Contents

Canada Lynx

Feature Description

S. Germain/USFWS

The Canada lynx (*Lynx canadensis*) is a medium-sized felid that ranges across the northern areas of North America including the Crown of the Continent. It is characterized by long, dense fur, triangular ears with black tufts at the tips, and broad, snowshoe-like paws which are a specialized adaptation allowing lynx to capture prey in winter. Canada lynx occurs predominantly in dense boreal forests, and its range strongly coincides with that of the snowshoe hare (*Lepus americanus*) on which it depends heavily as prey. The species is federally listed as Threatened in the coterminous United States (USFWS 2017).

Conceptual Model

We collaboratively developed a conceptual model (Figure 1) for Canada lynx using the Conservation Standards process (FOS 2012) through literature review (Krosby et al. 2016; USFWS 2016) and expert knowledge (Appendix X).

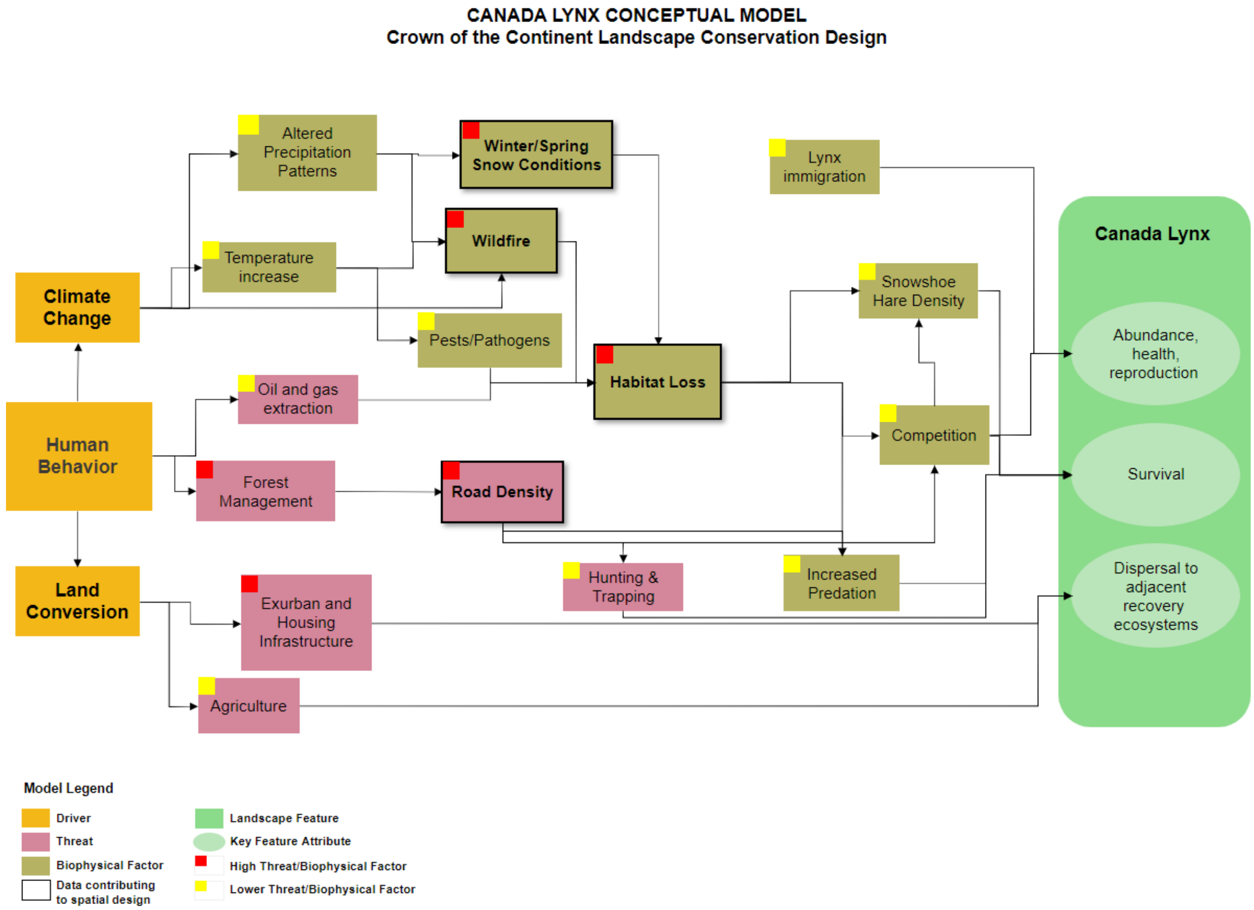

Figure 1. Conceptual Model (CM) framing the ecological setting for Canada lynx. Model was developed through literature review (Krosby et al. 2016; USFWS 2017) and lynx expert refinements using the Conservation Standards process. A CM displays relationships between key natural and anthropogenic factors believed to impact or influence the persistence or resilience of one or more conservation features. This CM, for the Canada lynx feature, describes key attributes relevant to lynx persistence in the Crown of the Continent along with drivers, biophysical factors, and threats to lynx population persistence. Drivers include indirect threats, opportunities, and other important variables that positively or negatively influence direct threats (FOS 2012). A direct threat is a human action or unsustainable use that immediately degrades one or more conservation features (FOS 2012). A biophysical factor describes how each climate threat (and some conventional threats) affect the conservation feature (CMP 2022). This CM structures our development of a spatial design for lynx in the Crown landscape. Expert elucidation informed relative threat importance (high, low) for which we applied available spatial data. High-level threats (red chits) for which there is available Crown-wide spatial data (thick border) were combined to develop a Cost layer used to develop the spatial design. In Phase 3 of the LCD, conceptual models will link conservation opportunities, stakeholders, and key intervention points to conservation features and threats leading to a complementary strategic design for lynx in the Crown landscape.

Feature Data

