Using a GIS Multi-Criteria Evaluation Model to Locate Potential New Conservation Areas and Wildlife Corridors for Grizzly Bears in Southwestern British Columbia

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Abstract

The British Columbia grizzly bear population accounts for more than half of the Canadian population of grizzlies (58%), yet the provincial government has not established sufficient amounts of protected habitat. In Southwestern British Columbia, grizzly bears are more threatened than anywhere else in the province and require increased protection. Patches of high-quality grizzly bear habitat in the region are also becoming disconnected due to urban development, increasing the need to identify key grizzly bear corridors. Research evaluating grizzly bear habitat quality in British Columbia has not combined ecological factors and human influences in a single study. However, it is important to include ecological factors, such as food and forest type, and human influences, such as proximity to roads and urban areas, when evaluating habitat quality since both affect grizzly bear survival. This study performed a Multi-Criteria Evaluation (MCE) analysis by combining both ecological factors and human influences to identify potential locations for new protected areas and wildlife corridors for grizzly bears in Southwestern British Columbia. Our study followed three objectives: (1) identifying criteria and constraints based on ecological factors and anthropogenic influences affecting grizzly bear habitat quality, (2) developing a MCE to produce a habitat quality classification, and (3) applying the MCE model to identify potential protected areas and wildlife corridors for grizzly bears. The habitat classification identified 9942 km^2 of high-quality habitat, which comprised 22% of our study site. Our corridor model identified five corridors connecting patches of high-quality habitat between six existing protected areas. These findings show that there is a large amount of high-quality habitat remaining where new conservation areas and wildlife corridors could be established. Specifically, we identified the South-Chilcotin Ranges region as the optimal location for the creation of new protected areas and wildlife corridors. Given these findings, our results have the potential to assist decision-makers in protecting key grizzly bear habitat in Southwestern British Columbia by improving their ability to make informed decisions.

1. Problem Context

Grizzly bears (*Ursus arctos horribilis*) are large mammals native to North America that serve as indicators of healthy ecosystems (Gailus, 2013). They are keystone species as they have a large influence on species at various trophic levels and play a crucial role in maintaining ecosystem structure and function (Nielsen et al., 2006). In Canada, there are approximately 26,000 grizzly bears and 58% (15,000) live in British Columbia (B.C.) (COSEWIC, 2012).

In 2012, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated grizzly bears as a species of 'special concern', which implies that they may become threatened or endangered because of anthropogenic (human-related) factors (COSEWIC, 2012). In B.C., nine out of 56 Grizzly Bear Population Units (GBPUs) are classified as threatened (Environmental Reporting B.C., 2012).

There are several reasons for grizzly bear population decline, including habitat loss, decreased food abundance, and human-caused mortality (Braid et al., 2016). To distinguish between environmental and anthropogenic factors that influence ecosystem integrity, two models are used by ecologists (Hamilton et al., 2018). The first model implies that grizzly bears are limited by ecological factors, such as food availability and habitat connectivity, that influence habitat quality (Mowat et al., 2013). In contrast, the second model suggests that anthropogenic factors, such as human-caused mortality and habitat degradation, limit grizzly bear survival (Proctor et al., 2017). Therefore, it is important to consider both ecological and anthropogenic effects, as this increases the accuracy of grizzly bear habitat assessment (Hamilton et al., 2018).

Grizzly bears are affected by ecological factors, as they consume a variety of different foods (Lamb et al., 2017). Hamilton et al. (2018) investigated bottom-up factors and evaluated grizzly bear habitat quality using available Broad Ecosystem Classifications (BEC) and Broad Ecosystem Inventory (BEI) datasets. This study produced maps that defined habitat capability (ability of the land to sustain grizzly bears) and habitat suitability (current capacity of an area to support grizzly bears). One limitation of this study was that only ecological factors were considered, leaving out human influences on grizzly bears.

Human development affects grizzly bears through habitat loss and degradation, population isolation, and human-bear conflicts (Nielsen et al., 2004). A study by

McLellan et al. (2020) assessed anthropogenic factors affecting grizzly bear habitat and investigated human-caused grizzly bear mortality. This study concluded that it is difficult to estimate the extent of anthropogenic influences on grizzly bear habitat quality since 88% of non-hunting grizzly bear mortalities were unreported.

Considering the importance of ecological and anthropogenic factors that influence grizzly bear survival, further research is required to provide a more holistic classification of grizzly bear habitat that considers both factors. In order to preserve the key ecological requirements of grizzlies and negate the negative anthropogenic factors, more protected areas must be established to improve grizzly bear conservation (COSEWIC, 2012). In addition, grizzly bear corridors (habitat connectivity routes) must be identified to maintain connectivity between patches of high-quality habitat (Proctor et al., 2015). By establishing protected areas and by identifying corridors, grizzly bears can be shielded from anthropogenic threats (Proctor et al., 2020).

In most wildlife conservation efforts, the determination of habitat quantity, quality, and connectivity can only be established from a spatial analysis approach (Gülci & Akay, 2015). Thus, Geographic Information Systems (GIS) are used to synthesize multiple factors affecting grizzly bear habitat to identify discrete areas of suitable habitat and key corridors (Hamilton et al., 2018). A Multi-Criteria Evaluation (MCE) is an effective GIS spatial analysis approach when applied to habitat classification for large mammals affected by human activity (Gülci & Akay, 2015). Once habitats are evaluated, high-quality patches can be identified, and corridors can be modelled between these patches using least-cost path analysis (Dilkina et al., 2017). Hence, maps that show regions of high-quality grizzly bear habitat can help facilitate the decision-making process for governments and stakeholders when it comes to establishing new protected areas and wildlife corridors (Cervell et al., 2017).

2. Research Purpose

The purpose of this project is to locate potential new conservation areas and wildlife corridors for grizzly bears in Southwestern British Columbia using a GIS Multi-Criteria Evaluation (MCE) analysis.

3. Study Area

Our study site consisted of five threatened GBPUs located in Southwestern B.C that cover an area of 46,016.2 km^2 and have an estimated population of 294 grizzlies (Environmental Reporting BC, 2012). The GBPUs were chosen because they represent different behavioral ecotypes that characterize grizzly bear subpopulations and because they are used in conservation planning (Apps, 2010; Environmental Reporting BC, 2012). Figure 1 shows the location and conservation status of the five GBPUs within the study area.

