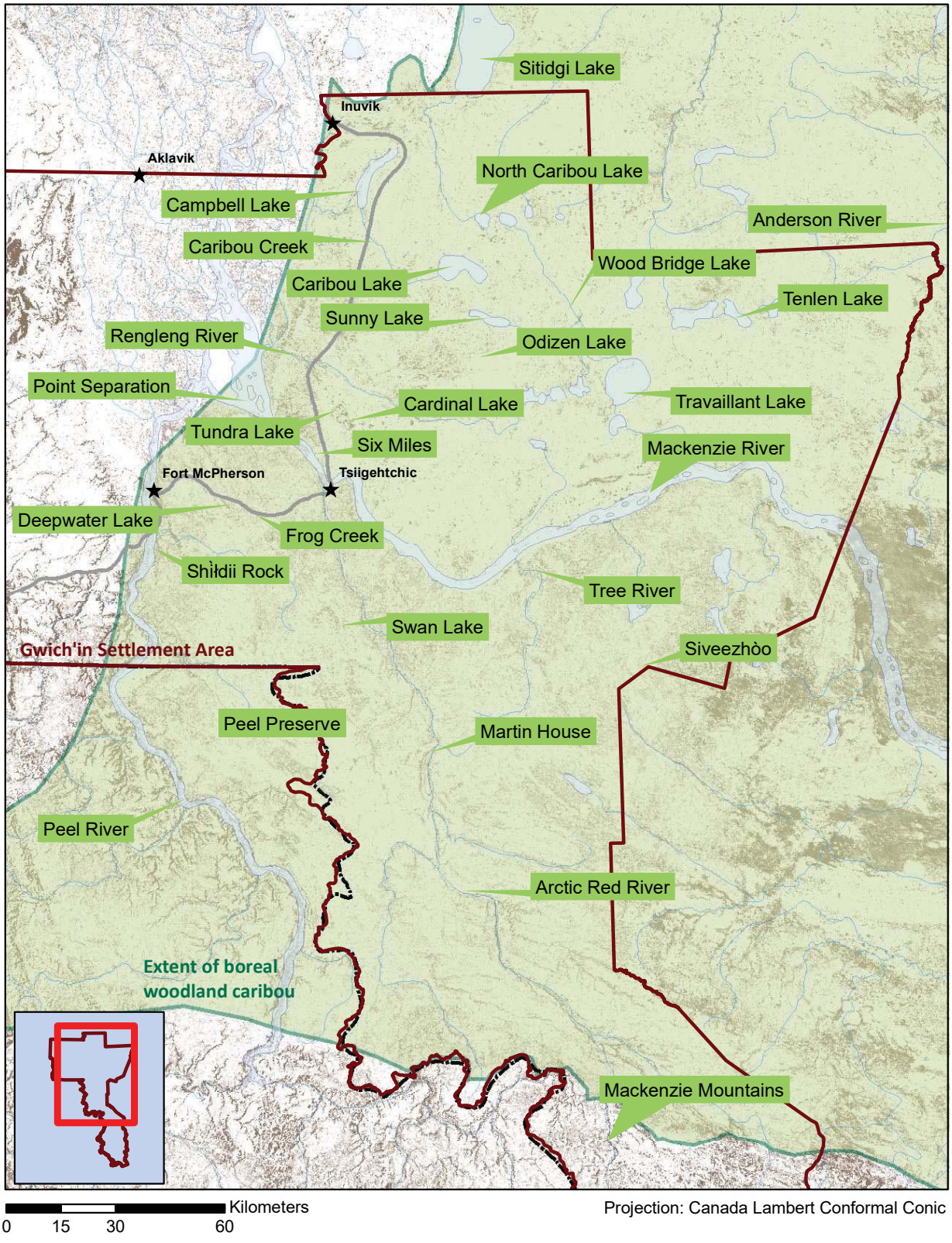


Figure 2. Place names mentioned in report.

Some interviewees also suggested that they are of increasing importance due to declining barren ground and Porcupine caribou. "They are getting more important as the days go by because the other ones [barren-ground and Porcupine caribou] are getting less; so ... people are going to be shooting them... everything is changing now" (Tom Wright Oct 12 2010). James Firth agreed that woodland caribou might become more important if other caribou are less available to hunters, and as such they need to be protected and conserved (Nov 3 2010).



Tom Wright

Photo: GSCI

However, a few interviewees commented on the low or lessening importance of woodland caribou as a food source. One Tsiigehtchic interviewee felt that the small population size meant that the woodland caribou are not important to his community compared to other caribou (Douglas Kendo Oct 18 2010). Another interviewee felt that the importance of woodland caribou has dropped in recent years, relating to a decline in their availability for hunters (Conrad Baetz Nov 12 2010).

The following table summarizes the differences between the woodland caribou, Porcupine caribou, and Bluenose caribou to the Gwich'in.

Table 1. Comparison between Woodland, Porcupine, and Bluenose caribou

	Species name	Gwich'in community	General location	Notes
Boreal woodland caribou	*Rangifer tarandus caribou*	Inuvik and Tsiigehtchic, mainly. Also used occasionally by Fort McPherson in recent years, rarely by Aklavik.	See map, above. West of the Mackenzie Delta and in the Peel Preserve.	Dispersed in small groups among a large territory.
Porcupine caribou (subspecies of Grant's caribou)	*Rangifer tarandus granti*	Very important for Fort McPherson and Aklavik, also used by Tsiigehtchic and Inuvik residents by travelling up the Dempster Highway.	Migrates from Arctic Coast into Yukon mountains, migrating by Fort McPherson and across the Dempster Highway to the west.	Most important caribou for Gwich'in. Easier to hunt than Woodland due to regular movement in large herds.
Bluenose caribou (herd of Barren-ground caribou)	*Rangifer tarandus groenlandicus*	Occasionally used by Tsiigehtchic residents, rarely others.	Migrates from the coastal areas of the Inuvialuit Settlement Region in the summer/calving time, into Sahtu area.	Used by Gwich'in although not as often as Porcupine caribou, due to access constraints.

3.2. Legends related to boreal caribou

As caribou have a place of great importance to the Gwich'in, it would be impossible to include all the legends which mention caribou or relate to caribou. Some stories are of a factual but historical nature, such as this account of near-starvation long in the past by Gwichya Gwich'in Elder Eliza Andre. The second part of this story (not included) ends with the lesson: "This is why, even today, the people still help and share with one another" (COPE story, Eliza Andre). This story does not specify which type of caribou referred to but is included to demonstrate the general importance of caribou to the Gwich'in.

Old Man and His Wife - Part #1

Once there was an old man and his wife who moved out into the bush. Early in the fall, we all understood that the caribou were all in good shape just before running *[rutting?]* season. It happened that this man was married to a very wise woman. In the fall people killed lots of caribou. That woman was very well known for her wisdom. Because the people had killed a few caribou, they figured they were well off for the winter, but the woman figured there would be a shortage of meat. She cut out a piece of caribou fat the size of her knife and put this in her bag. A little later on, the people were starving so they had to split up camp into groups. One group going one way and the other going in the other direction. This woman and her husband went by themselves.

The man was very hungry and didn't have the strength to even walk so his wife helped her husband until they stopped to make camp. Before they made this camp, they came across fresh caribou tracks. The woman, knowing her husband was very weak, took out the fat from her bag and cut the fat into small pieces to make ready a light soup for her husband. She gave this to her husband but he was so weak he could only take a little of the soup and return to sleep. When he awoke again she gave him another drink of the soup. This kept on until the morning. By morning, her husband told her, "I feel much better and I think I can go after the caribou now." He went out hunting and killed a bunch of caribou. When he came back to camp, he told his wife that he was going to go and look for the other hungry people that they had left. He gathered all those people and told them to return to his camp with him, that he had a bunch of caribou. The people wanted to buy meat off him but he told them, "If you want to buy meat, you can buy it off my wife, not me."

The following winter this same man and his wife moved into the bush. They were hungry, not having anything to eat. They made camp near two big mountains of snow. It happened that they now had a little boy who was so hungry he would ask his mom, "Mom, I want to eat caribou feet." His mom would ask him, "Where are we going to get it? We have nothing." They made a campfire near these two snow mountains and it happened that all the snow began to melt around the campfire and they discovered a moose leg. They began to shovel the snow and soon found two moose. What had happened was that two bulls had been fighting over a cow moose. As they fought with their horns, the horns became locked together. Yet now, they were still in good shape (having been preserved in the snow). The man went out in search of the other starving people and brought them back to camp. By this time it was getting warm, getting towards spring. It was just luck that this same man saved the other people who were in the need of food.

Other legends and stories reference how caribou meat, skins, and other parts were used in the day-to-day life and comfortable existence of the Gwich'in long in the past; use of the caribou for meat, drymeat, grease [edible fat], clothing, caribou leg skin sleds and mattresses, tents, blankets, babiche (sinew) and many others.

3.3. Place names and trails related to boreal caribou

Many place names in the Gwich'in area refer to caribou, although it is likely that they generally refer to the Porcupine herd, Bluenose herd, and even the mountain woodland caribou in the headwaters of the Arctic Red River in the Mackenzie Mountains. However, several Gwichya Gwich'in (Tsiigehtchic) names likely refer to woodland caribou:

- There are two lakes in the Gwichya Gwich'in area near Tree River, up the Mackenzie River, named Tatthał njj'ee choo and Tatthał njj'ee tsal [Translation: *Tatthał njj'ee* = a line of fence running (from lake to lake), *choo*= big (refers to the size of the lake); *tsal*=small (refers to the size of the lake). The names of the lakes refer to a possible caribou fence which may have been built between the large lake and the smaller lake. Gabe Andre indicated that woodland caribou are present in that area (Gwichya Gwich'in Place Names 1993 Tape 5). There is also another creek named Tatthał njj'ee near Point Separation (Gwichya Gwich'in Place Names Database).

- Caribou Lake and the creek flowing into Campbell Lake from Caribou Lake are both named after caribou in Gwich'in. Caribou Lake is Vadzaih van (literally caribou lake) and the creek is Vadzaih van tshik (caribou lake creek, Gwichya Gwich'in Place Names Database).

- The name Njhdàadąjj, refers to the lichen that the caribou eat, often called moss or white moss.

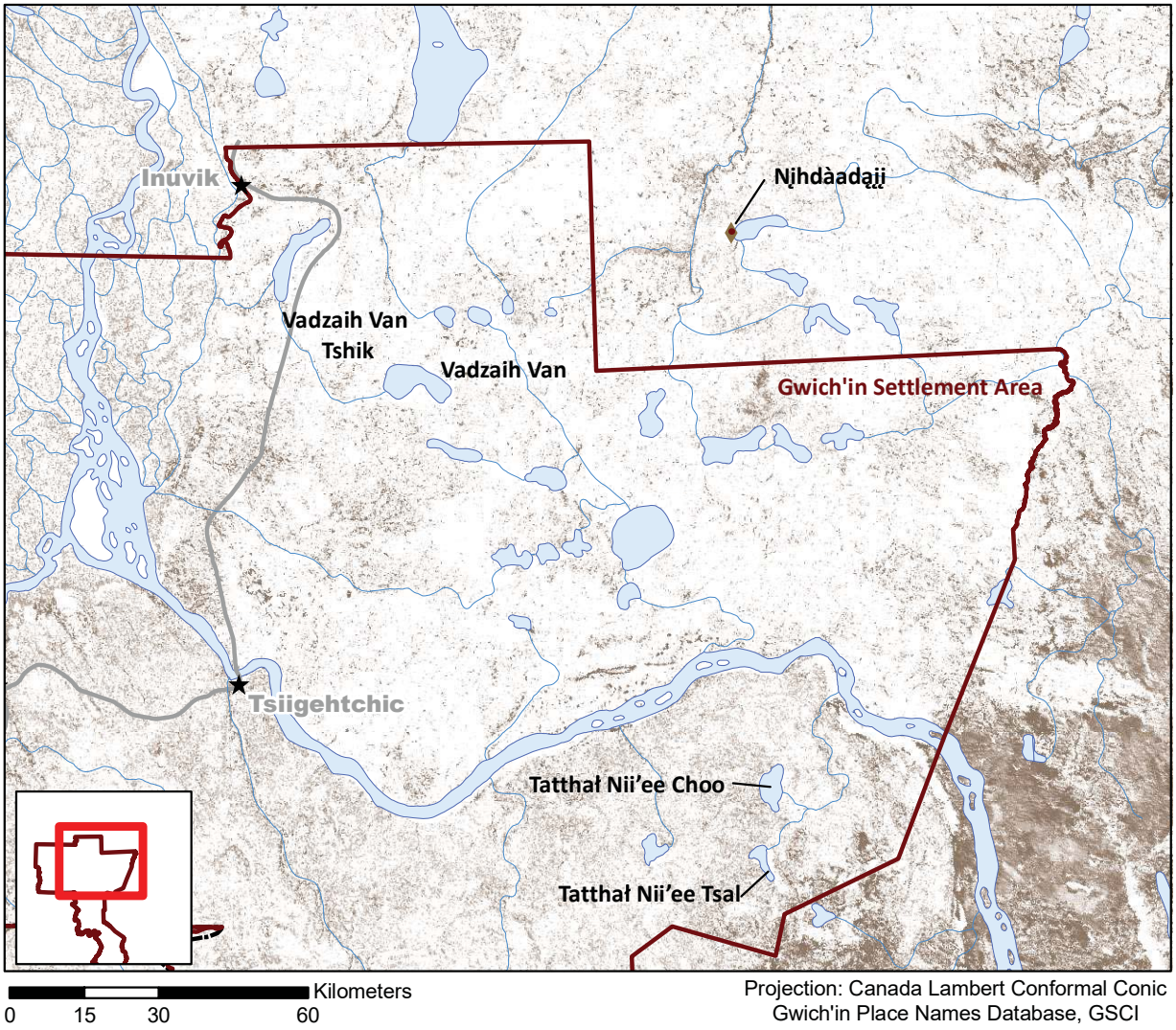


Figure 3: Gwichya Gwich'in Place Names referring to Woodland Caribou

Numerous Teetł'it Gwich'in (Fort McPherson) names refer to caribou but generally they refer to Porcupine caribou.

3.4. Physical description

Most interviewees indicated that woodland caribou are easily distinguishable from Porcupine caribou, especially when viewed from nearby. "Well it depends on how far you are from them. Because they are quite a bit bigger ...They are half between a caribou and a moose ... I think they usually have smaller horns, you see a big animal with smaller horns" (Tom Wright Oct 12 2010). However, Conrad Baetz feels they have larger antlers (Nov 12 2010). They are also a darker colour (Albert Frost Oct 12 2010, James Firth Nov 3 2010). It may be more difficult to distinguish between woodland caribou and Bluenose caribou than woodland and Porcupine (Julie Ann Andre Nov 12 2010).

Caribou are known for their ability to move quickly across rough or snowy ground, "You know they can really go, ... it is just amazing how you can't hardly walk out there, there are humps and holes and just rough – and they run like they were on a highway." (Tom Wright Oct 12 2010).

