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GIS modeling of suitable habitat for southern mountain caribou compared to priority places of conservation in British Columbia under climate prediction models.

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1. Abstract

Species classified as special concern, threatened, and endangered under the Species at Risk Act (SARA) are of key importance to protect under a changing climate where northern nations such as Canada are most susceptible to. Identifying adequate areas to invest conservation efforts into are crucial for sustaining these at-risk species and their habitats. We developed a habitat suitability index (HSI) for the indicator species southern mountain (SM) caribou and applied climate models to determine if the federally proposed conservation area in BC's dry interior will remain suitable under changing climate. The HSI was developed from classifying values within data layers of criteria and constraints. Each criterion was ranked as most beneficial to least for SM caribou survival and underwent a pairwise comparison to derive each criterion's weight. Through the application of this HSI with future climate scenarios, resulting time-series mapping was developed for the 2025, 2055 and 2085 periods. As a result, current suitable habitat will decrease in size with anthropogenic activity and changing climate. When comparing the federally designated priority place to the resulting habitat suitability index time series, most land had either low suitability or entirely unsuitable classifications for both present and future climate scenarios. It has become evident that the identified priority places are insufficient for current and future conservation of SM caribou.

2. Problem Context

Striking and adverse natural environments can be observed across the vast landscapes of Canada, supporting and sustaining valuable species and habitats. Reputable scientific consensus provides evidence indicating a degradation of Canadian habitat and wildlife diversity. The Species at Risk Act (SARA) is a part of Canadian law since 2002 that works to protect species from extinction (Legislative Services Branch, 2020). It was developed through status reports and recommendations from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), where species are designated as not at risk, special concern, threatened, endangered, extirpated, or extinct (Climate Change Canada, 2019). SARA is used in various practices supporting legislation developed to conserve species. In 2017, the World Wildlife Fund (WWF) published a report where they performed a Living Planet Index on Canadian wildlife which measures biodiversity levels based on populations (Gadallah *et* al. 2017). This evaluative index found that 451 of 903 of monitored Canadian wildlife species declined in abundance since 1970 (Gadallah *et* al. 2017). This report caused the Canadian federal government to develop the Pan-Canadian approach to transform species at risk conservation in Canada. The government designated 6 priority species and 11 priority places across Canada where conservation efforts are most needed (Climate Change

Canada, 2019b). These priority places and species were identified based on the SARA species list and requirements of having high biodiversity, compatible ecosystems and social distinction for residents (Climate Change Canada, 2019b). A concern is that in the Living Planet Index report the top two indicators of wildlife loss (habitat loss and climate change) were included in the requirements for designating Pan-Canadian priority places. Another concern is the lack of species included in SARA that have been designated by COSEWIC and the British Columbia Conservation Data Centre (CDC) as special concern, threatened, or endangered (Yezerinac and Moola, 2006; Mcdevitt-Irwin *et* al. 2015).

Under COSEWIC, SM caribou (*rangifer tarandus caribou*) are a threatened species as of 2002, listed as threatened under SARA as of 2003 and on the red list in the CDC (Environment Canada, 2014). These designations were due to habitat fragmentation, lack of suitability, and predation (Environment Canada, 2014). The species' threatened designation, indigenous significance and unique biophysical attributes characteristic to their habitat make them significant to protect (Climate Change Canada, 2019b). Scientific consensus identifies SM caribou as an important indicator species for their ecological regions and for conservation practices based on the reports in Glacier National Park (Hamer, 1975) to be used for the long-term in determining conservation practices (Johnson *et al.* 2004).

The literature identifies that large areas of conservation land are effective at protecting and recovering species when the implications of habitat loss and climate change are considered in policy implementation and area designation (Peterson *et al.* 1998; Kerkhoff *et al.* 2018). When these factors are considered, the conservation land is effective for a longer period of time (Kerkhoff *et al.* 2018). Conservation land should fall within intact continuous landscapes since habitat fragmentation separates species into several smaller and isolated populations that are vulnerable to edge effects of higher levels of disturbance and degradation (Dickson *et al.* 2014; Fahrig, 2003). It is evident that the identified Canadian priority places are insufficient for future conservation due to not considering the changing climate, edge effects, and fragmentation of populations. The selected priority place known as the 'dry interior' extends across the southern Rocky Mountains and Boreal Plains of British Columbia (BC) and can be found within the larger area of SM caribou sightings (Hamilton *et* al., 2000).

Species do best in a specific climate range under certain conditions such as dry or wet however, climate change may make current habitat reserves unsuitable for species (Johnson *et al.* 2004; Kerkhoff *et al.* 2018; Peterson *et al.* 1998). These reserve boundaries are important to understand where species can occur but more importantly for human understanding of where to direct resources (Dickson, 2014; Basurto, 2013). Conservation funding and management will occur on a multilevel governance scale (Basurto, 2013), as the area in question is federally designated (Climate Change Canada, 2019b) and could be managed at a provincial or municipal level, using public or private resources.

For the purpose of modelling a suitable habitat for SM caribou, habitat characteristics that are relevant to this species' lifecycle are benefited by having a spatial component to them to be interpreted more easily visually. Relevant parameters such as snow depth and distance from urban areas are inherently spatial, with distance and locations requiring a consideration of space (Senapathi *et al.* 2019). Thus, a GIS application is best suited for the habitat suitability analysis for SM caribou, specifically a multi-criterion evaluation (MCE) to account for multiple indicators.