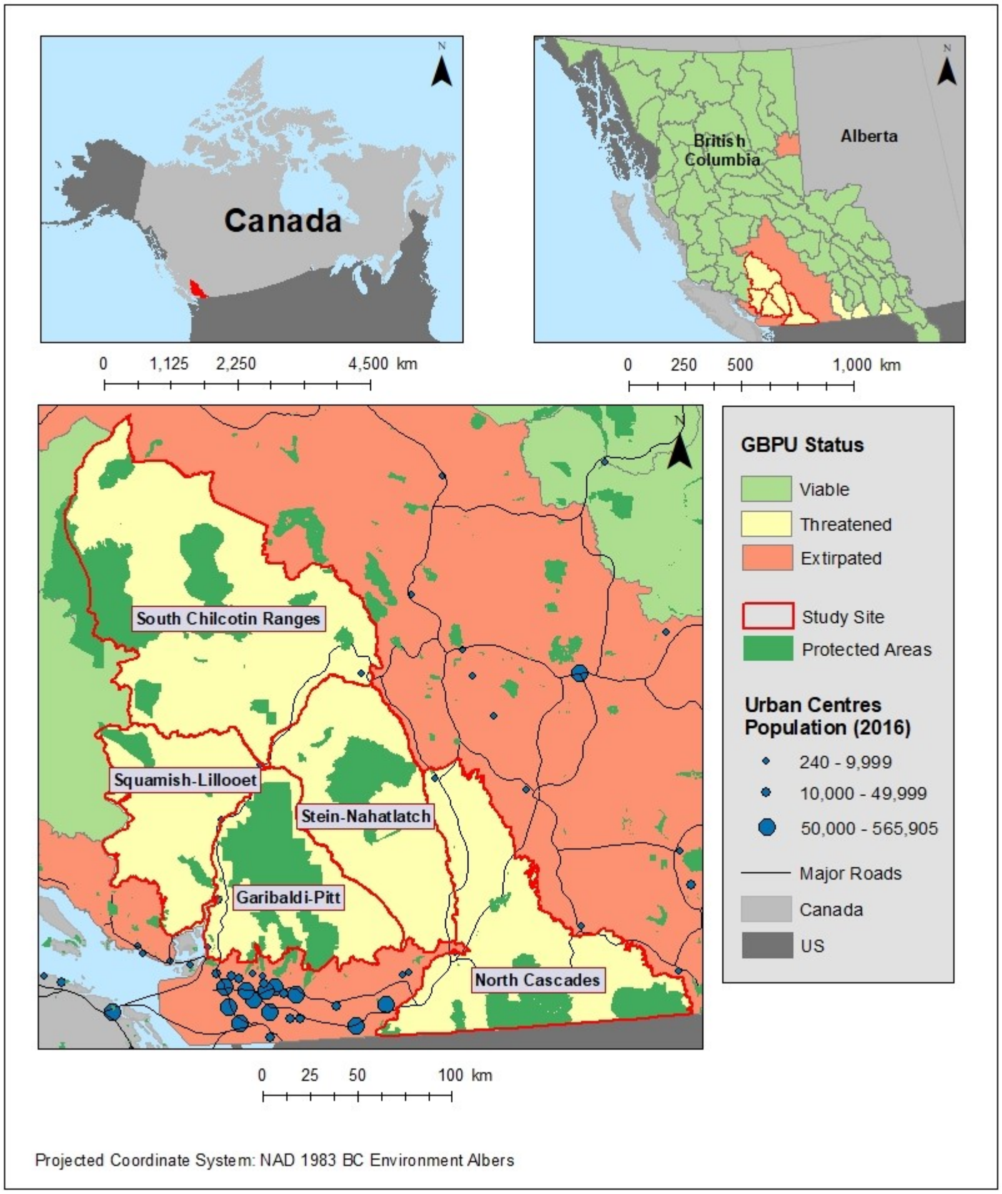

Figure 1. The five threatened GBPUs comprising the study site in Southwestern B.C.

Our study site included multiple anthropogenic influences on grizzly bears and scattered protected areas. Figure 1 shows the existing protected areas (11,399 km^2) and the key anthropogenic factors disrupting grizzly bear habitat, including major roads and urban centers (Proctor et al., 2020).

4. Research Objectives and Approach

Objective 1: Establishing criteria and constraints based on ecological and anthropogenic factors affecting grizzly bear habitat quality.

To establish our criteria and constraints, we carried out a literature review of grizzly bear ecological requirements and human threats in B.C. We synthesized this information and selected criteria and constraints to include in our MCE model. We then collected the appropriate spatial data, shown in Table 1.

Table 1. Data requirements for MCE analysis.

Data Name	Source	Year	Scale	Description
B.C. Parks, Ecological Reserves, and Protected Areas	B.C. Data Catalogue	2019	Provincial	Polygon features showing parks, ecological reserves, and protected areas.
Broad Ecosystem Classification (BEC)	B.C. Data Catalogue	2018	Provincial 1:250,000	Polygons showing biogeoclimatic regions in B.C.
Broad Ecosystem Inventory (BEI)	B.C. Data Catalogue	2018	Provincial 1:250,000	Polygons showing distribution of ecosystems throughout B.C.
Recreation Sites and Trails	B.C. Data Catalogue	2017	Provincial	Polygons showing recreation sites and lines showing trails in B.C.
B.C. Major Cities	B.C. Data Catalogue	2019	Provincial 1:2,000,000	Points showing major population centres.
Digital Road Atlas	B.C. Data Catalogue	2020	Provincial	Line features showing private and public roads in B.C.

Table 1. Data requirements for MCE analysis (continued).

Data Name	Source	Year	Scale	Description
Mines, Energy and Communication Networks in Canada	Open Government Canada	2019	Federal	Shapefile showing locations of all mines, energy production sites, roads and railroads across Canada.
Cartographic Boundary Files, 2016 Census	Statistics Canada	2016	Federal	Vector that includes Population Centres and Population Ecumene Census Divisions.

Objective 2: Developing a Multi-Criteria Evaluation (MCE) to produce habitat suitability raster.

Input criteria and constraint spatial data were prepared for the MCE by resampling all input data to a 30-meter pixel resolution. The input rasters were clipped to a 2-kilometre buffer around the study site to include nearby features. Each criteria raster was assigned values based on proximity to features or containment within features. The positive and negative criteria were standardized to a 0-100 suitability scale (Delft & Nijkamp, 1977) using the methods shown in Equations 1 and 2. Additionally, all constraints were reclassified as binary rasters.

Equation 1: Beneficial criteria: $x'_{ij} = 100\left(\frac{x_{ij}-x_{min}}{x_{max}-x_{min}}\right)$

Equation 2: Negative criteria: $x'_{ij} = 100\left(1-\left(\frac{x_{ij}-x_{min}}{x_{max}-x_{min}}\right)\right)$

Each criterion was multiplied by an assigned weight to reflect its level of importance to grizzly bear survival. Weights were determined using the Analytical Hierarchy Process (AHP) (Wind & Saaty, 1980). The AHP involved multiple pairwise comparisons between all the criteria and rated the importance of each criterion relative to the other criteria based on nine potential scores shown in Table 2. The pairwise comparisons are included in the Appendix.

Table 2. Relative level of importance scores.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very Strongly	Strongly	Moderately	Equal	Moderately	Strongly	Very Strongly	Extremely
Less Important			**Similar Importance**			**More Important**		

Next, the weight for each criterion was calculated by taking the sum of its pairwise comparison scores and dividing this by the total number of criteria (Qaddah & Abdelwahed, 2015). This is shown in Equation 3, where w_i represents the weight for criterion *i* and c_i represents the comparison score for criterion *i* compared to criterion *k*.

Equation 3: $w_i = \frac{\sum c_{ik}}{Number\ of\ Criteria}$

To complete the MCE, the final suitability raster was derived using a weighted linear combination MCE algorithm as is shown in Equation 4 (Berry, 1993). In this equation, the criteria rasters, denoted by x_i, were multiplying by their associated weights, signified by w_i, and summed. The summed criteria rasters were then multiplied by the product of all the constraint rasters as indicated to produce the final suitability raster (Berry, 1993).

Equation 4: Suitability = $\prod_{j=0}^{n} c_j \sum_{i=0}^{n} w_i x_i$

Figure 2 shows our overall research approach and how the literature review informed the design of our MCE model.