There may be differences in size of individuals between herds in different areas – in other words, some areas have larger woodland caribou than other areas (Willie Simon Nov 4 2010).

Abe Peterson has heard that some Porcupine caribou have crossed the Mackenzie River and become essentially woodland caribou. He heard that they crossed the Mackenzie around Six Miles, which is six miles below Tsiigehtchic (Oct 14 2010).

3.5. Diet

> In spring time, you see them eating the lichen [and] they eat the green, little leaf grass. And then come fall and winter that is when [they] really go after the lichen.
>
> (James Firth Nov 3 2010)
>
> They eat willows and ...tamarack bark but that is mainly in the winter when they cannot get to the ground.
>
> (Julie Ann Andre Nov 12 2010)

Although generally not observed in the summer, woodland caribou eat 'caribou moss' or lichen, as do other types of caribou. They also eat willows, willow leaves, sedges, and grass in the summer. They eat aquatic vegetation from the lakes (Walter Alexie Oct 14 2010, Tom Wright Oct 12 2010, Albert Frost Oct 12 2010). Although they are known to eat a variety of foods all year, when they are hunted in the winter their stomachs seem to be full of lichen, "when you cut their stomach, it's just straight that white stuff" (Emma Kay Oct 13 2010). However, they will dig through the snow to get at other food as well, "lichens, and grass all around the lake. They dig lots, you know...they dig around the lakes you know, [for] grass" (Robert Alexie Oct 13 2010). They'll also eat tree buds in the winter (Conrad Baetz Nov 18 2010). They seem to have a special ability to find lichen, "and then, they just seem to know right where it is, too, [does not matter] how much snow it is...that's their scent. They just know where to go, ...and they dig down and there's their food right there" (Abe Peterson, Gwich'in Traditional Knowledge of the Mackenzie Gas Project Area tape 94). Robert Alexie Sr. has seen signs of them feeding in the water in the spring (Robert Alexie Oct 13 2010).

Caribou must keep moving from area to area as they will consume much of the available lichen. The area is then avoided by caribou until the lichen grows back. This can take a decade or more (Albert Frost Oct 12 2010).

Caribou are known to eat at muskrat push-ups or houses, "I think they just clean off the lake with rat houses. The rat makes houses down there on the lakes and they just clean it right off" (Richard Ross Oct 28 2010). They may eat these houses for the minerals and other food they contain. They go for muskrat push-ups in the winter on the lakes, according to Conrad Baetz (Nov 18 2010).

3.6. Behaviour

Woodland caribou in the Gwich'in area tend to be in small groups. "Two or three, or there might be a bigger bunch but not that many" (Tom Wright Oct 12 2010); "Maybe four or five together" (Emma Kay Oct 13 2010). Mixed groups have been seen with cows, calves, yearlings or young animals, and bulls. Woodland caribou may also be alone. Robert Alexie Sr. has seen a solitary bull in the winter, as has Walter Alexie (Oct 13 2010, Oct 14 2010). Walter observed that the small groups tend to be cows and calves with a single bull. Douglas Kendo has participated in tagging fly-overs between Tsiigehtchic and Tree River, where groups of cows and calves were seen (Oct 18 2010). There may occasionally be larger groups up the Arctic Red River, where seeing ten to 15 might be normal, and Ernest Vittrekwa has seen about 50 together (Oct 15 2010). Although small, the herds may have leaders like the larger herds – one interviewee in the 2001 GRRB boreal woodland caribou study indicated that if a hunter shoots leader, then the rest of the herd will not run. The landscape may affect the group size as well, "they seem to spread out more when they get into the timber areas" (Harry Carmichael Oct 28 2010).


Photo: John Nagy ENR

Interviewees had not observed the migration habits of the caribou but generally felt they do move around. Although they do not follow a large-scale seasonal migration, interviewees did indicate that the ability to hunt them is seasonal, as travelling in some areas is restricted to winter due to ease of access. Additionally some interviewees indicated that caribou have seasonal behaviours such as seeking timbered hills in the winter and water in the summer. They may also move from area to area – Douglas Kendo noted that they approach the Arctic Red River in the winter "that Seven Mile Island down there? Or between say Tsiigehtchic and Martin House, there's going to be more caribou when they come to the shore, right? [After Christmas] they come to the river and islands, and then in the spring … they go back inland" (Oct 18 2010). Julie Ann Andre used to see woodland caribou on Travaillant Lake when she was young, and they would move away after several weeks, "but when we stayed out at Travaillant, like every single day, we would see caribou on the lake. And that would last for about two or three weeks. And they would be migrating probably up to Anderson River area" (Nov 12 2010).

Most interviewees indicated that there are not specific herds or groups that occupy a territory, although one Inuvik hunter described geographically-constrained small herds (Anonymous Nov 2 2010). His knowledge of these herds may relate to a greater hunting effort or time spent observing woodland caribou compared to hunters who more regularly go for Porcupine or Bluenose caribou. In general, interviewees indicated that woodland caribou are dispersed and seen irregularly. Woodland caribou are seen "anytime in the year, because it's all travelling here and there and they run around like" (Emma Kay Oct 13 2010). Conrad Baetz indicated that the small groups may intermingle, in particular during the rut when bulls may travel over long distances (Nov 12 2010).

Interviewees generally agreed that woodland caribou are 'wild.' They are known to run away before you see them, they will flee quickly, and are often considered to be hard to see and hunt.

Oh hard to hunt them things. Harder than our caribou, they are kind of wild eh? And once they take off, they go like crazy. They are real awkward to hunt, you know – they are very smart caribou. He'll go where it's real brushy and when you see them they take off. And they stay there until you come close to them and they take off again and you can't have a chance to get that, to me anyway (Michael Pascal Oct 14 2010)

… the only way I got caribou one time was it was spring time and the crusty snow, eh? And they don't want to step in that crust because it hurts them. … it's the only way I got them. But then the snow got soft and there's no chance in getting them because they can just take off (Ernest Vittrekwa Oct 15 2010)



Ernest Vittrekwa

Photo: GRRB

Interviewees often mentioned that woodland caribou will 'go and go' – however Richard Ross once hunted these caribou around Caribou Lakes and found they were quite cunning "we got them right on a lake, they were feeding. There was about 10, I think. They were feeding there and we went around the lake to them, and there they start going in the bush. Soon as they can't see you they will stop. But then as soon as they can see you they will take off again – they keep doing that" (Oct 28 2010). Several interviewees indicated that although many times the caribou will flee if they see you, sometimes they freeze instead, "sometimes they don't run away they just stand there" (Wally McPherson Oct 28 2010). This may be due to their curiosity (Louis Cardinal Gwich'in Traditional Knowledge of the Mackenzie Gas Project Area tape 4).

One Inuvik hunter felt they are easy to hunt, "they are very easy to hunt and if you follow them with ... a skidoo they will go in the trees, they stand like they are trying to hide." This is one behavioural difference with Porcupine or Bluenose caribou, who are more likely to try and outrun a hunter (James Firth Nov 3 2010). The herd may stop and start to stay together, by allowing slower members to catch up (Willie Simon Nov 4 2010). Conrad Baetz suggested that barren ground caribou are hunted more often and develop a habit of fleeing skidoos; whereas woodland caribou in areas where they are not hunted as much will be easier to hunt. But the learned behaviour to flee is not restricted to any type of caribou, it depends on the relationship between the caribou of an area and the hunters. Conrad also mentioned that barren ground caribou may be more cognisant of their surroundings and any danger due to a lack of trees to hide in (Nov 12 2010).

"You see them at the edge of trees or edge of clearings"
(Harry Carmichael Oct 28 2010).

In the winter, woodland caribou spend more time in treed locations, in particular if it's foggy. Spruce stands can be a cue to a hunter "if you were travelling along and you seen lots of willows but you seen spruce, you go to the spruce" (Tom Wright Oct 12 2010). The caribou may move between eating areas and forested areas "Right now [early November], they would be in open areas in the flats, feeding. But like

at night say [they] probably head up in the trees and more for protection I think" (James Firth Nov 3 2010). In the past when temperatures were colder in the winter, the tell-tale sign of steam rising from a timber patch would indicate that caribou were there (Walter Alexie Oct 14 2010). They can be found in timbered areas around Sitidgi Lake and Caribou Lakes (Albert Frost Oct 12 2010). Ernest Vittrekwa felt that the presence of hills and higher ground are more important to the caribou than tree cover, although trees are also important. He pointed out that the hills between Fort McPherson and Tsiigehtchic are prime woodland caribou locations (Oct 15 2010). Wally McPherson also indicated that woodland caribou are in flat areas with smaller trees and willows (Oct 28 2010). Caribou will use trees to rub the velvet off their antlers (Conrad Baetz Nov 12 2010).



James B Firth

Photo: GSCI

Interviewees generally agreed that woodland caribou, like most animals, will not necessarily be impacted by machines or industrial noise such as graders or pumping stations, or a skidoo driven at a reasonable pace (Tom Wright Oct 12, 2010, Abe Peterson Oct 14 2010). However, being chased at high speeds by a skidoo will stress caribou (Douglas Kendo Oct 18 2010), and unlike terrestrial disturbances, flights may disturb caribou (Wally McPherson Oct 28 2010). James Firth believes that low-flying planes at the Inuvik airport may unintentionally disturb caribou (Nov 3 2010). Some sudden novel sounds may frighten them, such as swooping planes – which should avoid wildlife areas as much as possible. The only good reason to disturb caribou is if the meat is needed. "...you shouldn't disturb [caribou]. Unless I want caribou... and need it, I'll get it; but [if you] don't need it, why should it be bothered?" (Robert Alexie Oct 13 2010). Walter Alexie indicated that in the past, animals including caribou and moose were more likely to be frightened by industrial or vehicular noises but have become accustomed over the years "because years ago when they use to hunt, they hear a little noise; they're gone" (Oct 14 2010). Abe Peterson remembered that when seismic work began around Fort McPherson there were fears that the caribou would be impacted negatively, but the caribou became used to the noises and disturbance (Oct 14 2010).

James Firth warns that there may be a point at which noise interference and vehicular disturbance is too great for caribou to adjust to. "Few years ago when Colt had their line up to Fort Good Hope, a lot of activity, a lot of trucks, a lot of noise in here, and they seemed like they pushed all the caribou. There was caribou all around my cabin now. And I think that was from all the noise that was further to the east." He did feel that caribou will adjust to pipeline noises, as seen around Alaska (Nov 3 2010). Some interviewees felt that all industrial and vehicular noises would be negative for the caribou and cause them to flee (Mary Teya Oct 14 2010, Albert Ross Oct 18 2010). One interviewee wondered if the sensitivity of caribou to lights and noise was why they are so rarely seen – they see and hear skidoos approach and are gone leaving only their tracks. The caribou may also have learned to associate skidoo noises with gunshots; whereas other loud noises are not followed by gunshots and are more easily accepted by caribou (Conrad Baetz Nov 12 2010).

Caribou will follow cleared seismic lines or other linear disturbance if it is heading in the direction of their travel, in particular in the summer months when they seem to use cut lines more (Tom Wright Oct 12, 2010). In general, the presence of linear disturbance does not impact caribou significantly, particularly if they are re-vegetated appropriately (Albert Frost Oct 12 2010). Linear disturbances however do create easy access for hunters, which will impact caribou. Seismic lines that are allowed to grow in will often have a lot of willows and attract moose, which can be considered a benefit (Ernest Vittrekwa Oct 15 2010).

Interviewees often reported seeing woodland caribou tracks rather than the caribou themselves. They are an elusive animal and not easy to spot, except for by chance. Willy Simon felt that the best way to hunt woodland caribou was to come upon them on foot, and to avoid detection by the caribou (Nov 4 2010).

Interviewees were generally not aware of where woodland caribou calve but generally agree that they calve throughout the area. Walter Alexie suggested that the cows would select a location where prevailing winds would keep flies and mosquitoes away. Albert Ross has recently seen tracks of caribou from the summer when they would have young calves, around the firebreak behind Tsiigehtchic (Oct 18 2010). Caribou may seek higher locations for the breeze, or they may stay close to water (Walter Alexie Oct 14 2010, Ernest Vittrekwa Oct 15 2010). James Firth has been told that in the Caribou Lakes region, the woodland caribou go up onto hills to calve. A hunter told him "they just go to the hills, where is it safe from predators and it is open and they have their young" (Nov 3 2010). Douglas Kendo has seen caribou with small calves, along the Dempster Highway north of Tsiigehtchic and towards Tree River. He suggests that woodland caribou will calve alone and then group together in the winters, "I think ... when they're calving they're probably separated and then in the winter they probably get together for protection against wolves and stuff" (Oct 18 2010). Julie Ann Andre was hunting woodland caribou around Swan Lake up the Arctic Red River in the spring time; they harvested two cows with young calves.

As the population is low and the use of the caribou is generally confined to non-calving times, interviewees generally did not comment on calf survival. However, Julie Ann Andre indicated that cows may not breed and calve if their body condition would not support it (Nov 12 2010).

3.7. Distribution

> "They're just here and there."
> (Emma Kay Oct 13 2010)

Interviewees had not seen woodland caribou in areas outside of the mapped area provided by Environment Canada (see Figure 1). They based their information on sightings while hunting, trapping, or otherwise travelling; and on experiences with fly-overs with caribou biologists. Interviewees generally see caribou when they are using the land in the winter for trapping and travelling. Only rarely did they head out to hunt woodland caribou specifically.

Many Fort McPherson interviewees were aware of woodland caribou sightings at Deepwater Lake near Fort McPherson, along the Dempster Highway between Fort McPherson and Tsiigehtchic, and in the Peel Preserve, "Just like I say on the [Peel] Preserve, it's way out around the lakes where it's trees, no

mountains. And same out this way. I never see woodland caribou around my mountains" (Emma Kay Oct 13 2010). Caribou are not seen in the delta (Tom Wright Oct 12 2010).

Robert Alexie Sr. sees signs of woodland caribou in the winter and spring up the Peel around his cabin at the mouth of Trail River – areas where the caribou have fed, and many tracks, in particular along the cutlines he travels upon when trapping. He only sees them on the east side of the Peel River (Oct 13 2010).

Douglas Kendo has seen woodland caribou between Tsiigehtchic and Tree River, around Tundra Lakes, and on the Dempster Highway between Tsiigehtchic and Rengleng River. His father would hunt woodland caribou around Cardinal Lakes as well (Oct 18 2010). John Norbert has also seen caribou around Odizen Lake and between Tsiigehtchic and Tree River (Oct 18 2010). Julie Ann Andre has seen woodland caribou in the summer along the Dempster between Tsiigehtchic and Inuvik, and in the winters up the Arctic Red River near Swan Lake.

