Prioritizing Zones for Caribou Habitat Restoration in British Columbia

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Executive Summary

Woodland caribou (*Rangifer tarandus caribou*, hereafter termed "caribou") are declining rapidly across much of British Columbia. Caribou declines are hypothesized to be primarily driven by anthropogenic habitat alteration which causes direct habitat loss and changes to predator-prey dynamics. As such, habitat restoration has been identified as an important management action to recover caribou populations, particularly in the long-term. While habitat restoration has been predicted to be effective at reducing caribou declines, the extent of disturbance within caribou range and the myriad of logistical constraints has highlighted the need to prioritize areas to increase effectiveness.

This project maps priority areas for habitat restoration within boreal and Southern Mountain Caribou (SMC) herds in British Columbia. We use an approach to direct restoration towards areas with higher gains in undisturbed caribou habitat relative to the cost of conducting restoration, while building off of existing habitat protection and focusing in areas more heavily used by caribou. We ranked landscape units across SMC and boreal caribou herds into five zones of ordered priority for restoration, such that an equal number of landscape units were in each zone for each herd. The report provides the rational, methods, and resulting maps of the prioritization process, and is paired with input data, analysis scripts and spatial layers of identified priority zones. We conclude by discussing additional considerations for operational treatment planning, and the multiple, hierarchical levels in which prioritization should be considered to facilitate effective caribou habitat restoration across British Columbia.

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Introduction

Woodland caribou (*Rangifer tarandus caribou*, hereafter termed "caribou") are declining rapidly across much of their range in Canada (Festa-Bianchet et al., 2011). In British Columbia, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has assessed the boreal population as Threatened and the Southern and Central populations as Endangered, while the Northern Mountain population is of Special Concern. Caribou declines are hypothesized to be primarily driven by anthropogenic habitat alteration which causes direct habitat loss and changes to predator-prey dynamics (Johnson et al., 2020; Serrouya et al., 2021). There is growing evidence that human-altered areas support higher moose and wolf densities, via increase early seral browse, which increases predation rates on caribou (Mumma et al., 2018; Serrouya et al., 2021). Furthermore, linear features, such as seismic lines, pipelines and roads, increase wolf hunting efficiency (Dickie et al., 2022, 2017) and access into peatlands which previously acted as refuge for caribou (DeMars and Boutin, 2017). Increased predator densities and hunting efficiency in human-altered areas has been shown to decrease adult survival and calf recruitment (Apps et al., 2013; McLoughlin et al., 2003; Wittmer et al., 2005b). Despite the small direct footprint of these linear features, they represent the most pervasive disturbance feature created by humans.

Habitat restoration on linear features, particularly historic conventional seismic lines and forestry roads, has been identified as a priority action to recover caribou habitat and populations (Environment and Climate Change Canada, 2020; Environment Canada, 2012). The density of linear features, both seismic lines and forestry roads, has increased drastically over time in caribou herds across British Columbia (Nagy-Reis et al., 2021). Only a small proportion of linear features show sufficient natural regeneration post-disturbance (Nagy-Reis et al., 2021; St-Pierre et al., 2021; Van Rensen et al., 2015). Habitat restoration is therefore necessary to facilitate return to forest cover on these features. However, habitat restoration can only target a fraction of these features because of high costs and limited equipment. Habitat restoration has been predicted to be effective at reducing caribou declines if conducted at the herd scale (Serrouya et al., 2020; Spangenberg et al., 2019). Given the constraints facing caribou habitat restoration, prioritizing areas for effective habitat restoration has been identified as an important planning exercise (Environment Canada, 2012).

The objective of this project is to prioritize habitat restoration within Southern Mountain Caribou (SMC) and Boreal caribou herds in British Columbia. Prioritization will facilitate the planning process for cost-effective caribou habitat restoration. This process compliments similar programs to rank restoration zones in northern Alberta (ABMI, 2020).

Methods

We prioritized habitat restoration within each Boreal and SMC herds in British Columbia (Figure 1). Our overall approach directed restoration towards areas with higher gains in undisturbed caribou habitat relative to the cost of conducting restoration. We also directed restoration towards areas more heavily used by caribou and areas with existing habitat protection to build off of. We used separate processes for herds where conventional seismic lines are the predominant features being targeted for restoration (boreal), herds where forestry roads are the predominant features targeted for restoration (SMC-northern and SMC-southern groups), and herds where both features are likely to be targeted for restoration (SMC-central group). Maps of all steps are provided in Appendix A.

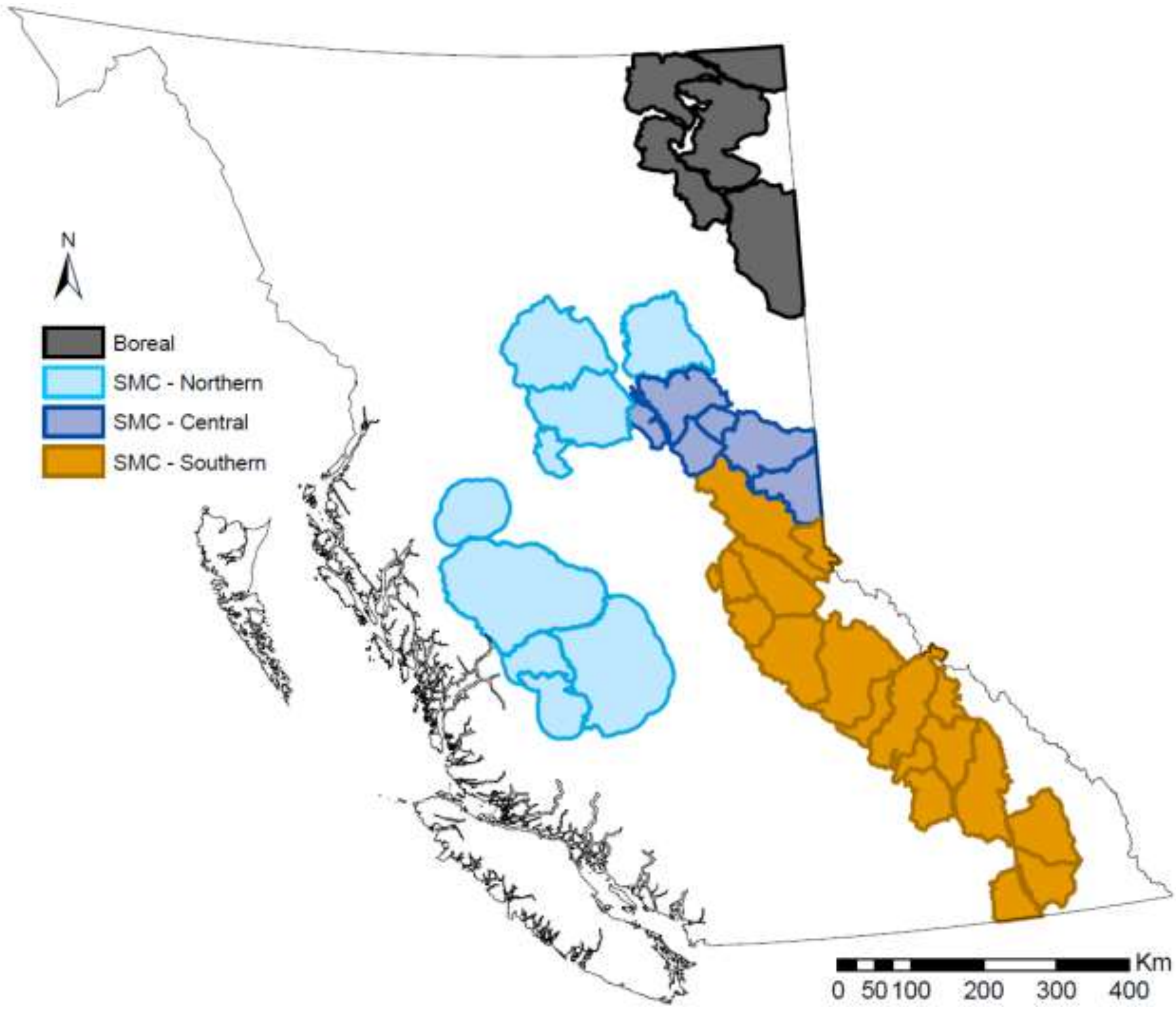

Figure 1: Southern Mountain Caribou and boreal caribou herd boundaries in British Columbia.