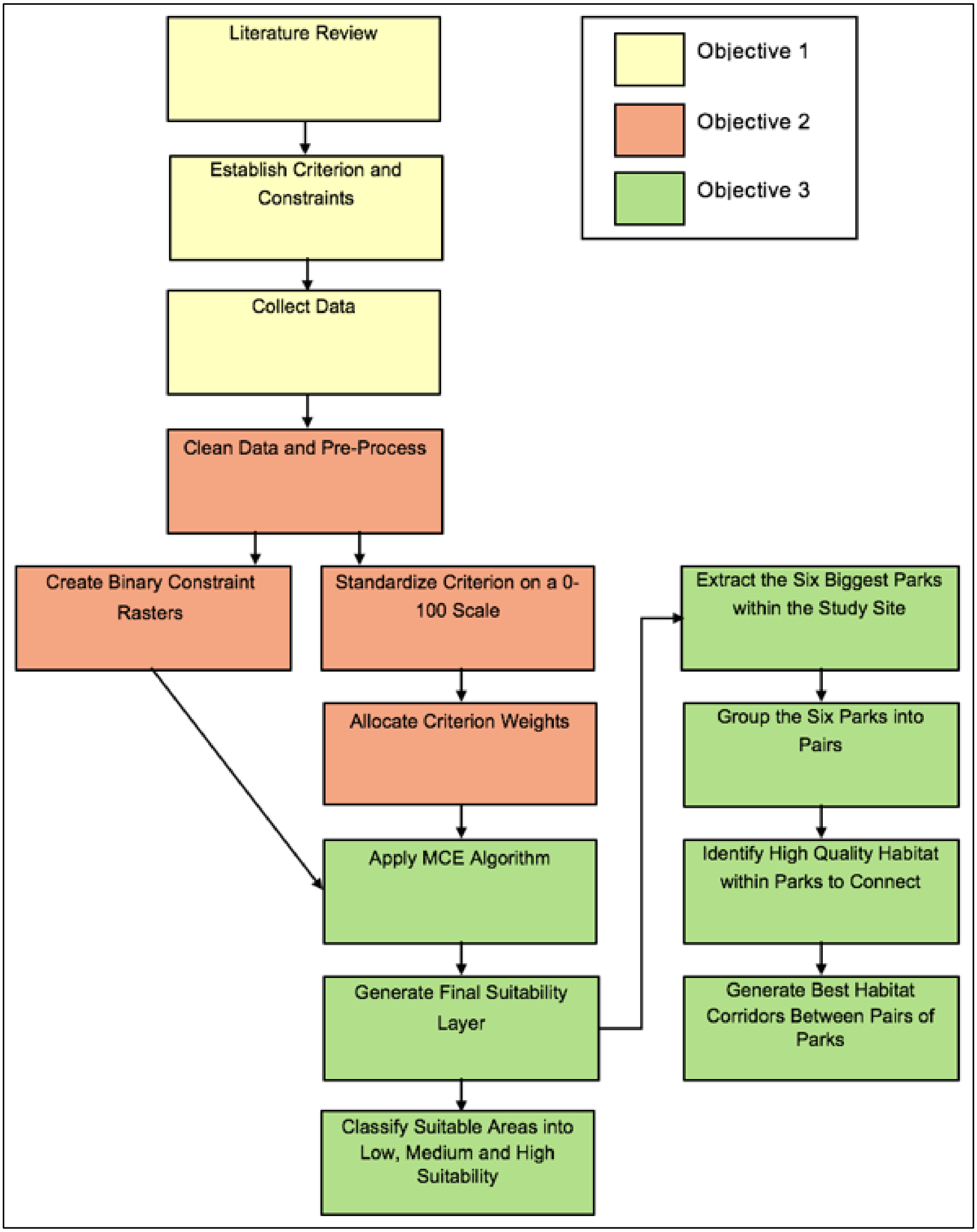

Figure 2. Generalized flow chart of our study methodology.

Objective 3: Applying the MCE model to identify potential conservation areas and wildlife corridors for grizzly bears in Southwestern British Columbia.

Research by Geneletti & van Duren (2008) demonstrated that after generating a MCE suitability output, key zones for proposed conservation areas can be identified by grouping adjacent cells with high suitability scores. Following this method, we reclassified the continuous suitability raster into a raster with three habitat quality classes: low, medium, and high. Each habitat class was defined by a 'bin' that contained a range of suitability scores. The bins were established using Jenks natural breaks method of classification, excluding zero (Lim et al., 2018). A histogram showing the frequency of each suitability score and the range of values within each bin is shown in Figure 3.

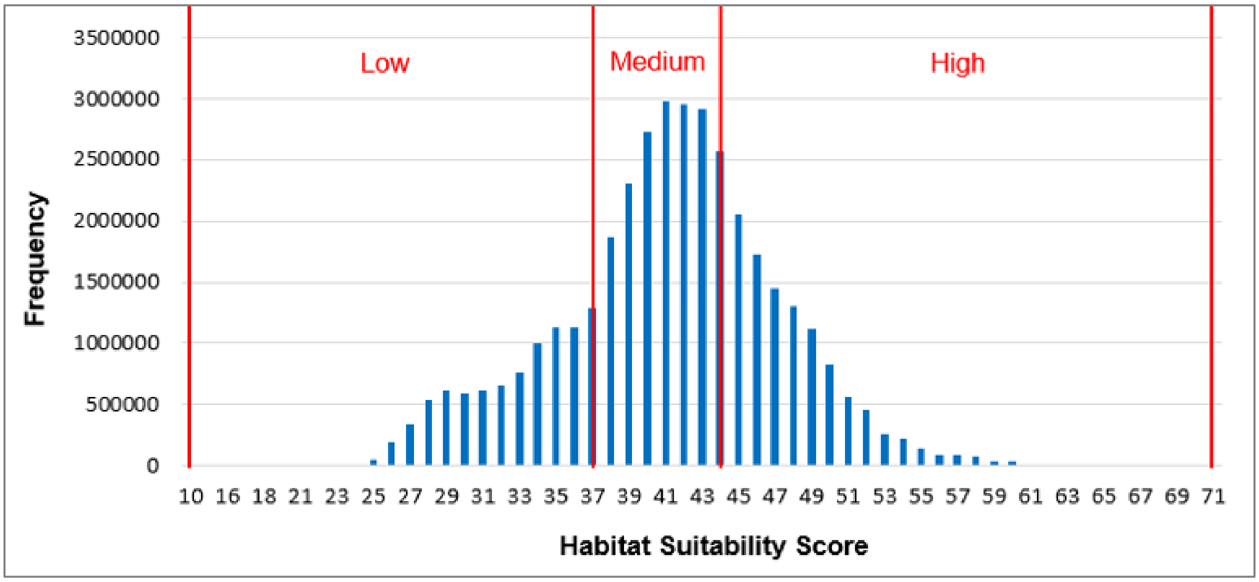

Figure 3. Histogram of the suitability raster cell value distribution and the three habitat suitability 'bins' defined using Jenks natural breaks (red lines).

Given that our habitat classification produced an output with 139 patches of high-quality (HQ) habitat greater than 5 km^2, it would have been too computationally intensive to model corridors between all the patches, as is done in other studies (Chetkiewicz & Boyce, 2009). As an alternative, we chose to only model corridors between patches of HQ habitat identified by Hamilton et al. (2018) that were within existing protected areas. There are three pairs of large Provincial parks within our study site that were selected for corridor modelling: Ts'il?os– South Chilcotin Mountains, Garibaldi – Stein Valley, and E.C. Manning – Cathedral.