Spatial data describing Canada Lynx presence on the landscape came from four sources (Table 1). These data were evaluated individually and collectively to estimate spatial extent, completeness, and relevance to key feature attributes (Figure 1). Feature data (Figures 2–5) were then assigned scores (Table 2) based on source data evaluation and subject matter expert consultation and merged into a single Canada lynx feature layer (Figure 11A) and used to estimate each PUs relative value for lynx. Metadata describing our lynx data processing can be found here.

Table 1. Source data used to develop feature data for Canada lynx. Additional information on these data can be found at Crown LCD Feature data Processing and DataLayers and Tools google sheet. Data stored here.

File Name	Description	Feature Attribute	Source
Camera Station (sensitive)	Remote camera database	Abundance	Clevenger, pers. comm.
MTNHP_Predicted_Habitat_ Suitability_CALY.shp	Lynx suitability model	Survival, dispersal	Montana Natural Heritage Program
Lynx_CH.shp	Lynx critical habitat designation	Survival, reproduction	US Fish and Wildlife Service
AB_Snow_layer\mosaic.tif	Spring snow persistence	Health, reproduction, dispersal	Alberta Parks and Environment

Based on expert responses we developed a consistent scoring system as an attempt to standardize the four independent spatial data layers describing Canada lynx in the project area. In general, data identifying lynx locations and habitat suitability were scored higher (Table 2). Maps displaying results of this scoring are in Figures 2–5. The scoring process will be revisited and refined in LCD Phase 3.

Table 2. Feature data and scoring for Canada lynx. Sub-class indicates thresholds or break points related to the relative value of source data for lynx and scores assigned are reclassifications of source data inputs to standardize derived feature layers across all features.

File Name	Source Field (used for scoring)	Sub-classes	Scores Assigned
Camera station	Detection	Lynx detection	10,000
		No detection	0
MTNHP_Predicted_Habitat_ Suitability_CALY.shp	Suitability	High suitability	10,000
		Moderate suitability	5,000
		Low suitability	2,000
		Unsuitable	0
Lynx_CH.shp	Critical habitat	Critical	1,500
		Not critical	0
AB_Snow_layer\mosaic.tif	Years with no spring snow cover	17	0
		10 – 16	1,500
		5 – 9	2,500
		1 – 4	5,000
		0 (non-forest)	0

Maps of source data used to describe feature

Individual maps (Figures 2–5) of feature data (Table 2). Note most source data do not extend across the full extent of the project area. These are the 'raw', unscored data acquired from providers.