3. Purpose of Research

The main purpose of this research is to construct a HSI based on the classification, comparison and weighting of criteria crucial for SM caribou lifecycles under future climate scenarios to re-evaluate the dry interior extent of BC for SM caribou conservation efforts.

4. Research Objectives

1. Identifying the relevant parameters indicating suitable habitats for SM caribou in our study area, the dry interior of BC.
2. Developing a habitat suitability index (HSI) for SM caribou through use of a multi-criteria evaluation (MCE).
3. Applying the climate scenarios to the HSI for the study site and predicting the future habitat extent.
4. Comparing the proposed HSI climate scenarios with the dry interior priority place.

5. Study Area

The study site, shown in *Figure 1*, consists of census districts in BC that cover the interior plateaus, the southern Rocky Mountains, and the boreal plains, all of which have had sightings of SM caribou in the past 50 years (Hamilton *et* al. 2000). Census districts that are majority arctic/subarctic and coastal ecozones are excluded since the ecosystems in these places vary enough that they allow the domination of different subspecies of caribou (Environment Canada, 2014), which would require different parameters used in an MCE. The benefit of using census districts over environmental regions is that conservation practices are human determined and managed (Basurto, 2019), so streamlining the analysis to adhere to governance increases the practicality of recommendations. This study site is suitable for our research question as it covers the area of dry interior, as well as ecosystems that SM caribou are known to be present throughout.

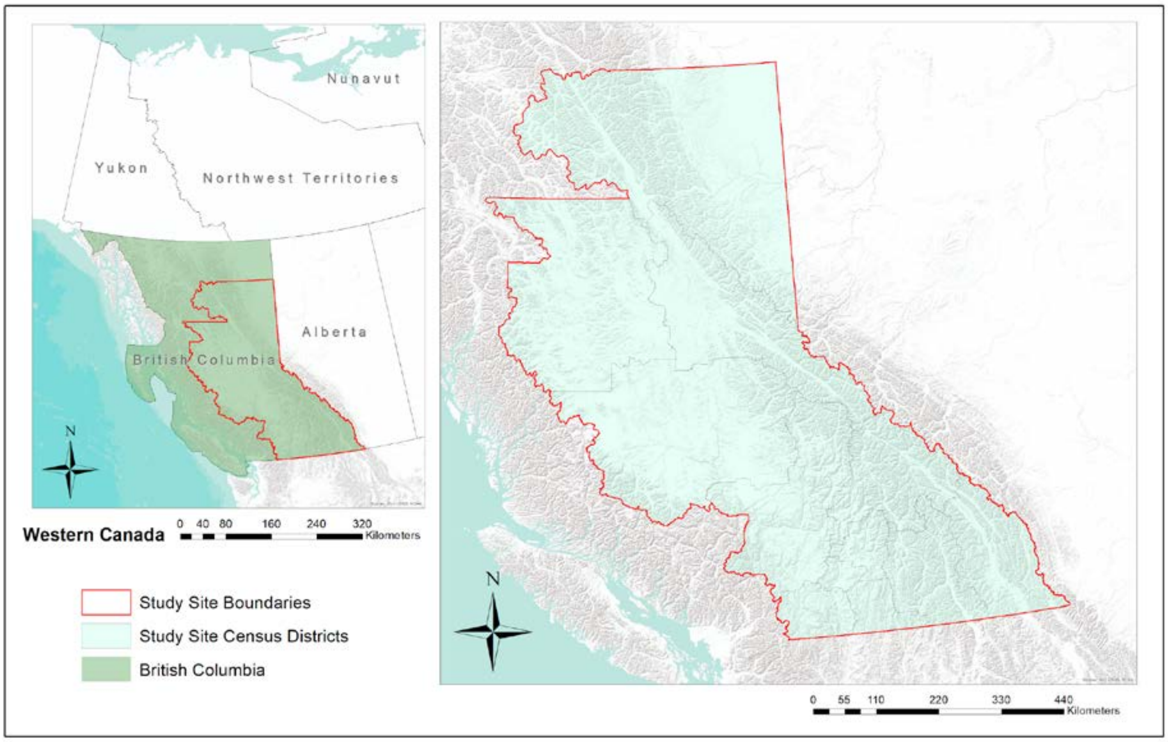

Figure 1: Study site in British Columbia the research approach will be applied to (British Columbia Data Catalogue, 2020).

6. Research Approach

We developed a Habitat Suitability Index (HSI), which is a numerical index containing environmental and anthropogenic habitat criteria that are critical to SM caribou lifecycles. These were assigned weights based on their importance to caribou survival. The study site was assessed based on its fulfillment of these criteria and were assigned an index score between 0 (unsuitable habitat) to 100 (most suitable habitat).

Constraint variables unsuitable for protected conservation land have been designated as urban areas, roads, and agricultural land as they do not provide a suitable habitat and changing these land use types would be inefficient. These were extracted from land use shapefiles and reclassified into binary rasters, with 1 representing suitable land and 0 representing unsuitable land, as shown in *Table 1*.

Table 1: Classification scheme for parameters.

