Contents

Forests

Feature Description

Forest habitats support more biodiversity than any other habitat type on earth. Of the 18 million acres that constitute the Crown of the Continent ecosystem (CCE), 39%, or 5,113 ha, is forested making forests the single most expansive single habitat type across the CCE. Forested ecosystems in the Crown are composed of dry ponderosa pine and Douglas fir; western larch/mixed conifer; lodgepole pine and aspen; mesic white pine; cedar, hemlock and grand fir; whitebark pine/spruce/fir forests, and limber pine. In the CCE, forest habitats support many at-risk species (e.g., Canada lynx, grizzly bear) along with an abundance and diversity of thriving, plant, animal, fungal and microbe communities.

USFS

Conceptual Model

We collaboratively developed a conceptual model (Figure 1) for forest using the Conservation Standards process (FOS 2012) through literature review (Halofsky et al. 2018) and expert knowledge (Appendix X).

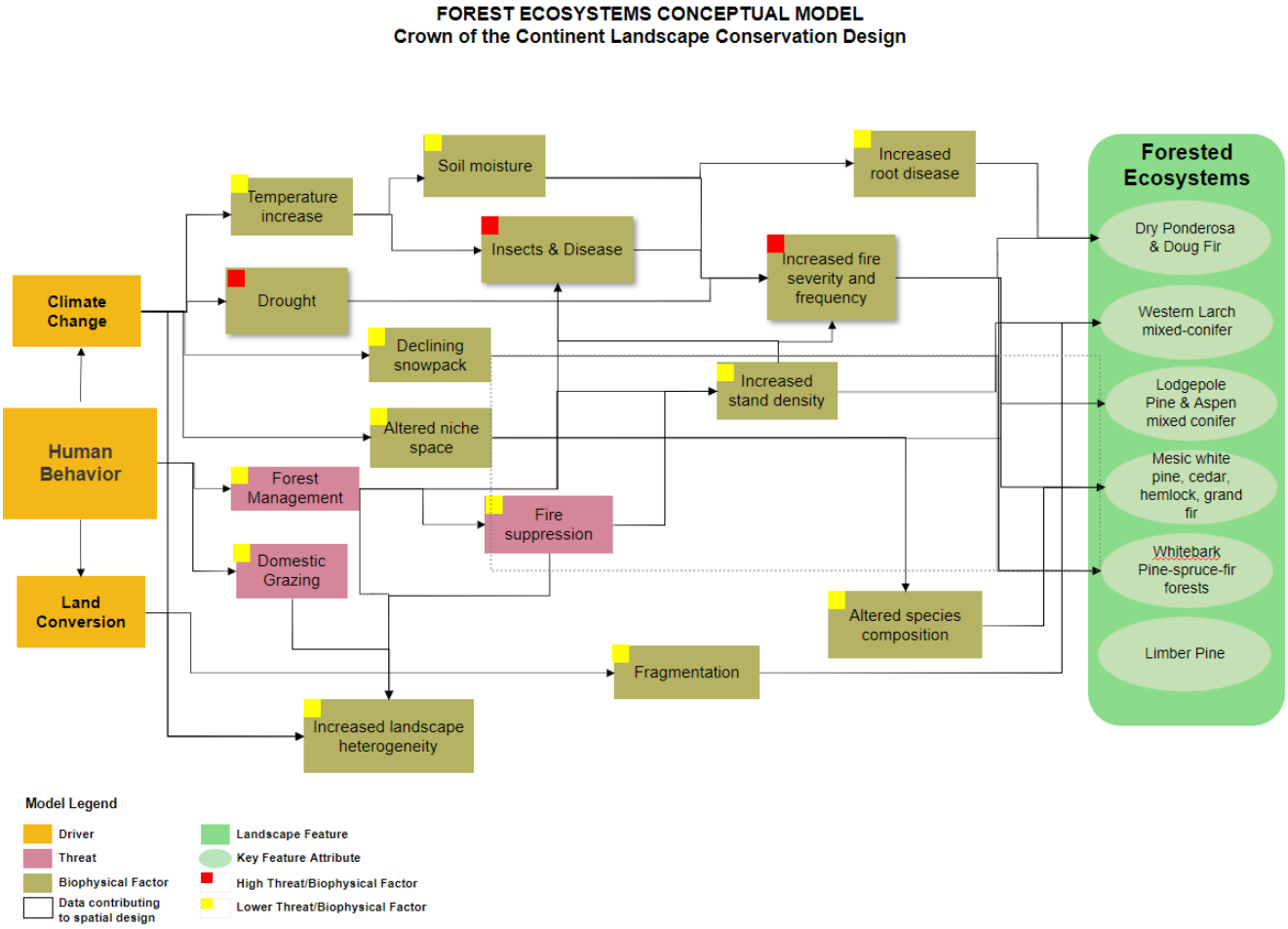

Figure 1. Conceptual Model (CM) framing the ecological setting for forest habitat. Model was developed through literature review (Halofsky et al. 2018) and forest expert refinements using the Conservation Standards process. A CM displays relationships between key natural and anthropogenic factors believed to impact or influence the persistence or resilience of one or more conservation features. This CM, where forest is the feature, describes drivers, biophysical factors, and threats to the persistence of functioning forested habitats in the Crown of the Continent. 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 forests 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. Forests throughout the Crown of the Continent Ecosystem are threatened by climate change, human behaviors, and land conversion. Human behaviors have contributed both to climate change and land conversion. Climate change has