Boreal Caribou

The Federal Recovery Strategy for boreal woodland caribou identifies that a minimum of 65% of the habitat with a caribou range is required to be undisturbed for the population to have a measurable probability (60%) to be self-sustaining (Environment Canada, 2012). Boreal caribou are distributed through the boreal forests of Canada, ranging from the Yukon to Labrador. Within British Columbia, boreal woodland caribou reside in the northeastern portion of the province (Peace Zone). Here, caribou space away from predators by living at low densities in muskegs, peatlands, and surrounding uplands (DeMars et al., 2016; DeMars and Boutin, 2017). Boreal caribou overlap areas with significant deposits of oil and gas, and as such British Columbia's boreal caribou ranges are highly disturbed (Nagy-Reis et al., 2021). It is estimated that there are approximately 350,000 km of conventional seismic lines in boreal caribou ranges across Alberta and British Columbia. Given the link between conventional seismic lines and caribou declines

(DeMars and Boutin, 2017; Dickie et al., 2017; McKenzie et al., 2012) and the omnipresence of these features across the landscape (Nagy-Reis et al., 2021), the need to prioritize areas for restoration to maximize the benefit to caribou has been recognized as a key measure for effective habitat restoration.

We chose a patch size of 1:50 000 using the National Topographic System (NTS) for all analyses (Figure 2). This patch size was chosen to align with the need of caribou for large areas of intact habitat and to facilitate operational implementation by spatially grouping areas of similar potential for restoration. This approach ignores fine scale variation in line density and configuration, but is appropriate for coarse-filter strategic planning. Additional considerations for fine scale operational and tactical planning are provided within this document.

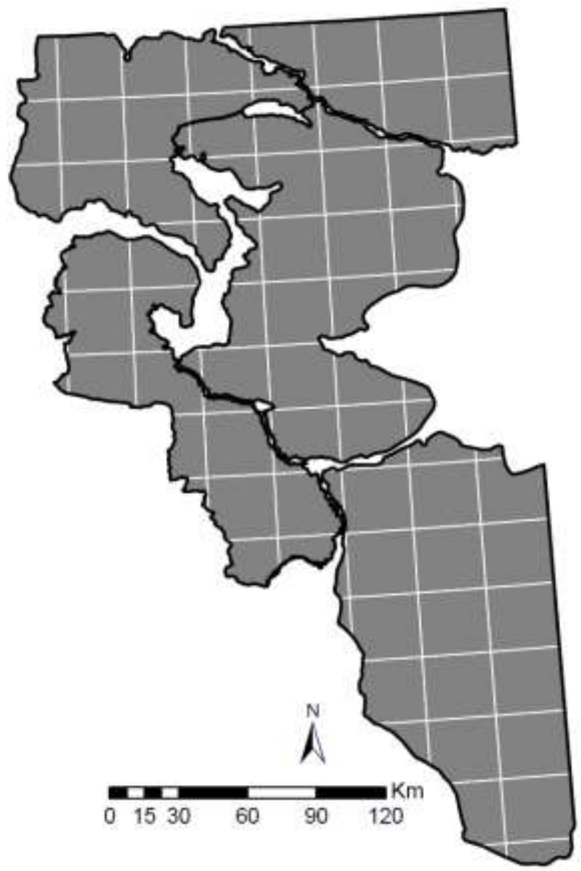

Figure 2: Boreal caribou herd boundaries in British Columbia with sub-Landscape Units (white) used for prioritization.

First, boreal caribou herds were overlaid with 1:50 000 NTS tiles to create sub-Landscape Units (LUs) in which to prioritize habitat restoration. We then mapped current habitat disturbance in each LU and simulated the reduction in disturbance following restoration. We did not include burned areas because burned areas may already be on a trajectory to recovery and the spatial arrangement of future fire disturbances are difficult to predict.

We quantified human disturbance within each LU by combining various datasets available from the Government of British Columbia and Oil and Gas Commission (Table 1). We used datasets with the highest resolution that were available, but did not conduct independent data quality and assurance. We calculated the current percent disturbance for each LU, buffered by 500 m, following the definition of human disturbance in the Federal Recovery Strategy for Boreal caribou (Environment Canada, 2012, 2011). We estimated the remaining percent disturbance following complete habitat restoration by removing all geophysical lines from the total disturbance, buffering the remaining disturbances by 500 m, and calculating the percent of each LU classified as disturbed. We then calculated the gain in undisturbed habitat (GIU) assuming that all geophysical lines were restored. We subtracted the percent disturbance after all treatable features were restored from the current percent of altered habitat. This step identifies LUs that offer the highest potential to gain undisturbed habitat.

To further direct restoration towards areas with higher GIU relative to the cost of conducting restoration, we assessed the "Bang-for-Buck" (B4B) by dividing the GIU by an index of "cost" needed to achieve this result. We used the density of geophysical lines (conventional seismic) within each LU as our index of cost. The monetary cost of restoration is highly variable and depends on what restoration treatments are being applied, season of application, the intensity of treatments, as well as local differences in equipment mobilization and labor costs. We therefore chose to use an index of restoration cost throughout this process that reflects a consistent metric across all herds.

To direct restoration towards areas used more frequently by caribou, we used individual caribou captured and collared with Global Positioning System (GPS) collars from 2010 to 2018 to identify areas of recent use. Utilization Distributions (UDs) were created using Kernel Density Estimators (KDE) in the package adehabitatHR (Calenge, 2006) by the Government of British Columbia (Perkins, 2020). KDEs were created for each individual in each herd. Only animals with collars operating for at least 60% of the year were included. First, the bandwidth/search radius ("href") for each individual collar was derived and the average was calculated by herd. Then, the density raster was generated for each individual. Individual density rasters were combined into binary surfaces with 1 indicating use (i.e., cells within the 95% UD contour) and 0 indicating no use. The individual rasters were then combined into a single raster for each herd by summing individual binary rasters, such that values indicate the frequency of use (i.e., the number of individuals that used a particular grid cell). Finally, the herd rasters were summed across herds, and the frequency of use values were classified into 4 quantiles, with 4 corresponding to high use and 1 to low use. We rescaled these quantile classes provided by the Government of British Columbia between 0 and 1, and calculated the mean value within each LU. We then multiplied the B4B, scaled between 0 and 1, by the average caribou use, scaled between 0 and 1, to calculate the weighted B4B. We note that this approach heavily weights restoration towards area where recent caribou use is known.

Finally, we ranked LUs from highest to lowest weighted B4B and grouped similarly-ranked landscape units into five hierarchical 'zones' of ordered priority for restoration, such that an equal number of LUs were in each zone for each caribou herd. Lowest priority zones included LUs with no potential benefits from restoration, either because there are no treatable features within a landscape unit, or because all treatable areas fall within other disturbances.

Table 1: Data layer sources and location used to create sub-landscape units, disturbance calculations, and weightings for prioritizing habitat restoration in British Columbia's boreal caribou herds.

Layer Category	Layer	Source	Source URL
Landscape Units	NTS Tiles	Government of Canada	https://open.canada.ca/data/en/dataset/055919c2-101e-4329-bfd7-1d0c333c0e62
Weighting	Caribou Utilization Distribution (UD)	Government of British Columbia	Proprietary
Disturbance	Pipeline Segments (Permitted)	British Columbia Oil and Gas Commission	https://data-bcogc.opendata.arcgis.com/datasets/359b7e14fafa4abc84ff873bc55015fb_0/about
Disturbance	Geophysical Lines (Permitted)	British Columbia Oil and Gas Commission	https://data-bcogc.opendata.arcgis.com/datasets/bd0a685c1f614b4b89ace6564e5e3cc4_0/about
Disturbance	Oil and Gas roads	British Columbia Oil and Gas Commission	https://data-bcogc.opendata.arcgis.com/datasets/b073031723eb44578e1e881939757fe2_0/about
Disturbance	Well and Facility Areas (Permitted)	British Columbia Oil and Gas Commission	https://data-bcogc.opendata.arcgis.com/datasets/3550539a554a426ba537223acf4642e9_1/about
Disturbance	Orphan wells	British Columbia Oil and Gas Commission	https://www.bcogc.ca/data-reports/data-centre/?category=60104
Disturbance	Dormant wells	British Columbia Oil and Gas Commission	https://www.bcogc.ca/data-reports/data-centre/?category=60040
Disturbance	Oil and Gas Associated and Ancillary Areas (Permitted)	British Columbia Oil and Gas Commission	https://data-bcogc.opendata.arcgis.com/datasets/bbd11f8029a949fb9ce6012f32111e31_1/about
Disturbance	Forestry Tenure Roads	Government of British Columbia	https://catalogue.data.gov.bc.ca/dataset/forest-tenure-road-segment-lines#edc-pow
Disturbance	Cutblocks	Government of British Columbia	https://catalogue.data.gov.bc.ca/dataset/harvested-areas-of-bc-consolidated-cutblocks-
Disturbance	Digital Roads Atlas Master	Government of British Columbia	https://catalogue.data.gov.bc.ca/dataset/bb060417-b6e6-4548-b837-f9060d94743e#edc-pow
Disturbance	TRIM miscellaneous lines	Government of British Columbia	https://catalogue.data.gov.bc.ca/dataset/trim-miscellaneous-lines

Southern Mountain Caribou

The Federal Recovery Strategy recognizes 38 SMC sub-populations, broken into three groups; SMC-northern group, SMC-central group, and SMC-southern group. SMC-southern group, which are adapted to deep snow and feed on arboreal lichen, tend to use high elevation habitat to avoid predators that are primarily at low elevations, but have seasonal migrations between high-elevation alpine during calving and summer, to mature old growth stands in winter to access arboreal lichen (Theoret et al., 2022). SMC-central and SMC-northern groups tend to feed on terrestrial lichens in winter at low elevation and migrate to higher elevations in summer. SMC populations with increased human disturbance within their range, particularly decreased old growth forest as a result of forest harvest, have lower survival (Apps et al., 2013; Wittmer et al., 2007). As with boreal populations, SMC have lower survival in areas with increased human disturbance. Increased predation occurs in areas with higher amounts of early seral forests as a result of forestry activities (Apps et al., 2013; Wittmer et al., 2005a). However, low-elevation habitat within SMC-central herds are also prominently influenced by oil and gas development (Environment Canada, 2014).