Criteria/ Constraints	**Classification**	**Ranking**	**Data Source**
Mean annual temperature	Lower the better	100 - 0	Climate BC, 2012.
Mean annual precipitation	Higher the better	0 - 100	Climate BC, 2012.
Precipitation as snow	Higher the better	0 - 100	Climate BC, 2012.
Slope	Higher the better	0 - 100	Natural Resources Canada, 2002.
Forest age	Older the better	Logged/newly planted = 0 Young = 50 Mature = 100	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019c.
Distance to water	Closer the better	100 - 0	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019d.
Distance from roads	Further the better	0 - 100	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019b.
Distance from urban areas	Further the better	0 - 100	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019a.
Constraint: Agriculture	Cannot be agricultural land	Agriculture = 0 Non agriculture = 1	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019a.
Constraint: Urban	Cannot be urban land	Urban = 0 Non-urban = 1	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019a.
Constraint: Roads	Cannot be roads	Roads = 0 Non roads = 1	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2019b.

Each criterion within the HSI was reclassified into standardized raster maps (clipped to the study site extent) from a scale of 0 to 100 using a linear transformation, with a larger value indicating optimum habitat suitability as shown in *Table 1*. The slope parameter was calculated from a digital elevation model and linearly scaled so the higher slopes have higher values in the HSI. Forest age data had three classes, logged/newly planted, young forest, and mature forest, with the linear scale being applied as 0 to logged/newly planted, 50 to young, and 100 to mature. Distance criteria were calculated by their euclidean distance and then linearly scaled, with higher distances from roads and urban areas having higher values and lower distances to water having higher values. Once reclassification and standardization of the criteria were completed, each criterion was assigned a weight from a pairwise comparison based on a 9-point scale, with importance levels shown in *Table 2* and *Table 3*. For the purpose of this study, most to least important order of criterion is climatic variables (mean annual temperature, mean annual precipitation, and precipitation as snow), slope, distance to isolated sites (represented by distance from roads, urban areas, and to water) and forest age. From creating this ranking of importance in criteria, it was apparent that HSI structures can be susceptible to bias as it is up to our discretion to quantify the importance of criteria based on qualitative scientific literature.

Table 2: Pairwise comparison among all 8 criteria. The ranking of each criterion (from 1/9 to 9) in a row was divided by the associated criterion in the column, until all criteria were compared to each other. The sum of each comparison within each column was taken in the final row.

Criteria	Mean Annual Temperature	Mean Annual Precipitation	Precipitation as Snow	Slope	Forest Age	Distance from Water	Distance from Roads	Distance from Urban Areas
Mean Annual Temperature	1	1	1	3	7	5	5	5
Mean Annual Precipitation	1	1	1	3	7	5	5	5
Precipitation as Snow	1	1	1	3	5	5	5	5
Slope	0.3333	0.3333	0.3333	1	3	3	3	3
Forest Age	0.1429	0.1429	0.2	0.3333	1	0.3333	0.3333	0.3333
Distance from Water	1	0.2	0.2	0.3333	3	1	1	1
Distance from Roads	1	0.2	0.2	0.3333	3	1	1	1
Distance from Urban Areas	1	0.2	0.2	0.3333	3	1	1	1
SUM	6.4762	4.0762	4.1333	11.3333	32	21.3333	21.3333	21.3333

This criteria order was made as climatic variables are significant drivers of SM caribou distribution in terms of long-term climate change where rapid adaptation is needed, and these variables can reflect the areas dominant vegetation classification (Government of Canada, 2011). Next, high slopes and isolated sites are necessary refuge for successful SM caribou calving due to their low predation frequencies. Anthropogenic materials such as roads and urban areas can directly affect crown closure and deforestation, which contribute to an unideal reduction in isolated sites (Government of Canada, 2011). Finally, SM caribou are predominantly found in mature forests characterized by a dense crown closure since this is where high lichen abundance occurs (Government of Canada, 2011).

Table 3: Each pairwise comparison was divided by the sum of pairwise comparisons for each associated column to result in the final sum of 1. For each criterion row, the pairwise comparisons were summed to create the total weights for each associated criterion to be used in Equation 1.

Criteria	Mean Annual Temperature	Mean Annual Precipitation	Precipitation as Snow	Slope	Forest Age	Distance from Water	Distance from Roads	Distance from Urban Areas	**Total Weights**
Mean Annual Temperature	0.1544	0.2453	0.2419	0.2647	0.2188	0.2344	0.2344	0.2344	**0.2285**
Mean Annual Precipitation	0.1544	0.2453	0.2419	0.2647	0.2188	0.2344	0.2344	0.2344	**0.2285**
Precipitation as Snow	0.1544	0.2453	0.2419	0.2647	0.1563	0.2344	0.2344	0.2344	**0.2207**
Slope	0.0515	0.0818	0.0806	0.0882	0.0938	0.1406	0.1406	0.1406	**0.1022**
Forest Age	0.0221	0.0350	0.0484	0.0294	0.0313	0.0156	0.0156	0.0156	**0.02663**
Distance from Water	0.1544	0.0491	0.0484	0.0294	0.0938	0.0469	0.0469	0.0469	**0.06446**
Distance from Roads	0.1544	0.0491	0.0484	0.0294	0.0938	0.0469	0.0469	0.0469	**0.06446**
Distance from Urban Areas	0.1544	0.0491	0.0484	0.0294	0.0938	0.0469	0.0469	0.0469	**0.06446**
SUM	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

With the weights of each criterion defined, they were utilized to rank a geographic extent through the HSI equation, a basic multiple criterion evaluation (MCE) equation. This method was derived from the summation of each criterion multiplied by their weight of importance, producing a sum of habitat suitability between 0 to 100. *Equation 1* presents the summation of each criterion with their associated weights and abbreviations as shown in *Table 4*.