According to Albert Frost, barren ground caribou and woodland caribou intermingle around North Caribou Lake, although in this area the woodland caribou are not too plentiful any more (Oct 12 2010). There are a lot of woodland caribou west of the CN line, a large decommissioned transmission line crossing from northwest to southeast across the GSA. They mingle with the Bluenose caribou in the Travaillant Lake/Anderson River region, and can be seen around Siveezhòo south of the Mackenzie near Tree River. The Bluenose caribou moved into the area in the 1960s and have recently changed their migration away from this region (Willie Simon Nov 4 2010). Woodland caribou will also share habitat with moose, based on tracks in the snow (Robert Alexie Oct 13 2010).



Willie Simon

Photo: GSCI

Most Fort McPherson interviewees indicated that woodland caribou sightings around town (and possibly even on the Peel Preserve) are a relatively recent – within the last one or two decades – phenomenon (Emma Kay, Robert Alexie Oct 13 2010). Walter Alexie indicated that there was not a noticeable population of woodland caribou on the Peel Preserve in the past, "I never seen that ... when I was young, never see woodland caribou around there" – he first heard of them in the preserve in the 1970s or 1980s. "They come from some place but I really don't know where they come from. But years ago you don't see those." Walter suggested that an increased rate of plant growth and more caribou food may be responsible for the change, or that they were hunted more previously. "People used to live on the land and they probably thin it down that time. Years ago I mean, 50s, I remember 50 and late 48, hardly any caribou" (Oct 14 2010). It is possible that the caribou have always been in the area and were just noticed more recently due to changes in their behaviour, as Emma Kay notes their tracks were always around, "Maybe four or five years, but last year that's when they see. I always heard they see tracks just not ah our caribou tracks, but must [have] been woodland caribou" (Oct 13 2010). In the last few years, woodland caribou have been seen

quite close to town – possibly related to the incidence of forest fires in the nearby areas. Emma Kay's father saw caribou crossing the Peel River while fleeing forest fires:

> *Many years ago, about ten, fifteen years ago my dad he stay at Shìłdii Rock and he see caribou coming across this way there's fires all over. He see caribou and they never see caribou for many years though. He grab his gun. He even shot it when he got to the shore and it was just good and it was so fat; good healthy caribou. And he said it was woodland. He know it, it's different caribou. See, he's running away from fire. So maybe woodland caribou up on the hills, we don't know it (Oct 13 2010).*

Several interviewees felt that woodland caribou have always been in the Peel Preserve area, "my dad used to get caribou up that way" (Ernest Vittrekwa Oct 15 2010).

Many Fort McPherson interviewees regularly see woodland caribou along the Dempster Highway between Fort McPherson and Tsiigehtchic, in particular in the winter. Summer sightings of woodland caribou seem to be rare, perhaps due to the increased travel on the land relating to the winter activities of hunting and trapping.

The following maps show woodland caribou mapped information from the interviews conducted in 2010 for this report, as well as caribou information as mapped during the 2001 GRRB woodland caribou study (Denise Auriat, 2001-2002), which included the mountain woodland population area in the Mackenzie Mountains at the headwaters of the Arctic Red River. 2010 map data indicates that caribou are seen and harvested along the Dempster Highway between Inuvik and Tsiigehtchic and to the south of the Dempster into the Yukon. Tracks, harvest areas, and sightings are noted as far south as the mouth of Trail River, where several interviewees have a camp. Harvest/sighting areas are also south of the Mackenzie River upriver from Tsiigehtchic to the GSA/Sahtu border; south and northwest of Travaillant Lake to Campbell Lake, and between Tsiigehtchic and Rengleng River. One caribou area is outside of the GSA along the Anderson River (Figure 4).

The 2001 project data shows winter hunting areas between Tsiigehtchic and Rengleng River as well as a concentration around Caribou Lake and northwest and east of Travaillant Lake. Winter hunting locations also were noted up the Arctic Red River and above the Forks of the Arctic Red and Cranswick Rivers and in the Mountain Woodland area. One spring harvest location was noted up the Peel River in the Yukon. Fall harvest locations were in a similar geographic spread as winter locations, and only two summer locations were mapped – north of Caribou Lake and on the right shore of the Mackenzie upriver from Tsiigehtchic (Figure 5). The 2001 study mapped more caribou sightings, which are shown in an intensity map in Figure 6. The greatest intensity of sightings is north of the Mackenzie River and east of the Arctic Red River.

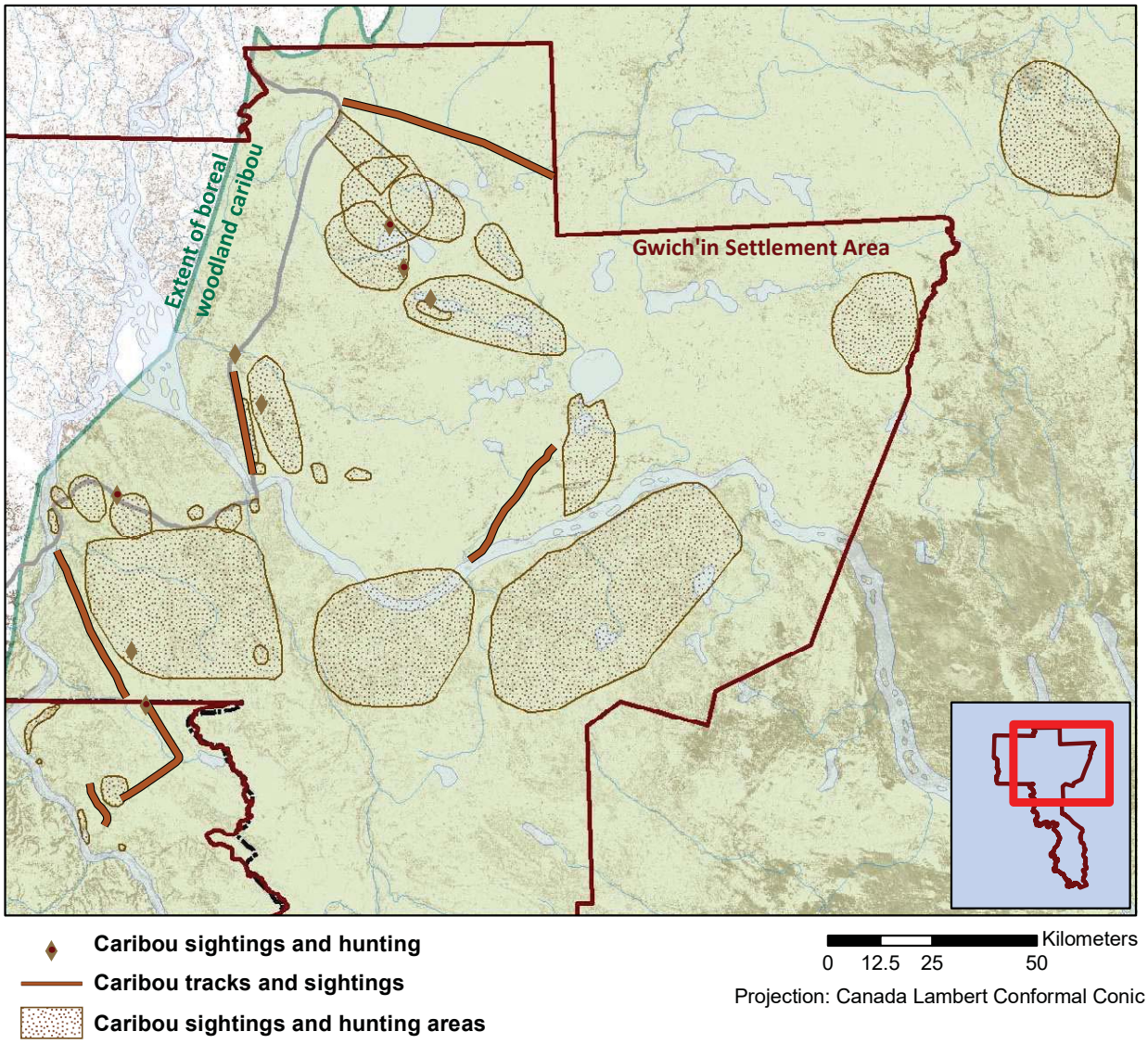


Figure 4. Caribou sightings, tracks, and hunting areas (2010 data)

3.8. Population size and trend

Interviewees had different opinions about whether or not the population of woodland caribou was stable, increasing or decreasing. Conrad Baetz felt this may relate to several factors;

> *One, they are elusive to begin with... Two, they come in smaller groups; they don't come in bigger herds. Three, they can be tougher to distinguish the difference between a Woodland and a barren ground caribou. Barren ground caribou have been known to come in that neck of the woods so to me it is really hard to tell whether or not their numbers are up or down or if you see more of them or see less of them or not, right? (Nov 12 2010)*

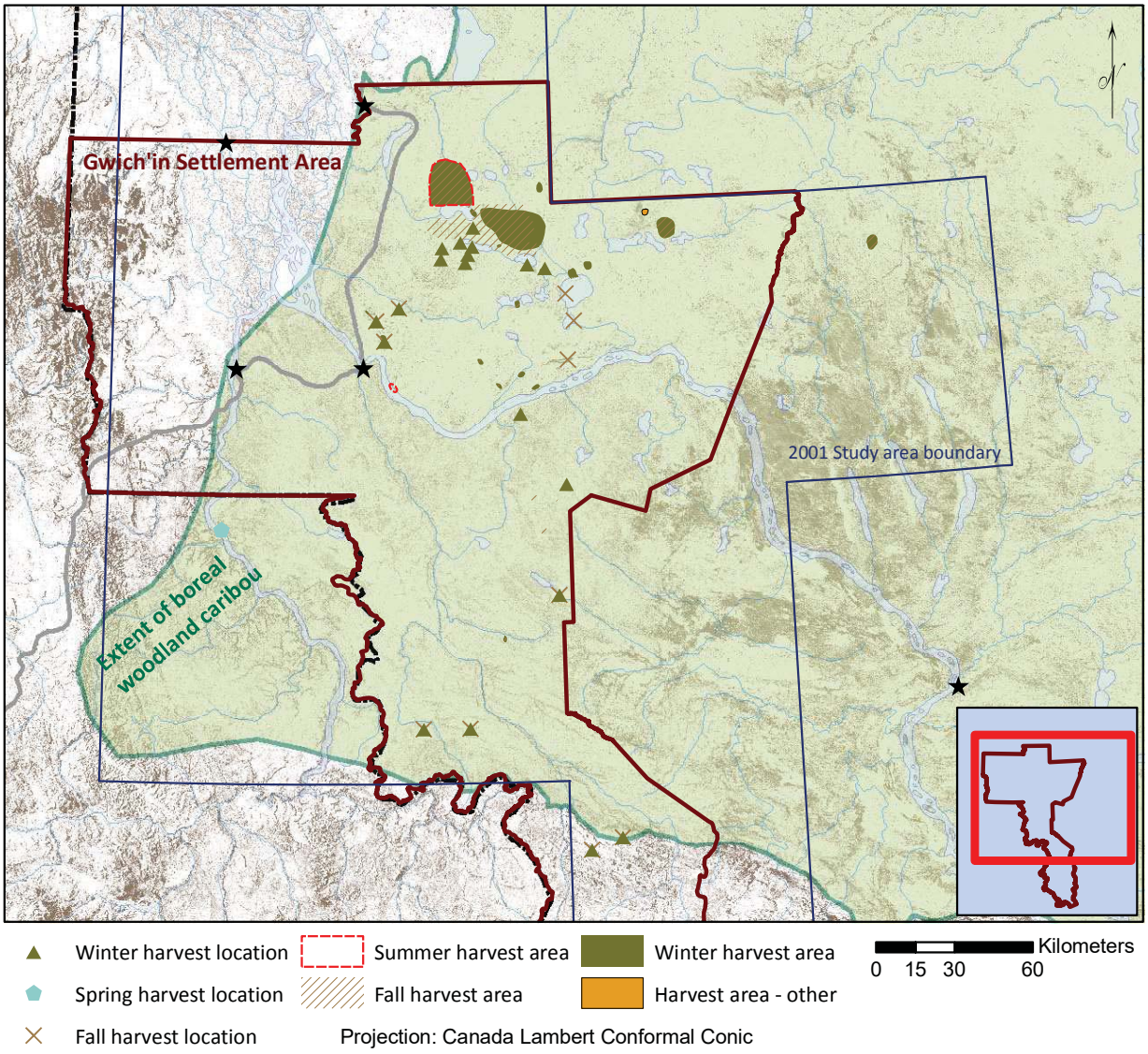


Figure 5. Hunting locations from GRRB 2001 study.

Abe Peterson felt that the woodland caribou may move away from areas where they experience hunting pressure, which may give the appearance of a declining population to hunters. Also, he guessed a four-year stay in one area was reasonable for the food the woodland caribou will eat, "And then every year growing, just like this. They move over here for four years and move back there another four years" (Oct 14 2010). Wally McPherson was told that the population or their presence nearby is cyclic, "I always ask the elders in McPherson and Tsiigehtchic and they tell me, they said [woodland caribou] are going make a comeback, they said. You won't see them for four years, five years, six years and all of a sudden they are going to come back. I always ask them where they go? Doesn't know he said. They are there but they will come back all of a sudden" (Oct 28 2010). They may also be pushed away from areas where melting permafrost and slumping is impacting their ability to eat (Douglas Kendo Oct 18 2010).