To effectively model corridors between these protected areas, we followed the methods outlined by Glover-Kapfer (2015) using the Corridor Designer ArcMap toolbox (Majka et al., 2007). The HQ habitat patches within each pair of parks were used as source polygons and the final suitability score output was used as the resistance raster.

5. Results

5.1 Literature Review and MCE Inputs

Through the literature review, we established 11 criteria and four constraints for our MCE analysis, shown in Tables 3 and 4, respectfully. The binary constraint maps and standardized criteria suitability maps are shown in Figures 4 and 5, respectably.

Table 3. Identified criteria.

Criteria	Relevance
Roads	Proximity to roads increases the probability of grizzly mortality. We considered roads ≥40 km/h as negative criteria (Proctor et al., 2020).
Highly Populated Census Subdivisions	Humans are responsible for 85-98% of all grizzly bear deaths (Gailus, 2013).
Urban Areas	Urban areas cause grizzly bear habitat fragmentation (Gailus, 2013).
Broad Ecosystem Classification (BEC)	Ecosystems were evaluated based on vegetation, climate, seral progression and elevation (Hamilton et al., 2018).
Broad Ecosystem Inventory (BEI) - Suitability	Habitat suitability was ranked based on the current ability of the land to support grizzly bears (Hamilton et al., 2018).
Broad Ecosystem Inventory (BEI) - Capability	Habitat capability was ranked based on the idealized ability of the land to support grizzly bears (Hamilton et al., 2018).
Protected Areas	These areas offer grizzly bears legal protection from anthropogenic threats (Nielsen et al., 2006).
Resource Extraction and Industrial Development	These economic activities have led to grizzly bear isolation and habitat fragmentation (Nielsen et al., 2004).

Table 3. Identified criteria (continued).

Criteria	Relevance
High Use Trails	Many grizzly bear deaths occur within 200 metres of high use trails in national parks (Nielsen et al., 2004).
Recreational Areas	Recreational development has fragmented and degraded grizzly bear habitat (Nielsen et al., 2004).
Railways	Railways have isolated grizzly bears within the nine threatened GBPUs (Gailus, 2014).

Table 4. Identified constraints.

Constraint	Relevance	Description
Major Roads	Many grizzly bear deaths occur within 500 metres of roads (Benn & Herrero, 2002).	Areas within 500 meters of major roads that $\geq$80 kilometers per hour are unsuitable (Proctor et al., 2020).
Urban Areas	Human development has fragmented grizzly bears into smaller subpopulations (Gailus, 2014).	Urban areas are unsuitable.
Private Land	Conservation areas are prioritized on Crown land (BC Parks, 2020).	Private land is less desirable.
Protected Areas	These cannot be established where land is already protected (BC Parks, 2020).	Protected areas were not considered

Figure 4. Input constraint maps: protected areas (A), major roads (B), private land (C), and urban areas (D).

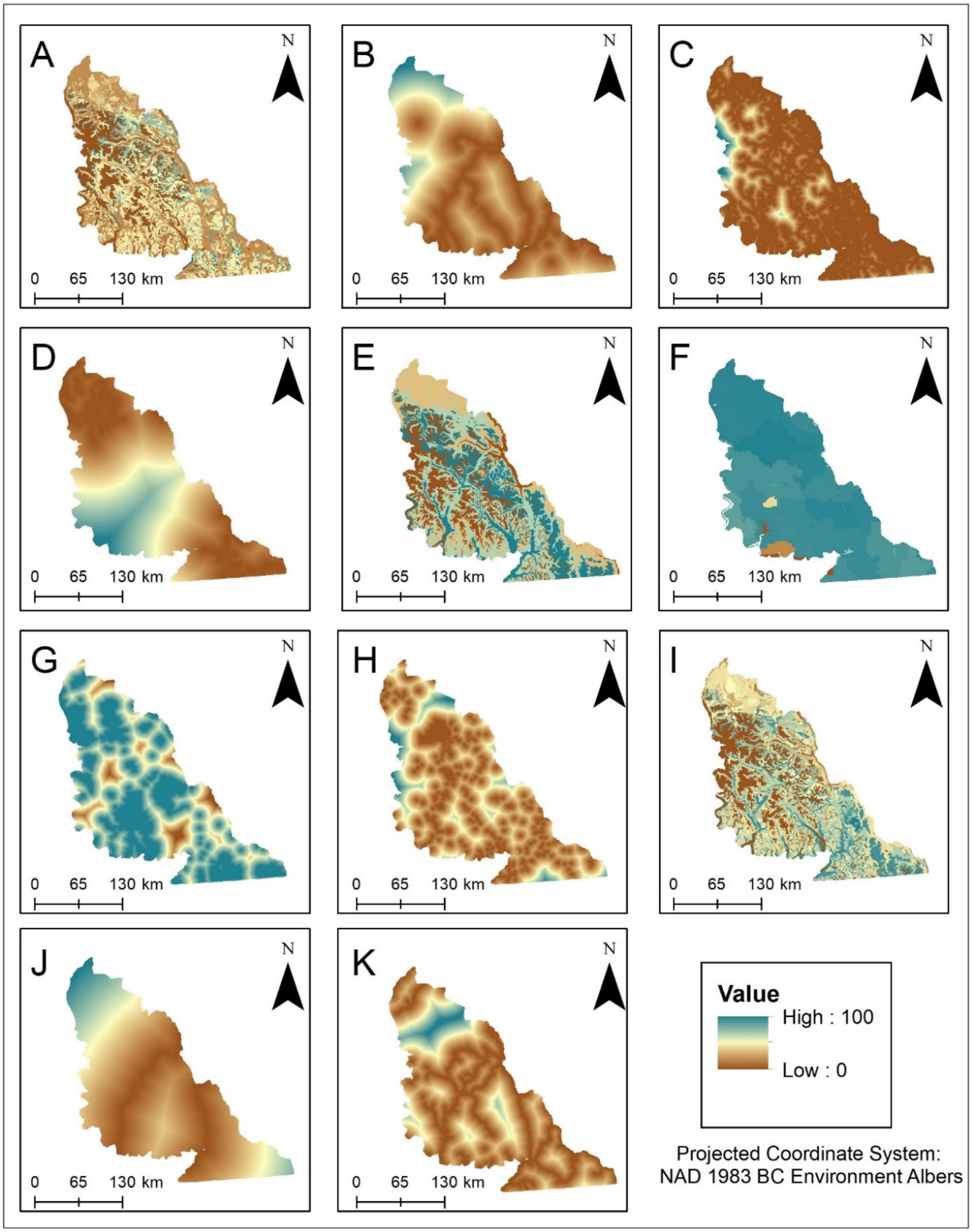

Figure 5. Standardized criteria maps: Broad Ecosystem Inventory (BEI) - Suitability (A), resource extraction and industrial development (B), roads (C), high use trails (D), Broad Ecosystem Classification (BEC) (E), highly populated census subdivisions (F), protected areas (G), recreational areas (H), Broad Ecosystem Inventory (BEI) - Capability (I), railways (J), and urban areas (K).

5.2 MCE

Our MCE evaluated grizzly bear habitat in 74% of our study site, with the rest belonging to constraints, as can be seen in Figure 6.

