Climate Change Conscious Systematic Conservation Planning: A case study in the Wild Harts Study Area, Peace River Break, British Columbia

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Study Background

As humans transform the biosphere in unprecedented ways and rates, loss of biodiversity is one of the planet's prevailing environmental challenges. Worldwide, the rapidly-expanding human footprint threatens the persistence of wilderness areas that serve as refuges for species and ecosystems. Furthermore, human induced climate change perturbs regional precipitation patterns and temperature regimes, thereby altering ecosystem composition, structure, and function, forcing species to quickly adapt to new environmental conditions, migrate, or perish. Against this backdrop, protected areas play a critical role in the long-term conservation of biodiversity by ensuring the persistence of wilderness areas that sustain species and ecosystems. Consequently, establishing protected area networks has been the cornerstone of global biodiversity conservation efforts. Now more than ever, pre-emptive systematic conservation planning is required to combat the novel challenges of unprecedented anthropogenic pressures in a future characterized by unpredictable climate conditions.

Three quarters of the planet's terrestrial areas have already been altered by anthropogenic activities (Venter et al., 2016) to the point that they can no longer be considered natural (Watson et al., 2016). Between 2.8 and 3.0 million km^2 of the planet's wilderness is projected to be lost by 2030 (Venter, Watson, Atkinson and Marco, in press). This would result in a total of 5.6-5.8 million km^2 of wilderness lost since 1993: an alarming ~15% loss in less than 40 years. Even in areas such as North America where the threat of wilderness loss is much lower, a large projected loss is anticipated in the region by 2030 (0.21 – 0.22 million km^2) (Venter, Watson, Atkinson and Marco, in press). Globally, wilderness conversion exceeds protection by a ratio of 8:1 in temperate grasslands and Mediterranean biomes, and 10:1 in more than 140 ecoregions (Hoekstra, Boucher, Ricketts, & Roberts, 2005). Human impacts on the natural environment have reached such proportions that the term "biome crisis" has been coined to describe the emergence of substantial and widespread disparities between habitat loss and protection across ecoregions and, at a global scale, across entire biomes (Hoekstra et al., 2005).

In addition to the rapid conversion of our planet's wilderness areas, the long-term impacts of climate change pose a significant threat to biodiversity that is challenging to predict. Anthropogenically-driven climate change has already begun to impact critical climate regions and is now recognized to be one of the most serious threats to biodiversity and the conservation thereof (Lemieux, Beechey, Scott, & Gray, 2011). Climate change induced by human-generated greenhouse gas (GHG) emissions is now implicated in a myriad of coincident impacts. These include disturbances in regional precipitation patterns and temperature regimes, sea level rise, severe weather events, and changes in ecosystem composition, structure, and function (IPCC 2007a, 2007b; Lemmen et al. 2008).

Global climate change is proceeding at unprecedented rates and further unparalleled climatic changes are expected for the 21st century (IPCC 2007a, 2007b). An increase in carbon dioxide and other human-made emissions into the atmosphere has increased the average global surface temperature by approximately 1.1 ºC since the late 19th century (GISTEMP Team, 2017; Hansen, Sato & Lo, 2010). Most of the warming occurred within the last 35 years, with 16 of the 17 warmest years on record occurring since 2001. Not only was 2016 the third year in a row to set a new record for global average surface temperatures, making it the warmest year on record, but eight of the 12 months that made up the year (January through September with the exception of June) were the warmest on record for those respective months (GISTEMP Team, 2017; Hansen, Sato & Lo, 2010). Within Canada, warming rates have increased at nearly double the global average (Environment & Climate Change Canada, 2016).

The Intergovernmental Panel on Climate Change (2007b) has suggested that approximately 20–30% of the planet's species are likely to be at increased risk of extinction if increases in global average temperatures exceed 1.5–2.5ºC. Of concern, these estimates may be optimistic when the synergistic effects of habitat fragmentation and climate change are considered. Rapidly declining rates of biodiversity resulting from such synergistic effects have led to discussions of an impending sixth major mass extinction analogous to the five previously documented (Pimm et al., 2014). Scientists estimate the planet is already losing species at 1,000 to 10,000 times the background rate (Chivian & Bernstein, 2008) with as many as 30 to 50 percent of all species possibly heading toward extinction by mid-century (Thomas et al., 2004). According to the International Union for Conservation of Nature (IUCN, 2017) Red List of threatened and endangered species (Version 2017.3), 25% of mammal species, 41% of amphibians and 43% of conifers are currently threatened. Furthermore, the Living Planet Index calculates that on average, global vertebrate populations of 3,706 monitored vertebrate species, declined an average of 58% between 1970 and 2012 (McGill, Dornelas, Gotelli, & Magurran, 2015). If current trends continue to 2020 vertebrate populations could decline by an average of 67% compared to 1970. The Living Planet Report Canada (WWF-Canada, 2017) found that from 1970 - 2014 half of monitored wildlife species in Canada declined in abundance. Approximately half of the mammals (54 per cent), birds (48 per cent), fish (51 per cent), as well as amphibians and reptiles (50 per cent) included in the analysis exhibited declining trends. What's more, of those species with declining trends, the Living Planet Report Canada found an average decline of 83%, from 1970 to 2014 (WWF-Canada, 2017).

Against this grim backdrop, protected areas are widely recognized as the cornerstone of strategies to tackle the biodiversity crisis. Protected areas are "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural value" (Dudley, 2008). Protected areas are intended to protect biodiversity, preserve ecological integrity, provide refuge for species, store carbon to mitigate the adverse effects of climate change, provide critical ecosystem services such as clean water and air, as well as provide economic, social and cultural benefits. They help to mitigate the effects of habitat conversion, fragmentation, and climate change on biodiversity by retaining intact ecosystems and facilitating the movement of species responding to changing conditions. While protected areas were initially established to preserve scenic wonders and tourist attractions, their purpose has evolved to that of a strategic tool for conservation of biodiversity and ecological sustainability, as well as an important indicator of world ecosystem health (Lemieux et al., 2011).