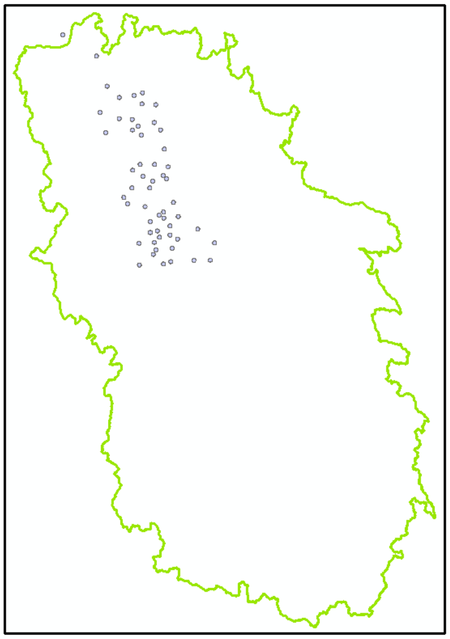

Figure 2. Canada lynx camera detections buffered by 800 m (Clevenger, personal communication).

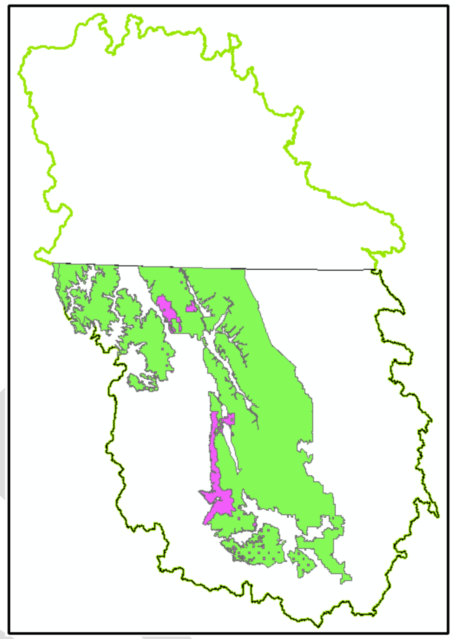

Figure 3. Canada lynx critical habitat designations (USFWS 2017).

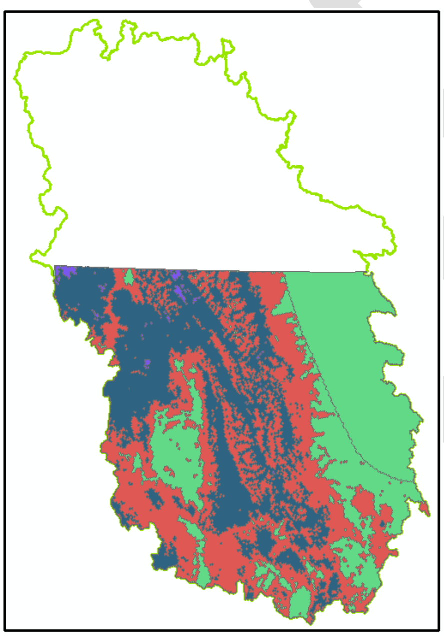

Figure 4. Canada lynx habitat suitability model (MTNHP 2022).