We defined habitat patches for SMC (i.e., LUs) using sub-units of the British Columbia (Government of British Columbia, 2008) Landscape Units. These sub-units are largely on watershed boundaries (Provincial Moose Technical Working Group, 2017). Same as for the boreal process, the sub-units align with the need of caribou for large areas of intact habitat and to facilitate operational implementation by spatially grouping areas of similar potential for restoration. Because the sub-units are also used for processes such as moose habitat assessment and cumulative effects framework (Provincial Moose Technical Working Group, 2017), they are transferable to other habitat assessment and management actions. We intersected the sub-units with caribou herd boundaries provided by the Government of British Columbia to create final LUs for the prioritization process. LUs had a mean area of 186 km^2 (minimum = 50 km^2, maximum = 940 km^2), with the majority of LUs being under 400 km^2. As with the boreal population, additional considerations for fine-scale operational and tactical planning within the LUs are provided in the discussion.

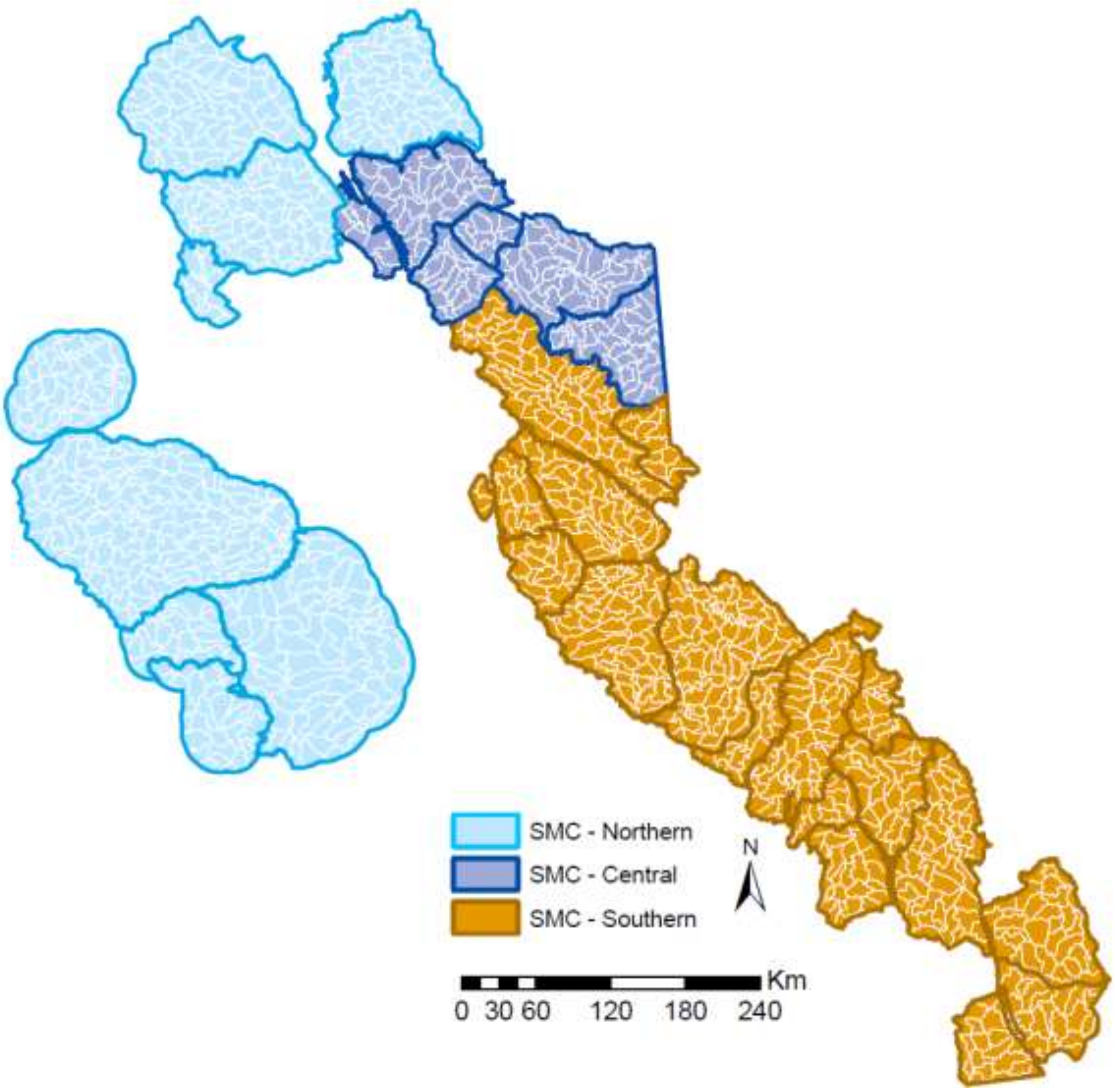

Figure 3: Southern Mountain Caribou (SMC) herd boundaries in British Columbia with sub-Landscape Units (white) used for prioritization.

Southern and Northern Group

For the SMC-southern group and SMC-northern group we used an approach that focusses restoration into areas where human habitat alteration is high relative to the density of restorable roads. This approach prioritizes the recovery of disturbed caribou habitat while reducing the cost of conducting restoration. We calculated the current proportion of each LU covered by anthropogenic habitat alteration using human habitat alteration data from Environment and Climate Change Canada's Canadian Wildlife Service (Canadian Wildlife Service, 2022). We defined altered caribou habitat as anthropogenic features buffered by 500m merged with wildfires, where only cutblocks and fires under 40 years old were included, as per the federal recovery strategy (Environment Canada, 2014, 2012). We then divided the percent anthropogenic habitat alteration by restoration cost to calculate the B4B. We used the

Government of British Columbia's Digital Road Atlas (Table 1) to calculate road density as an index of restoration cost. We only included roads classified as resource roads and recreational roads, and did not include permanent roads such as highways, driveways, etc. As with the boreal process, we did not estimate the monetary cost of restoration per LU, but instead used density of restorable roads as an index of the cost of restoration.

To focus restoration into areas with increased importance to caribou, we increased the weighting of LUs with higher proportion of core caribou habitat. We calculated the proportion of each LU designated as core habitat using spatial layers from the Government of British Columbia (Dodd and Carswell, 2019). For the SMC-northern group, core habitat was only available in Telkwa, Itcha-Ilgachuz, Charlotte, and Rainbows. Therefore, Chase, Graham, Takla, Tweedsmuir, and Wolverine did not include weighting towards areas with core caribou habitat. We also increased the weighting of LUs by calculating by the proportion of the LU covered by existing caribou habitat protection to create larger patches of undisturbed caribou habitat. We used caribou Ungulate Winter Range designated by Government Actions Regulation (Government of British Columbia, 2005) to calculate the proportion of each LU currently protected. Finally, we decreased the weighting of LUs with higher proportion of habitat directly altered by human preferred by moose to avoid cutting off hunter harvest in areas where moose are likely to be at higher densities (Mumma et al., 2020). We used the Canadian Wildlife Service (2022) habitat alteration data and defined human habitat alteration preferred by moose as the direct area altered by cutblocks and fire less than 20 years old because these are more likely to be selected by moose (Mumma et al., 2020).

We scaled the B4B, proportion core habitat, proportion Ungulate Winter Range, and the inverse proportion of moose-preferred habitat, between 0 and 1, and calculated the "additive" B4B by summing the scaled values. This approach weights the variables equally, while ensuring that LUs with 0 in any one metric don't become immediately relegated to 0 ranking. Finally, we ranked LUs from highest to lowest additive B4B and grouped similarly-ranked LUs into five zones of ordered priority for restoration, such that an equal number of LUs were in each zone for each herd.