The protected area movement in Canada began with the creation of Banff Hot Springs Reserve (now Banff National Park) in 1885. The incremental growth of Canada's protected areas network that followed was characterized by accelerated spurts in response to economic, social, and environmental pressures as well as opportunities for conservation action. Rapid expansion in the post-war era generated rapid growth in Canada's protected areas network, which now comprises just over 10% of the land and fresh water base of the nation (Environment and Climate Change Canada, 2016). Despite this growth, a history of protected area establishment for reasons other than nature conservation has fostered a legacy of residual reserves in Canada and across the globe (Pressey & Bottrill, 2008).

Residual reserves result when protection is applied residually to extractive uses. As a result, these protected areas are typically biased towards economically marginal lands characterized by steep slopes, low soil fertility, and low land degradation pressure (Brooks et al., 2004; Rodrigues et al., 2004; Joppa & Pfaff, 2009). Worldwide, protected areas with higher protection status tend to exhibit more location bias and less land degradation pressure than protected areas with lower protection statuses (Joppa & Pfaff, 2009; Hoekstra et al., 2005). Studies of global protection demonstrate that these biases are not an artifact from the utilitarian protected area planning practices of the late 19th and early 20th centuries. Rather, these biases continue to exist in modern protected areas said to be established based on ecological principles (Baldi, Texeira, Martin, Grau, & Jobbágy, 2017; Venter et al., 2017). This suggests that even though modern conservation planning has evolved into a mature and robust science informed by ecological principles, a utilitarian mindset still largely influences conservation initiatives, resulting in the continued establishment of residual reserves at the cost of vitally important habitats.

Despite the worldwide trend for inefficient protected area planning and residual reservation (Joppa & Pfaff, 2009; Baldi et al., 2017; Venter et al., 2017), a recent study has quantitatively demonstrated the value of protected areas as an effective strategy for conserving biodiversity (Coetzee, Gaston, & Chown, 2014). Coetzee, Gaston and Chown (2014) found that globally, species richness is 10.6% higher and abundance is 14.5% higher inside protected areas than in adjacent unprotected areas. The positive effects of protection were found to mostly be attributable to differences in land use between protected and unprotected areas. Protected areas were found to be most effective where they minimize human-dominated land use. Furthermore, although the Living Planet Report (WWF, 2014) highlighted a grim outlook for global vertebrate species populations, it also noted that declining trends within terrestrial protected areas are occurring less rapidly (-18%) than in unprotected areas. The Living Planet Report found that within protected areas, global bird, mammal and fish populations have, on average, increased 57%, 10%, and 182% respectively. In a world that has been so transformed by anthropogenic activities that it can now be characterized more readily by a set of human biomes than by the classic biogeographic regions (Juffe-Bignoli et al, 2014), protected areas help retain intact ecosystems, thereby preserving the origins and maintenance of global biodiversity and ecological integrity.

Despite the incremental growth of Canada's protected areas network since its inception, the current percentage of protected land in Canada remains well under the global average of 15.4% (Juffe-Bignoli, 2014) and internationally agreed upon interim target of 17%. As of the end of 2016, more than 7000 terrestrial protected areas cover 10.5% of Canada's terrestrial and freshwater base. British Columbia is leading the way with 15.3% of its terrestrial area protected (Environment and Climate Change Canada, 2016) with positive outlooks for meeting the 17% target by 2020. While the distribution and size of individual protected areas is highly variable across Canada, the existing network is currently comprised of relatively disconnected and small (<10km^2) protected areas. Few of Canada's protected areas meet the minimum size thresholds (>3000km^2) deemed necessary for ecological persistence (Wright, 2016) and the ones that do meet these thresholds tend to be located in northern regions characterized by less competing land uses (Environment and Climate Change Canada, 2016).

The apparent disparity between the intention and practice of protected area planning (Joppa & Pfaff, 2009; Knight & Cowling, 2007; Venter et al., 2017), the deepening environmental crisis (Johnson et al., 2017), and advancements in the fields of ecology and decision support software tools, fueled the development of the systematic conservation planning (SCP) framework in the 1980s (Margules & Pressey, 1988). As increasing pressure for competing land uses reduces the amount of land available for the protection of biodiversity, the prioritization of areas for the allocation of scarce conservation resources was deemed imperative (Margules & Pressey, 2000; Sarkar & Illoldi, 2010). While the prioritization of conservation areas still remains central to SCP, it is now incorporated into a structured multi-component stage-wise approach to identifying conservation areas and devising management policy, with opportunities for feedback, revision, and reiteration, at any stage (Sarkar & Illoldi, 2010). Today there are many versions of the SCP framework which can provide guidance for protected area planning and design (Margules &

Pressey, 2000; Pressey & McKinnon, 2009; Sarkar & Illoldi, 2010). Broadly, SCP has three main goals: (1) adequate representation of biodiversity within a set of prioritized conservation areas; (2) ensuring the persistence of biodiversity through the design of effective adaptive management strategies; and (3) cost-effectiveness (Sarkar, Sánchez-Cordero, & Margules, 2017).

SCP is widely considered the most effective approach for designing protected area and other ecological networks. It has continued to evolve since its inception and has influenced planning in major governments and organizations such as The Nature Conservancy, inspired hundreds of scientific publications, and shaped policy, legislation and conservation (Pressey, Cabeza, Watts, Cowling, & Wilson, 2007). The success and effectiveness of SCP can be attributed to its efficiency in using limited resources to achieve conservation goals, its flexibility and defensibility in the face of competing land uses, and its accountability in allowing decisions to be critically reviewed (Margules & Pressey, 2000). Despite its efficacy, the inherent complexity of the framework has limited its utility in government protected area initiatives.