Equation 1: Habitat Suitability MCE equation

$$\textbf{HABITAT SUITABILITY INDEX} = (\text{Constraint}_{\text{Water}} * \text{Constraint}_{\text{Urban}} * \text{Constraint}_{\text{Roads}}) * [(W_{AT} * \text{Criteria}_{\text{Temp}}) + (W_{AP} * \text{Criteria}_{\text{Precip}}) + (W_{PS} * \text{Criteria}_{\text{Snow}}) + (W_{S} * \text{Criteria}_{\text{Slope}}) + (W_{F} * \text{Criteria}_{\text{ForestAge}}) + (W_{DW} * \text{Criteria}_{\text{WaterDist}}) + (W_{DR} * \text{Criteria}_{\text{RoadDist}}) + (W_{DU} * \text{Criteria}_{\text{UrbanDist}})]$$

Table 4. Criteria with their associated variable label applied in Equation 2 with their corresponding weights.

Criteria	Criteria Abbreviation	Variable Label	Weight
Mean Annual Temperature	Temp	W_{AT}	0.2285
Mean Annual Precipitation	Precip	W_{AP}	0.2285
Precipitation as Snow	Snow	W_{PS}	0.2207
Slope	Slope	W_{S}	0.1022
Forest Age	ForestAge	W_{F}	0.02663
Distance from Water	WaterDist	W_{DW}	0.06446
Distance from Roads	RoadDist	W_{DR}	0.06446
Distance from Urban Areas	UrbanDist	W_{DU}	0.06446

In order to determine the future habitat extent of SM caribou, key parameters reflecting climate change such as mean annual temperature, mean annual precipitation, and precipitation as snow were altered according to a climate prediction model representing 2055 and 2085 changes. To identify areas of change between years we calculated differences between HSI scores from 2025 to 2055, 2055 to 2085, and 2025 to 2085. The identified changes reflected the long-term capability of potential regions of conservation. This time-series prediction analysis assisted in re-evaluating the extent of dry interior and providing recommendations that will be the most beneficial to protect the species long-term.

7. Research Findings

Figure 2 shows the final constraint variables reclassified into their individual binary rasters, with all areas consisting of these land uses being classified as 0 (unsuitable land) and all other land being classified as 1 (suitable land). The final criteria values can be seen linearly scaled in *Figure 3*.