Central Group

To prioritize areas for restoration within SMC-central, we combined the approaches from the boreal populations where restoration is focused on restoring seismic lines and the northern and southern sub-groups where restoration is focused on restoring non-permanent roads. SMC-central caribou migrate to low-elevation habitat that is highly disturbed by oil and gas (Environment Canada, 2014; Theoret et al., 2022), where conventional seismic lines are more likely to be the predominant features being restored in the near-term Forestry road decommissioning and restoration is also likely to occur in these herd areas as well, particularly in valley bottoms up to alpine habitat.

To prioritize LUs that offer the highest potential to gain undisturbed habitat following restoration of seismic lines and non-permanent roads, we calculated GIU by subtracting the current disturbance in each landscape unit by simulated future disturbance. We quantified disturbance within each landscape unit using the Canadian Wildlife Service (2022) habitat alteration data. The current percent area disturbed was calculated by buffering anthropogenic features by 500 m, and merging these with wildfires. We included fires and cutblocks under 40 years only as per the Federal Recovery Strategy for Southern Mountain Caribou (Environment Canada, 2014). We estimated the future percent area disturbed following restoration by removing seismic lines and non-permanent roads from the linear feature layer before buffering and merging with polygonal disturbances.

As with the boreal populations, we directed restoration towards areas with higher GIU relative to the cost of conducting restoration, by assessing the B4B. We calculated the B4B by dividing the GIU by a metric of "cost" of restoring seismic lines and non-permanent roads within each LU. To calculate our index of cost, we added the normalized density of non-permanent roads in each LU to the normalized proportion area of each LU directly disturbed by seismic lines as our index of cost. We were unable to use density of seismic lines, as with the boreal process, because seismic lines within the Canadian Wildlife Service (2022) spatial layers are represented by polygons instead of polylines. However, direct area of the seismic polygon and length of seismic polylines are highly correlated, and represent similar metrics of cost. In both cases (i.e. cost measured as the density of seismic lines or the proportion of the LU directly impacted by seismic lines), the B4B reflects the reduction in percent disturbance relative to the effort, or cost, needed to achieve this result.

We directed restoration towards areas used more frequently by caribou using information from GPS collared caribou. The Government of British Columbia provided caribou UD 95 % Isopleths from individuals monitored in the SMC-central group from January 1, 2016 to December 31, 2020. UDs were created for each individual for early winter, late winter, and spring for the Burnt Pine, Kennedy Siding, Klinse-za, and Quintette herds. We merged all 95% UDs, calculated the cumulative area covered by 95% UDs for each LU, and divided this by the area of the LU to standardize by the size of the LU. We then multiplied the B4B by the standardized cumulative area covered by 95 % UDs. Unlike with the boreal process, there were many LUs with no caribou use, particularly in the Narraway herd. We therefore calculated the "additive" B4B by summing the B4B, scaled between 0 and 1, and the caribou use index, scaled between 0 and 1. We use the additive B4B in the ranking process, but present the raw B4B in Appendix A.

Finally, we ranked LUs from highest to lowest additive B4B and grouped similarly-ranked LUs into five zones of ordered priority for restoration, such that an equal number of LUs were in each zone for each herd.

Because the Federal Recovery Strategy for Southern Mountain Caribou (Environment Canada, 2014) does not adopt the same disturbance threshold of 65 % disturbed by buffered human footprint plus wildfires as is identified for boreal caribou (Environment Canada, 2012, 2011), we investigated how sensitive final Zones were to the assumption of buffering polygonal anthropogenic features versus only linear features. Buffering all types of anthropogenic habitat alteration versus only linear features had little impact on the final zone rankings across all SMC groups, though central group zones changed more so as a result of including the restoration of non-permanent roads (Appendix B).

All analyses were conducted in R version 3.6.2 (R Core Team, 2019) or ArcGIS 10.3 (ESRI, 2015). Analyses scripts and spatial layers used for each calculation are included within this report package.

Results

Priority zones in boreal caribou herds are presented in Figure 4. Priority zones in SMC herds are presented in Figure 5.

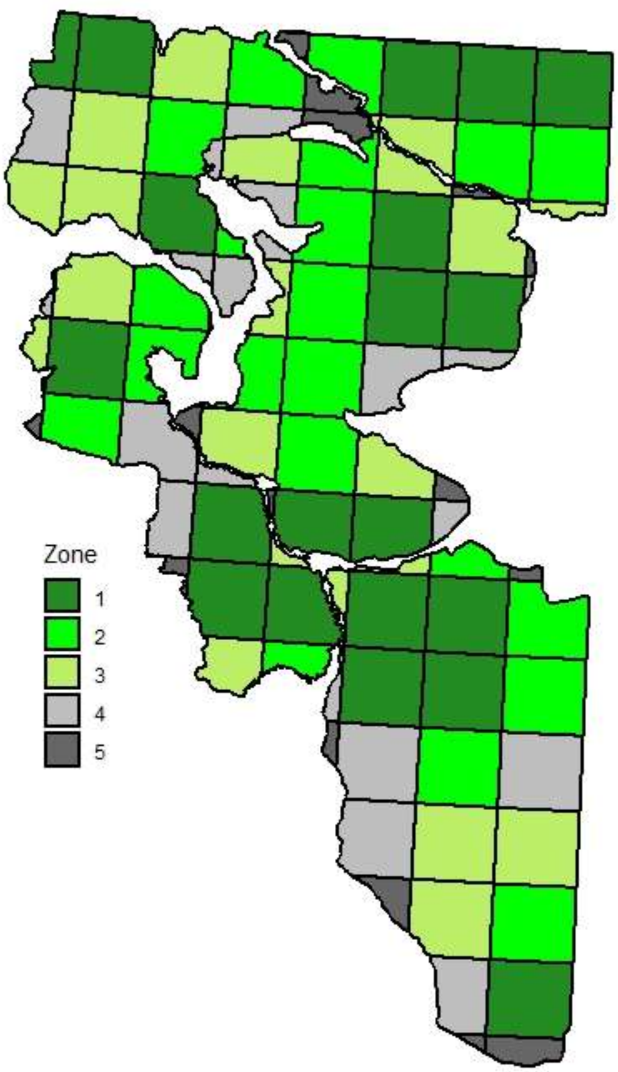

Figure 4: Restoration priority zones within boreal caribou herds in British Columbia. Landscape Units are prioritized based on the highest gain in undisturbed caribou habitat following seismic restoration, relative to the cost of restoring seismic lines, and weighted towards areas with high caribou use.

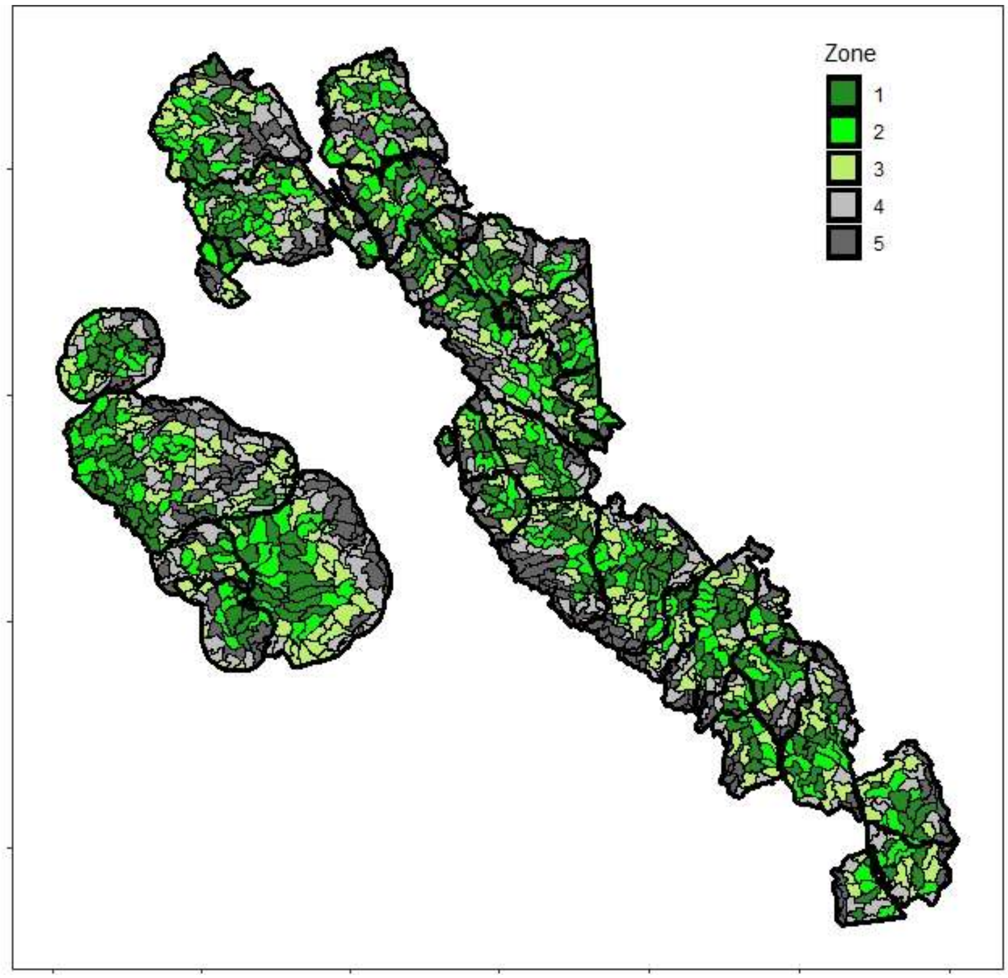

Figure 5: Restoration priority zones within Southern Mountain Caribou (SMC) herds in British Columbia. For the SMC-southern and SMC-northern groups, priority zones are based on focussing restoration into Landscape Units (LUs) with higher human habitat alteration relative to the density of restorable roads, higher proportion of core caribou habitat, higher proportion of existing habitat protection, and lower proportions of moose-preferred habitat. For the SMC-central group, LU are prioritized based on the highest gain in undisturbed caribou habitat following seismic line and non-permanent road restoration, relative to the cost of restoring these features, and weighted towards areas with high caribou use.