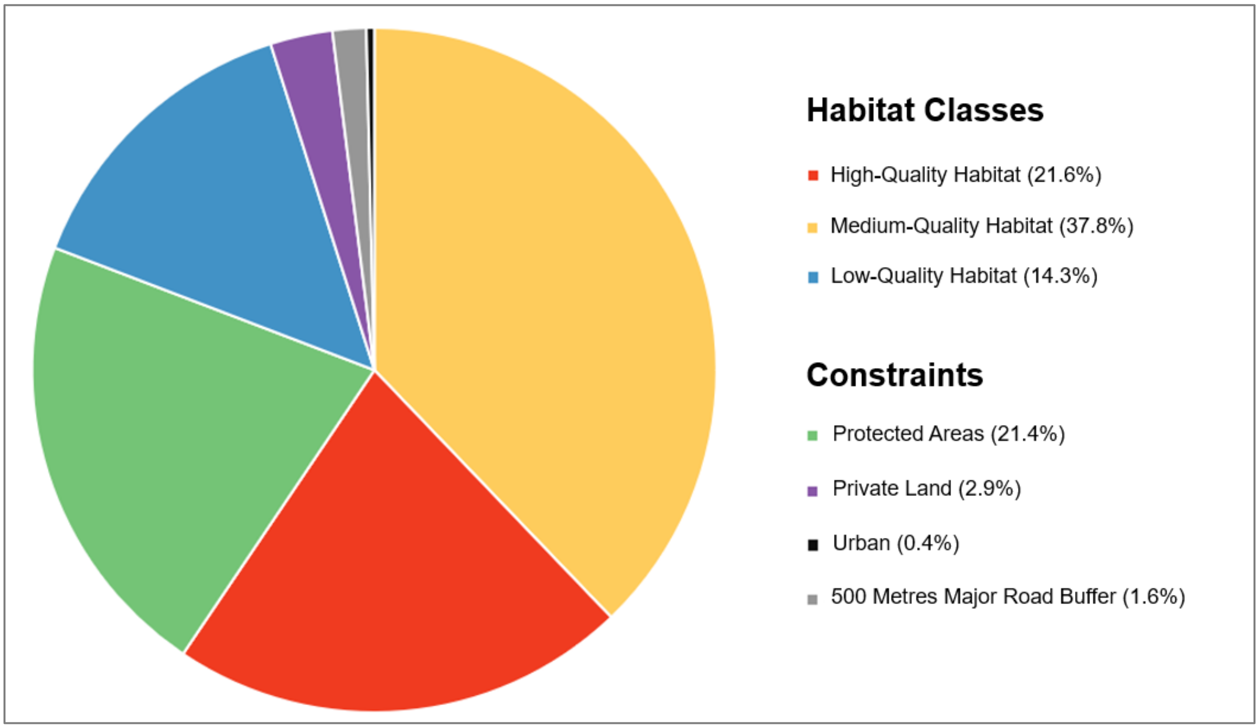

Figure 6. Pie chart displaying the land cover composition of the study site.

We generated a continuous habitat suitability raster shown in Figure 7 that shows the variation in habitat quality across the study site. Among the three habitat classifications, 22% of the study site was high-quality (HQ), 38% was medium-quality (MQ), and 14% was low-quality (LQ). The spatial distribution of each habitat class and the various constraints are shown in Figure 8.

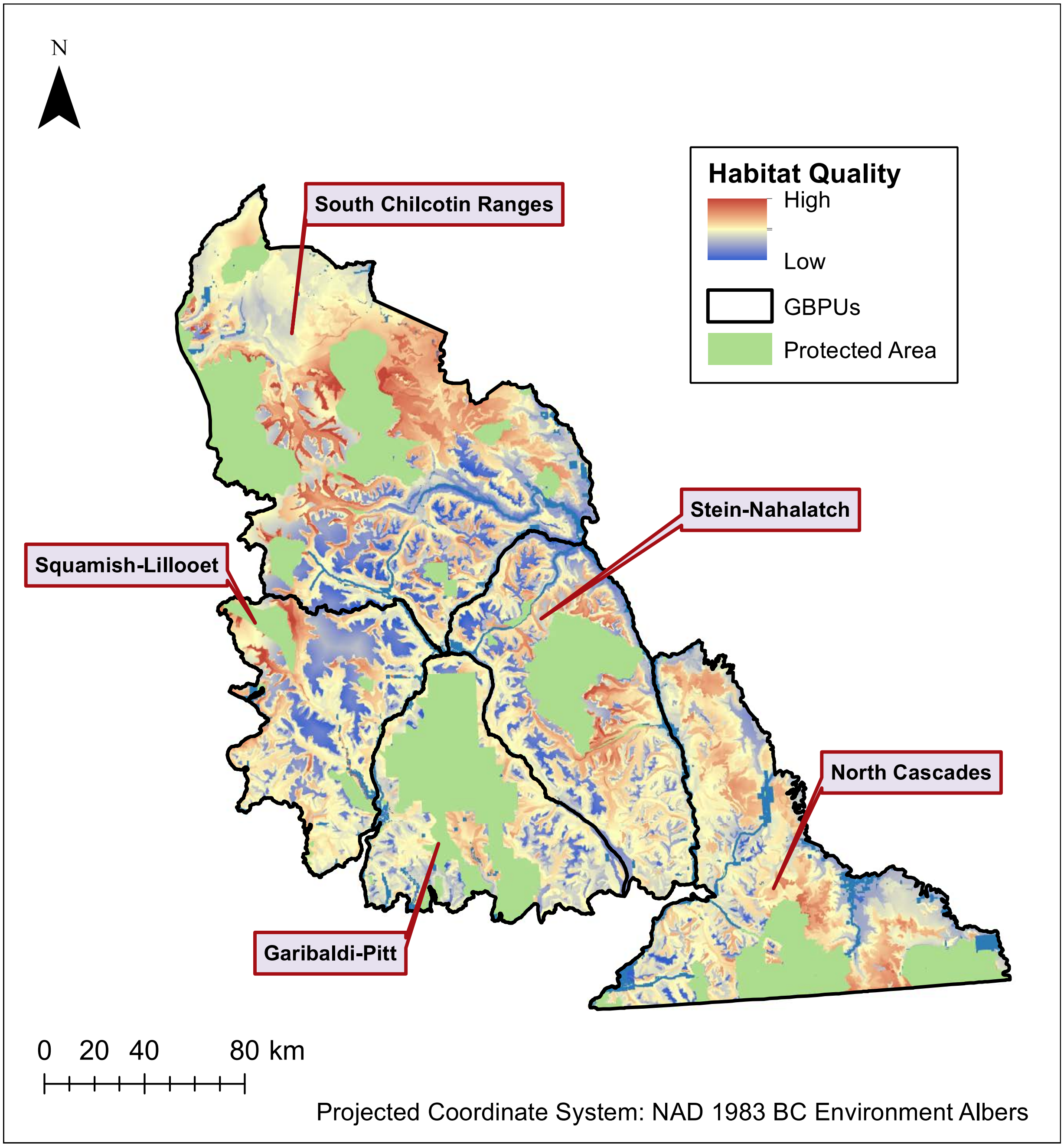

Figure 7. Continuous suitability score map with study site protected areas.