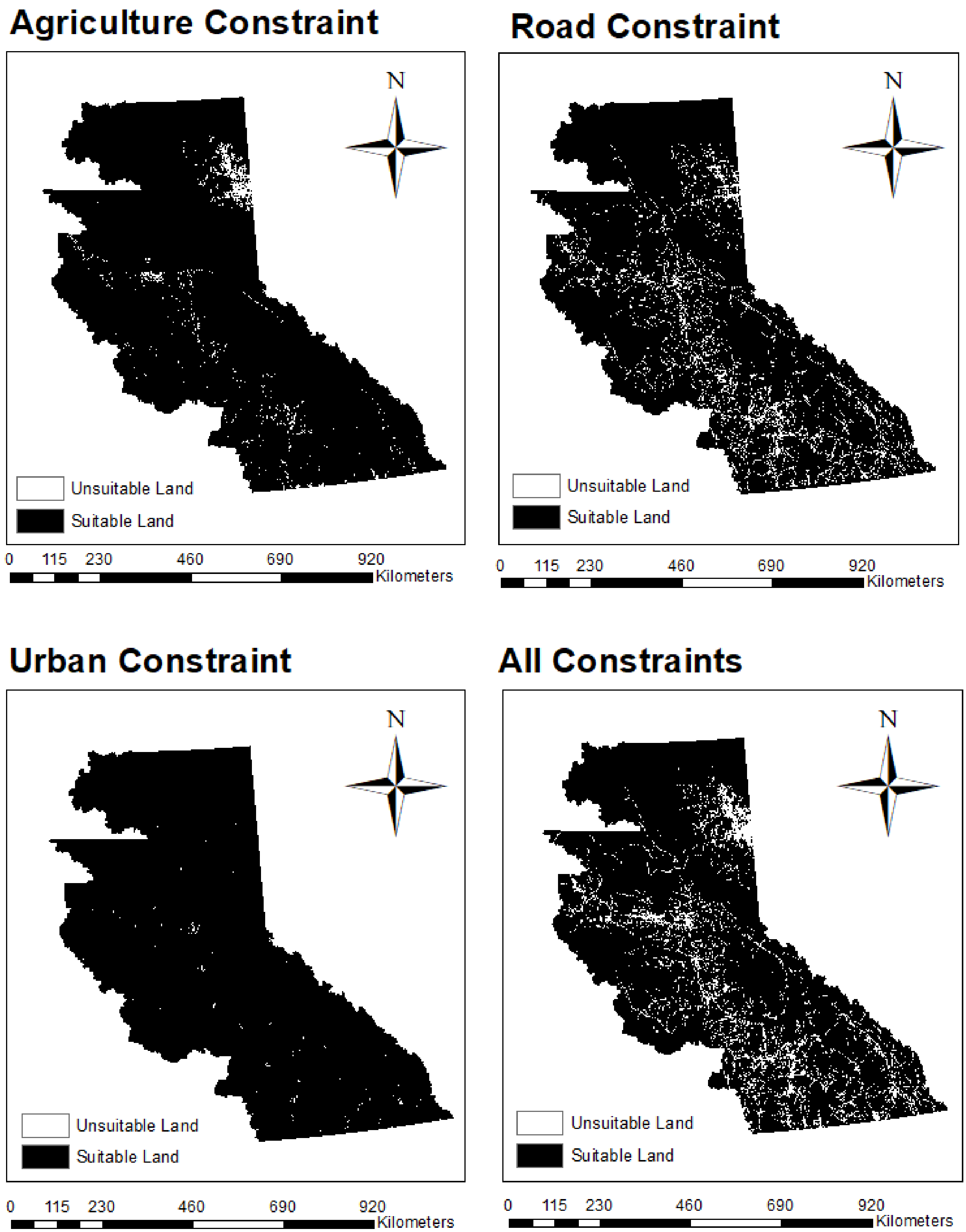

Figure 2: Binary reclassification of constraint variables used in the HSI.

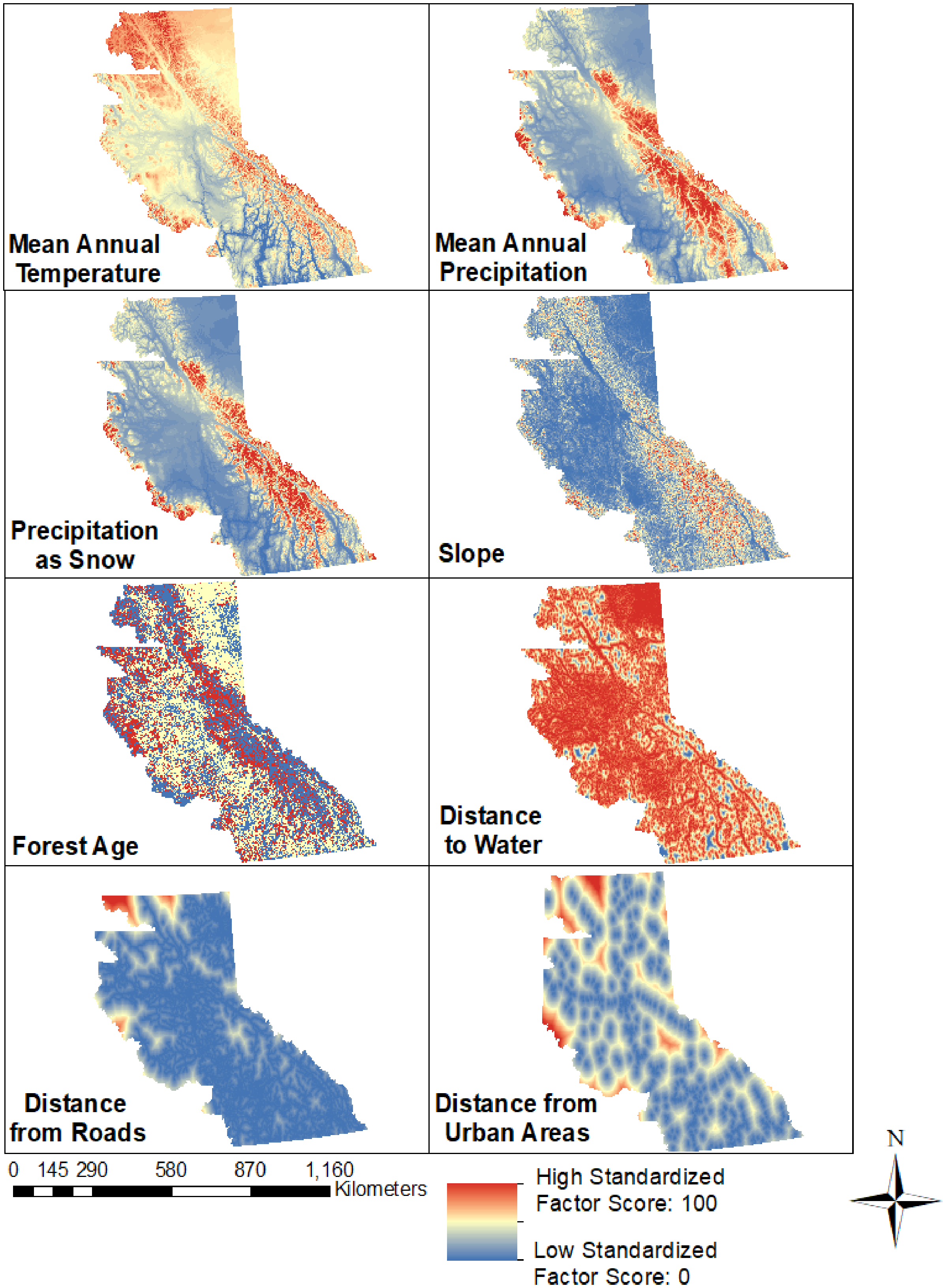

Figure 3: Study site linearly transformed final 2025 (which reflect present day) criteria parameters.

A time-series of HSIs for SM caribou were developed for the study site in 2025, 2055 and 2085 and shown in *Figure 4*, which displays no major or abrupt changes at this scale. Based on the known geography of the study site, *Figure 4* displays that the highest suitability scores occur through mountainous regions while the less suitable scores occur in the boreal plains, where most roads and urban areas exist as shown in the *Figure 2* constraint maps.