Discussion

In this report we provide high-level strategic guidance on prioritizing areas for caribou habitat restoration by mapping priority zones within caribou herds based on the potential gain in undisturbed caribou habitat, the cost of restoration, building off existing habitat protection, and current caribou use. However, when managers are choosing between areas to prioritize restoration activities, there are additional socioeconomic considerations that should be incorporated. The priority zones identified within this report represent a starting point in which additional perspectives and values can be incorporated. For example, Traditional Knowledge of areas that are important to local communities, caribou, or both, should be incorporate. Likewise, engagement with the forestry and energy industries can reduce the potential for re-disturbing restored features by incorporating information on areas that are likely to be developed in the future. Incorporating additional values can be accomplished during the engagement and consultation phase of restoration planning, or in an iterative fashion whereby spatial layers representing other core values and costs can be explicitly incorporated in the prioritization process.

The high-level guidance on restoration priority areas provided within this report also does not incorporate information on specific features that may influence operational restoration planning. It must be recognized that not all features are equal. Some features may already be recovering, reducing the benefit of restoration on that given feature. Some features may be more difficult to access, or costlier to treat. In an extreme example, some features may need additional access corridors to be built, reducing the overall benefit of restoration while increasing the cost. Additionally, restoring specific features may cut off access to other features that require treatments. Optimizing restoration treatment plans should consider the network of roads and seismic lines that need restoration treatments, those that are sufficiently regenerating, as well as the need to leave some features open for continued traditional, recreational, or industrial use.

Effective habitat restoration is likely to be best achieved when prioritized at multiple, hierarchical levels. At the highest level, prioritization is needed between caribou herds to choose herds where habitat restoration is expected to have the highest impact. Because habitat restoration is a longer-term measure that may take decades to see population-level benefits (Johnson et al., 2019; Serrouya et al., 2020), restoration may be more effective for caribou herds that are more likely to recover or where additional conservation measures are already occurring. High-level guidance towards prioritizing between caribou herds is out of scope of this project, but should be considered prior to identifying where restoration should be prioritized within herds. Once caribou herds are chosen for restoration, it is important to choose areas that creates the most intact caribou habitat with the lowest cost. This second-level of prioritization is targeted by the work within this report. Landscape units are designated based on creating “bite-sized” chunks where restoration can be mobilized effectively, and optimized based on a set of criteria. Following the second-level prioritization comes the finest level of prioritizing where particular features or sections of features are prioritized for treatments (Yemshanov et al., 2021). Given the extent of caribou habitat disturbance across British Columbia, effective habitat restoration will require prioritization across all three of these levels.

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Appendix A: Maps of each index used to calculate priority zones for boreal and Southern Mountain Caribou in British Columbia

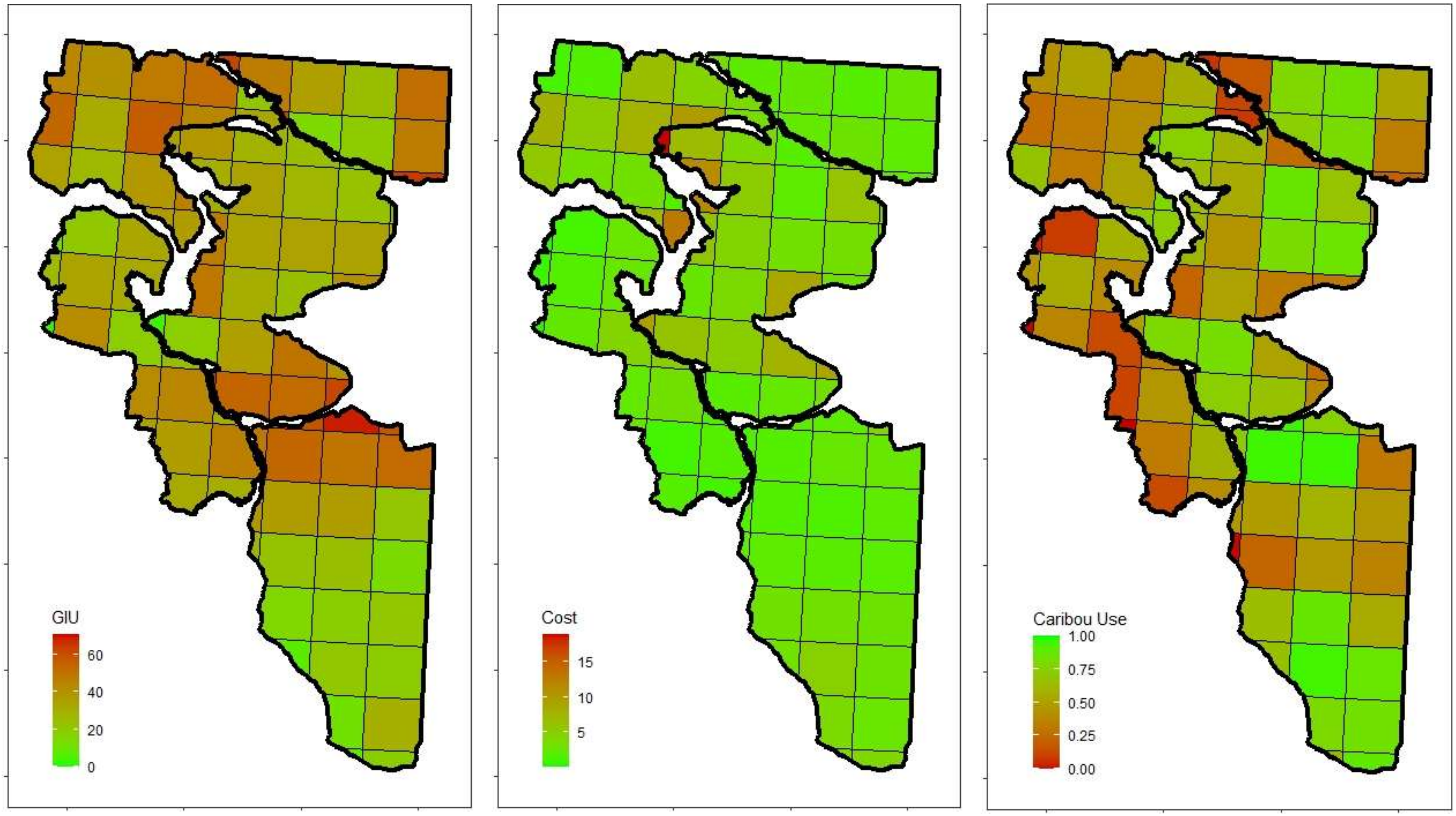

Figure A. 1: Percent gain in undisturbed habitat (GIU), cost of restoration, and mean caribou use across boreal ranges in British Columbia. Gain in undisturbed caribou habitat calculated as the proportion disturbed under current conditions minus the simulated percent disturbance following restoration. Cost of restoration is indexed by the density of geophysical lines (km/km^2). Caribou use is indexed by the average caribou use from Kernel Density Estimators from GPS collared caribou, scaled between 0 and 1. See Methods for additional details.