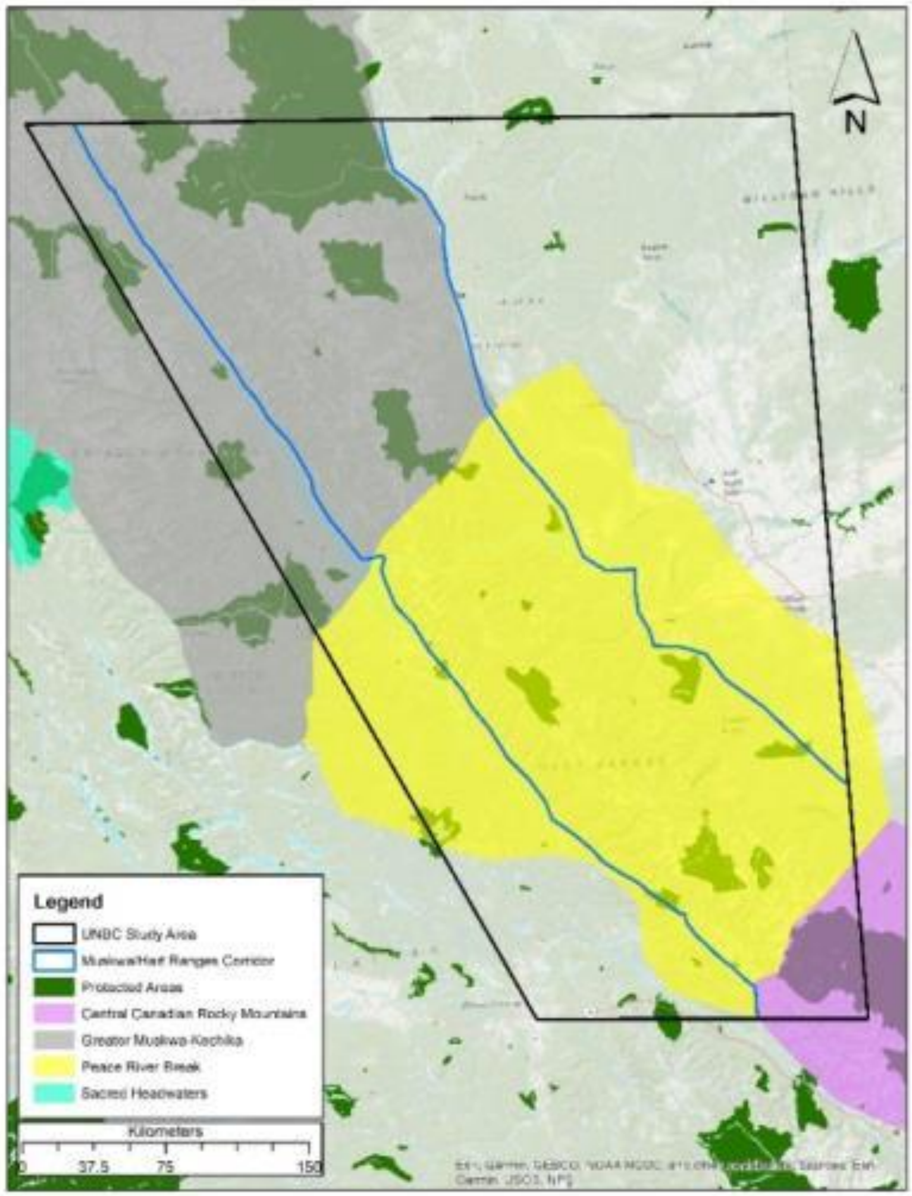
SCP uses detailed biogeographical information and selection algorithms to identify priority conservation areas (Knight & Cowling, 2007; Watson, Grantham, Wilson, & Possingham, 2011) and strives to move the prioritization of protected areas beyond opportunism and toward scientific defensibility and improved efficacy (Pressey, Humphries, Margules, Vane-Wright, & Williams, 1993). SCP is founded on the principle that conservation decisions should be guided by explicit goals, the identification of priorities in regional or broader contexts, and clear choices between potential conservation areas and alternative forms of management (Margules & Pressey, 2000). It seeks to identify the most important areas for conservation by weighing ecological values, levels of threat and vulnerability, representativeness, and irreplaceability. The framework improves the efficacy of protected area network designs by identifying configurations of complementary areas that achieve explicit, and typically quantitative, conservation objectives (Margules & Pressey, 2000). Furthermore, SCP supports identification of protected area networks that represent regional species and ecosystems diversity, be comprised of enough habitat of specific types to maintain viable species populations, enable continued community and population processes, including shifts in species' ranges, and allow natural patterns of disturbance (Baldwin, Scherzinger, Lipscomb, Mockrin, & Stein, 2014). SCP ensures that protection is established in areas of significant importance to conservation of biodiversity. Accordingly, the SCP framework can serve as an effective tool in the battle to conserve our planet's biodiversity and the fight against climate change by guiding the targeted expansion of protected areas networks. Moreover, SCP can effectively inform and combat the powerful economic and political drivers that promote the establishment of residual reserves by being flexible and defensible, economical, and accountable (Margules & Pressey, 2000).

Systematic conservation planning continues to rapidly evolve as new information and tools become available, and increasingly sophisticated approaches are being developed every day. As the field progressively expands its scope and perspectives, it becomes more effective at incorporating previously poorly understood or connected variables. Although the SCP framework has been refined and improved over time, no existing versions have attempted to explicitly incorporate a climate change lens with the goal of pre-emptively planning for future climate conditions and climate change impacts. With the recent widespread availability of emission scenarios and reliable climate change data (www.adaptwest.databasin.com; Wang et al. 2016), the SCP framework is well poised to take advantage of climate information and evolve into a climate change conscious approach to conservation planning. Conservation scientists now more than ever need to utilize this framework in combination with sophisticated software tools (Sarkar et al., 2006) and reliable climate change data to recognize and respond to opportunities for action, conserve our planet's biodiversity and mitigate the effects of climate change. The extent to which ongoing attrition of valuable wilderness areas compromises biodiversity and contributes to global warming can be greatly minimized by the prompt and targeted expansion of the global protected areas network under the SCP framework.