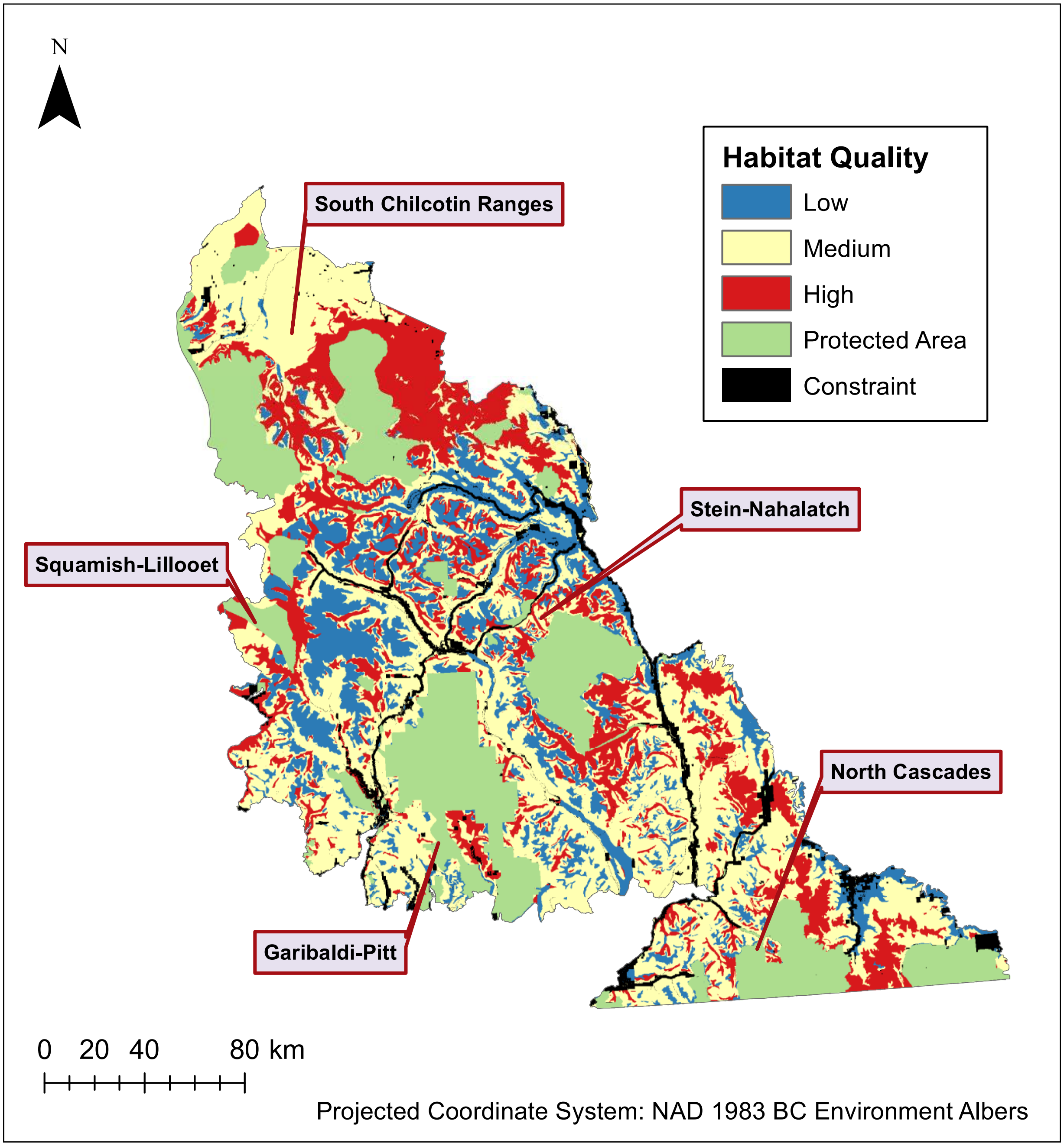

Figure 8. Discrete suitable area map of habitat quality.

5.3 Habitat Quality in GBPUs

The five GBPUs contained different amounts of each habitat quality type, as is shown in Table 5. Notably, the South Chilcotin Ranges GBPU had the largest percentage of HQ habitat (28%) and accounted for 45% of all the HQ habitat in our study site. The historic grizzly bear population estimate was highest in the GBPU with the highest proportion of HQ habitat (South Chilcotin Ranges), while the lowest population estimate was in the GBPU with the most LQ habitat (Garibaldi-Pitt) (Environmental Reporting BC, 2012). The GBPU with the largest amount of unprotected HQ habitat (South Chilcotin Ranges) had over 2.5 times more HQ habitat than all other GBPUs (Table 6).

Table 5. The total area of each GBPU and the percentage of each habitat type within each GBPU.

	South Chilcotin Ranges	Stein-Nahatlatch	Squamish-Lillooet	North Cascades	Garibaldi-Pitt
GBPU Area (km^2)	16201	7798	5689	9801	6541
Grizzly Bears/km^2	0.0125	0.0031	0.0104	0.0006	0.0003
High-Quality Habitat (%)	27.9	21.5	19.4	21.2	8.4
Medium-Quality Habitat (%)	33.8	38.4	43.0	42.6	35.4
Low-Quality Habitat (%)	13.8	17.6	25.0	9.9	8.9
Protected Area (%)	21.1	18.0	8.3	17.5	43.1
Urban Areas, Major Roads, Private Land (%)	3.4	4.4	4.3	8.7	4.1

Table 6. The relative amount of unprotected area compared to high-quality (HQ) habitat in each GBPU.

GBPU	Unprotected GBPU (%)	High-Quality Habitat Within Unprotected Area (%)	High-Quality Habitat Area (km^2)
South Chilcotin Ranges	78.9	35.4	4522.9
Stein-Nahatlatch	82.0	26.3	1679.6
North Cascades	82.5	25.8	2082.1
Squamish-Lillooet	91.7	21.2	1104.9
Garibaldi-Pitt	56.9	14.9	552.7

5.4 Corridors

Our corridor modelling between three pairs of protected areas produced five potential corridors as shown in Figure 9, with additional details provided in Table 7. Overall, there was substantial variation in habitat quality among the corridors. The Ts'il?os - Chilcotin corridors contained over 50% HQ habitat; however, this is likely due to their distance from urban areas. The Garibaldi – Stein Valley corridors contained lower amounts of HQ habitat, with the Northern corridor only containing 0.3% HQ habitat. Finally, the Manning – Cathedral corridor contained the highest amount of HQ habitat (71%).