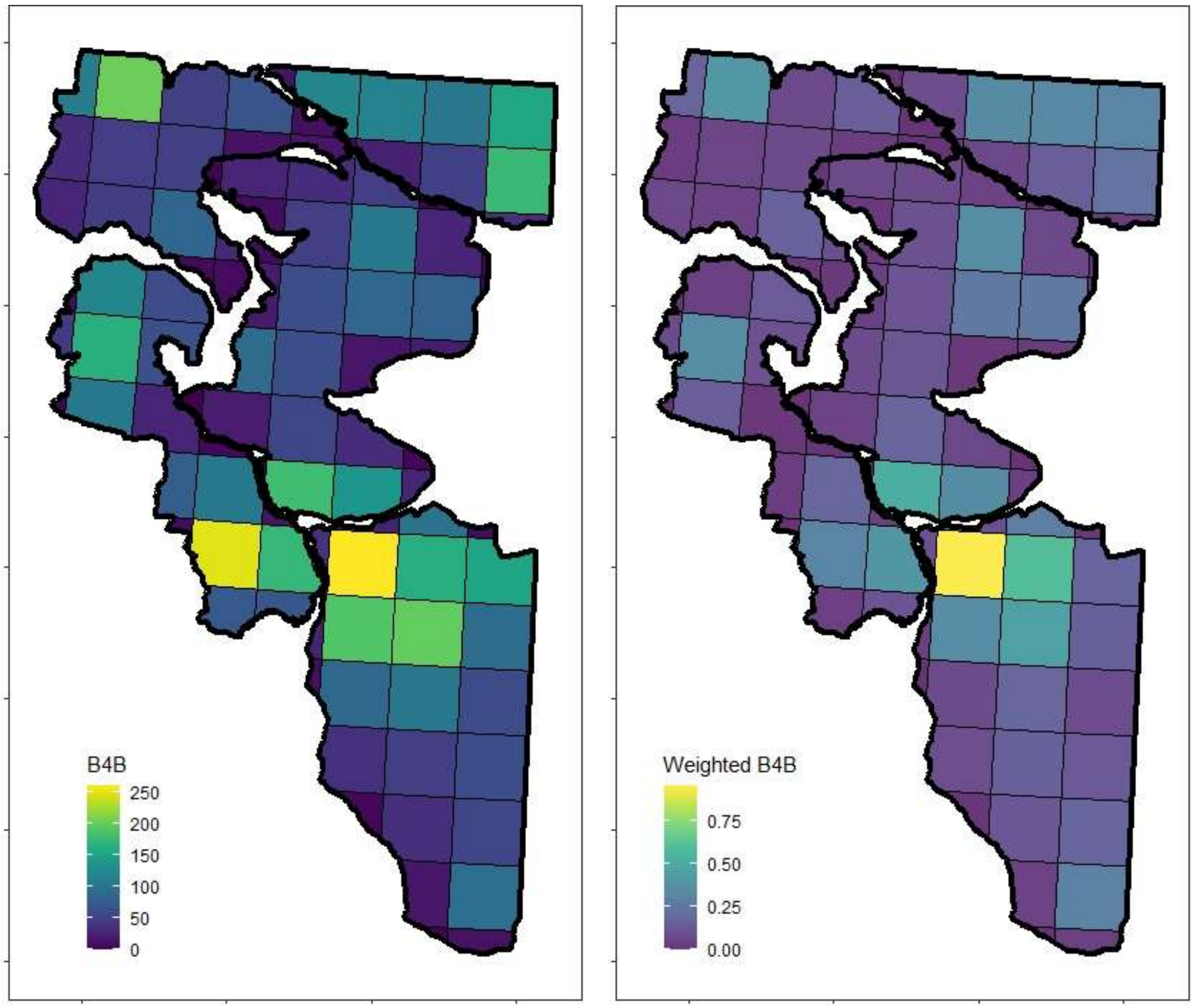

Figure A. 2: Bang for Buck (B4B) and weighted B4B across boreal ranges in British Columbia. Bang for Buck (B4B) was calculated as the percent gain in undisturbed habitat (GIU) divided by the cost of restoration. The weighted B4B was calculated my multiplying the B4B, scaled from 0 to 1, and the caribou use index, scaled between 0 and 1. See Methods for additional details.

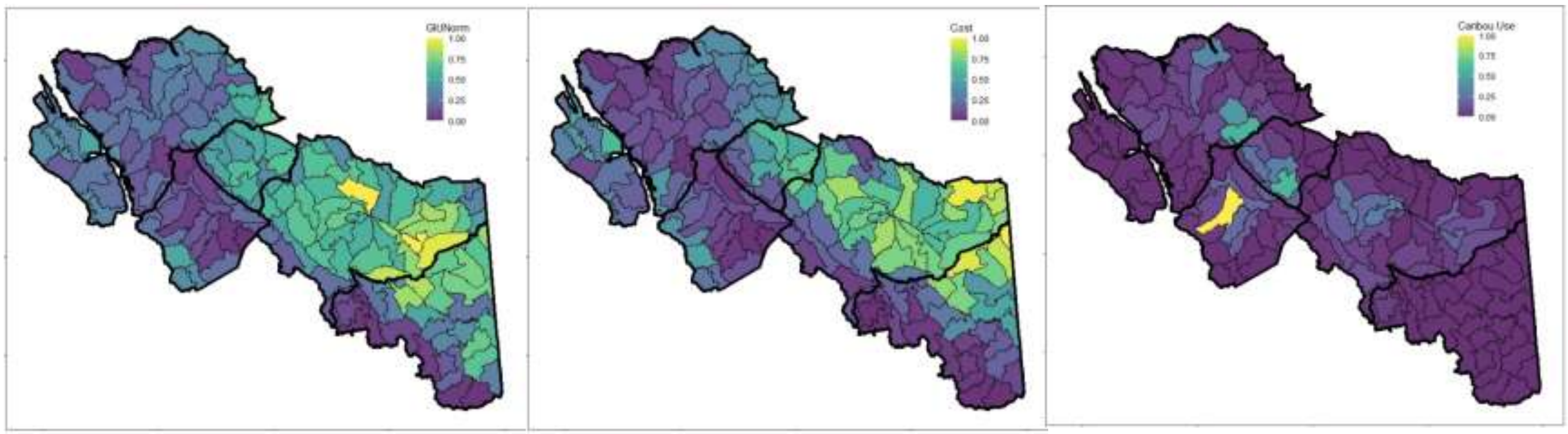

Figure A. 3: Percent gain in undisturbed habitat (GIU), cost of restoration, and caribou use index across Southern Mountain Caribou (SMC) central group in British Columbia. All values are shown scaled from 0 to 1 across the SMC-central group. Gain in undisturbed caribou habitat calculated as the proportion disturbed under current conditions minus the simulated percent disturbance following restoration. Cost of restoration is indexed by the proportion of each Landscape Unit (LU) directly covered by seismic lines (km^2/km^2). Caribou use is indexed by the average caribou use from Kernel Density Estimators from GPS collared caribou. See Methods for additional details.