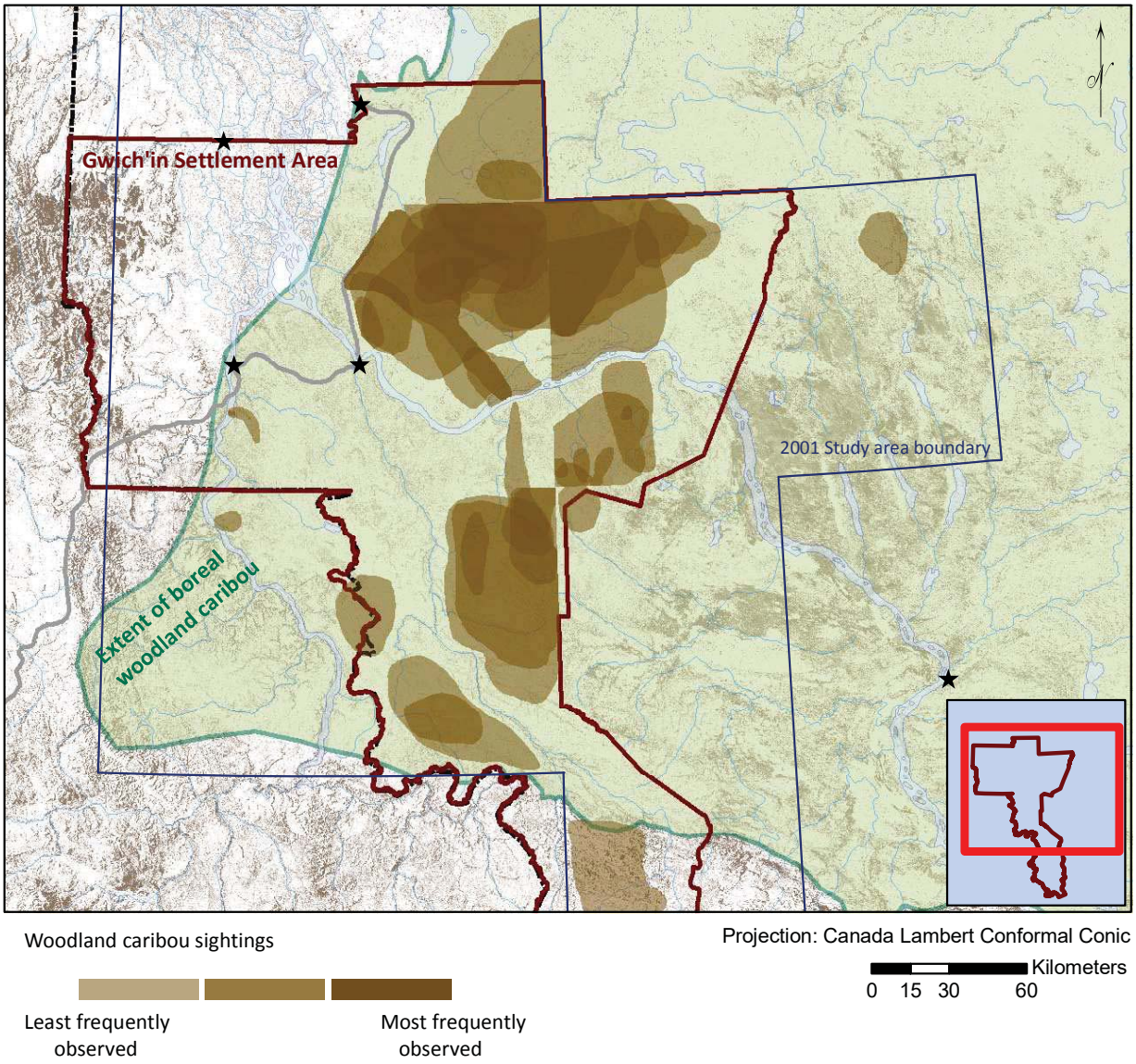


Figure 6. Caribou sightings intensity map from GRRB 2001 study.

Tom Wright felt that the woodland caribou population around Inuvik was stable or increasing in the last several decades. "A few years ago you could hunt caribou anyplace in here there was caribou all over" but they have declined in the last few years (Tom Wright Oct 12 2010). However, Albert Frost indicated that woodland caribou numbers were declining over the last two decades, in particular with ease of access into good woodland caribou habitat along the CN line. However, with recent bans on hunting, the caribou are making a comeback and moving back into areas where they were hunted from or left (Oct 12 2010). James Firth has seen an increasing number of woodland caribou from the Dempster Highway between Inuvik and Fort McPherson, although indicated that they are declining overall. He has trapped around Caribou Lake and Sunny Lake and said they are always in that general area, "you see them just about every time you go checking traps" (Nov 3 2010). Julie Ann Andre

remembered a population of around 200 near Cardinal Lakes when she was younger; which has been much reduced in recent years (Nov 12 2010).

Woodland caribou population around Fort McPherson is stable, according to Fort McPherson elder Ernest Vittrekwa (Oct 15 2010). Douglas Kendo of Tsiigehtchic believes that woodland caribou are decreasing in population. He sees them north and east of Tsiigehtchic, and believes they are being over-harvested. He mentioned increased access to Cardinal Lakes due to an ice road one year. "It was easier for them – that trail was made – so they were taking more than what they needed or could handle." (Oct 18 2010).

However, Albert Ross feels that the woodland caribou may be increasing in the area near Tsiigehtchic, despite increases in wolf populations – he has observed a wolf pack of 14 individuals across the Mackenzie River (Oct 18 2010).

Interviewees generally indicated that woodland caribou are not overharvested in the Peel Preserve area. However, several interviewees expressed concern that they could be hunted out of an area if conditions were right – and these interviewees were careful of who they spoke to about caribou for that reason. A Fort McPherson interviewee said "I don't say nothing about it, because if I said that, then [a] whole pile of people will go on my trapline. Kill the whole thing off...that's what's going to happen."

Oral history indicates that caribou and all large animals were extremely scarce long ago, "I was talking with old Hyacinthe Andre and he said that when he was young he said you had to go two hundred miles to get caribou" (Tom Wright Oct 12 2010). Albert Frost concurs that there are 'way less' woodland caribou now, compared to his grandparent's time (Oct 12 2010). Tsiigehtchic residents had to travel great distances for meat, including to the headwaters of the Arctic Red River in the Mackenzie Mountains. "When I was a kid going to school here, caribou and moose was very scarce. You had to go to the mountains, which is about three, four hundred miles, to go and get caribou" (John Norbert Oct 18 2010). Robert Alexie remembered a time in the 1950s when black bears were regularly shot for meat, which he said is nicest tasting when smoked. "Smoked, I like it, I like it when it's smoked, black bear anyway. We use to shoot black bear all the time, summer time. Any time of the year we used to get black bear, because [there was] no meat around. Can hardly get moose, hardly get meat. This is the 50s" (Oct 13 2010).

3.9. Limiting factors and threats

Wolves and humans were mentioned as the two most important factors in caribou population decline. Other predators were also noted, but wolf numbers are dramatically increasing; and they are having an effect on caribou numbers, according to most interviewees.

Wolves may hunt adults but can be particularly hard on young caribou (John Norbert Oct 18 2010). Wolves are known to hunt beyond what they need. "Doesn't matter to them they are funny... They'll kill caribou and eat the tongue, and go get another one. People have seen that over the years. I don't know why. Or they will get the liver out" (Tom Wright Oct 12 2010). Walter Alexie blames the increase in wolf population on a lack of hunting and trapping in recent times. He said that wolves are excellent

hunters. They generally stay in a pack of seven or eight family members, sometimes more, and can easily take a large moose or caribou and 'clean it right up' (Walter Alexie Oct 14 2010). Although the reason for the increase in wolf population was not clear to the interviewees, many felt that it might relate to a lack of population control by people in recent times. However, wolves are not that easy to control – Abe Peterson indicated that hunters "just don't see them. And they know trap too." He felt that the poison used by the Game Wardens in the past was effective (Oct 14 2010). In the past, people would hunt, trap, and poison wolves. Their fur was used as well – it is very warm (Mary Teya Oct 14 2010). There may be a bounty on wolves (John Norbert Oct 18 2010) – GRRB to confirm.

James Firth suggested that in the Caribou Lakes area, wolf population or distribution follows the Bluenose caribou herd – the Bluenose herd has not been around his area for about ten years, and he has noticed a drop in wolves (Nov 3 2010, also Conrad Baetz Nov 12 2010).

Other predators noted include grizzly bears who will hunt caribou, as well as scavenge from human hunters, drawn in by the sound of gunshots. Grizzlies will prey upon calves (Albert Frost Oct 12 2010). Wolves and bears were controlled in the past to some degree by people. Bear meat was harvested for dog feed; both bears and wolves were harvested for their furs (Tom Wright Oct 12 2010). "Black bears, they're all over too. We use to live on black bear but nobody bother with that now. After the highway went through, nobody, nobody eat bear" (Emma Kay Oct 13 2010).

Bear populations are increasing, and their behaviour may also be changing. Mary Teya indicated bears used to be shyer of people and camps, but their behaviour has changed,



Mary Teya

Photo: GRRB

...it seems that ... there's so much more of them around. I remember when we used to be out on the land and maybe because we always had a lot of dogs too and dogs are always barking and that kind of... kept the bears away. [These days] they're kind of tame, like you know, even if you're there. You try to threaten them, to scare them away, they just stay there and they just look at you, you know. Scary. ... it's just like they're not scared? ...It looks like they're depending on what they can get more easily. Long ago you never saw bears doing that, you know they're out feeding on berries and stuff like that. They [don't] even come around the camp really. But now it seems like, since ...sometimes people leave stuff around at their cabins or, oil company has used it, you know have garbage ... And they get after that, and that is more easy for them to get and it just looks to me like they're more dependent on what they can get ...from people. (Mary Teya Oct 14 2010)

Bears are not being hunted by people as often as in the past, and have lost their fear of humans. They will now be drawn to sound of gunfire and scavenge from a recent kill (Wally McPherson Oct 28 2010).

Wolverine and lynx are also known to predate upon caribou, although it is a rare occurrence. They would probably have the most success with calves (Douglas Kendo Oct 18 2010). Wolverine populations may be on the rise, according to Ernest Vittrekwa. "Wolverine too is getting more all the

time. I see it and I caught a few too. Usually it would be hard to get them" (Oct 15 2010). Lynx will jump onto a caribou and chew through the spinal cord, a caribou hunter told Albert Frost. Both wolverines and lynx will hide up trees to pounce on caribou. "Wherever there's caribou there's wolverine, wolves." (Oct 12 2010). Wolverine and lynx also scavenge (Mary Teya Oct 14 2010, Ernest Vittrekwa Oct 15 2010).

> In the spring time you see grizzly bear tracks. Winter I see wolf tracks too.
> (Ernest Vittrekwa Oct 15 2010)

Muskoxen are sometimes identified as competing for food resources with caribou, although specific overlap with woodland caribou was not described. "See, the muskox seem to thrive ... better than everything else. And then they kind of take over. I'm definitely sure that we are not going to change that, nature kind of regulates that" (Tom Wright Oct 12 2010). Emma Kay had heard that caribou will avoid areas where muskoxen have urinated. She heard of a small group of muskoxen appearing at the border. "And then when they eat ... they take big ground, and they could eat a big patch in one day. They really could eat." Emma and her daughter saw eleven muskoxen at a lake near the NWT/Yukon border on the Dempster Highway, around 2002 or 2003 (Oct 13 2010).

Global climate change may be impacting caribou populations in a variety of ways (see section on changes to the land, below).

Woodland caribou have been observed in proximity to barren ground caribou, with no apparent issues (Tom Wright Oct 12 2010). "But [woodland caribou] are in here and they mingle; because on the surveys we've seen woodland caribou and Bluenose caribou in the same herd, just feeding at that particular time" (Willard Hagen Gwich'in Traditional Knowledge of the Mackenzie Gas Project Area tape 60).

Interviewees discussed two separate timelines for caribou re-entry into areas burned by forest fires. One was a short timeline of a few years; the other was a long-term timeline of between two and four (or more) decades. The two different numbers may relate to how quickly deciduous feed such as grass and browse are available, compared to how much time lichen may take to return; and may also relate to the intensity of the burn. A hotter burn will take all the lichen off which requires several decades to grow (Anonymous Nov 2 2010). Conrad Baetz categorized fires as slow, hot fires which burned most or all organic matter, compared to a fast-moving fire which may leave some food (Nov 12 2010). Willie Simon wondered whether some fires were set by people (Nov 4 2010). Many interviewees agreed that forest fires have a rejuvenating effect on the land, and will not prevent caribou from using an area for long. Caribou may return between one and four years after a burn, when the vegetation has grown (Tom Wright Oct 12 2010, Albert Frost Oct 12 2010). Michael Pascal indicated that although some vegetation flourishes quickly after a fire, the lichen that caribou reply upon takes longer to re-establish (Oct 14 2010). Ernest Vittrekwa agreed that that caribou may take much longer to return to an area – "my dad used to tell me when the place burned, the caribou move for about 30, 35 years" (Oct 15 2010). Willard Hagen indicated that woodland caribou in particular will avoid burned out areas, "But Woodland caribou, we noticed in the surveys we've been doing—it's the first time I've done surveys of

Woodland caribou—ah, they stay totally away from any burnt out area. Completely away from it" (Gwich'in Traditional Knowledge of the Mackenzie Gas Project Area tape 60).

Some species, like moose, may experience a population boom after a forest fire, relating to the increase in available food. However, woodland caribou population does not follow this pattern, possibly due to their habitat requirements (Tom Wright Oct 12 2010). Although interviewees knew of specific forest fires, it was recommended that the forest fire maps produced by the GNWT would be the best source for location and extent of forest fires. Several particularly large fires were noted – one that crossed the Peel River in the Yukon before it enters the NWT (Walter Alexie Oct 14 2010) and another that burned from Frog Creek towards Fort McPherson (Abe Peterson Oct 14 2010).



Abe Peterson

Photo: GRRB

Forest fires will impact caribou and other animals directly during the fire itself – and the effect may be amplified due to the dispersed nature of woodland caribou (John Norbert Oct 18 2010). It will burn small animals trapped within the burn area, and large animals may succumb to smoke inhalation even as they attempt escape (Abe Peterson Oct 14 2010).

Michael Pascal indicated that using calcium on the Dempster was affecting the land in general. "One thing that I really don't like about the way they treat the highway, [is] putting calcium on the road. ...Absolutely I am against that. Yeah, the dust control; because I think it is real harmful stuff, that. [It's] even killing trees along the highway so it got to be bad" (Oct 14 2010). Garbage such as wires or chemicals left out on the land could impact caribou if they come across it. A caribou may get tangled in wires or inadvertently consume antifreeze or other chemicals (Willie Simon Nov 4 2010).

An anonymous Inuvik interviewee identified habitat fragmentation as a concern. He also indicated that industrial activities that impact caribou could be mitigated by having seasonal restrictions on particular activities to lessen their effect on caribou (Nov 2 2010). Although many interviewees agreed that development like seismic lines would not necessarily impact caribou populations, increased access will allow greater hunting pressure – from people and wolves. James Firth felt that development would impact caribou, "definitely the pipeline, definitely the highway, definitely if there is going to be say, oil activity in that area. And they are just going to open up the country and just be a free for all, basically. And you are going to be going right through the habitat, right through it." James felt that the proposed Mackenzie Valley Highway and Mackenzie Gas Project will drastically alter the Gwich'in Settlement Area by creating access for many more people than now use the land. He felt that in anticipation for these changes, there needs to be strong Land Use Planning processes, trespassing protection and laws, and other policy and legal changes to protect animals. He used the example of the Colt line near Fort Good Hope, which allowed people to access new areas for fishing, firewood hauling, and woodland caribou hunting (Nov 3 2010). He considered this to be a negative impact.

Conrad Baetz has some specific examples of industry-related damages which will impact caribou. Activities which destroy or remove the vegetation layer will cause melting of the permafrost and damage the surface of the land. He also described several methods to prevent damaging the vegetation, such as mushroom shoes for cats (Nov 12 2010).

3.10. Animal health

There was general consensus that caribou in general and woodland caribou in particular are healthy animals. Woodland caribou may be healthier than Porcupine caribou as they don't migrate the same distance. Also, they do not experience the same hunting pressure, "because nobody bother them. They just eat out there." (Ernest Vittrekwa Oct 15 2010). There was only an occasional observation of spotted livers or a poor animal. Even some variation in the carcass quality was considered normal – infected portions, if not systemic, could be removed for example.