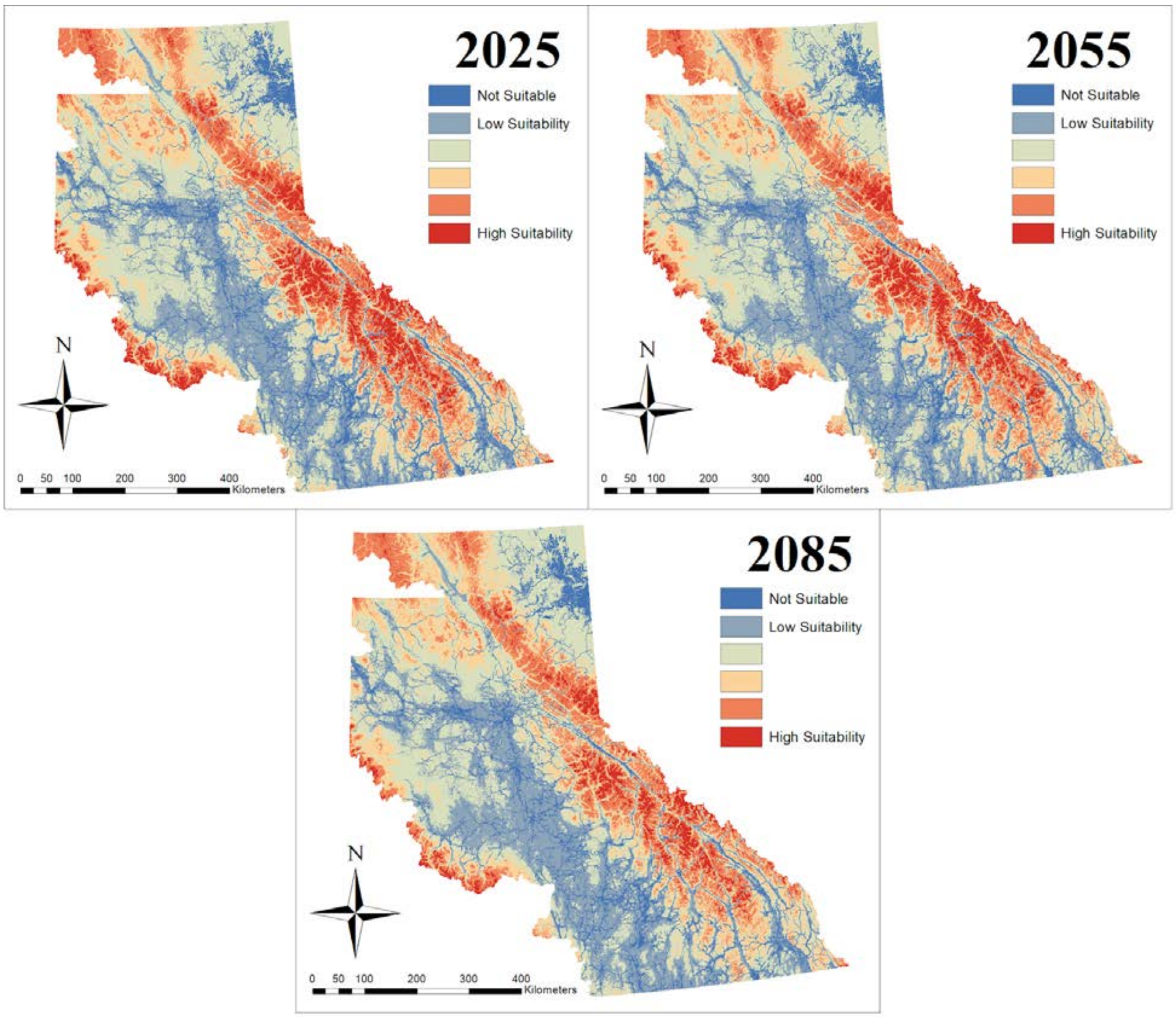

Figure 4: Reclassified HSI time series, displaying not suitable land, and land ranging from low suitability to high suitability.

Figure 5 illustrates the changes that occur from 2025 to 2055, 2055 to 2085, and 2025 to 2085. From 2025 to 2055, the HSI shows no change, thus the 2055 to 2085 and 2025 to 2085 maps indicate the same changes, with the suitability decreasing in more areas than increasing. This loss in suitability can be seen on the western edge of the study site (the boreal plains), with a growth in lower suitability scores surrounding roads and urban areas as identified in

Figure 2. A similar impact can be seen in the mountainous regions along the eastern edge of the study site, with the overall suitability score decreasing or displaying no change. In the northeastern corner there is a small area displaying an increase in suitability scores around a predominantly agricultural region as identified in *Figure 2*.