caused increased temperatures, droughts, and snowpack decline. These factors have collectively contributed to altered fire regimes, and increases in insect and disease outbreaks. Also contributing to forest declines are land conversion through habitat fragmentation and increased landscape heterogeneity. Collectively, these variables have caused declines in stands of: dry ponderosa pine and Douglas fir; western larch/mixed conifer; lodgepole pine and aspen; mesic white pine, cedar, hemlock, grand fir; whitebark pine/spruce/fir forests, and limber pine. 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 the Crown landscape.

Feature Data

Spatial data describing forest presence on the landscape came from a single source: the Commission for Environmental Cooperation's North American Land Cover data (CEC 2020). We merged four forest cover classes (temperate or sub-polar needleleaf forest, sub-polar tiaga needleleaf forest, temperate or sub-polar broadleaf deciduous forest, mixed forest) described by the source data the source data (Table 1). Metadata describing our forests data processing can be found here.

Table 1. Source data used to develop feature data for forest. 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
land_cover_2020_30m_tif	North American Landcover, 30 m resolution	All	Commission for Environmental Cooperation

Table 2. Feature data and scoring for forest. Sub-class indicates forest types, all of which were scored consistently for Phase 2 coarse feature models.

File Name	Source field used for scoring	Sub-classes	Scores assigned
land_cover_2020_30m_tif	Value / CoverClass	temperate or sub-polar needleleaf forest; sub-polar tiaga needleleaf forest; temperate or sub-polar broadleaf deciduous forest; mixed forest	10,000
		[other]	0

Maps of data used to describe feature

Map (Figure 2) of feature data (Table 2). These are the 'raw', unscored data as acquired from the data source.