A hunter assesses caribou health before and after shooting it. From a distance, an unhealthy caribou will appear thin, with the ribs showing, or may appear wobbly (Tom Wright Oct 12, 2010). A good indicator of animal health is presence of subcutaneous fat – so important is this fat that hunters often use the word 'fat' to mean a good, healthy looking animal. From a distance, a hunter can assess the amount of fat in the rump area, where the appearance of the hip bones is an indicator that they are in poor shape (Julie Ann Andre Nov 12 2010). A sickly caribou might have an empty stomach and not be eating, and have no fat under the skin (Albert Frost Oct 12 2010, Walter Alexie Oct 14 2010). When skinning and butchering, hunters assess the organs against their knowledge of what healthy caribou look like, so any deviation from the norm in colour, firmness, or other condition can be noted. Unhealthy caribou are not generally harvested. However, some animals with minor spots or discolouration on the liver and lungs may be eaten as long as it is cooked properly. Also, if an injury or infection is only within one part of the body, the rest of the animal may be taken for meat.



Harry Carmichael

Photo: GRRB

Tom Wright once saw a caribou with a foot disease on the west side of the delta. The animal did not run when approached (Oct 12 2010). Albert Frost has seen an increasing trend towards unhealthy caribou. "There's a lot of things in a caribou that I never used to see. Parasites or fungus, lumps in the legs [and] meat once in a while – white, hard lumps, outside of the meat, between the skin and the meat. A lot of them, in the last 10 years. Their joints are full of yellow coloured fluid, you never see them before like that" (Oct 12 2010). Hunters like Abe Peterson, Douglas Kendo, and Ernest Vittrekwa indicated that they look to the caribou's coat for clues about their health. "If you're a really good hunter you'd know which ones [are] fat, you know, because they're all just like white like. There's your fat caribou there. You see a dark one, that's poor caribou" (Abe Peterson Oct 14 2010). If the caribou are shedding their coats at the wrong time of year, it may indicate they are not healthy as well (Harry Carmichael Oct 28 2010).

Also, animals are in poorer shape naturally during the rut or mating season. Generally people avoid hunting during this time for that reason, and because the meat may be tainted (Richard Ross, however, has heard that woodland caribou do not become poor-tasting like the Porcupine herd bulls, Oct 28 2010). Abe avoids hunting the larger males because they have used up their reserves; he prefers younger animals with small horns, "If you... get them big ones...it's spoiled already. All their good fat's gone away" (Abe Peterson Oct 14 2010).

Brucellosis has been seen occasionally in woodland caribou. It appears as a problem with the caribou's joints (Tom Wright Oct 12 2010). John Norbert has also harvested a single caribou with strange fluid in the joints, "I was up around Tenlen Lake, we shot two caribou one day and I was skinning it and I could see around the joints were pus and stuff like that." John did not take the caribou for eating (Oct 18 2010).

Parasites are found on caribou. In the spring, caribou may have parasites in their noses which they sneeze to expel. They also have warble flies in their coats, in particular on their backs (Tom Wright Oct 12 2010). Warbles are considered normal and are found in the spring; the holes are healed by the fall making fall-hunted skins nicer (Douglas Kendo Oct 18 2010). Wally McPherson indicated that warbles, which he calls bulldogs, do not spoil the caribou for eating. They emerge from the skin when temperatures warm up after the spring (Oct 28 2010).

3.11. Gwich'in language names for caribou

The Gwich'in name for caribou is *vadzaih*. For Gwich'in elders, *vadzaih* refers to all caribou – barren ground, Porcupine, and woodland. However, interviewees used geographic markers to identify different populations of caribou when asked. According to Emma Kay, Peel Preserve woodland caribou could be identified as such. Robert Alexie Sr. mentioned a mountain woodland population in the Yukon known as Hart River Caribou, and also referred to Snake River Caribou, the boreal woodland caribou in the Snake River area (Oct 13 2010). Walter Alexie indicated that woodland caribou could be called *Dachan tat gwavadzaih* which translates as 'amongst the timber caribou' (Oct 14 2010; William George Firth pers. comm. December 2010). Several interviewees called them *vadzaih choo* or 'large caribou' (John Norbert Oct 18 2010, Michael Pascal Oct 14 2010).

3.12. Changes to the land

> *And I noticed that the permafrost is melting. We used to... go for berries, use to go out on the land, and we could drink water from anywhere. ...Where we go for berries ... sometimes [there were] little holes with water in it [and we would] take the water out and as you feel inside there's ice, right there. That permafrost is that close to the surface. And now you don't even see that, and it's scary to drink water any place. (Mary Teya Oct 14 2010)*

Gwich'in have been noticing worrisome changes to the land and the climate. Although not a focus of these interviews, several interviewees commented on these changes as they are seen as inextricable from the well-being of the animals and plants harvested by the Gwich'in. Forest fire prevalence has increased since the 1960s, with one possible factor being increased lightening strikes (Tom Wright Oct 12 2010). Landslides are often mentioned as increasing in prevalence – Robert Alexie Sr. mentioned a large land slide along the Peel which happened in November 2009 (Oct 13 2010), and Mary Teya

indicated that the ground can absorb much more rainwater now that it used to, likely due to melting permafrost (Oct 14 2010). The amount of precipitation has changed, and summers are warmer and longer than before (Douglas Kendo Oct 18 2010). Michael Pascal also worried that warmer temperatures were changing freeze up and permafrost conditions,



Michael Pascal Sr

Photo: GRRB

> *Should have been frozen already almost [in mid-October]. It is minus 10, usually the river is plugged up with ice already. ...You know few years ago when we used to live out in the bush with my parents, we used to go out and if we have meat or something we just, we are always living by hill, [so we] just take it back, like lard or butter or something, cut the moss [in a] big square like that and you just unroll it, it is only this thin, but it is just solid ice there. Just put everything there and put that moss back on and just like in deep freeze, just freeze solid. Now you got to dig down about two feet or more to get to that ice. That is a big change – whereas we used to just cut with knife now you got to dig down damn near three feet before you hit ice. We're going to see lots of landslides pretty soon (Michael Pascal Oct 14 2010).*

The general warming trend may impact caribou's bodies as well – for example, the triggers that a caribou has to grow a winter coat might not relate to the actual weather conditions any more (Julie Ann Andre Nov 12 2010).

The melting permafrost is causing changes in the lakes as well, possibly due to increased ability of the ground to absorb water. Lower lake levels impact many animals including beaver, and caribou. "All them lakes going to dry out pretty soon maybe and the water goes through the ground and the caribou's going to have to move" (Ernest Vittrekwa Oct 15 2010). Caribou may also be impacted if increasing rainfall causes rivers that the caribou normally cross to be running more swiftly; and some interviewees did note that the amount of rainfall seems to be increasing (Douglas Kendo Oct 18 2010, Willie Simon Nov 4 2010).

Walter Alexie described how some of the changes to the land are impacting their ability to hunt. Areas where forest fires have burned grow in very quickly with brush, making it impassable. Even other timbered areas which used to be passable on snowshoe to track moose, are no longer passable due to willows and birch trees growing in profusion. Seismic lines are also growing in to a point where they are less useful for trapping. In the past, trails and traplines did not have to be cleared, but now clearing is required to keep them open (Walter Alexie Oct 14 2010). Wally McPherson also indicated that climate change is affecting the way people use the land – freeze-up is later and at a different pace than before, making conditions unsafe for travel (Oct 28 2010).

> Fall time weather – that is the biggest threat right now
> (James Simon Nov 3 2010)

Fall rain and freezing rain during early winter was mentioned by several interviewees. The freezing rain causes a thicker crust to form on the ice, making it difficult for the caribou to travel (Anonymous Nov 2 2010, James Firth Nov 3 2010). It impacts their ability to move freely which makes them easier

for predators as well (Julie Ann Andre Nov 12 2010). Late rains and winter rains can also freeze the food upon which the caribou rely (John Norbert Oct 18 2010). Richard Ross has heard of several instances of caribou and muskoxen perishing from fall or winter rains which have made winter feed unavailable to the animals; causing them to starve (Oct 28 2010). The frozen crust on the snow may cause groups of woodland caribou to leave an area, at least for a time (Douglas Kendo Gwich'in Traditional Knowledge of the Mackenzie Gas Project Area tape 11). The crust on the snow can also happen with warm winter winds, although it's unclear if these winds are related to climate change or happen with some regularity (Willie Simon Gwich'in Traditional Knowledge of the Mackenzie Gas Project Area Tape 62).

Animals have also changed in behaviour and distribution. Beavers are very common now, many say overpopulated, and building their dams and lodges in places where they haven't in the past. However, the beaver population does not seem to be impacting the caribou (Walter Alexie Oct 14 2010, Abe Peterson Oct 14 2010). Some interviewees indicated that otters are also expanding in numbers or extent and some consider them dangerous. Cranes have also been noted as possibly dangerous when protecting their young ones. Several people around Fort McPherson have seen a cougar in recent years (Emma Kay Oct 13 2010, Robert Alexie Oct 13 2010). Willie Simon may have seen a cougar in the 1960s and has also wondered if some tracks he's noticed recently in the delta might be coyote (Nov 4 2010).

Not all interviewees agreed that climate change was the root of the changes seen on the land. Some wondered if natural cyclical weather patterns were the reason for the freezing rain conditions seen recently and causing trouble for caribou (Conrad Baetz Nov 12 2010).

4. Management of Boreal Caribou

4.1. Subsistence use of boreal caribou

Woodland caribou are generally harvested incidentally. If they are seen while out on the trapline and the situation allows, they will be shot and the meat brought into camp or town. Participants have hunted woodland caribou from all areas within the known habitat where they trap and travel, see mapped locations in Figure 4, Figure 5, and Figure 6, above.

A few interviewees humorously said that a person is most likely to see woodland caribou when they are not carrying a firearm.

Albert Frost has changed the locations he hunts for woodland caribou based on population decline and subsequent hunting bans (Oct 12 2010). Conrad Baetz indicated that he has stopped hunting caribou over the last several years, out of concern for the population (Nov 12 2010). Julie Ann Andre has started to hunt only when the size of the herd allows it, "Well if I run into one caribou, I will not shoot it, but if I run into five or six, maybe I will get one" (Nov 12 2010).

If woodland caribou and barren ground caribou were both available to shoot, interviewees had different opinions of which they would take. Albert Frost would take a woodland caribou – he

indicated that the reason for this relates to the bans on hunting barren ground. There was some confusion expressed by interviewees about whether or not the population is declining.

In the past, caribou meat was prepared for storage by drying or smoke-drying, "they cut it up...out on the land and, just like half smoke it, and dry it." It is still made into drymeat today (Emma Kay Oct 13 2010). In the past, as much of the caribou was taken for food or other uses, as possible. The meat from the head was used, the skins were used including the legs, and even the tendons. "[In] hard times, you can soak it and ...cook it, and you can even make soup and a broth" (Mary Teya Oct 14 2010). The small hooves on the back of the legs were made into a noise-maker to attract caribou when hunting. "They take them off and they put strings through it. And they keep it for when they go out hunting, like in the winter, [when it's] cold. They take it with them and they kind of just shake it and...the caribou hear it, it's just like when they're digging for snow" (Mary Teya Oct 14 2010). Caribou hides were tanned and used for many purposes or sold, or dried with the hair on for their exceptional warmth (Mary Teya Oct 14 2010). Bones were pounded and boiled to make grease which was eaten with drymeat or boiled meat; and marrow was also saved. The marrow or grease was saved in one of the stomachs of the caribou.

In the past, hunters in the area north of the Mackenzie River may have had greater hunting success - Barney Natsie recalled a winter a long time ago when they hunted 40 woodland caribou by dog sled, around Wood Bridge Lake. Even though he had a large eight dog team, he was still only able to move two caribou at once in his sled (Gwichya Gwich'in Place Names study 1992 Tape 31).

Interviewees had different opinions on whether or not woodland caribou tastes different than Porcupine or Bluenose caribou; it seems to be a matter of personal taste. People who grow up eating Porcupine caribou are more likely to say they prefer those caribou. However, there was general agreement that all caribou are tasty. The difference in taste likely relates to a different diet (Walter Alexie Oct 14 2010). Michael Pascal indicated that the meat from the woodland caribou is tougher, and said that his family doesn't enjoy eating it compared to the Porcupine caribou. "Well I think they eat willow like moose, you know, taste more like moose meat" (Michael Pascal Oct 14 2010). Wally McPherson agreed that woodland caribou eat more willows and leaves, which imparts flavour to the meat (Oct 28 2010).

The Gwich'in Renewable Resource Board conducted a study of Boreal Woodland Caribou in 2001, which focussed on mapping. However, several Gwich'in interviewees indicated the following seasonal information about preferred animals to hunt: Bulls are hunted in September and October and again in January and February; cows from the end of October through December. Dry cows (cows without a calf for some reason) are hunted at any time and are often the 'fattest.'

4.2. Protection

It may be difficult to set aside a specific area to protect woodland caribou as they wander so freely over a large area. However, Albert Frost did indicate that an area just north of South Caribou Lake should be protected. Albert notes that in areas where caribou hunting has been banned, the caribou population seems to be increasing. Hunting in several areas around Inuvik is controlled through a tag system. Additionally, he notes that if an area is being hunted the caribou may move into other areas

(Oct 12 2010). Walter Alexie notes that the Peel Preserve is important woodland caribou habitat and should be protected (Oct 14 2010).

Ernest Vittrekwa indicated that woodland caribou make use of small hills in the Peel Preserve during winter, "wherever you see little hills. Because there's not much snow on them and it's easier for them to dig their food." He also felt that the area between Frog Creek and Point Separation was important summer habitat for the caribou (Oct 15 2010).

> [Elders] knew when to stop. They knew how to hunt. They just take enough to live on. But they don't, now it's like they're cowboys and that, and shooting just awful you know. Maybe now ... you going to see caribou limping around ... I see it that's why I talk. And it's not good.
>
> (Emma Kay Oct 13 2010).

Population counts by caribou biologists using planes may be inadequate, according to some interviewees. They may miss portions of the caribou herds and underestimate. A balanced perspective is important.

An anonymous interviewee indicated that he feels it is unethical to collar caribou for scientific research. Other types of research should be substituted for collaring projects (Nov 2 2010).

4.3. Traditional management practices

Traditional hunting practises were based on respect and meat was generally shared. In modern times when there is social turbulence, young people are not necessarily being taught the values of respecting caribou or other animals and may hunt in a fashion which is not acceptable – including shooting without a clear kill shot and wasting meat.

> *People, like myself, say we're not better than anybody. But we grew up where we were really dependant on meat, on caribou meat, on moose meat, whatever we could get, we depended on it. And, we have to survive so we really depended on it and we took care of what we got, you know. We took care of meat. Even now ...I save every little bit of meat (Mary Teya Oct 14 2010)*

Traditional Gwich'in practise was to kill respectfully, take all the animal for food, and share with your neighbours and family. A calve would only be shot if the cow was killed (GRRB Boreal Woodland Caribou Study 2001).