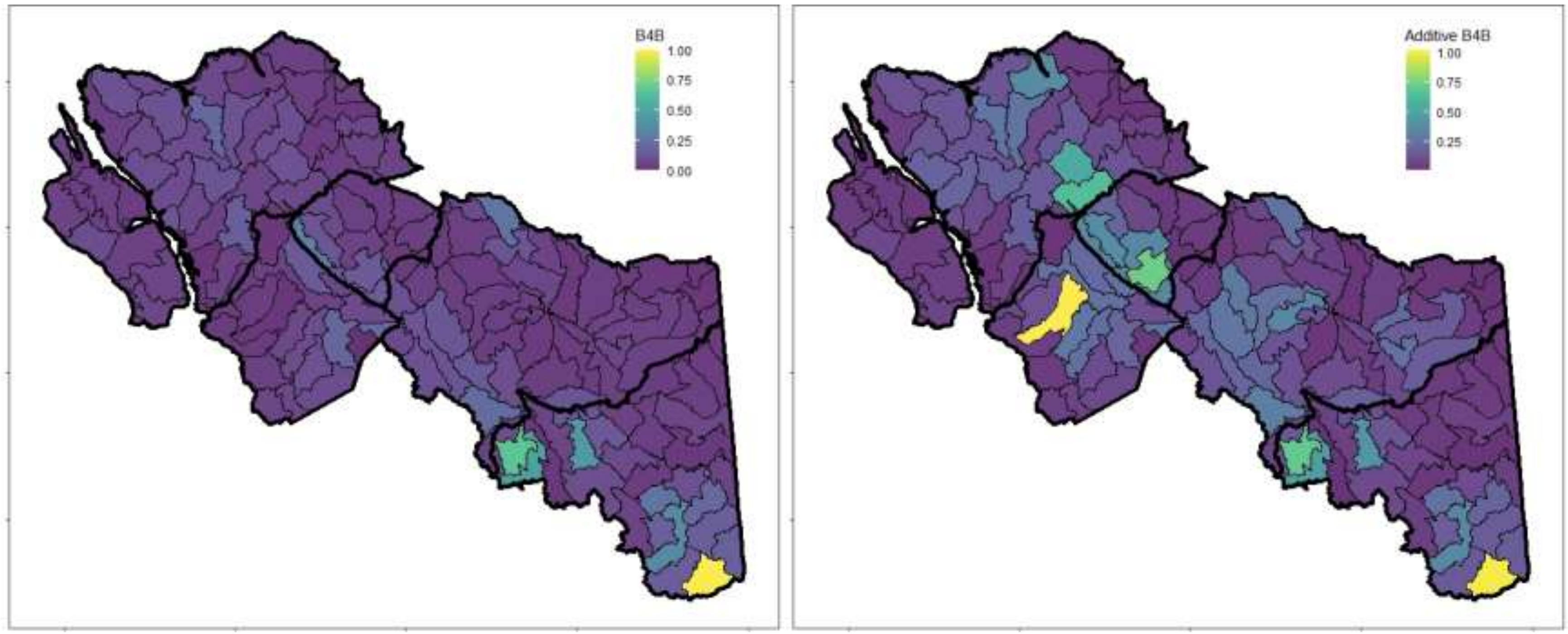

Figure A. 4: Bang for Buck (B4B) and additive B4B across Southern Mountain Caribou (SMC) central group in British Columbia. Bang for Buck (B4B) was calculated as the percent gain in undisturbed habitat (GIU) divided by the cost of restoration, and scaled from 0 to 1. The additive B4B was calculated by adding the B4B, scaled from 0 to 1, and the caribou use index, scaled between 0 and 1. See Methods for additional details.

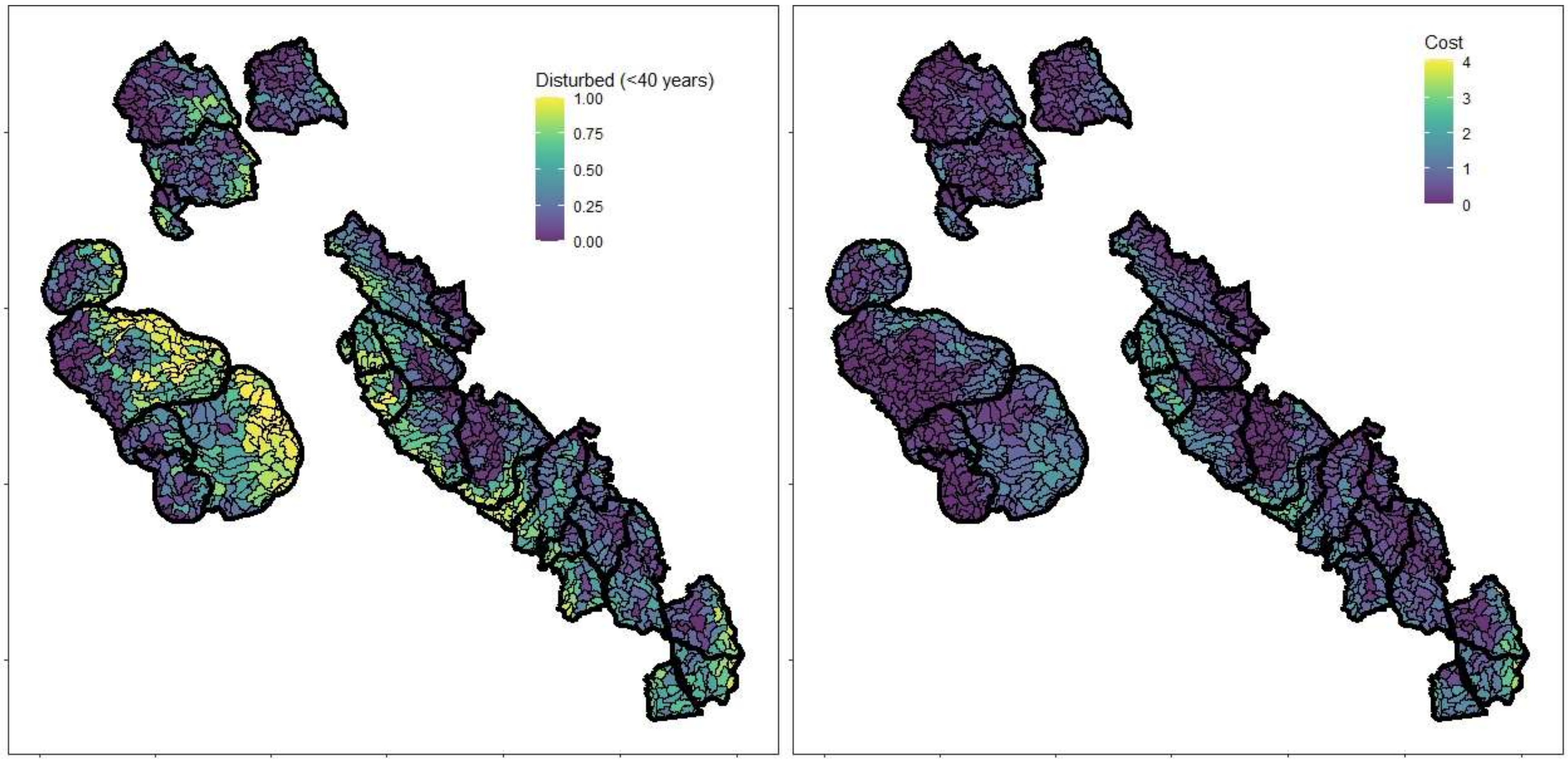

Figure A. 5: Proportion disturbed habitat and the cost of restoration across Southern Mountain Caribou (SMC) northern and southern groups in British Columbia. Proportion disturbed habitat was calculated with cutblocks and fires over 40 years old excluded, and is shown scaled between 0 and 1. Cost of restoration is indexed by the density of restorable roads (km/km^2) in each Landscape Unit (LU). See Methods for additional details.

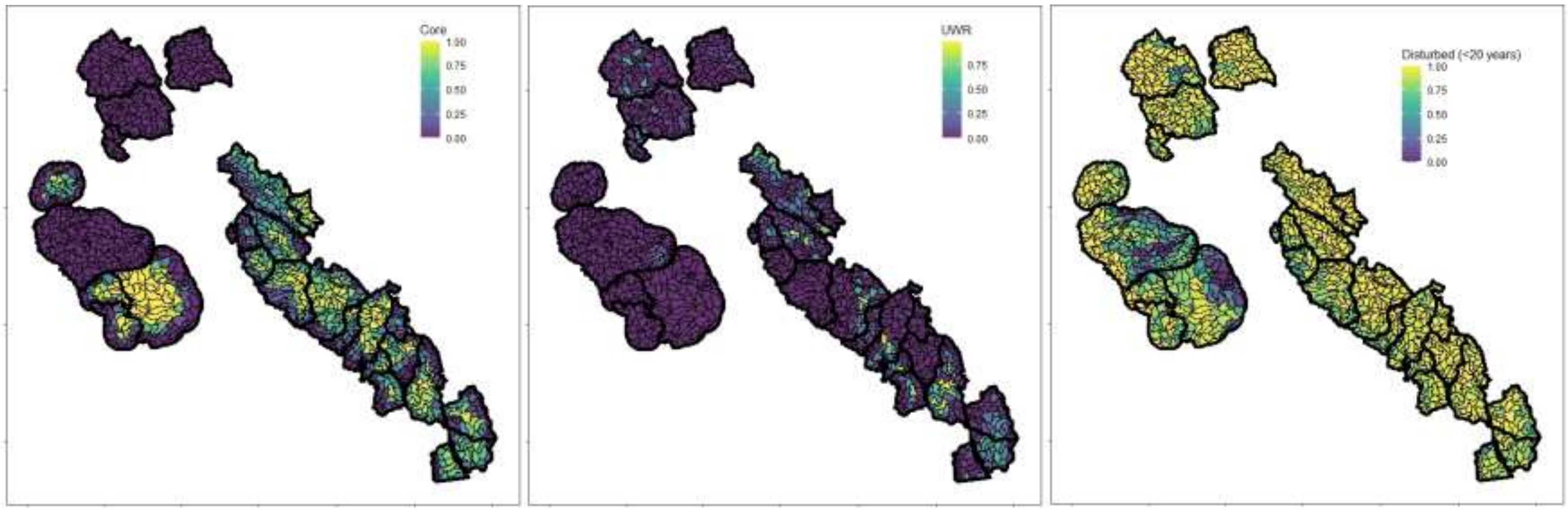

Figure A. 6: Proportion of core caribou habitat, Ungulate Winter Range (UWR) and disturbed habitat less than 20 years in each Landscape Unit (LU) across the Southern Mountain Caribou (SMC) northern and southern groups. All values are shown scaled from 0 to 1. Proportion disturbed habitat was calculated with cutblocks and fires over 20 years old excluded as an index of preferred moose habitat. See Methods for additional details.