Overview of the Peace River Break

Situated within the Rocky Mountain Cordillera, straddling the Peace River watershed in northeastern British Columbia, lies an area referred to as the Peace River Break (PRB) (Fig 1.) – a geographical designation coined by the Yellowstone to Yukon Conservation Initiative (Apps, 2013). The Peace River itself has the distinction of being the only watercourse to travel eastward through the Rocky Mountains. Where Arctic air typically dominates the majority of the Rocky Mountains, the Peace River provides a channel for warm Pacific to flow through, resulting in a moderated climate and unique ecological conditions. Six physiographically distinct ecoregions merge at the PRB to provide a high diversity of ecosystems and organisms alike (Apps, 2013).

Figure 1. Wild Harts/Hart Muskwa Corridor within the Peace River Break



This pathway, through an otherwise impassible physical boundary, and the temperate climate it provides, made the PRB a logical area for First Nations and early European settlers to congregate (Apps, 2013). The arable soils of the Peace River valley drew agricultural interests to the region at the turn of the 20th century. By the 1950's, two major transportation corridors (Alaska Highway and John Hart Highway) had been constructed and now provide access to what was previously a remote and isolated area. This led to the development of a natural resource industry in the PRB and, consequently, the establishment of several communities to support the growing sector (Apps, 2013).

In recent times, the PRB has become one of British Columbia's prominent regions for resource-related industry and extraction (Apps, 2013). With the proposal of several large-scale development projects on the table (i.e. Site C Dam, Northwest Transmission Line, Pacific Northwest LNG), the area could see considerable growth in human population and resource-related infrastructure in the years ahead. Current industrial expansion in the region has created an ecogeographical bottleneck in the PRB –turning some portions of the PRB into vital corridors that connect functional landscapes along the north-south extent of the Canadian Rocky Mountains. Considering the PRB is currently underrepresented by protected areas, landscape connectivity and associated biodiversity values in the area are vulnerable to the cumulative effects of future anthropogenic disturbance (Apps, 2013).

Historical and Projected Climates in the PRB

In addition to the already pressing conservation demand in the area, the PRB is projected to experience significant climate change impacts. Climate change models can serve as valuable tools and help planners cope with the challenges of planning for different climate conditions. Furthermore, climate change models can help scientists and planners better understand local climate change hazards such as severe droughts, floods, heat waves, and losses to agricultural productivity.

Climate projections for the Peace River region in the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099) are summarized below. Projections are derived from PCIC's online tool, "Plan2Adapt." Projected changes are calculated from the baseline historical period (1961-1990) for average (mean) temperature, precipitation and several climate variables. The projected changes represent the ensemble median, which is a mid-point value, chosen from a PCIC's standard set of Global Climate Model (GCM) projections.

Annual mean temperatures, frost-free days and growing degree-days are all projected to increase in the Peace River region (Fig. 2 & 3). Annual mean temperatures are projected to increase by 1°C in the 2020s, 1.8°C in the 2050s, and 2.8°C in the 2080s (Fig.2). Frost-free days are projected to increase annually by 9, 16, and 26 days in the 2020s, 2050s and 2080s respectively (Fig. 3). The 2020s, 2050s and 2080 are projected to experience 129, 225, and 364 more growing degree-days annually (Fig. 3).

Annual precipitation and snowfall rates are projected to increase in the 2020s, 2050s, and 2080s (Fig 3). Annual mean precipitation is projected to increase 5% by the 2020s, 8% by the 2050s and 10% by the 2080s. Summer precipitation is projected to increase by 2% by the 2020s, 3% by the 2050s and 1% by the 2080s. Winter precipitation is projected to increase by 7% by the 2020s, 11% by the 2050s, and 16% by the 2080s. Winter snowfall is projected to increase by

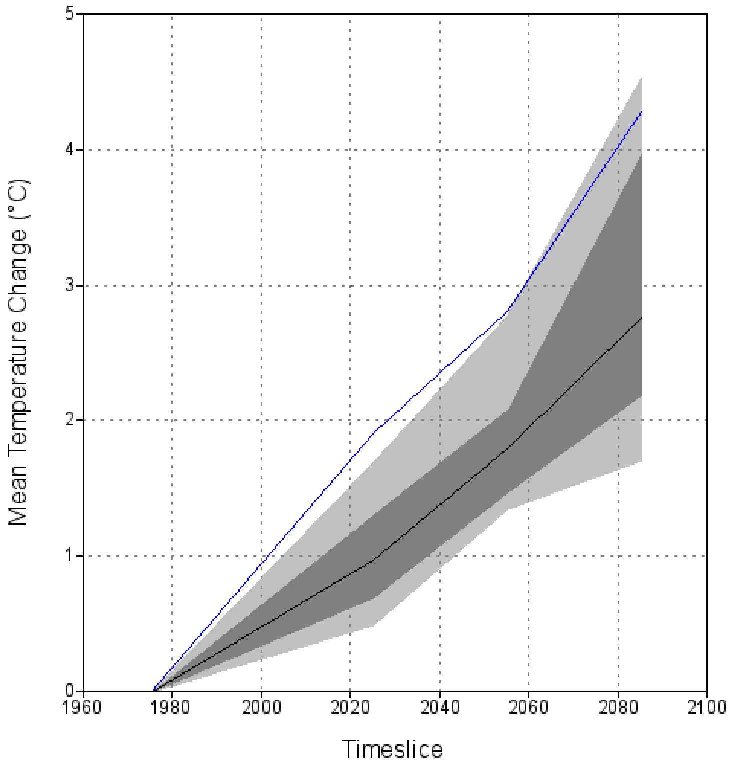
5% by the 2020s, 7% by the 2050s and 8% by the 2050s whereas spring snowfall is projected to decrease by 30% by the 2020s, 55% by the 2050s and 70% by the 2050s.