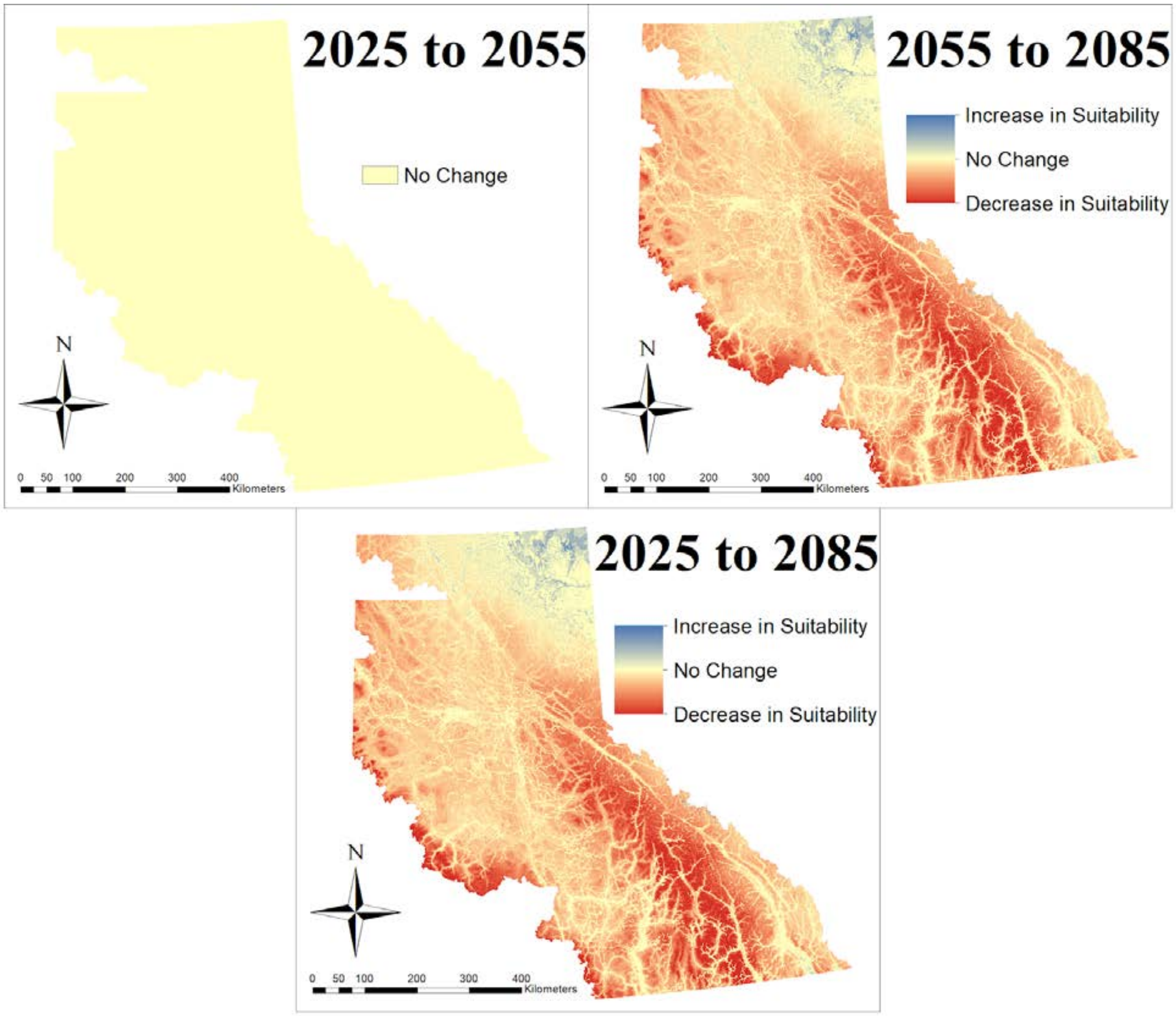

Figure 5: Changes in suitability scores from 2025 to 2055, 2055 to 2085, and 2025 to 2085.

Based on the changes *Figure 5* identifies, when looking closer at the resulting HSIs in *Figure 4*, the loss of high habitat suitability regions from 2025 to 2085 is more prevalent as is evident in *Figure 6*. The mountainous area in the central eastern zone of the study site identified in *Figure 6* can be seen to have a decrease in land classified as high suitability from 2025 to 2085, and what is still considered highly suitable in 2085 becomes far more fragmented. Fragmented suitable habitat poses issues for multiple species, with worsened edge effects such as degradation occurring at higher scales (Fahrig, 2003). In the case of SM caribou specifically, edge effects impose on their need for isolated sites for calving

(Government of Canada, 2011) and thus for their preservation, contiguous undisturbed areas would be more beneficial to designate as priority places.

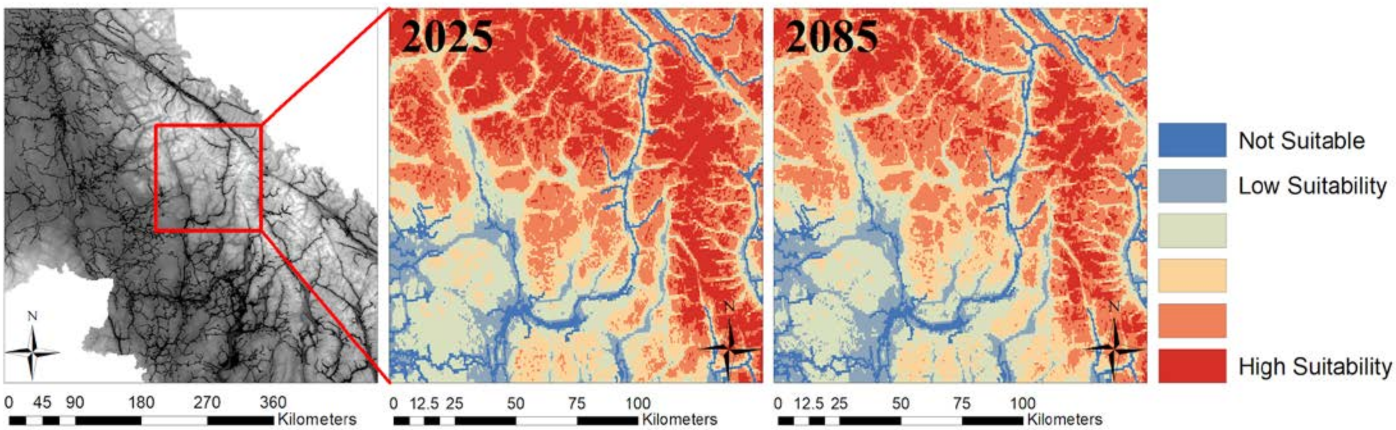

Figure 6: Zoomed in view of HSIs with a decrease in high suitability.