> *Now I wish I could help all my grandchildren. Teach them all what I know. Now what we do telling our stories and sharing our stories, all our children will learn from this in the future. We tell stories, from this they will learn. [Teach] your children. When... hunting is done and the game is killed, the food, the meat or the game used to be so respected and the meat was prepared with great care, with respect. Now I see that it is done differently also. At one time when we travelled the mountains and meat was prepared, the men went hunting and they kill their game and they prepare it. First they skinned it and butchered. It was done with the upmost care and respect. I used to go to the kill site and it was prepared so well. Not even a hair on the meat and first I used to put the skin in the sled then I put all the meat on the inside. (Eunice Mitchell, Elders Biography Project Tape 8 July 9, 2000)*

Additionally, the traditional family and inter-family system for establishing rules is not as it was in the past, and government regulations have taken the place of following the advice and direction of those who earned respect through experience. However, government regulations are not always followed.

"You can make all the rules in the world but if you don't enforce them, what do you doing?" (Tom Wright Oct 12 2010). In the past, necessity also guided the respectful harvest of caribou.

> *..[I saw] an old guy in McPherson like he would have been 75 years old at least. He goes to the hills with three or four ... dogs. He has three shots. He goes to the hills with three bullets; come back with four caribou. He is going to let them line up and then kill, shoot them. I mean people used to be really good at doing stuff, a lot of that is gone. They don't care, it's too easy now. (Tom Wright Oct 12 2010)*

Some hunters do not follow traditional practises when hunting. They may chase the caribou on skidoo and shoot recklessly injuring caribou or shooting too many. These practises must be curtailed for the health of the caribou populations, according to several interviewees (Tom Wright Oct 12, 2010, Albert Frost Oct 12 2010). "I see one year, what I didn't like to see – somebody chasing caribou with big skidoo. It's not right for them to do that, because, these caribou, their tongue was just hanging out" (Emma Kay Oct 13 2010). Wally McPherson thought that undisciplined eagerness of young hunters also had a role in their hunting style – instead of a measured approach and consultation between hunters, they speed towards caribou with their skidoos. Their less-than-careful approach also ensures their hunting success is lower than it could be, and he has seen injured caribou with infections left alive but in poor shape after being hit with a bullet. Wally has also seen people poaching caribou illegally from the highway, and has seen evidence that people are only taking the saddle and hindquarters of caribou leaving a large amount of the carcass to rot (Oct 28 2010).

Mary Teya spoke of a lack of respect for caribou she sees and hears about from members of her family who hunt. She mentioned wasted meat left out on the land, and was saddened to hear about how people do not follow traditional practises of respecting the caribou. She expressed that if people do not follow the Gwich'in principles of respecting the caribou – take only what is required, don't hunt if you already have meat, don't hunt just to sell it, don't leave meat to waste – then the caribou may change their migration or areas of use and not be available any longer. "If they want to continue to have caribou they're going to have to use respect in every way. How they handle it, how they hunt it" (Oct 14 2010).

> And I believe that if I don't use the whole animal, I am going to get bad luck next time.
> (Julie Ann Andre Nov 12 2010)

In the past, the requirement of many caribou skins for clothing and methods of preserving meat would have also limited the time available for hunting (Douglas Kendo Oct 18 2010). Old time hunters and their families would move to new areas and food resources frequently – which would alleviate hunting pressure. "They never used the same place too long, like maybe two years, and then they moved to a different area. Like I say, up the Red? People would go up there and then… next year, maybe they'd move down to the Travaillant Lake area where there's lots of fish and everything like that." People also processed, saved, and used much more of the carcass – including the tendons of the foot inside the hoof, which could be dried and used in times of hunger (John Norbert Oct 18 2010). Inedible portions of the carcass may have been used for tools or clothing, or as bait for traps or dog food (James Firth Nov 3 2010).

> *You even go back to the days of [when] the snowmobiles became popular, and the older skidoos, they were slower and more rough to travel on, you beat the heck out of your kidneys to*

> *go from Inuvik up to Parsons Lake and back. I mean that is a long day. And you would only be able to haul back maybe five caribou in a tub sled. Nowadays, in the last ten or fifteen years, you got these big 800 liquid cooled snowmobiles that can pull a house and can get you from Tuk to Anderson River for example in an afternoon. So back in the really old days, caribou always had a chance to kind of recover... when they don't come around a community. Now, if they don't come around a community, people will log on to the internet and find out where the satellite collars are maybe and they will say there is a bunch out at Anderson River and then in an afternoon, they are out there but [by] the time of night is over they are back with a toboggan full of 25 caribou. Maybe not 25 but it is an exaggeration. The bigger more powerful snowmobiles, the fact that we have got more people in our communities, has just added hunting pressure to the caribou that I don't believe is truly recognized (Conrad Baetz Nov 12 2010).*



John Norbert

Photo: GRRB

John Norbert suggested that both caribou's importance as a traditional food and the importance of conserving the animals for the future must both be balanced;

> *Caribou is our food. But then again, we have to learn how to manage also. ...In some area, the caribou are going down, and then they say you could only shoot one. Well, go ahead and shoot one, only. Because you'll have to learn how to manage your animals and your land. You know, so, you can't say just because I eat caribou, if the law says you're only allowed one caribou in a certain zone, you could still just because caribou is your food, you could shoot ten. Then you're breaking the law and on top of that... you're taking too much (Oct 18 2010).*

Interviewees suggested that training and educating young people, with on-the-land programming in schools, life-long education by parents, and apprenticeship-type requirements for young people to learn from elders, might be a good way to reinvigorate the traditional harvesting patterns of the Gwich'in and to promote respectful use of caribou.

5. Knowledge Experts Consulted

The following hunters and Elders were interviewed for the Gwich'in traditional knowledge of woodland caribou study in 2010.

Tommy Wright	Inuvik
Albert Frost	Inuvik
Emma Kay	Fort McPherson
Robert Alexie Sr	Fort McPherson
Walter Alexie	Fort McPherson
Michael Pascal Sr	Fort McPherson
Mary Teya	Fort McPherson
Abe Peterson	Fort McPherson
Ernest Vittrekwa	Inuvik
Doug Kendo	Tsiigehtchic
John Norbert	Tsiigehtchic

Albert Ross	Tsiigehtchic
Harry Carmichael	Aklavik
Richard Ross Sr	Aklavik
Wally McPherson	Aklavik
ANONYMOUS	Inuvik
James B. Firth	Inuvik
Willie Simon	Inuvik
Conrad Baetz	Inuvik
Julie Ann Andre	Inuvik/Tsiigehtchic

APPENDIX 1: Informed Consent Statement

Gwich'in Traditional Knowledge of Woodland Caribou (Boreal Population)

Interviewee: _____

Interview Number: _____ Date: _____

Community: _____

Location: _____

Interviewer(s):_____

Translator: _____

Others Individuals Present: _____

This consent form will be read by or to the interviewee and/or translated, as needed, to participants at the beginning of the interview session. The interviewer will ensure that the participants fully understand the project before being asked to give their consent.

Background

Environment Canada is preparing a national recovery strategy for Woodland Caribou, boreal population (woodland caribou), which are listed as a threatened species under the federal S*pecies at Risk Act*. Environment Canada believes that traditional knowledge can play an important role in recovery planning for woodland caribou.

The Gwich'in Renewable Resource Board and the Gwich'in Social and Cultural Institute are interviewing holders of Gwich'in traditional knowledge, on behalf of Environment Canada, to gather information that will be used in recovery planning for woodland caribou. Recovery planning includes both the preparation of a recovery strategy and one or more action plans.

Study Goals

The objectives of this study are to collect community knowledge about woodland caribou including observations on the land, special significance, physical description, distribution, habitat, population size and trend, limiting factors and threats, and animal health. This knowledge will benefit the communities in that it will be a permanent record available for future generations and that it will be useful in recovery planning and resource management.

Recording of interview

With your permission, the interview will be recorded and a transcript made. The transcript is a typed record of the interview and is useful for report writing and extracting information later on. The information marked on the maps will be digitized or traced into a computerized mapping system.

Verification of information
The interviews will be transcribed and a summary report will be completed. Following the interview you will receive a copy of the transcript if you wish and will have opportunity to correct any of the information that was recorded. There will be a verification meeting at a later date to go over the TK study results, which will include caribou hunters from all Gwich'in communities. Corrections and changes can be made at the meeting.

Language
If you would prefer to be interviewed in Gwich'in, we can arrange for a translator.

☐ YES (I need a translator) ☐ NO (I don't need a translator)

Data Storage
Original materials, which may include audio files, written notes, transcripts, translations, maps, videos, and photographs, will be kept at the Gwich'in Renewable Resource Board office in Inuvik. A copy of the final report will be distributed to each organization identified by the Aurora Research Institute for consultation. According to the Gwich'in Traditional Knowledge Policy (GTC 2004), a copy of the community interviews will be supplied to the Gwich'in Social and Cultural Institute for its archives and for their use in future heritage or traditional knowledge studies, if you agree. The GSCI will also be supplied with any reports, maps, posters, etc. that come out of this research. Environment Canada will receive a summary report and paper and digital maps for use in the recovery planning process for woodland caribou, which will be housed in the Yellowknife office and also provided to the team drafting the national recovery strategy for woodland caribou.

A copy of all research materials will also be deposited in the GSCI section of the Territorial Archives, for safekeeping in the case of fire.

Use of information
The information collected in the study will be used to write a report that will be distributed to community organizations and will be made public.
This summary report will then be shared with Environment Canada for use in the recovery planning. The summary report may also be shared with the relevant province or territory so that they can benefit from this knowledge and avoid asking knowledge holders for the same information. In the future, other researchers may be interested in using this information. Access to the original materials will be controlled by the GRRB and GSCI (holders of the original materials).

Funding
The funding for this study has been provided by Environment Canada, with in-kind support from GRRB and GSCI.

Payment

You will be paid an honorarium of $50 per hour for your time and knowledge. You will be paid by cheque from the GRRB office in Inuvik, and it will be mailed to you within a week. An invoice will be filled out at the end of the interview.

Confidentiality

The names of interviewees will remain confidential unless permission has been obtained. However the GSCI suggests that Gwich'in Elders and participants interviewed provide their names in the research. GSCI finds Gwich'in like to know who provided traditional knowledge information and their names on tapes and/or transcripts and final reports will add credibility to the traditional knowledge provided.

Participation

Your participation in this interview is completely voluntary. You have the right to refuse to answer questions you are not comfortable with. You also have the right to stop the interview at any time and withdraw your participation from the study at any time, even after the interview is complete.

You do not have to answer any questions you do not want to, and you can stop the interview at any time.

May we interview you for this report? ☐ YES ☐ NO [INTERVIEW ENDS]

Do you wish to be given credit for the information you provide? That is, have your name in the report? If not, confidentiality of your name is ensured.

☐ I want to be acknowledged specifically (such as at the end of quotes).

☐ I want to be acknowledged generally: my name will not be associated with specific comments but I will be acknowledged as a contributor.

☐ I do not want my name used or associated with the information I give or included in the report; I want to remain anonymous.

May we record this interview?	☐ YES ☐ NO
May the GSCI and GRRB use the audio tapes and the transcripts in future for other purposes such as publications, reports, website, etc.?	☐ YES ☐ NO
May we take your photo for use in this report?	☐ YES ☐ NO
May we use these photos in future for other purposes such as publications, reports, posters, website, etc.?	☐ YES ☐ NO

Would you like a copy of the taped interview?	☐ YES ☐ NO
Would you like a copy of the transcript of the interview?	☐ YES ☐ NO

By signing below, you give informed consent for this interview. We respect the choices you made filling this consent form.

X_____ Witness _____

Date: _____ Date: _____

APPENDIX 2: Interview questionnaire

Questionnaire for Gwich'in Traditional Knowledge Interviews on Woodland Caribou

INTERVIEWERS TO BRING:
Large maps to draw on
Coloured markers
Map showing extent of woodland caribou
Questionnaire
Informed consent statement

The following questions have been developed to gain information and understanding of the Woodland caribou related to the following areas: their range boundaries and population information; habitat use and population trends and threats. It is expected that interviews with knowledge holders will follow their own course depending on the person being interviewed and not every question will be posed to the knowledge holder. Rather, these questions are provided to the interviewer so that they can raise the appropriate questions as the interview unfolds. It is required that the interview address, to some extent, the main areas identified above. To assist the interviewer a number of sections and questions have been highlighted below which, if asked, would draw out the key information that is required.

Review Informed Consent statement. Interviewee to sign Informed Consent statement

Rapport Development/Background Information:

Inform interviewees that interview may take one hour or more.
What year were you born? (if they would like to share it). *This will give some sense of temporal scale to relate to the information they share with us on boreal caribou.*

Have you always lived in _____? If not, where else have you lived?

How much time do you spend on the land each year? What months do you usually spend on the land?

What types of activities do you do on the land now? What types of activities did you do on the land when you were younger?

When/how/what time of year do you usually encounter/observe caribou?

Can you easily tell if the caribou you see are woodland caribou, compared to either the Bluenose or Porcupine herds?

Is there a separate name for woodland caribou in Gwich'in? What is it?

How important are woodland caribou to you and your community?

Mapping Exercise:

Can you mark on this map (fine-scale map of the local area):

- the areas where you spend time on the land, now and in the past? Outline the areas that you know best. If the areas are discreet, indicate how long your experience is in each.
- SPECIFY WOODLAND VS. OTHER CARIBOU
- areas that you see caribou use now and in the past during the winter. Would you consider any of these areas important to caribou during the winter?

- areas that you see caribou use now and in the past during summer. Would you consider any of these areas important to caribou in the summer?
- areas that you see caribou use now and in the past during calving . Would you consider any of these areas important to caribou during calving?
- any areas that have been burned by a forest fire within the last 50 years (since the 1960s).
- any areas that have been burned by a forest fire more than 50 years ago (before the 1960s).
- any areas that you feel are the most important to protect for woodland caribou

Range Boundaries

Do woodland caribou stay in groups or herds?
If so, can you tell which group is which?
What herds or groups do you know of in your area?
How do you differentiate these from other woodland caribou?
If there is more than one herd, do they intermix or overlap?
Could you draw on the map the ranges of local populations that you are aware of?

Have you seen woodland caribou outside the known or mapped range shown on this map?

Habitat Use

What types of plants do caribou eat in the summer? Fall? Winter? Spring?
Do they use plants or trees for anything other than eating?
Is there any landscape features (provide example) that caribou use? For what, and when?

Population Trends:

Have the number of woodland caribou in your area changed over time?

a) Do you see more or less caribou now than you did when you were younger?
b) Compared with what your parents/grandparents said, would you say there are more or less caribou now?

Did you hunt woodland caribou in the past? If so, have you changed your hunting practices because of a decline or increase in woodland caribou?

Do you still hunt woodland caribou? Are they easier or harder to hunt now? Do you prefer to hunt other species – which ones and why?

Calf survival (specific to a given area, based on information from the Scientific Review)

Do you have any information about calf survival for woodland caribou?