Although climate models project both increasing and decreasing annual precipitation in the future, the median trend indicates a slight increase (Fig. 3). While the amount of summer precipitation is projected to largely remain the same, indicating that a slight increase or decrease is probable, a slight increase in the amount of precipitation falling as snow over the winter is projected. Conversely, a significant decrease in the amount of snowfall is projected in the spring seasons.

Within the Peace River region, the distribution of projected precipitation and temperature varies across the landscape. Precipitation is largely influenced by topography while temperature is influenced by elevation. Cooler temperatures and wetter conditions are found in the higher elevation mountainous areas to the west in the Peace River Region, while temperatures are higher in the eastern plateau (British Columbia Agriculture & Food Climate Action Initiative, 2013).

The magnitude, frequency and intensity of extreme events in the Peace River region are projected to increase for both rainfall and temperature due to climate change. Extreme cold temperatures are projected to occur less frequently, whereas extreme high temperatures are projected to occur more frequently. The intensity and magnitude of extreme rainfall events is anticipated to continue to increase while longer dry periods are projected in the summers (British Columbia Agriculture & Food Climate Action Initiative, 2013).

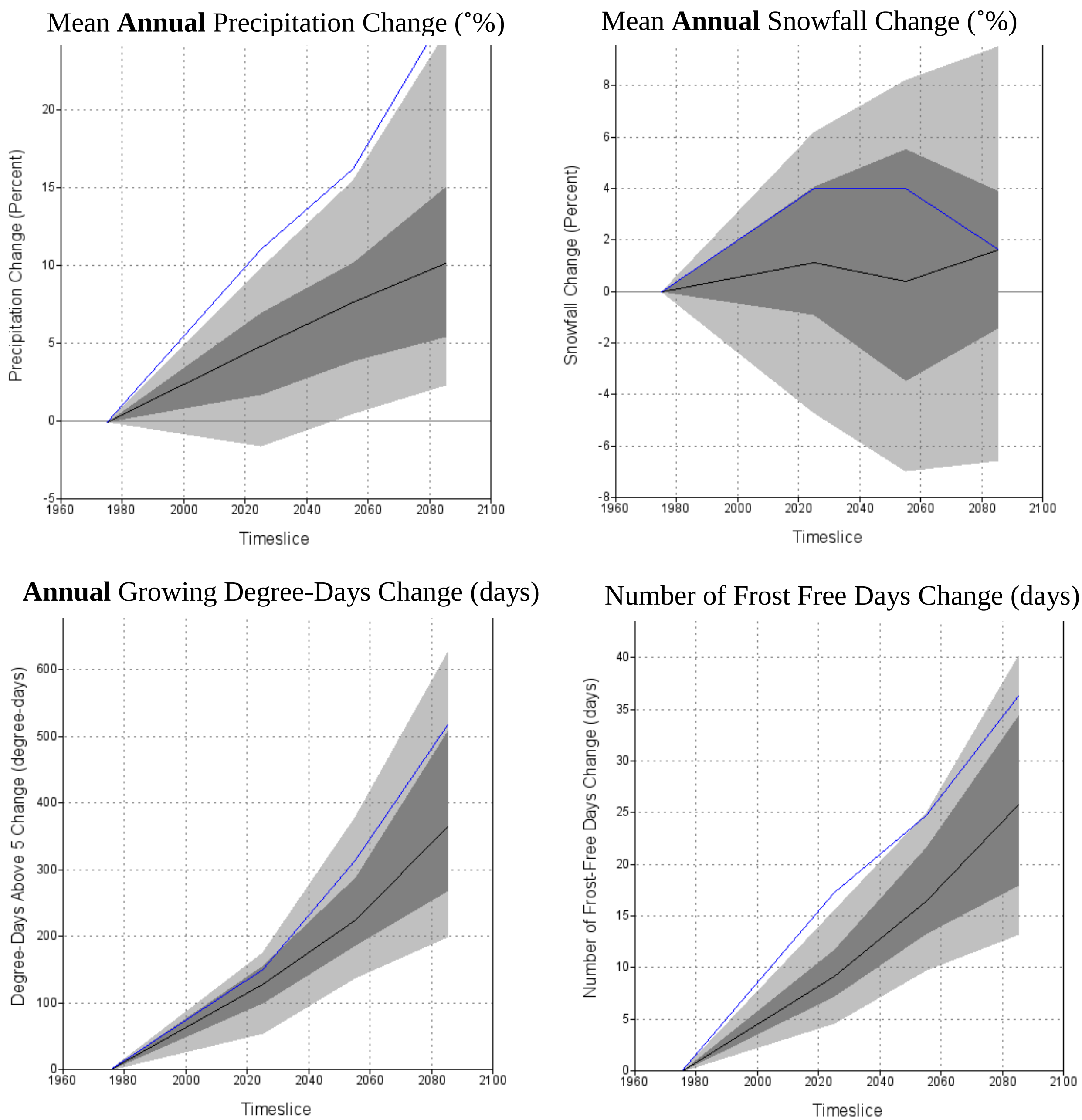
Figure 2. Mean **Annual** Temperature Change (˚C), for the **Peace River** Region from 1970 – 2099



*Projections were modeled according to a PCIC-standard set of GCM projections using the PCIC's online tool, "Plan2Adapt."

- The black line indicates the mid-point (median) in the set.
- The blue line indicates the model used for display purposes (CGCM3 A2 run 4).
- The dark grey shading shows the middle 50% (25th to 75th percentiles), representing half of the projections in the set.
- The light grey shading shows the range according to 80% of the climate change projections used (10th to 90th percentiles).

Figure 3. Mean Annual Climate Changes in the Peace River Region from 1970 – 2099.



*Projections were modeled according to a PCIC-standard set of GCM projections using the PCIC's online tool, "Plan2Adapt."

- The black line indicates the mid-point (median) in the set.
- The blue line indicates the model used for display purposes (CGCM3 A2 run 4).
- The dark grey shading shows the middle 50% (25th to 75th percentiles), representing half of the projections in the set.
- The light grey shading shows the range according to 80% of the climate change projections used (10th to 90th percentiles).