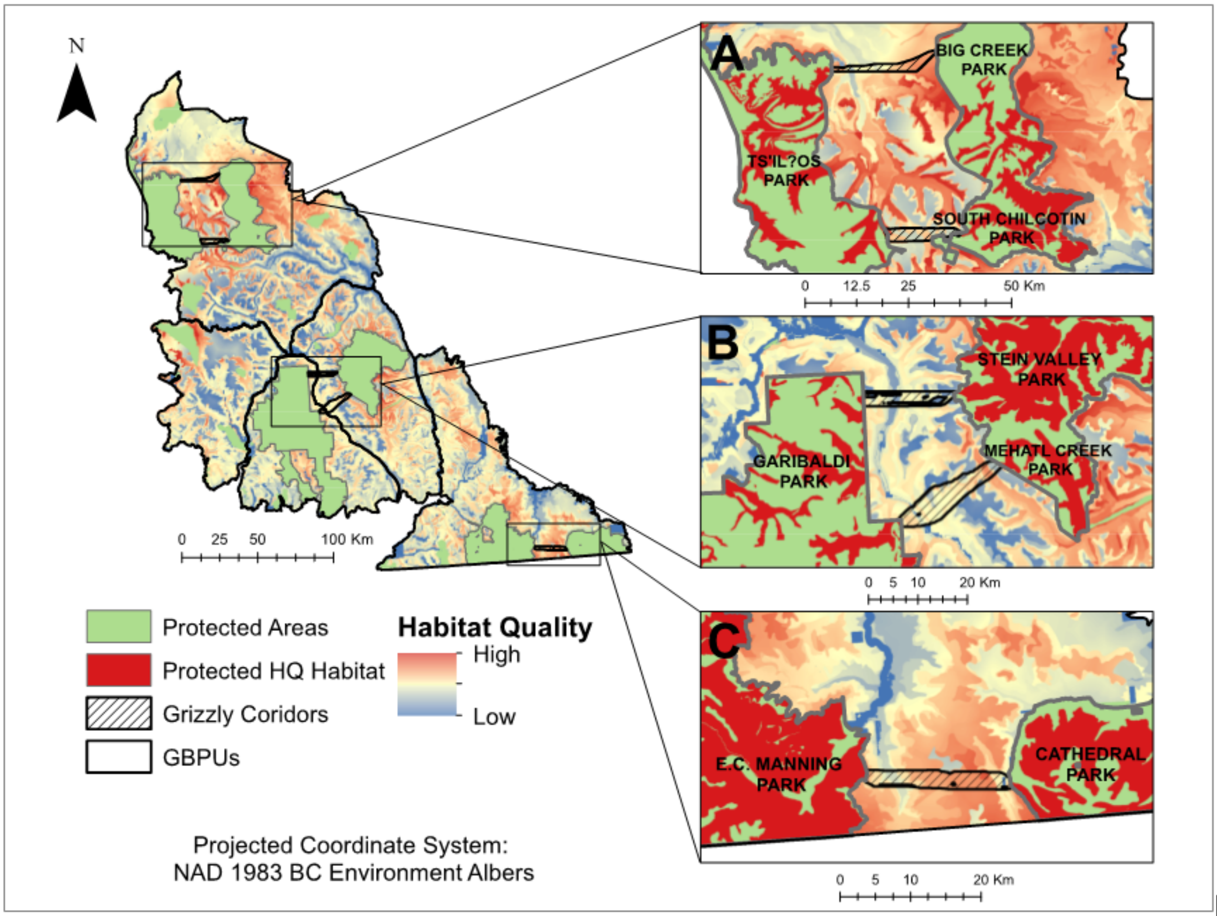

Figure 9. The five corridors modelled between the three pairs of protected areas: Ts'il?os - Chilcotin (A), Garibaldi - Stein Valley (B), Manning - Cathedral (C). The high-quality (HQ) habitat within each protected area is also shown.

Table 7. Summary of the five corridors identified using the suitability score raster and corridor model.

Corridor Name	Area (km^2)	Length (km)	High-Quality Habitat (%)	Medium-Quality Habitat (%)	Low-Quality Habitat (%)
Garibaldi - Stein Valley (North)	47.1	106.0	0.3	76.1	21.4
Garibaldi - Stein Valley (South)	94.7	70.9	22.5	65.8	9.9
Manning - Cathedral	47.4	69.7	71.3	26.7	0.0

Table 7. Summary of the five corridors identified using the suitability score raster and corridor model (continued).

Corridor Name	Area (km^2)	Length (km)	High-Quality Habitat (%)	Medium-Quality Habitat (%)	Low-Quality Habitat (%)
Ts'il?os - Chilcotin (North)	46.1	61.6	60.2	37.2	2.5
Ts'il?os - Chilcotin (South)	47.6	45.8	50.5	44.5	0.0

6. Conclusion

The goal of this project was to identify potential new conservation areas and wildlife corridors for grizzly bears in Southwestern British Columbia (B.C.) to provide increased protection for the species. Our results present patches of high-quality habitat within each Grizzly Bear Population Unit (GBPUs) where new protected areas that meet both ecological and anthropogenic criteria could be established.

Among the five GBPUs, South Chilcotin Ranges was found to have the most potential for the establishment of new protected areas and corridors because of its abundance of high-quality habitat (4523 km^2). This, however, is mostly due to the fact that the South Chilcotin Ranges GBPU is the most remote location in our study site and has so far avoided significant anthropogenic disturbance. Other favourable GBPUs, such as Stein-Nahatlach and Squamish - Lillooet, could still benefit from the establishment of new conservation areas as they have sustained moderate grizzly bear populations in the past (Environmental Reporting BC, 2012).

The major strength of our research is the MCE approach, which enabled a structured and traceable suitability analysis. This methodology allowed us to combine, analyze, and compare multiple criteria and constraints affecting grizzly bears at the same time. Throughout the project, we have minimized the limitations of our approach by reconciling our methodology with other habitat quality MCE studies. However, one of our greatest weaknesses has been the subjectivity of the weighting process and the habitat classification method (Drobne & Lisec, 2009). Consequently, future research should attempt to apply alternative weighting methods such as the Reduction Coefficient approach as defined by Agarski et al., 2012 which synthesizes multiple weighting procedures to reduce MCE subjectivity (Agarski et al., 2012). It should be noted that we did not pinpoint precise locations for new protected areas as this was beyond the scope of our study. Thus, future research could apply our results to identify suitable sites for new protected areas in Southwestern B.C. at a more localized spatial scale.

Our habitat classification could be used by wildlife managers to establish tactical protected areas and corridors that could help support a sustainable grizzly population. Therefore, by incorporating ecological and anthropogenic factors, we hope that our findings can improve the ability of decision-makers to protect grizzly bears in Southwestern B.C.

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Appendix

Table A. Cartographic data.

Data Name	Data Source	Year	Scale	Data Description
Cartographic Boundary Files, 2016 Census	Statistics Canada	2016	Federal	Vector that includes population centres and population census divisions.
Major Roads in B.C.	B.C. Data Catalogue	2019	Provincial	Line features of major roads in B.C.
Major Cities in B.C.	B.C. Data Catalogue	2019	Provincial 1:2,000,000	Point features of major cities in B.C.
B.C. Parks, Ecological Reserves, and Protected Areas	B.C. Data Catalogue	2019	Provincial	Polygon features showing parks, ecological reserves, and protected areas in B.C.
Grizzly Bear Population Units	B.C. Data Catalogue	2019	Provincial	Polygon features showing grizzly population management units and their status.

Table B. Pairwise comparison matrix.