Factors that have led to increased/decreased local populations (threats)

Habitat

What kinds of activities alter or destroy caribou habitat?

What changes have you observed on the land in your lifetime that may have changed the way caribou use the land?

Forest fires

How do forest fires change the way woodland caribou use the land?

Do woodland caribou return to burned out areas? If yes, how long does it take for the caribou to come back? What are they doing there?

Industry and Development

Have you observed woodland caribou using or avoiding areas that have been altered by industrial activity or developments? Can you provide specific examples? For example, seismic lines, roads, etc.?

Predation

Are there more predators (such as wolves, bears, or lynx) in areas where there are woodland caribou than there were in the past in your area?

Have you seen changes in the populations of other prey species, such as beaver, muskox, moose, or barren-ground caribou, in areas shared with woodland caribou?

Are any of these prey species new to your area?

If there is a change in the number of predators, do you think these changes are having an effect on woodland caribou?

If there is a change in the number of beavers, moose, or other 'prey' species, do you think these changes are having an effect on woodland caribou?

Caribou parasites and disease

How do you know if a caribou is healthy? Have you seen a change in caribou health in your region? Are there other indications of caribou health, (such as size, behaviour, parasites, or increased mortality) that you have noticed changes in?

What do you think is the cause?

Have you seen a relationship between caribou health and the arrival of new species?

Noise and light disturbance

Have you observed noise or light disturbance from aircraft, skidoos, ATVs, or industry affecting woodland caribou in your area?

If so, how is it affecting the caribou?

Do you notice areas where it is more of a problem?

Do you have suggestions for how to address this?

Over-harvesting

Are woodland caribou being over-harvested in your area?

Have there been changes in hunting pressure on woodland caribou in your area? (that is, how much woodland caribou hunting there is)

Vehicle collisions

From your experience or observations, are vehicle collisions or crashes with woodland caribou occurring in your area?

To what extent are these collisions occurring? For example, how many or how often are they occurring?

Are there particular areas where vehicle collisions are more of a problem? If so, where are they?

Do you have suggestions for addressing this problem?

Climate change

Have you observed any changes related to climate change such as changes in snow condition, temperature, or precipitation in your area?

If so, have you noticed if these changes have affected woodland caribou or their habitat in your area? How?

Threats - general

From your experience or observations, are there any other things that negatively affect caribou that we haven't already discussed? If so, what are they?

Which of these threats stand out to you as having the most impact upon woodland caribou in your region?

Are there potential solutions to these threats?

Other observations or beneficial practices

Do you know of any traditional Gwich'in conservation practices or activities to conserve woodland caribou now or in the past?

EXTRA QUESTIONS ABOUT PORCUPINE CARIBOU
To help with the Species At Risk Act process concerning other caribou – the Gwich'in Renewable Resources Board would also like to ask the following questions.

What are the differences between Porcupine and woodland caribou?
What are the differences between Porcupine and Bluenose or other herds?
Can you easily tell just by looking? Is there any other clues, for example from the organs? Do they act differently?
Does the Porcupine herd mix with any other herds? With Woodland caribou?
Does the Porcupine cross the Mackenzie?
Have you ever heard, even long ago, that the Porcupine herd mixed with other herds or crossed the Mackenzie?

Gwich'in Social and Cultural Institute: Gwich'in Traditional Knowledge of Boreal Woodland Caribou 2010

The following table outlines previous studies that gathered Gwich'in traditional knowledge about caribou. Many of the studies were not specific to caribou; and the studies that focused on caribou tended to focus on barren-ground or Porcupine caribou.

APPENDIX 3: Previous studies including Gwich'in traditional knowledge of caribou.

Year	Project name	Organization/Ownership	Content (weaknesses and strengths)	Access constraints
Various	Ethnographic Literature	Various	Mention of caribou hunting in ethnographic literature is generally limited to historic traditional use. Ethnographic literature focuses on the Teetł'it Gwich'in.	Public documents include various academic papers and ethnographies. See list, below table.
1970s-1980s	Committee on Original People's Entitlement (COPE) Stories and recordings	Gwich'in Social and Cultural Institute	Life stories and legends include references to caribou and caribou hunting. Not specific to woodland caribou.	Stories and transcripts are confidential and available only with permission of GSCI.
1970s-1980s	Dene Mapping Project	Dene Nation/Gwich'in Tribal Council	GIS files of mapped trails and traplines, including caribou hunting, over entire Mackenzie Valley in NWT. No distinction between sub-species of caribou.	GIS files: Only with permission of GTC. Transcripts from Delta Report and Land Research interviews are confidential and available only with permission of the GSCI.
1975-1976	Berger Community Hearings Transcripts	Unclear. Prepared by AllWest Reporting from original transcripts.	Information from residents of Mackenzie Valley about concerns of proposed pipeline. Includes references to caribou. Not specific to woodland caribou, and often not spatially oriented.	Hearing transcripts are public – see www.allwestbc.com

Gwich'in Social and Cultural Institute: Gwich'in Traditional Knowledge of Boreal Woodland Caribou 2010

1992-2007	Gwichya Gwich'in Place Names projects and History Project	Gwich'in Social and Cultural Institute	Project focus was much broader than caribou, although some information about hunting is included in transcripts. Not specific to woodland caribou. Tsiigehtchic area.	Transcripts are confidential and available only with permission of GSCI. Reports are publically available but don't have much information on caribou hunting. General history book Gwichya Gwich'in Googwandak is available from GSCI and has some information from these studies: Heine, Michael, Alestine Andre, Ingrid Kritsch, Alma Cardinal and the Elders of Tsiigehtshik 2007 Gwichya Gwich'in Googwandak: The History and Stories of the Gwichya Gwich'in Revised Edition. Gwich'in Social and Cultural Institute. Originally published 2001. 405 pp.
1994-2010	Northern Yukon/ Arctic Borderlands Ecological Knowledge Co-op database	Borderlands Co-op (www.taiga.net)	Database of ecological observations recorded in workshops. Focuses on Porcupine caribou area.	Database confidential. Unsure of access constraints.
1994	Gwich'in Territorial Park (Campbell Lake) Oral History & Place Names Project	Gwich'in Social and Cultural Institute	Project focus was much broader than caribou, although some information about hunting is included in transcripts. Not specific to woodland caribou.	Transcripts are confidential and available only with permission of GSCI.

Gwich'in Social and Cultural Institute: Gwich'in Traditional Knowledge of Boreal Woodland Caribou 2010

1995-2008	Teetł'it Gwich'in Place Names projects	Gwich'in Social and Cultural Institute	Project focus was much broader than caribou, although some information about hunting is included in transcripts. Not specific to woodland caribou. Fort McPherson area.	Transcripts and draft report are confidential and available only with permission of GSCI.
1997-2001	Gwich'in Environmental Knowledge Project (GEKP Database)/ Gwich'in Words About the Land	Gwich'in Renewable Resources Board	Interviews were conducted about caribou (and many other species). Includes information about habitat and use. Not specific to woodland caribou. Gwich'in-language words about caribou also recorded.	Filemaker Pro database is confidential and may be used with permission at the GRRB office in Inuvik. Books are publicly available: Nành' Kak Geenjit Gwich'in Ginjik (Gwich'in Words About the Land) Gwich'in Elders. 1997. 212 pp. (Out of stock, but available for viewing at GRRB office) Gwìndòo Nành' Kak Geenjit Gwich'in Ginjik (More Gwich'in Words About the Land) Gwich'in Elders. 2001. 184 pp.
1997-2002	Gwich'in Ethnobotany Project	Gwich'in Social and Cultural Institute	Project focus was of human use but some relevant data about plants included. Whole GSA.	Gwich'in Ethnobotany book is available publically: Andre, Alestine and Alan Fehr 2002. Gwich'in Ethnobotany: Plants Used by the Gwich'in for Food, Medicine, Shelter and Tools. 2nd Edition. Published by Gwich'in Social and Cultural Institute and Aurora Research Institute. 68pp.

Gwich'in Social and Cultural Institute: Gwich'in Traditional Knowledge of Boreal Woodland Caribou 2010

1999	Ehdiitat Gwich'in Place Names Project	Gwich'in Social and Cultural Institute	Project focus was much broader than caribou, although some information about hunting is included in transcripts. Not specific to woodland caribou. Aklavik area.	Transcripts and draft report are confidential and available only with permission of GSCI.
1998-2008	Gwich'in Traditional Caribou Skin Clothing Project	Gwich'in Social and Cultural Institute	Project focus was on repatriating sewing skills, but information about caribou skin preparation was also gathered. Not specific to woodland caribou. Whole GSA.	Transcripts are confidential and available only with permission of GSCI. Book publicly available: Thompson, Judy and Ingrid Kritsch 2005. Yeenoo Dài' K'è'tr'ijilkai' Ganagwaandaii: Long Ago Sewing We Will Remember. Mercury Series. Canadian Ethnology Service Paper 143. Canadian Museum of Civilization. 61 pp.
1989-1999	Beaufort Delta Self Government Traditional Governance Project	Beaufort Delta Self-Government Office	Project focus was on traditional governance but interviews mention caribou hunting in passing.	Interview transcripts are confidential. Permission to use from GSCI / GTC.
1999-2003	Elder's Biography Project	Gwich'in Social and Cultural institute	Project focus was on life stories but some information on caribou harvesting is included. Not specific to woodland caribou. Whole GSA.	Transcripts and stories are confidential and available only with permission of GSCI. Several calendars about Elders were produced and are now out of print, but information is available on the GSCI website (www.gwichin.ca). An Elder's biography book is in progress.

2000-2002	Sustainable Forestry in the Gwich'in Settlement Area	University of Alberta Sustainable Forestry Management Network	Project focus was on forestry and history, but several publications include references to caribou. Not specific to woodland caribou, and more focussed on Teetł'it area.	Publications are publicly available from: www.sfmnetwork.ca.
2002	Devlan Oral History Project	Gwich'in Social and Cultural Institute	Project gathered traditional use and knowledge about Tree River area along Mackenzie, included some information about caribou hunting. Not specific to woodland caribou.	Transcripts and report are confidential and available only with permission of GSCI.
2002	Snowchange Project in Tsiigehtchic	Snowchange Project/Kaisu Pulli Mustonen	Project gathered traditional knowledge information about climate change from Tsiigehtchic elders. Some information in general about how climate change is affecting caribou. Not specific to woodland caribou.	Transcripts are confidential and available only with permission (to be determined – possibly from interviewee, from Snowchange, or from GSCI). Bachelors' thesis: Pulli, Kaisu 2003. There is a big change from way back – traditional knowledge of ecological and climatic changes in the community of Tsiigehtchic, Northwest Territories, Canada. Unpublished manuscript.

Gwich'in Social and Cultural Institute: Gwich'in Traditional Knowledge of Boreal Woodland Caribou 2010

2003-2005	Gwich'in Traditional Knowledge of Mackenzie Gas Project Area	Gwich'in Social and Cultural Institute	Project gathered biophysical TK and TLU of area to the north of the Mackenzie River. Information gathered about caribou, including some information specifically on woodland caribou. However, the focus was on general use and information relating to the potential impact of the proposed pipeline.	Transcripts, report, and map booklet are confidential and available only with permission of the GSCI.
2004	Local Knowledge of Fish Movements and Habitat Use in the Travaillant Lake System, and Arctic Red River fish study	Gwich'in Renewable Resources Board	Projects focussed on fish harvest, but contain some reference to areas where caribou were hunted, and other passing caribou references.	Report may be public, transcripts are confidential. Permission from GRRB required.
2004-2007	Headwaters of the Arctic Red River: Gaps Analysis (Phase I) in 2005, Cultural Assessment - Interviewing Elders (Phase II) in 2006, and Heritage and Cultural Assessment (Phase III) in 2007.	Gwich'in Social and Cultural Institute	The interview questions and map work in Phase II related to traditional use, names places, old time trails, gravesites, etc. plus traditional environmental knowledge (terrestrial). The animals reports in the study area include: caribou, moose, sheep, grizzly bear, etc. and habitat for caribou, moose, sheep, grizzly bear.	Transcripts and GIS data are confidential and available only with permission of the GSCI. Report may be obtained from GSCI.

Gwich'in Social and Cultural Institute: Gwich'in Traditional Knowledge of Boreal Woodland Caribou 2010

2004-2005	Using Hunter Observations and Ecological Knowledge Together With Science to Understand Past and Current Occurrence of Wildlife Diseases in the North	Canadian Cooperative Wildlife Health Centre, Western College of Veterinary Medicine (and GRRB)	Workshops (?) to gather TK about animal disease, including caribou disease. (Data not currently held by GSCI)	Transcripts and reports (?) held by Canadian Cooperative Wildlife Health Centre, Western College of Veterinary Medicine and/or GRRB. Contacted Susan Kutz for further information.
2006-2007	Repatriating Traditional Gwich'in Skills and Knowledge	Gwich'in Social and Cultural Institute	Workshop with Teetł'it Gwich'in on traditional skills includes some information on processing caribou hides. Not specific to woodland caribou. Includes Gwich'in words for various items, some made from caribou hide.	Report is available from GSCI: Lyons, Natasha, 2007. Repatriating Traditional Gwich'in Skills and Knowledge 2006—2007: Report on a Pilot Project with Gwich'in Elders from Fort McPherson. Report prepared for the Gwich'in Social & Cultural Institute. Report on file with the Gwich'in Social & Cultural Institute. 23pp.
2007-2008	Ways We Respect the Caribou: Hunting in Teetl'it Zheh.	Brenda Parlee and Kristine Wray	Research on Porcupine herd, focussing on: 1) documenting elder/hunter perceptions of caribou health and population, 2) documenting traditional practices for respecting caribou and 3) exploring the extent to which harvesters draw upon local knowledge, TK and/or scientific data or other info to make decisions about where, when and with whom to harvest.	Forthcoming.

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2008-2009	Vegetation – Caribou-Wolf Food Chain Project	Aurora Research Institute, Gwich'in Social and Cultural Institute	Interviews with Gwich'in (and other) harvesters about caribou and wolves. Focussed mainly on Porcupine herd, but includes recording of Teetł'it Gwich'in dialect words for caribou and parts of the caribou.	Transcripts are confidential and available only with permission of the GSCI. Report available from ARI: Katz, Sharon. 2010. Traditional Knowledge on Caribou Ecology: Vegetation -> Caribou -> Wolf Food Chain. Aurora Research Institute, Inuvik.