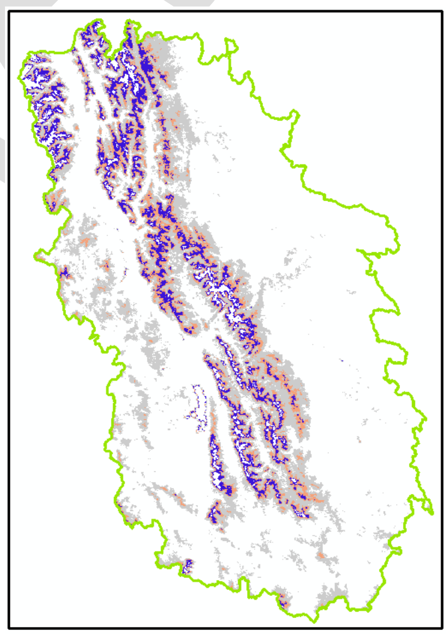

Figure 5. Snow persistence model for the Crown of the Continent ecosystem (G. Mowat, personal communication).

These vetted and scored source data sets were overlayed by converting each to 30m raster data and then mosaicked to a summary raster using a 'maximum' mosaic operator (ArcMap 10.8.1, ESRI 2020). The Phase 2 Canada lynx feature distribution data layer used as input for optimization modeling is in Figure 11A.

Cost Data

Estimating ecological cost to delivering conservation for Canada lynx was based on conceptual model development (Figure 1). A first-draft model was developed based on information from USFWS (2016) and Krosby et al. (2017) using Miradi software. We then shared the draft with lynx experts through structured feedback form. Two experts responded to the form (see Appendix X) identifying themselves as having worked in Alberta, British Columbia, and Montana. Collectively responders indicated a sum of 27 years of experience working with lynx in the Crown landscape. Responding experts indicated they believe lynx populations in the Crown landscape are vulnerable to apparently secure.

In response to the question "Please briefly critique the DRAFT Conceptual Model", experts indicated "Maybe fragmentation of populations due to loss of habitat connectivity? Or loss of smaller populations in a larger metapopulation context?" and "No changes, this looks fairly comprehensive." In response we added a lynx immigration element and augmented elements of the CM describing sources of fragmentation (forest management, road density, housing, agriculture, etc.).

When asked "In your opinion, what is the single most critical threat to the long-term persistence and viability of this feature in the Crown ecosystem?", the experts responded, "destruction of contiguous mature forest habitat" and "habitat loss through landscape development". Other critical threats experts identified include:

- large scale wildfire
- mortality from trapping by-catch
- loss of prey due to changing climate
- climate change leading to reduced snow persistence

We refined the CM to include these expert contributions and constructed a cost layer (Fig. 11B) based on the refined CM and the availability and veracity of spatial data describing direct threats.

Cost data development

We vetted available spatial data describing ecological threats (aka Costs) to Canada lynx conservation. The following data were selected and applied as described below and in metadata files.

Table 3: Threats, key attributes of each threat and quantifiable indicators of the threat. The first three columns of this table track linkage from conceptual model to spatially explicit optimization model. These are augmented with description of the ecological linkage among threat and lynx and citation of the source spatial data used to develop a cost layer.

Threat	Ecological Attribute	Indicator	Ecological Linkage	File Name / Source
Spring snow conditions	Snow cover	Spring snow persistence	Prey availability – snowshoe hare and other	Mosaic.tif / Mowat & Alberta Environment and Parks
Forest cover change	Forested landscapes	Habitat type	Lynx associate with dense, mature boreal forest	Landcover 30 m / CEC 2020
Wildfire	Wildfire history	Years since fire	Lynx prefer mid-seral forest; recently burned areas and forest stands without recent disturbance are lees preferred	InteragencyFirePerimeter History.shp (US) / NIFC NFDB_Poly_20210707 / (CAN)

Fragmentation	Road-caused	Traffic volume	Lynx avoid heavy road traffic volume	DRA_MPAR_line / BC Data Catalogue) NRN_AB_14_0_ROADSEG / Alberta Gov Roads / MT Digital Library)
	Industrial development-caused	Distance to industry	Lynx avoid industrial area with high human presence	IndDev_LCC.shp

Cost justifications

Climate change (snow cover)

Several possible effects of climate change on lynx can reasonably be anticipated, including 1) potential upward shifts in elevation or latitudinal distribution of lynx and their prey; 2) changes in the periodicity or loss of snowshoe hare cycles in the north; 3) reductions in the amount of lynx habitat and associated lynx population size due to changes in precipitation, particularly snow suitability and persistence, and changes in the frequency and pattern of disturbance events (e.g., fire, insect outbreaks); 4) changes in demographic rates, such as survival and reproduction; and 5) changes in predator-prey relationships (Ruediger et al. 2000). Of these, the best single data at our disposal in a Crown-wide snow persistence model provided by Garth Mowat via Danielle Pendlebury and Trevor Reid.