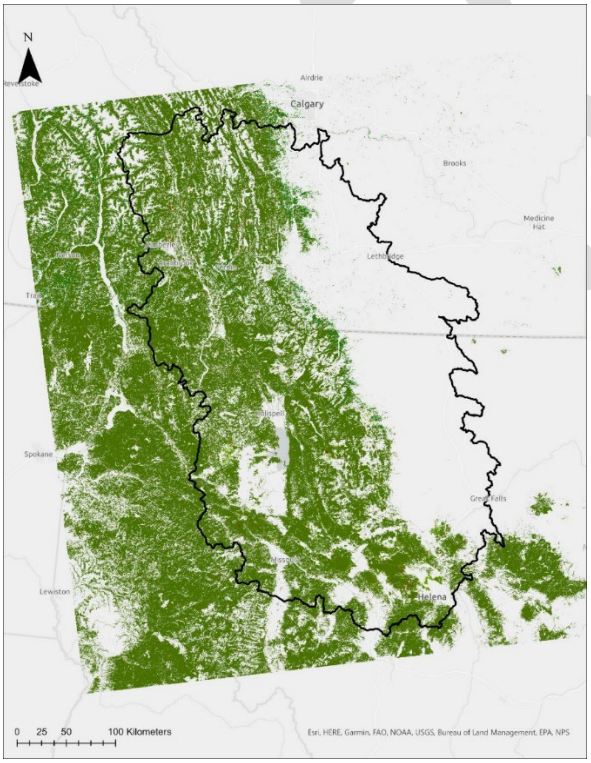

Figure 2. Forested habitat within the Crown of the Continent Ecosystem. Data was collected from the Commission for Environmental Cooperation.

Cost Data

Estimating ecological cost to delivering conservation for forest was based on conceptual model development (Figure 1). A first-draft model was developed by based on information from Holofsky et al (2018) using Miradi software. We then shared the draft with forest experts through a structured survey using Survey Monkey. Four experts responded to the survey (See Appendix X) identifying themselves as having worked in AB, BC and MT. Collectively responders indicated a sum of 34.5 years of experience working in Crown forests. Responding experts indicated they believe forests vulnerable to imperiled.

In response to the question "Please briefly critique the DRAFT Conceptual Model", experts indicated "perhaps increased human recreation in these forests (OHVs, mountain biking, hiking) should be in a pink box" and "While I see 'soil moisture', erosion is also a problem, "Forest management is not a threat to ecosystem persistence and viability, rather it's a tool to maintain/promote these. Also, fire suppression is listed as a direct threat; fire suppression is not a threat but a management response. Shouldn't this threat be uncharacteristic wildfire," and "White pine blister rust could be its own box. Consider adding invasive plants, as a contributor to fire exclusion and altered landscape fire regimes along with grazing." In response we minimized emphasis on forest management and fire suppression as threats (and expect to further vet these elements during Phase 3).

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?", our experts responded, "resource extraction" and "climate driven disturbances (e.g. severe wildfires)". Other critical threats experts identified include:

- Climate change leading to pest outbreaks
- recreation
- pests/invasive species/disease
- fire exclusion and drought

We refined the CM to include these expert contributions and constructed a Cost Layer 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 forest 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 forests and citation of the source spatial data used to develop a cost layer.

Threat	Ecological Attribute	Indicator	Ecological Linkage	File Name / Source
Land conversion	Ownership	Private land	Less costly to initiate conservation actions on public land	Jurisdictions_c2012.shp / CMP
Severe wildfire	Fire severity	Severity	Severely burned areas lower/slower recovery	Wildfire Perimeters 1931 – 2021 / Alberta; Historical Fire Burn Severity / British Columbia; Monitoring Trends in Burn Severity / US MTBS program
Wildfire	Wildfire history	Years since fire		Historical Wildfire Perimeter Data / Alberta

				Fire Perimeters Historical / British Columbia InterAgencyFirePerimeterHistory_All_Years_View.shp / US NIFC
Insects and disease	Outbreak severity	Mountain pine beetle severity		Mountain Pine Beetle Severity / CMP Hi5 Working Group

Cost justifications

Land stewardship

The Crown of Continent ecosystem is comprised of over 31,000 km^2 million ha managed by 42 different entities. Managing forests across a fragmented landscape comes with inherit economic costs, variable by land ownership (Newburn et al. 2005). Public lands (e.g. USFS, BLM) often have lower economic costs compared to private land because there is no acquisition or transactional costs associated (Naidoo et al. 2006). Further, despite incentive programs, private land owners may fear an economic loss by participating in conservation implantation (Knight et al. 2010; Grodzinska-Jurczak & Cent 2011); thus, implementation of forest management plans can be restricted on highly variable land owners willingness and interest in participation (Knight et al. 2010, Winter et al 2005).