December 2010

Boreal Caribou Traditional Knowledge Collection Study



Sahtu Settlement Area

Boreal Caribou Traditional Knowledge Collection Study

The Sahtu Settlement Area

Prepared by

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The Sahtu Renewable Resources Board

For the Canadian Wildlife Service

Environment Canada

December 2010

Cover Photo: Hammar Mountain, Norman Wells - Boreal Woodland Caribou

Photo taken by Boyan Tracz- GNWT

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1. Executive Summary

As their name implies, boreal woodland caribou reside in old-growth boreal forest environments that stretch across Canada's northern regions and rely upon predictable food reserves during winter months to survive. Negative impacts to this environment, whether through meteorological or humanly induced changes, are of great concern to the people of the Sahtu Settlement Area (SSA). While these animals played a larger role in the past as a prey species (principally due to modern human distribution), they remain an important harvest species. The elders and hunters of the SSA have long known that boreal woodland caribou were different from the vast barren-ground herds and are often referred to as the "Secret" animals, as they are stealthy and often opportunistic kills. Boreal woodland caribou habitat supports many other important harvest species including marten, fox, wolverine and wolf. Disturbances to this habitat will lead to reduced productivity. This will have a serious impact on subsistence trapping practices of the Sahtu Dene and Métis peoples and could lead to economic instability in many households. Moreover, boreal forest habitat supports watersheds that are necessary for clean water and healthy subsistence fish species. There is a general consensus that boreal woodland caribou populations in the SSA are currently healthy. However, they caution that many changes are occurring that could impact these populations and cite climate change and industrial activities as causes for concern. Boreal woodland caribou do not like noise or activity and all attempts should be made to avoid disturbing the animals and their habitat.

2. Introduction

2.1 Description of Project

Boreal woodland caribou are found throughout Canada and are currently listed as a threatened species under the Species at Risk Act (SARA). The following study was undertaken to gain traditional knowledge from the Aboriginal people living in the Sahtu Settlement area in the Northwest Territories of Canada. The traditional knowledge obtained from this study is crucial as it will be used to help with the development of the national recovery strategy and future recovery planning for the boreal woodland caribou.

There are 5 communities located in the Sahtu Settlement area, Colville Lake, Fort Good Hope, Norman Wells, Deline (formerly Fort Franklin) and Tulita (formerly Fort Norman). This study consists of fourteen participants, including elders, harvesters and key knowledge holders from the Sahtu communities. Interviews were conducted in Norman Wells, NT with an interpreter present to translate and relay information gathered back to the interviewer. The participants were asked a series of questions to gain knowledge about the boreal woodland caribou and its habitat. Maps were also available for participants to identify important areas related to caribou distribution.

2.2 Previous traditional knowledge work on boreal caribou in the region

Title: Historic and Current Movements and Distribution of Boreal Woodland Caribou Below Treeline in the Sahtu, Gwich'in, and Inuvialuit Settlement Areas, *(8 August, 2002)*
Authors: Denise Auriat (Gwich'in Renewable Resource Board, Inuvik), John Nagy (Department of Resources, Wildlife & Economic Development, Inuvik), Arianna Zimmer, Richard Popko, and Alasdair Veitch (Department of Resources, Wildlife & Economic Development, Norman Wells)
Public document
Access available on SRRB website (www.srrb.nt.ca)

3.1 Aboriginal Names for Boreal Woodland Caribou

Each Sahtu Settlement Area (SSA) community has a descriptive North Slavey name for boreal woodland caribou. Slight differences in dialects are reflected in the pronunciation and inflections used to describe the animal.

Deline	T'onzi
Tulita	Tohzi
Fort Good Hope/Colville	T'ondzi

Norman Wells interviewees used the English name throughout the interviews.

3.2 Special Significance of Boreal Woodland Caribou

All the interviewee's considered boreal woodland caribou to be very important. The families in the communities use the hides for clothing and the meat is used as a food source.

In the Tulita District of the SSA there are several families known as the Mountain Dene. They traditionally resided on the West side of the Mackenzie River in the foothills of the Mackenzie Mountains. They hunted boreal woodland caribou during the winter months and utilized the hides for clothing. The harvest of Boreal woodland caribou took place in the Stewart lake area southward towards the mouth of the Keele and Redstone Rivers. This practice no longer occurs.

3.3 Legends related to Boreal Woodland Caribou

There were no legends provided by interviewees

3.4 Place Names and trails related to Boreal Woodland Caribou

There were no place names or trails provided by interviewees

3.5 Physical Description

The participants described boreal woodland caribou as being smaller in size than mountain woodland caribou and larger in size than the barren-ground caribou. The elders said that long ago, "They did not call the caribou either mountain woodland or boreal woodland." "They just knew they were different in their markings, color and hoof prints." (Tulita elder)

3.6 Distribution within the Sahtu Settlement Area

Tulita District

Boreal woodland caribou can be found in two general areas on each side of the Mackenzie River. The east side of the river includes areas around Kelly Lake, Lennie Lake and Oscar Lake. Boreal woodland caribou are also found on the west side of the Mackenzie River between Stewart Lake, Tate Lake and Rusty Lake to the south along the Keele River. Participants identified two other lakes by name (Clarke Lake and Fish Lake). However, their locations were not provided so they cannot be included with the others. Both, elders and active hunters stated that these groups tend to stay away from cut lines and roads.

Deline District

Small groups of boreal woodland caribou have been observed around the community of Deline on occasion. Several groups have also been seen along the North Shore of Great Bear Lake. These boreal woodland caribou have been observed in association with the Bluenose-east barren-ground caribou herd in the late fall and early winter months. At least one small group, if not more, have always lived on Ehdaila (Caribou Point) along the northeast end of Great Bear Lake.

K'asho Go'tine District

Boreal woodland caribou in the K'asho Go'tine District occur mostly in small groups and occupy the area along the Mackenzie River on the west side from the Ramparts south of Fort Good Hope, down river to McBride Lake, and then east towards Muskeg Lake past Colville Lake. This area seems to be the prime habitat for boreal woodland caribou in the Sahtu Settlement Area and an area where the majority of the opportunistic kills occur. Elders from Colville Lake reported seeing signs of boreal woodland caribou south and west of Lac de Bois on a regular basis.

3.7 Habitat


Glen Guthrie(SRRB), 2006

According to the participants, the primary food consumed by boreal woodland caribou includes willow tips, grasses, white lichen, and spruce tree moss. Salt licks are also actively sought out by the caribou. The Sahtu boreal woodland caribou groups do not migrate very far during any time of the year. Primary habitat has remained fairly stable in recent years due to the low incidence of disturbance by fire and the populations have remained fairly stable. In the mid 1990's however, there were drastic habitat losses due to abundant forest fires. Old habitat that was burnt has now been taken over by new and expanded moose populations.

Small populations can be observed within the Tulita area during the summer months. These are located in open meadows on high ground, where they forage for mosses. They are also found near rivers and lakes during times of high insect infestation. Elders reported that there is a resident group of 10-15 animals in the Kelly Lake area that are present throughout the year. They are seen near rivers in the spring when they seek out salt licks. During winter, they travel wherever there is adequate cover provided by forest growth and hard ground. During the fall time, they go to the high ground and come together for the annual rut, but not in large numbers.

3.8 Population size and trends

The general consensus of the people interviewed is that there are more caribou within the region now. All interviewees reported seeing more signs of groups of caribou. This is attributed to a decrease in industrial activities throughout their habitat in recent years; as caribou tend to avoid developed areas including roads and seismic lines. Lots of tracks are evident throughout the year and caribou are only hunted when opportunistically encountered by hunters.

3.9 Limiting factors and threats

a) Habitat

Noise is given as a major factor that impacts boreal woodland caribou. These disturbances include drilling, seismic cut-line activities, slashing, and machines including helicopters and All-terrain vehicles that conduct work during the summer. Caribou prefer old growth areas and have a tendency to stay away from winter roads because of noise pollution. Weather also plays a significant role in the health and well-being of boreal woodland caribou. Increasing extremes in annual temperatures and flooding negatively impact herds.

b) Forest Fires

Forest fires lead to the destruction of the boreal woodland caribou habitat and seriously impacts their ability to acquire food. These events force caribou to relocate to more desirable locations. Some interviewees stated that boreal woodland caribou return to burned areas once there is new growth; while others stated that caribou will never return to these sites again.

c) Industry & Development

Industry and general development are major factors that affect caribou. Noise pollution produced by these activities precludes animals from taking advantage of resources in these areas.

d) Predation

People from all SSA communities have observed an increase in wolf populations in recent years. This increase appears to be linked to a decrease in wolf trapping activities by SSA residents in recent years. Other observations include a general increase in the abundance of moose, muskox and beavers. The elders are adamant that there is a connection between the numbers of kinds of

prey species and the availability of food resources. Muskox are a fairly new inhabitant in many parts of the SSA. An increase in the number of prey species like muskox and moose results in less caribou being taken by predators. This is definitely having an effect on the boreal woodland caribou populations. If there is a decrease in the number of prey species like muskox, then predators will hunt caribou.

e) Caribou Parasites & Disease

Participants noted a change observed on collard caribou. The area around the neck where the collar sits is worn raw and may become infected.

f) Noise & Light Disturbance

Noise and lights disturb caribou. Any development should not occur during the calving season or near caribou habitat.

g) Over Harvesting

Over harvesting is not a concern in the SSA as they are mostly opportunistically harvested.

h) Vehicle Collisions

Boreal woodland caribou are typically found in old growth forested areas and stay away from winter roads because of the noise pollution. Therefore motor vehicle collisions with boreal woodland caribou do not occur in the SSA.

i) Climate Change

Recent changes in climate are significant which include warmer temperatures, increased rain in November, milder winters and increasing summer storms. Boreal woodland caribou food sources are affected by precipitation. During colder times, food becomes less accessible as it is covered by more snow, making it harder for caribou to access.

j) General Threats

Several general threats were identified. Both winter road and boat access to the SSA by non-resident hunters' may impact populations. However, climate change, development, industry and predation were cited as the most significant impacts to boreal woodland caribou populations. Suggested mitigations include less development, encouraging trapping of predators, regulations, and avoidance.

3.10 Animal Health

The boreal woodland caribou populations are healthy according to the participants. The caribou have also been observed to have a healthy fat content.

4. Management of Boreal Woodland Caribou

4.1 Subsistence use of boreal woodland caribou

Boreal woodland caribou are used as a subsistence food source throughout the Sahtu region. However, not many people actively pursue these animals and most are harvested opportunistically when encountered while hunting other species.

4.2 Traditional management practices

When groups of boreal woodland caribou are encountered, only a few caribou from each group are harvested. More bulls are harvested than cows and calves.

5. Acknowledgements

Environment & Natural Resources, Government of the Northwest Territories

Aurora College

Sahtu Renewable Resource Board

Colville Lake Renewable Resource Council

Deline Renewable Resource Council

Fort Good Hope Renewable Resource Council

Norman Wells Renewable Resource Council

Tulita Renewable Resource Council

6. Literature Cited

Historic and Current Movements and Distribution of Boreal Woodland Caribou Below Treeline in the Sahtu Settlement Area by Arianna Zimmer, Alasdair Veitch and Richard Popko, Department of Resources, Wildlife & Economic Development, Norman Wells, NWT.

7. Knowledge Experts Consulted

Frank Pierrot, Fort Good Hope

Clayton MacCauley, Tulita

Julie Lennie, Tulita

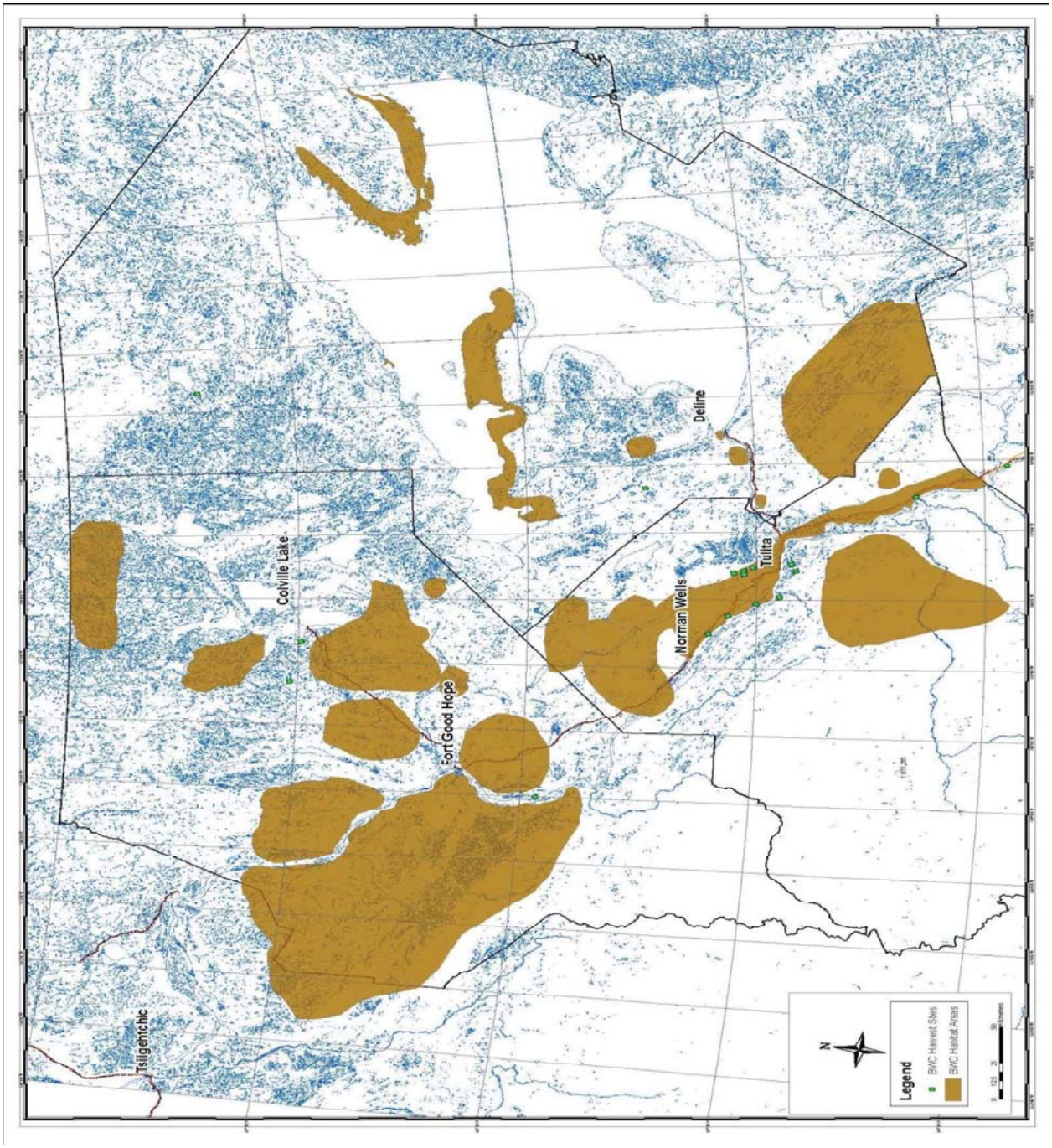
David Etchinelle, Tulita

Richard Kochon, Colville Lake

Edward Oudzi, Norman Wells

Sahtu GIS Project, GNWT Department of Environment and Natural Resources

8. Maps


Deline
Tulita
Norman Wells
Colville Lake
Fort Good Hope
Tsiigehtchic
N
Legend
BWC Harvest Sites
BWC Habitat Areas