Table 4. Snow persistence cost data scoring.

			Relative Condition			
Direct Threat	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Spring snow conditions	Spring snow persistence	Percent years with May snow	0 – 6%	7 – 24%	25 – 53%	54 – 100%
		Assigned cost scores	4000	2000	500	0

Forest cover change

Natural and human-caused disturbance processes (e.g., fire, wind, insect infestations, forest management, and development) may influence the spatial and temporal distribution of lynx populations by affecting the distribution of high-quality habitat for snowshoe hares (Agee 2000; Ruediger et al. 2000). In montane and subalpine forests in northwest Montana, the highest snowshoe hare densities in summer are generally in younger stands with dense forest structure, but winter hare densities are as high or higher in mature stands with dense understory forest structure (Griffin 2004, p. 53). In Montana in winter, hare and lynx use multistoried stands, often in older-age classes, where the tree boughs touch the snow surface but where the stem density is low (Griffin and Mills 2009; Squires et al. 2006a; Squires et al. 2010).

Table 5. Landcover cost data scoring.

			Relative Condition			
Direct Threat	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Habitat loss	Forest presence	Presence/Absence	Non-forest			Forest
		Assigned cost scores	4000			0

Wildfire

Periodic vegetation disturbances stimulate development of dense understory or early successional habitat for snowshoe hares (Ruediger et al. 2000). In Maine, lynx are positively associated with landscapes that were clearcut 15 to 35 years previously (Hoving et al. 2004, p. 291; Simons-Legaard et al. 2013b), some of which were also treated with herbicides to promote conifer regeneration (Scott 2009). Lynx avoided mature stands (>40 years old) and short (3.4–4.3 m [11–14 ft]) regenerating clear-cut or partial harvested stands <10 years post-harvest (Fuller et al. 2007). Surface fires, avalanches, insects, and forest pathogens have also been important agents of disturbance, creating more structural diversity at a smaller scale. Fire regimes in the northern Rocky Mountains are extremely complex, reflecting the great variation in climate, topography, vegetation, and productivity (Kilgore and Heinselman 1990).

Table 6. Wildfire cost data scoring.

			Relative Condition			
Direct Threat	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Wildfire	Burned area	Years since last fire	< 10 yrs	> 40 yrs	10-15 yrs	15-35 yrs
		Assigned cost scores	4000	2000	500	0

Fragmentation (traffic volume)

Research from Alberta suggests high road densities, human activity, and associated developments appeared to reduce lynx habitat quality based on decreased occupancy (Bayne et al. 2008). Apps et al. (2007) found lynx were 13 times less likely to cross the Trans-Canada Highway relative to random expectation, but only 2.2 and 3.1 times less likely to cross Highway 93 and Highway 1A, respectively, compared to random expectation. Highways pose a risk of direct mortality to lynx and may inhibit lynx movement between previously connected habitats. If lynx avoid crossing highways, this could lead to a loss of effective habitat within a home range and reduced interaction within a local population (Apps et al. 2007). Lynx and other carnivores may avoid using habitat adjacent to highways, or become intimidated by highway traffic when attempting to cross (Forman and Alexander 1998; Gibeau and Heuer 1996). As the standard of road increases from gravel to 2-lane or 4-lane highways, traffic volumes and the degree of impact are expected to increase. Four-lane highways, such as the interstate highway system, commonly have barriers that make successful crossing more difficult, or impossible. Alexander et al. (2005) suggested traffic volumes between 3,000 and 5,000 vehicles per day may be the threshold above which successful crossings by carnivores are impeded. Between 2000 and 2011, 33 lynx were reported to have been killed on roads (both paved and unpaved) in Maine, Minnesota, Idaho and Montana (Vashon et al. 2012; U.S. Fish and Wildlife Service 2012). Between 1995 and 2011, 15 lynx were reported killed on British Columbia highways (British Columbia Wildlife Accident Reporting System 2012). Like McKelvey et al. (2000d), Squires et al. (2010) concluded that forest roads with low vehicular or snowmobile traffic had little effect on lynx seasonal resource selection patterns in Montana.