To recognize the impacts fragmented land ownership has on forest stewardship, we reclassified ownership into three broad categories: public (BLM, Federal Montana FWP, National Park, Provincial/State, Provincially Protected Area, State Trust Land, US Fish and Wildlife, USFS), private (Local/Municipal Government, Plum Creek, Private, Private Conservation, Uncertain), and tribal. Thus, public land was r\scored 0 to represent to threat to forest habitats, and Tribal were scored at fair and poor, respectively, to represent any challenge that may occur with land access. The land ownership layer was developed by the Crown Managers Partnership in 2012 and is stored on ScienceBase.

Table 4. Land ownership cost data scoring.

			Relative Condition			
Threat	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Land conversion	Land ownership	Land stewardship	Private land	Tribal land	Public land	Public land
		Assigned cost scores	3000	1000	0	0

Insect impacts

Mountain Pine Beetle (MPB) is a native bark beetle that tunnels into pine trees, disrupting the transport of nutrients in the tree by girdling (Gibson et al. 2009). Within the CoC, MPB primarily attacks ponderosa and lodgepole pine, however attacks on whitebark and limber pine have been observed (Gibson et al. 2009). Outbreaks vary depending on weather, proximity to other populations, and stand health. Severe outbreaks have resulted in the loss of over 1 million ha of forest in the United States (Jorgensen & Mocettini 2005) and nine million ha in Canada (Westfall & Ebata 2007). Using mountain pine beetle mortality surveys, modelers can estimate the threat of mountain pine beetles (e.g., Coops et al. 2006, Wulder et al. 2012). Synthesizing modeling data, the Hi5 working group determined thresholds and scores for Mountain pine beetle severity.

Table 5. Insects and disease cost data scoring.

			Relative Condition			
Threat	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Insect & disease	Outbreak severity	Mountain pine beetle severity	High	Moderate	Low	None
		Assigned cost scores	3000	2000	1000	0

Fire recurrence

As a consequence of climate change, warmer and drier seasons have contributed towards more frequent wildfires (IPCC 2018). Increases in fire occurrence, coupled with an increase in intensity (see below), has had determinantal impacts on forest health already (e.g. Xu et al. 2020, IPCC 2018).

Data was used from multiple sources. For fires in British Columbia, data was collected through the BC Data Catalog. For Alberta, data acquired from the government of Alberta. In the US, data from National Interagency Fire Council was used. Layers were standardized by adding fields for year and size (Ha). Once layers were standardized, all were merged to create a consistent layer for fires across the CCE. To increase consistency, we only used fire data from 1990-2022. To determine recurrence, the 'Count Overlapping Features' tool was used to count the number of overlapping fire perimeters. Areas with 5 or more recurrences were considered poor for forest health; 2-5 overlapping areas were considered fair; zero overlapping areas were good; 1 fire since 1990.

Table 6. Fire recurrence cost data scoring.

			Relative Condition			
Threat	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Fire frequency	Fire return interval	Fire recurrence	≥ 5 fires since 1990	2-5 fires since 1990	Zero fires since 1990	1 fire since 1990
		Assigned cost scores	8000	4000	1000	0

Burn severity

In addition to increased fire frequency caused by climate change, wildfire intensity has also intensified (Fried et al. 2004, Halofsky et al 2020). Data was used from a variety of sources. For Alberta, data was collected from the Fire Information Resource Evaluation System. For British Columbia, from the BC Data Catalogue. For Montana, the Monitoring Trends in Burn Severity program. To standardize the layers, a field for Burn Rate was created. See <Crown_Fire_Cost_Layer_Process_Steps.docx> for how severity was quantified within each region.