Research Purpose

The purpose of our research project was to sharpen the focus of the SCP framework through the explicit incorporation of a climate change lens incorporating connectivity. We were guided by the SCP framework, utilized a variety of spatial planning tools, and used publicly available climate change data to identify high priority areas for conservation within the PRB and produce a proposed protected areas network. The proposed protected areas network should meet targets for connectivity, size and representativeness, as well as promote climate change resiliency in the region. To achieve this, we were guided by a series of questions:

(1) What areas contain high conservation value for select coarse- and fine-filter features?
(2) What areas retain conservation value despite the presence of resource development?
(3) What is an optimal portfolio (i.e., spatial solution for conservation) from which to direct conservation planning efforts?
(4) What are the probable future climate conditions for the PB?
(5) What characterizes a climate resilient landscape and what elements of climate resiliency should be selected to guide conservation planning in the PB?
(6) How do high priority sites for landscape level conservation in the PB differ between a biodiversity-based approach, and a climate resiliency based approach to conservation area design?

Methods

This Living Labs project brings together approaches developed and undertaken by two graduate students: Ian Curtis and Jerrica Mann. Ian Curtis' work sets the context for this study through the use of systematic conservation planning using Marxan ILP to produce a proposed reserve system that identifies a critical portfolio of conservation lands. Climate is included in this first model through the inclusion of geodiversity values (Land Facet diversity and rarity derived from AdaptWest data) as one of the coarse filter values. Jerrica Mann's work used the same coarse and fine filter conservation elements in the same modeling software (Marxan ILP) but added explicit connectivity analysis (using OmniScape) as a pre and post analysis tool and incorporates climate change conscious metrics such as forward and backward velocity, novel ecosystems and climate refugia as variables for selection.

The methods described below are a summary of the combined steps of both projects. More complete write-ups of the methods, results and discussion that informed this work can be found in:

> Curtis, Ian. 2018. Systematic Conservation Planning in the Wild Harts Study Area. MSc Thesis, Natural Resource and Environmental Studies. University of Northern British Columbia.
>
> Mann, Jerrica. Forthcoming/2020. Climate Change Conscious Systematic Conservation Planning: A case study in the Peace River Break, British Columbia. MSc Thesis, Natural Resource and Environmental Studies. University of Northern British Columbia.

This project involved sharpening the focus of Margules and Pressey's (2000) systematic conservation planning (SCP) framework through the explicit incorporation of a climate lens. This involved build on the previous analysis completed by Curtis (2018), that was then refined and embellished to overcome identified limitations. This component was guided by the methods described by Littlefield, McRae, Michalak, Lawler, and Carroll (2017) to revise the methodologies in an attempt to overcome identified limitations. The eight steps involved in the SCP methods (Table 1) included: (1) selected, compiled, and developed conservation feature data; (2) performed a thorough analysis on anthropogenic disturbance in the study area; (3) used Gnarly Landscape Utilities and Linkage Mapper to quantify landscape permeability and identify important corridors for connectivity; (4) identified conservation goals and targets; (5) reviewed the existing protected areas to determine the extent to which the existing protected areas network achieves the identified targets for conservation in the WHSA; (6) selected additional conservation areas using MARXAN-ILP; (7) compared the resulting proposed protected areas network with another protected areas network solutions; (8) performed a comparative analysis to analyze complementarity (extent to which a biodiversity conservation targets, contribute to climate change resiliency conservation targets and vice versa) within the study area.

Table 1. The seven steps of systematic conservation planning used to prioritize lands for conservation in the Wild Harts Study Area.

1. Select, Compile and Develop Conservation Feature Data
a) Review literature, previous analysis by Curtis (2019), and existing data to identify which previously used datasets could be improved, and source additional multi-spatial surrogates for current biodiversity in the WHSA. b) Review literature and existing data to identify multi-spatial surrogates for future biodiversity in the WHSA, projected future species distribution data, climate change refugia and climate connectivity data. c) Select data with sufficient rigor and consistency for inclusion in the analysis. d) Develop spatial layers in ArcGIS that represent the extent of the selected conservation features within the WHSA.
2. Perform a Thorough Analysis on Anthropogenic Disturbance in the Study Area
e) Review literature and existing data sources to identify features that represent anthropogenic disturbance within the WHSA. f) Compile a human footprint model to quantify and spatially model the current state of anthropogenic disturbance in the WHSA. g) Perform land use/cover conversion analyses to identify the rate of land conversion within the WHSA. h) Perform resource development potential models to spatially identify which areas are most susceptible to future development.
3. Use Gnarly Landscape Utilities and Linkage Mapper to Quantify Landscape Permeability and Identify Important Corridors for Connectivity
i) Review literature and existing data to identify features that affect landscape permeability. j) Acquire and develop spatial layers in ArcGIS that represent landscape resistance in the WHSA. k) Create a landscape resistance spatial layer using Gnarly Landscape Utilities. k) Perform a landscape connectivity analysis between protected areas in the WHSA using the previously created landscape resistance layer and Linkage Mapper.
4. Identify Conservation Goals and Targets

l) Review literature and previous analysis results to set goals for conservation in the WHSA that promote climate change resiliency, facilitate climate change induced migrations, facilitate landscape connectivity, and promote current and future biodiversity. m) Translate these goals into quantifiable targets.
5. Review Existing Protected Areas
n) Determine the extent to which the existing protected areas network achieves the identified targets for conservation in the WHSA.
6. Use MARXAN with ILP to Generate a Portfolio of Additional Protected Areas
o) Use MARXAN - ILP to identify gaps the current protected areas network in the WHSA in order to spatially delineate additional areas for conservation. p) Spatially prioritize lands for conservation in the WHSA that achieve optimal targets while minimizing user-defined costs. q) Create a portfolio of proposed protected areas network designs for application in land-use planning decisions.
7. Perform a Comparative Analysis Between the Climate Change Conscious SCP Proposed Protected Areas Network and a Proposed Protected Areas Network Created Using Traditional Static SCP Methods
r) compare the resulting proposed protected areas network with another protected areas network that was created using the traditional SCP framework that did not include climate change projections.
8. Analyze Conservation Feature Complementarity and Representativeness Zones
s) Analyze the extent to which biodiversity conservation targets contribute to climate change resiliency conservation targets and vice versa within the study area.