Table 7. Traffic volume cost data scoring.

			Relative Condition			
Threat	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Traffic volume	Roads	Road density (km/km^2)	Paved roads	Unknown surface	Unpaved roads	No roads
		Assigned cost scores	4000	2000	500	0

Fragmentation (industry)

Intense oil and gas development, such as is occurring in the Wyoming Range, may fragment habitat and may reduce or isolate already small populations of lynx. Activities associated with exploration and development of leasable minerals could affect lynx habitat by changing or eliminating the native vegetation and contributing to habitat fragmentation. Development of a high density of wells, as is typical of coal-bed methane development (e.g., 1 well per 2–4 ha [5–10 ac]), could affect lynx by directly removing habitat.

Mechanisms through which recreational activities could impact lynx may include loss of habitat, reductions in habitat availability due to disturbance, or changes in competition for snowshoe hare prey. Construction or expansion of developed areas such as large ski areas and four-season resorts, as well as smaller recreational sites like nordic ski huts or campgrounds, may directly remove forest cover. Such removal in lynx habitat could decrease prey availability, affect lynx movement within home ranges, or result in a more fragmented landscape. Few studies have examined how lynx react to human presence. Some anecdotal information suggests that lynx are quite tolerant of humans, although given differences in individuals and contexts, a variety of behavioral responses to human presence may be expected (Mowat et al. 2000; Staples 1995). Preliminary information from winter recreation studies in Colorado indicates that some recreation uses are compatible, but lynx may avoid some developed ski areas.

Table 8. Industry cost data scoring.

			Relative Condition			
Ecological Attribute	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Oil/Gas	Nearby Industrial Development	Distance to Development	< 5 km from development			> 5km from development
		Assigned Cost Scores	4000			0

Maps of data used to describe costs

Visuals of data used to develop spatial model of conservation cost for Canada lynx.

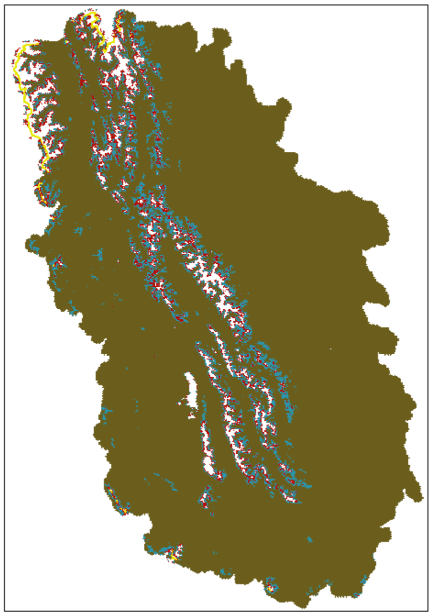

Figure 6. Snow persistence cost Layer for Canada Lynx.

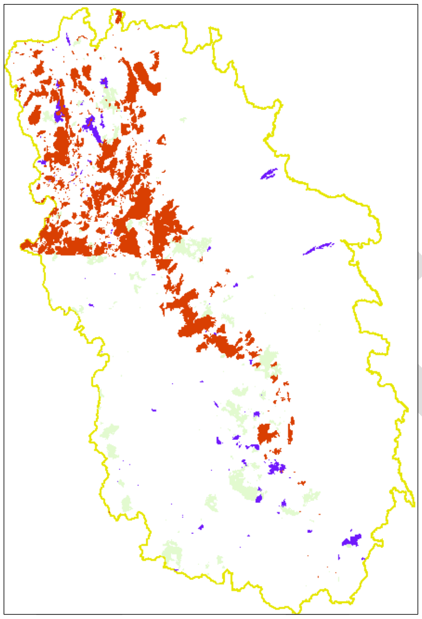

Figure 7. Wildfire cost Layer for Canada Lynx.