Table 7. Burn severity cost data scoring.

			Relative Condition			
Threat	**Indicator**	**Metric**	**Poor**	**Fair**	**Good**	**Very Good**
Fire severity	Burn severity	Burn severity	High	Moderate	Low	No measurable severity
		Assigned cost scores	6000	4000	2000	0

Maps of data used to describe costs

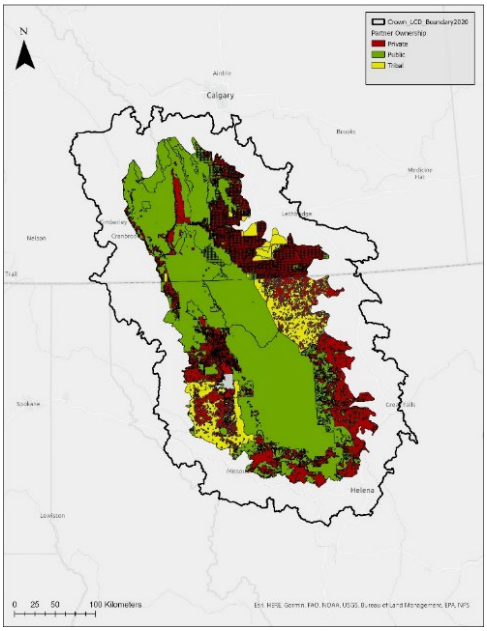

Figure 3. Coarse scale land ownership metrics within the Crown of the Continent ecosystem. Due to accessibility, Private land was scored 3000, tribal land 1000, and public land 0.

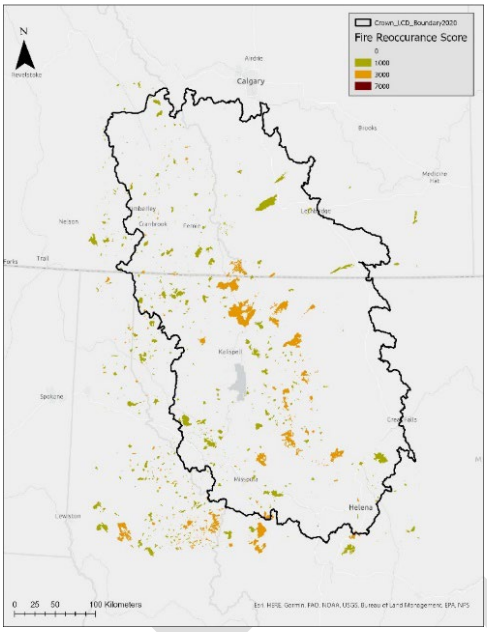

Figure 4. Fire recurrence within the Crown of the Continent Ecosystem. Areas with 0 fires since 1990 are scored 1000 (green). Areas with 2-5 since 1990 are scored 3000 and areas with more than 5 fires since 1990 are scored 7000.

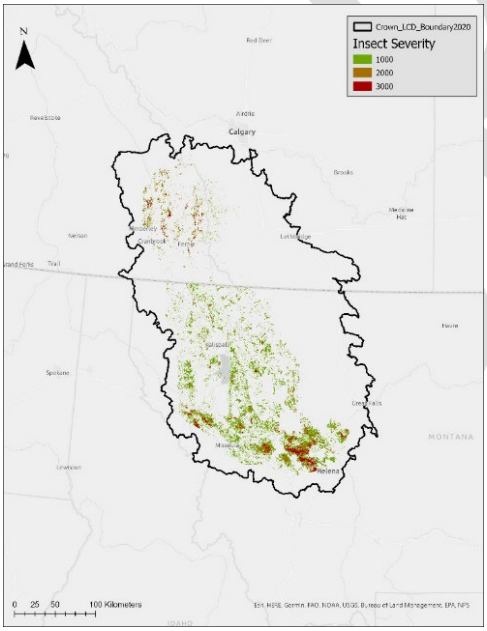

Figure 5. Mountain Pine Beetle Severity within the Crown of the Continent Ecosystems. Areas with high Mountain Pine Beetle Severity were scored at 3000, moderate 2000, and low at 1000.