The boundaries of the federally designated priority place of dry interior is overlaid on the resulting HSIs of 2025 and 2085 from *Figure 4* in *Figure 7*. The extent of dry interior falls upon land that was identified in the HSIs as being mostly unsuitable or having a low suitability score in 2025 as well as 2085. Interestingly, dry interior largely follows the land we classified as constraints (agriculture, roads, and urban areas) in *Figure 2*. This suggests that dry interior is unsuitable for conservation efforts based on a SM caribou HSI in 2025, 2055, and 2085.

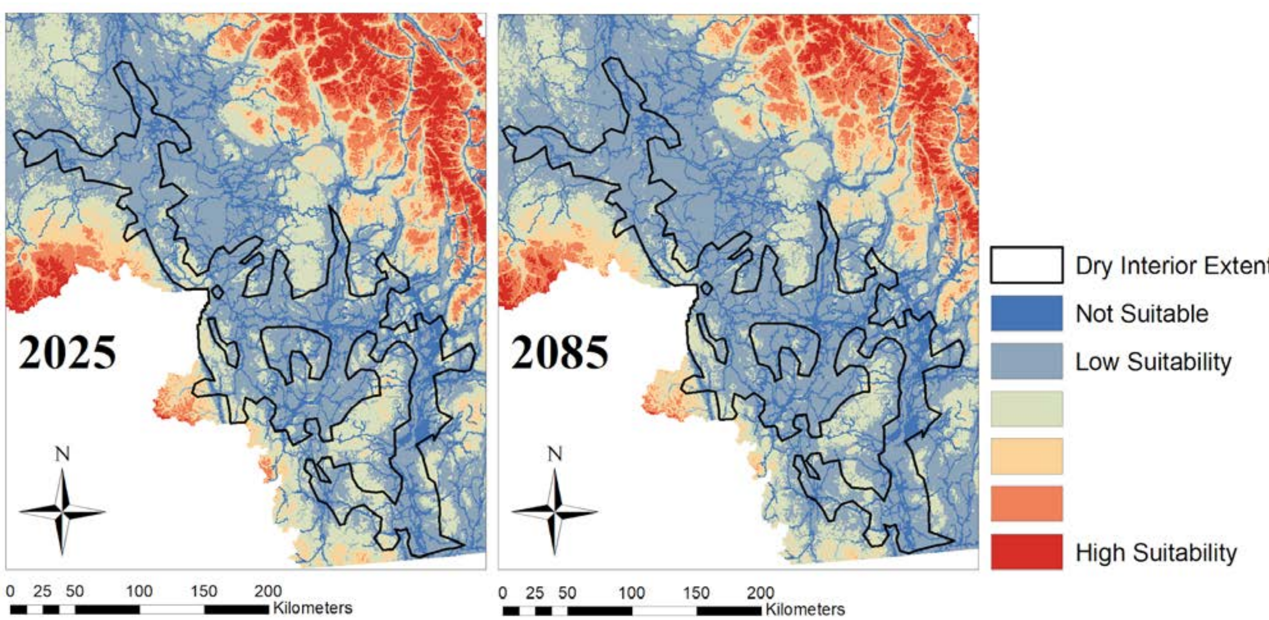

Figure 7: Dry interior extent compared to HSI 2025 and HSI 2085 (British Columbia Data Catalogue, 2020).

8. Conclusion

With dynamic processes such as climate change and urbanization, current stationary habitat reserves are often questioned on whether they will stay adequate for endangered species in the future. Due to this uncertainty, our study focused on creating a HSI for endangered SM caribou in BC and projecting future climate onto this suitability model to determine whether current BC reserves can continue to support future SM caribou populations. Based on the research findings and literature review on SM caribou as an indicator species and effective sites for conservation, we have concluded the federally designated dry interior priority place is an inadequate location to direct conservation efforts. SM caribou act as an indicator species and are priority species to protect under the federal government, thus the lack of coordination between the dry interior priority place and areas of high suitability in the HSI will not be effective conservation. Specifically, the dry interior following the roads and urban constraint layers is of greatest concern due to high fragmentation occurring within the designated area of conservation. Fragmentation reduces the amount and quality of isolated sites for SM calving and increases disturbances due to edge effects. Based on the climatic variables we used, areas of suitable habitat are decreasing from 2025 to 2085 with the most suitable areas occurring within the Rocky Mountains. Future research should entail urban change into HSI models for SM caribou as well as other critical BC wildlife to accurately critique current reserve suitability as well as inform the planning of future reserves.

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Appendix

Appendix 1: MCE weight development

Table A: 9-Point rating scale.

1/9	**1/7**	**1/5**	**1/3**	**1**	**3**	**5**	**7**	**9**
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely
Less important				Equal				More important