Step 1. Select, Compile and Develop Conservation Feature Data

We reviewed the data that was previously used in Curtis (2018) as well as other existing data sources in order to identify which previously used datasets could be improved, and what additional datasets could enhance the analysis. We identified previously compiled binary datasets (Curtis, 2018) that could be improved through conversion into a scaled format and performed geospatial analyses to convert these binary data into a continuous, scaled datasets in ArcMap. We analyzed government and non-government databases and drew upon expert opinion to identify and obtain geospatial datasets that were reliable and consistent across the WHSA. By doing this we were able to identify additional current biodiversity surrogates and surrogates for future biodiversity. We also identified and created connectivity datasets that would enhance the analyses. Numerous current and future biodiversity feature datasets were obtained, processed, created, and combined using geospatial analysis in ArcGIS for inclusion in the WHSA SCP.

The literature review, data availability and expert opinion lead to the inclusion of three conservation feature classes in the MARXAN-ILP conservation prioritization analysis; (1) coarse-filter biodiversity surrogates; (2) fine-filter biodiversity surrogates and; (3) climate change conservation features (Table 2). It also led to the inclusion of representational conservation zones and connectivity conservation features. The following conservation features, unless stated otherwise, were developed in a continuous format, thus allowing for the preferred selection of those areas with the highest conservation values, both individually and cumulatively.

This study utilized a multi-scale prioritization strategy for current and future biodiversity refugia identification / conservation prioritization by seeking to incorporate the known extant of current biodiversity as well as future biodiversity by capturing high-diversity microrefugia within areas of low climatic velocity, across landscape types.

Table 2. Conservation Features used in MARXAN-ILP Analysis

	Coarse-Filter Features		Coarse-Filter Features		Climate Change Features
Land Facets	Land Facet Diversity	Grizzly Bear	Grizzly Habitat Capability		Backward Velocity Refugia
	Land Facet Rarity		Grizzly Habitat Suitability		Biotic Refugia
Environmental Diversity	Elevation Diversity	Woodland Caribou Herds	Burnt Pine Caribou Herd		Novel Climates
	Heat Load Index Diversity		Finlay Caribou Herd		
	Ecotypic Diversity		Gataga Caribou Herd		
	Climatic Diversity		Graham Caribou Herd		
Forest Patterns and Processes	NDT1-ESSF-Burned		Hart Ranges Caribou Herd		
	NDT1-ESSF-Mature/Old		Kennedy Caribou Herd		
	NDT1-ICH-Burned		Moberly Caribou Herd		
	NDT1-ICH-Mature/Old		Muskwa Caribou Herd		
	NDT2-ESSF-Burned		Narraway Caribou Herd		
	NDT2-ESSF-Mature/Old		Pink Mountain Caribou Herd		
	NDT2-SBS-Burned		Quintette Caribou Herd		
	NDT2-SBS-Mature/Old		Scott Caribou Herd		
	NDT2-SWB-Burned		Fisher		
	NDT2-SWB-Mature/Old		Bull Trout		
	NDT3-BWBS-Burned		Special Features		
	NDT3-BWBS-Mature/Old				
	NDT3-SBS-Burned				
	NDT3-SBS-Mature/Old				

Although this analysis incorporated a healthy diversity of conservation features, certain representational targets that are often overlooked but undeniably important to a healthy protected areas network were also deemed beneficial and thus, incorporated in this SCP. While these representational zones were not set as targets within MARXAN-ILP, their representational results were reviewed and considered in the assessment of each resulting MARXAN-ILP solution. The representational zones assessed in this SCP were ecoregional representativeness, elevational representativeness and climate representativeness.

Step 2. Analyze Anthropogenic Disturbance in the Study Area

The PRB region has experienced the development of a significant human footprint dominated by industrial landscape conversions. In spite of the extensive nature of these anthropogenic disturbances and the future resource development potential of the area, there is still a narrow band of intact forest landscapes running from Kakwa Provincial Park and the adjoining mountain park complex to the southeast and north to the Muskwa-Kechika Management Area. This Hart/Muskwa Ranges corridor that runs the length of the WHSA is not devoid of anthropogenic disturbances. Developments are creeping into the southern and central portions of this and future resource development potential suggests that these impacts will only increase.

In order to assess the severity and distribution of anthropogenic disturbance a thorough "human footprint" analysis was performed within the broader PRB region which encompasses the WHSA priority area and Hart/Muskwa Ranges corridor (Mann & Wright, 2018). To do this, data for each of 25 different types of human use was obtained from the Provincial BC Data Catalogue, consolidated, variably buffered, mapped and analyzed for the broader study area and for the Hart/Muskwa Ranges. Using ArcGIS, variable buffers were applied to the various forms of development based on woodland caribou avoidance behaviours (Mann & Wright, 2018). These buffers were considered suitable for this SCP given their large sizes, the avoidance buffers were able to address the needs of caribou, but also were likely to increase the probability of accommodating the needs of species that exhibited less sensitivity to resource development.

Since all human disturbance is not equal and ephemeral disturbances may recover over time, we created a semi-permanent (soft) footprint for those developments and land uses that create impacts that are more ephemeral in nature as well as a hard or more permanent human footprint. The hard human footprint created in this analysis was used in the creation of both the cost layer requires by MARXAN-ILP, as well as in the creation of the current landscape connectivity model.