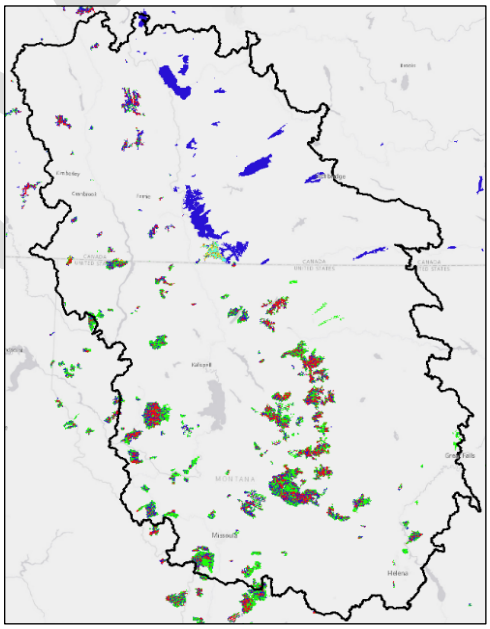

Figure 6. Burn Severity of evaluated fires in the Crown of the Continent Ecosystem.

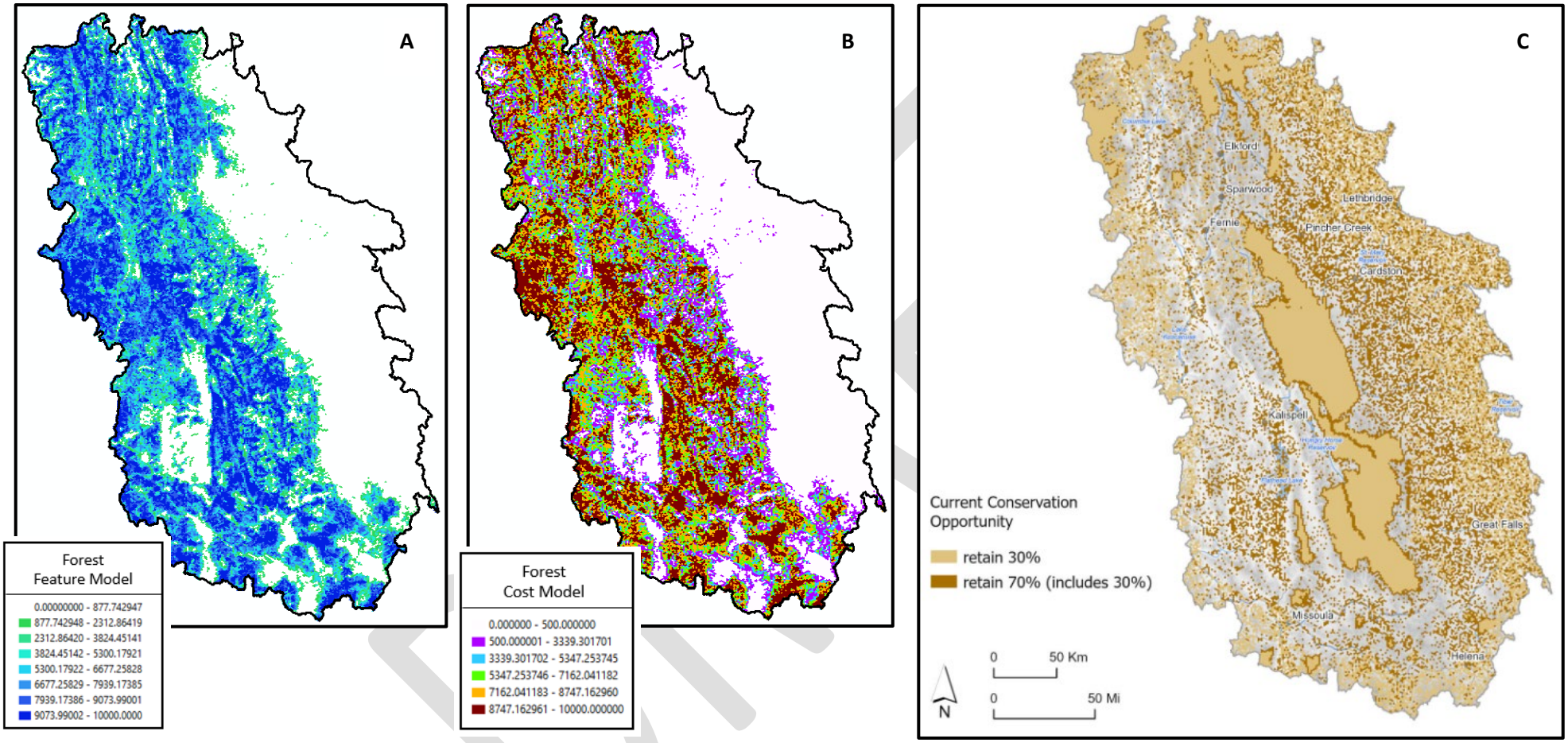

Figure 7. Forest spatial design for the Crown of the Continent Landscape Conservation Design. Panel A is the sum 'Feature' model depicting relative value of the Crown landscape for forest as estimated by compiling, evaluating, and scoring the single input data source. Score values range from 0 (no value for forest) to 10,000 (high value). Panel B is the sum 'Cost' model depicting relative cost to deliver conservation for forests in the Crown landscape for as estimated by compiling, evaluating, and scoring four input data sources. Score values range from 0 (no value for forest) to 21,715 (high value). Panel C displays the output of two Marxan run, 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 forest conservation value across the Crown landscape.

Citations

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Appendix

Table describing Cost data (Variables in green were used in for costs. Red layers weren't used)

Threat	Key ecological attribute	Indicator (metric)	Poor	Fair	Good	Very Good	Source/ documentation