	Parks	BEC	BEI Suitability	BEI Capability	Major Roads	High Use Trails	High Population	Recreation Polygons	Urban Areas	Railways	Industrial, Resource Extraction
Parks	1	1/3	1/3	1/3	1/5	7	1/5	1	1	7	7
BEC	5	1	1	1	1/3	7	1/3	7	1/3	9	9
BEI Suitability	5	1	1	1	1/3	7	1/3	7	1/3	9	9
BEI Capability	5	1	1	1	1/3	7	1/3	7	1/3	9	9
Major Roads	9	3	3	3	1	5	3	1	3	7	5
High Use Trails	1/3	1/3	1/3	1/3	1/9	1	1/3	1	1/7	3	1/5
High Population	7	3	3	3	1/3	9	1	7	5	9	5
Recreation Polygons	1	1/5	1/5	1/5	1/7	1	1/5	1	1/7	3	1/5
Urban Areas	1	3	3	3	1/3	5	1/3	5	1	7	5
Railways	1/5	1/7	1/7	1/7	1/7	1/3	1/5	1/3	1/5	1	1/3
Industrial, Resource Extraction	1/5	1/3	1/3	1/3	1/3	5	1/3	5	1/3	3	1

Weighted Overlay Formula:

$$(Conland * 0.0608) + (BEC * 0.1042) + (BEI\_SUIT * 0.1042) + (BEI\_CAP * 0.1042) + (Roads * 0.2040) + (Trails * 0.0242) + (Population * 0.1917) + (Recreation * 0.0224) + (Urban * 0.1222) + (Railways * 0.0145) + (Resource\_Extraction * 0.0477)$$

MCE Algorithm Formula:

$$Conland\_CON * Urban\_CON * Major\_Roads\_CON * Private\_Land\_CON * Sum\_of\ Weighted\_Criteria$$

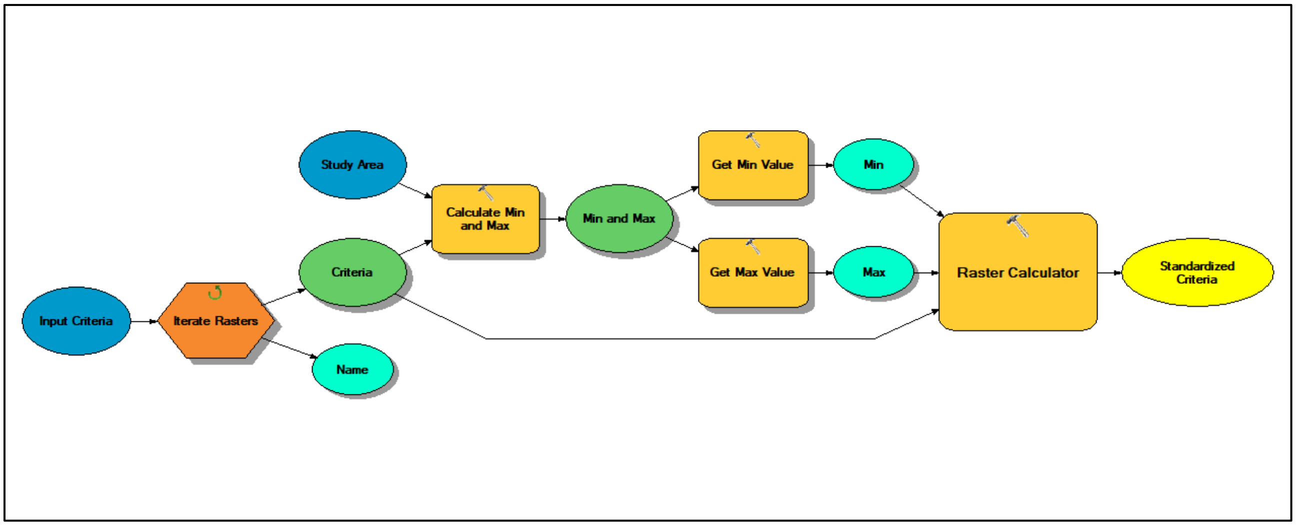

Figure A. The model used to standardize the input criteria to a common 0-100 score. The raster calculator tool at the end of the model implemented the standardizing method shown in Equations 1 and 2 for each input raster. Since positive and negative criteria rasters have different standardizing equations, the model was run twice: once for the positive criteria and once for the negative criteria.

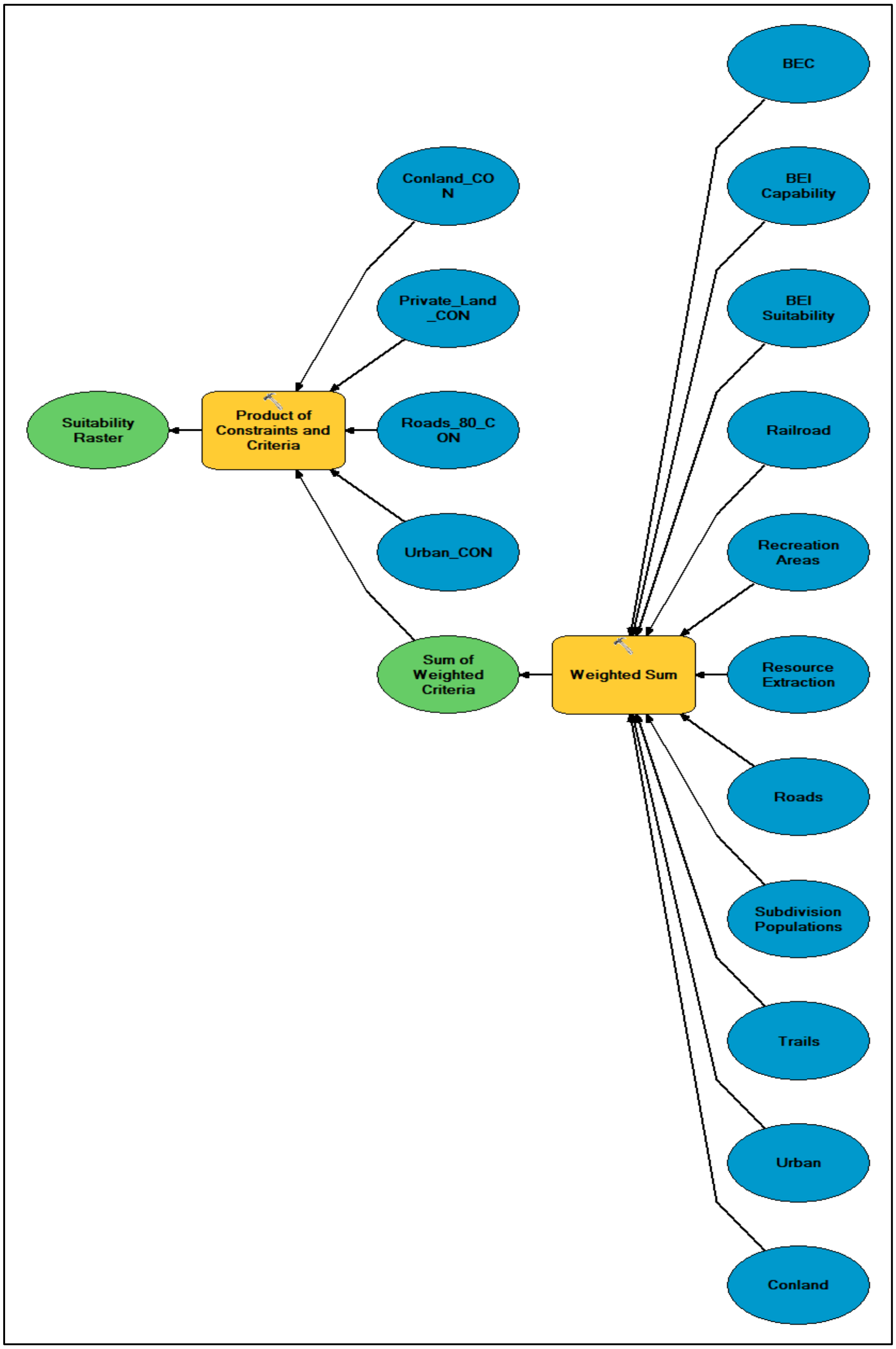

Figure B. The model used to combine the criteria and constraints using weighted sum and the MCE algorithm. The weighted sum tool involves multiplying each standardized raster by its associated weight and then adding all the rasters together. The combined weighted criteria could then be multiplied by all the constraints to achieve the final suitability output.