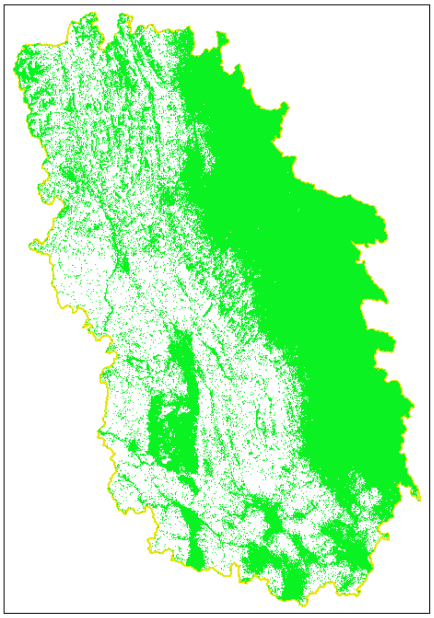

Figure 8. Landcover cost Layer for Canada Lynx.

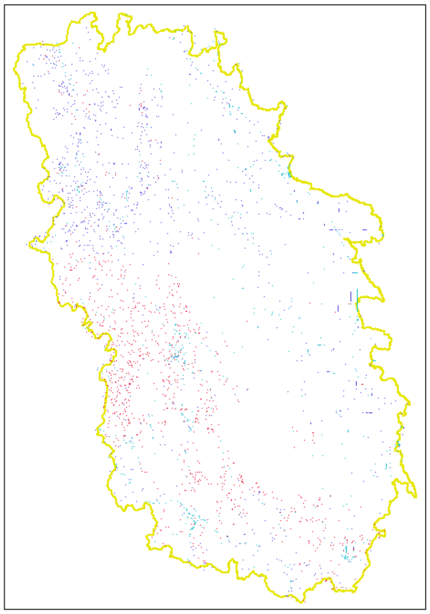

Figure 9. Traffic Volume cost Layer for Canada Lynx.

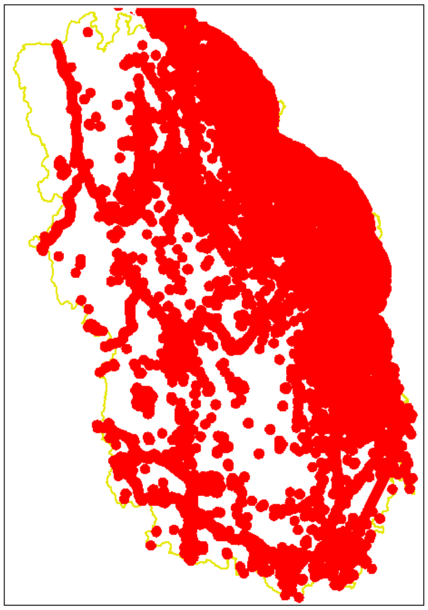

Figure 10. Industry cost Layer for Canada Lynx.