Land conversion	Industrial extraction/ fragmentation	Land Stewardship	private land	private land	public land	public land	Alberta Eastern Slopes Land Use and Zoning (line 21), Alberta Human footprint (23), Forest Areas (263), Canopy closure (264), Habitat elements (incl. canopy closure, dead vegetation, soil characteristics) (265), Agriculture/Logging (361 but no link ??), Revenue Final Land Unit (FLU) Classification, 2019 (370), Alberta Vegetation Inventory (AVI) Crown Post-Inventory Harvest Areas (377)
		KEA1-Indicator 2					
	Invasive plants	KEA1-Indicator 1					
		KEA1-Indicator 2					
Climate risk	Severe Wildfire	wildfire severity	very high severity	high severity	lower severity		North American Wildland Fuel Database (266), **Fires (422)**, Fire History (424), Fire Disturbance (426), Fire History (US) (427)
		fire recurrence	>5 recurring fires since 1990	2-5 recurring fires since 1990	Zero fires since 1990	1 fire since 1990	
	Drought	KEA2-Indicator 1					Macrorefugia - Trees (388)
	Soil Moisture	KEA2-Indicator 2					Regridded Harmonized World Soil data (253), Climate change vulnerability and adaptation in the managed Canadian boreal forest (392), Spring snow cover dataset (393)
	Insect and Disease outbreaks	KEA2-Indicator 1					Aspen Defoliators (405), Mountain Pine Beetle (406), White pine blister rust (407)
Human Behavior	Fire management (Exclusion)	Land Stewardship	private land	private land	public land	public land	
	Recreation						Cutlines and OHV Trails (364)