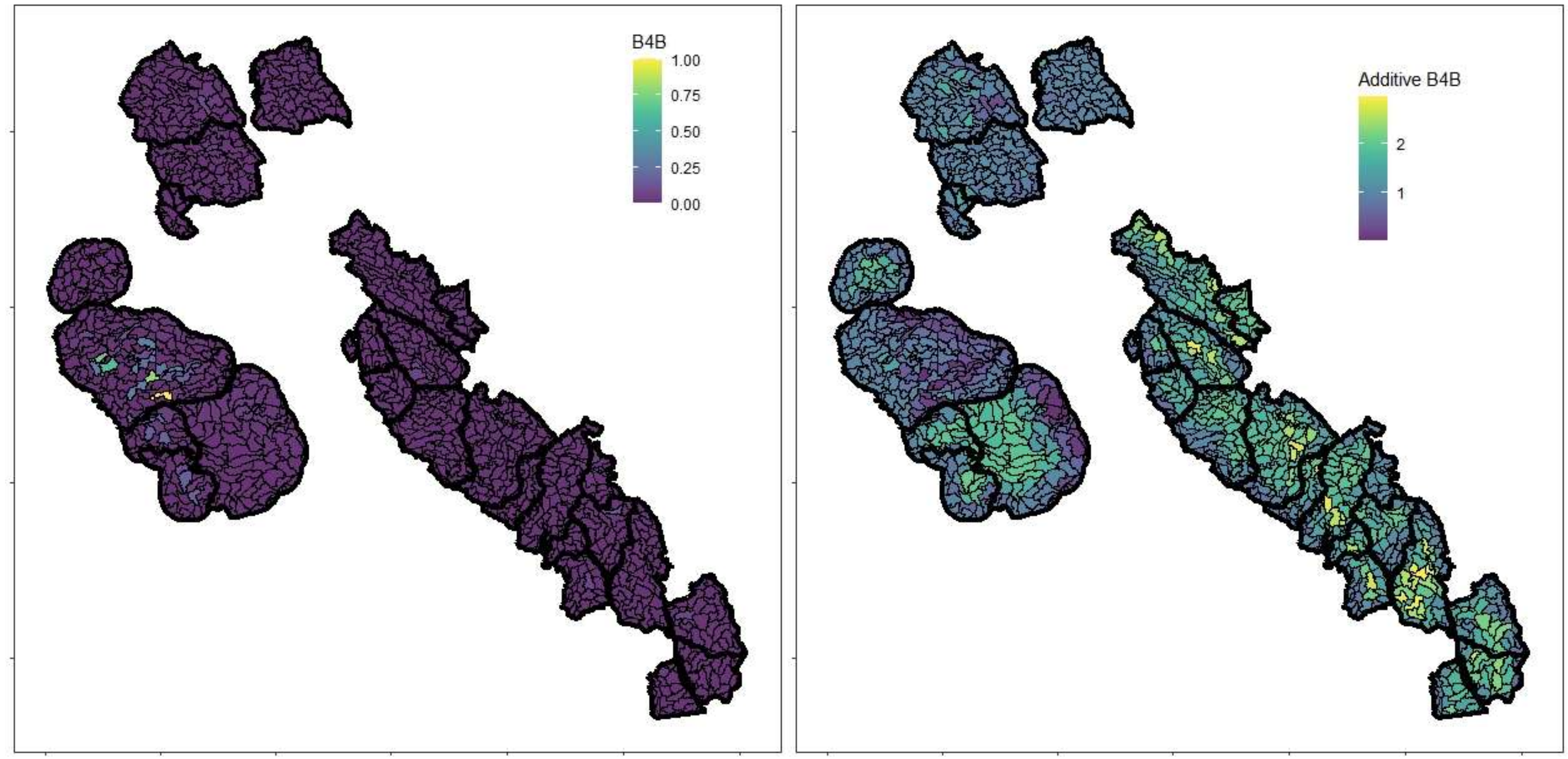

Figure A. 7: Bang for Buck (B4B) and additive B4B across Southern Mountain Caribou (SMC) northern and southern groups in British Columbia. Bang for Buck (B4B) was calculated as the disturbance <40 years divided by the cost of restoration, and scaled from 0 to 1. The additive B4B was calculated by adding the B4B, scaled from 0 to 1, proportion core caribou habitat, scaled between 0 and 1, the proportion Ungulate Winter Range, scaled from 0 to 1, and the inverse of the disturbance <20 years, scaled between 0 and 1. See Methods for additional details.

Appendix B: Sensitivity of Results to Decision Rules

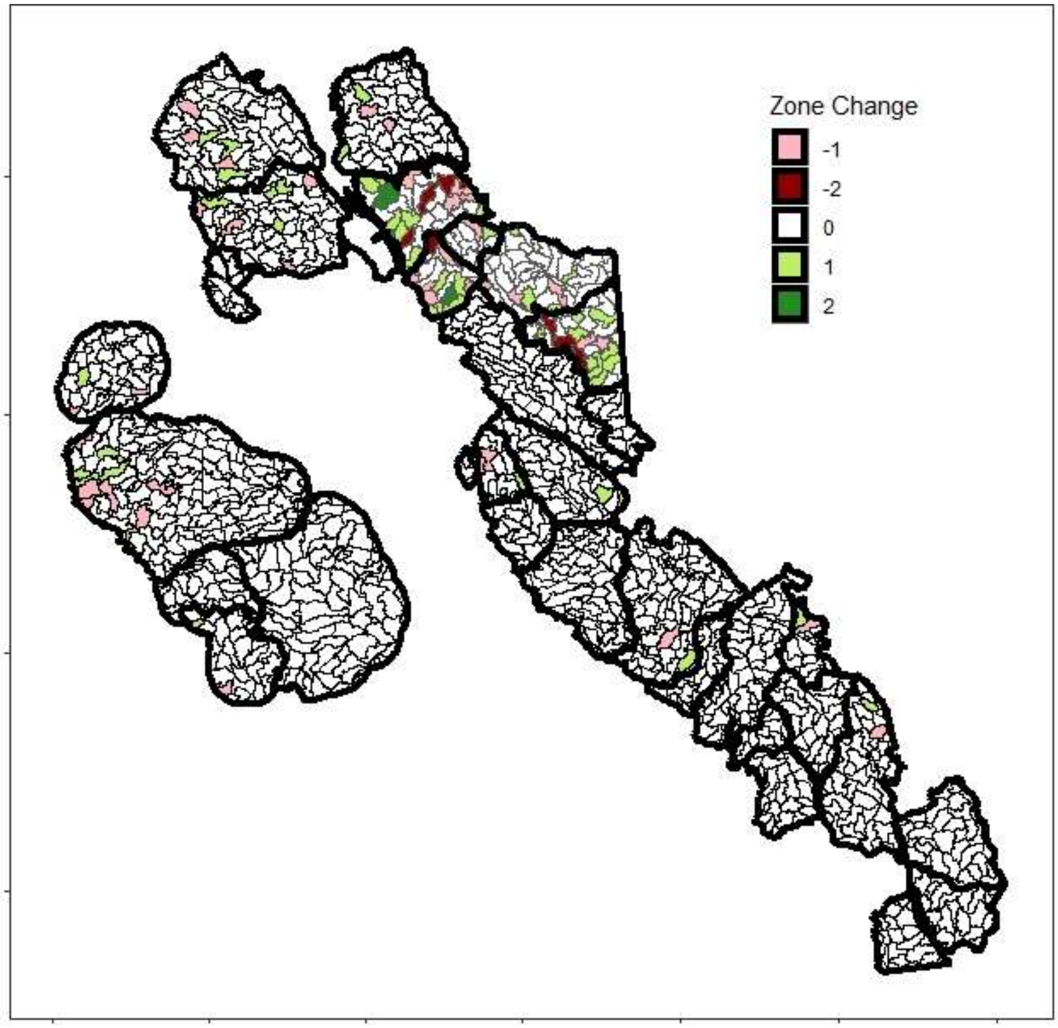

Figure B.1: Change in zones as a result of decision rules. In the Southern and Northern groups, zone changes reflect the decision rule to buffer all anthropogenic habitat alteration by 500m versus only linear features. A negative zone change reflects sub-landscape units decreasing in priority when all anthropogenic habitat alteration is buffered, relative to only linear features. A positive zone change reflects sub-landscape units increasing in priority when all anthropogenic habitat alteration is buffered, relative to only linear features. In the Central group, zone changes reflect the decision rule to only buffer linear features and restoring only seismic lines versus buffering all anthropogenic disturbances and restoring seismic lines and non-permanent roads. A negative zone change reflects sub-landscape units decreasing in priority when all anthropogenic habitat alteration is buffered and both seismic and non-permanent roads are restored. A positive zone change reflects sub-landscape units increasing in priority when all anthropogenic habitat alteration is buffered and both seismic and non-permanent roads are restored. Scott East is not shown because zones could not be provided in the case of restoring seismic lines only.