Spatial Design

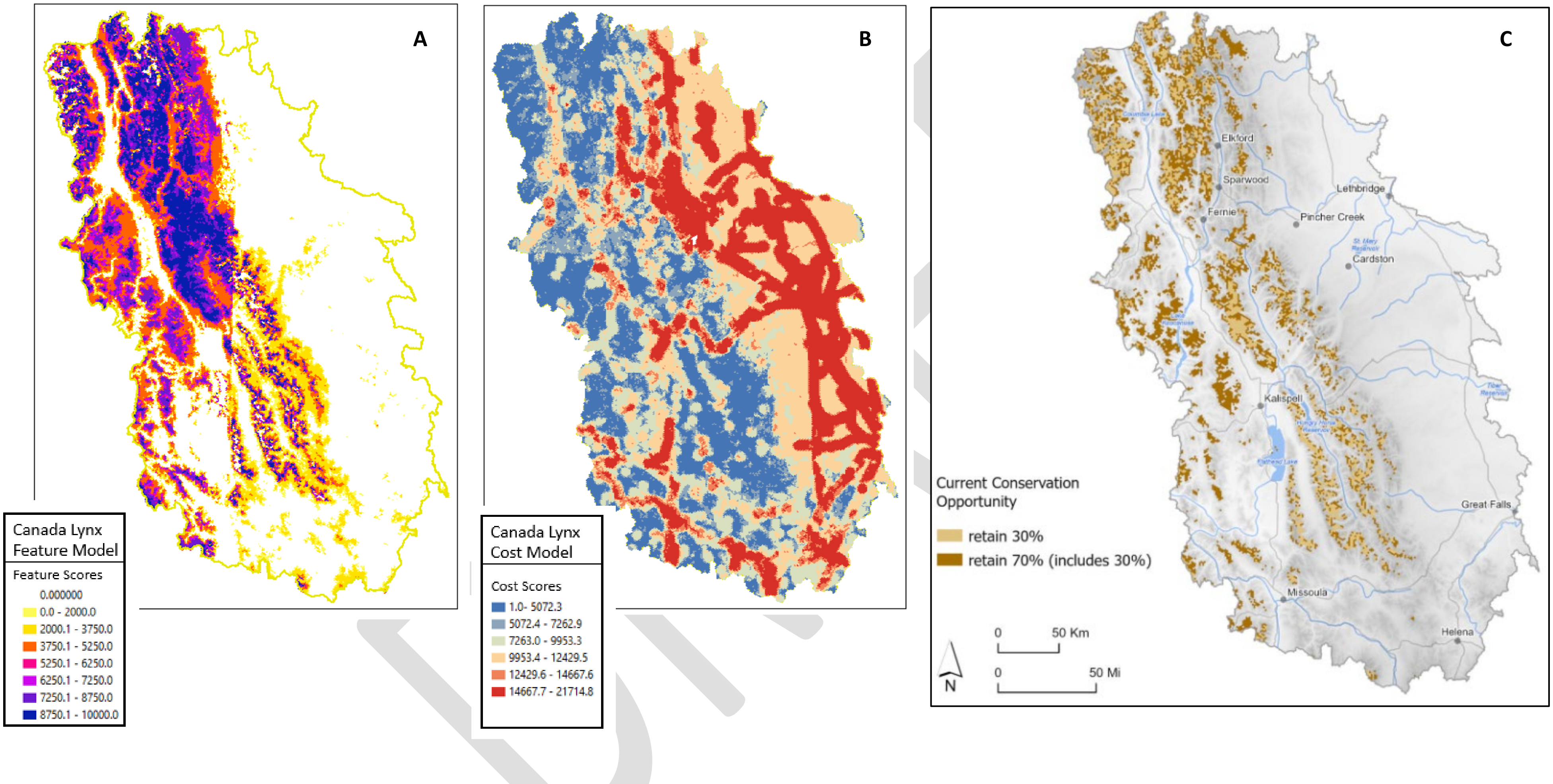

Figure 11. Canada lynx spatial design for the Crown of the Continent Landscape Conservation Design. Panel A: Sum **feature model** depicting relative value of the Crown landscape for Canada lynx as estimated by compiling, evaluating, and scoring four input data sources. Score values range from 0 (no value for lynx) to 10,000 (high value). Panel B: Sum **cost model** depicting relative cost to deliver conservation for lynx in the Crown landscape for as estimated by compiling, evaluating, and scoring five input data sources. Score values range from 0 (no value for lynx) to 21,715 (high value). Panel C: Output of two Marxan runs, each based on 10,000 repetitions. Independent models were generated where the Feature Representation Target was set a 0.30 and 0.70, calling for the model to identify 30% and 70%, respectively, of lynx conservation value across the Crown landscape.

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Additional Data Providers

- Anthony Clevenger
- Garth Mowat