Step 3. Use Gnarly Landscape Utilities and Linkage Mapper to Quantify Landscape Permeability and Identify Important Corridors for Connectivity

Connectivity between protected areas promotes ecological persistence by facilitating dispersal, allowing for critical ecological exchanges at the genetic and population levels (Wright, 2016). As the majority of protected areas in Canada are small compared to the evidence of what is needed as scientific benchmarks, connectivity between protected areas is vitally important. By enhancing the structural connectivity (landscape permeability) between protected areas and across landscapes, functional connectivity (actual movement of organisms and their genetic material) can be significantly improved, thus promoting ecological persistence (Doerr, Barrett, & Doerr, 2011). As only a handful of Canadian protected areas meet the minimum size thresholds (>3000 km^2) deemed necessary for ecological persistence (Wright, 2016), the existing Canadian protected areas network is limited in its ability to sustain and promote biodiversity. Building connectivity between protected areas would allows smaller habitat patches or protected areas to function as a protected areas network that collectively supports ecological persistence by allowing linked subpopulations to function as one larger, more resilient population.

While the climate corridors identified by Carroll et al. (2018) identified paths between current climate types and their future analogs that could be used by species as they track shifting climates while avoiding non-analogous climates, the creation of these corridors did not attempt to connect large intact habitats minimally impacted by anthropogenic barriers/disturbances. Accordingly, in order to build connectivity between protected areas into the WHSA protected areas network, we performed a landscape connectivity analysis in the broader Peace River Break region to identify those areas most likely to serve as wildlife corridors between the protected areas in the region.

We completed a landscape connectivity analysis using Gnarly Landscape Utilities and Linkage Mapper software. Linkage Mapper is a relatively new tool that utilizes both random walk analysis and electric circuit theory to measure the matrix permeability of all possible pathways available to moving organisms across a landscape/surface (McRae, Dickson, Keitt, & Shah, 2008). This allows measures of current (movement of organisms) and resistance (opposition to individual movement) between nodes (habitat patches) to be interpreted as the movement probabilities of organisms across a resistance raster/landscape. As a result, Linkage Mapper is capable of removing potential sources of bias and produces an intuitive output map of connectivity across a study area. The output connectivity map is not species-specific, but rather, focuses on the structural connectivity of natural lands.

We modelled landscape connectivity (connecting habitat patches as Protected Areas across space) using Gnarly Landscape Utilities and Linkage Mapper to map landscape connectivity within the broad Peace River Break study area. Gnarly Landscape Utilities was used to create the resistance layer and core habitat map layers required by Linkage Mapper. The resistance layer was created using data from the Provincial BC data catalogue. Land cover from the Vegetation Resource Inventory, slope, the hard human footprint data layers and their caribou avoidance buffers compiled in the human footprint project were all given a resistance value (0-100) and converted into a single continuous landscape resistance dataset using Gnarly Landscape Utilities. We used the protected areas polygons as the core areas/habitat patches and the “Sum” resistance calculation method to obtain a landscape resistance layer depicting those areas from lowest (1) to highest (326) resistance.

The resistance layer created using the ArcMap Gnarly Landscape Utilities toolbox was then used as an input in the Linkage Mapper Toolkit’s Linkage Pathways Tool. The results show a continuous fabric as measures of current (or movement of organisms) and resistance (or opposition to movement) between habitat patches which can be interpreted as movement probabilities of organisms across a landscape. In order to remove those areas of poor connectivity and more clearly define the landscape connectivity corridors wetruncated the data values at 200,000. This truncation value was found to most clearly depict those areas with the highest connectivity values (movement probabilities) while removing those areas that have negligible movement probabilities.

We incorporated the resultant landscape connectivity dataset into this SCP as supplemental information that was excluded from the MARXAN-ILP analysis. If this corridor data was included in the MARXAN-ILP analysis there would be no way to discourage the tool from selecting small portions of disparate corridors without first assigning each corridor a relative importance, unique identity, and target. As the importance/value of each individual corridor would change with the establishment of new protected areas and the conservation goal, connectivity corridors were not included into the MARXAN-ILP analysis but rather provided as an overlay to identify important areas of connectivity between the existing protected areas network.

Step 4: Identify conservation goals for the PRB

One of the primary goals of this study was to prioritize lands for conservation in the WHSA that would strengthen the existing protected areas network within the region by promoting climate change resiliency, biodiversity and ecological sustainability, connectivity, and maintaining disturbance regimes. The conservation features, representational targets, and connectivity models previously described were carefully curated and developed with these goals in mind. Land facet diversity and rarity were selected for due to the strong evidence for this geophysical approach being effective at predicting current and future biodiversity. Environmental diversity metrics were selected due to their simple, and generalizable approach to identifying potential micro-refugia which can increase the probability that species will be able to find suitable habitat within close proximity as climate changes as well as their ability to maximize landscape-level adaptive capacity. Forest pattern and process were selected as they represent distinct disturbance regimes in combination with forest types containing high levels of biodiversity. Each individual species chosen as fine-filter conservation features were selected due to their vulnerability and ability to represent a wide range of ecosystems and the habitat needs making them effective surrogates for biodiversity. Climatic refugia was selected for as these sites are anticipated to experience climate change at slower rates and smaller magnitudes making them vital refugia for climate-displaced species. Biotic refugia were selected as these increasingly rare climatic conditions are required by, and will be within reach of, species in the future. Novel climates were selected for as they provide a potentially strong driving mechanism for disaggregation of existing species associations, assembly into novel associations and other unexpected ecological responses or 'ecological surprises' and present novel opportunities for testing ecological theory. Representational targets and connectivity corridors were included in this SCP in order to assess the effectiveness of the conservation features at meeting the goals of this study and provide supplemental information that would be used to evaluate the MARXAN-ILP solutions.

Step 5: Review Existing Protected Areas in the WHSA

In order to determine the extent to which existing protected areas have already contributed to conservation targets WHSA, we dissolved all of the protected areas within the study area into one multi-part polygon. This protected areas feature was then incorporated into MARXAN-ILP and scenarios were run with a 100% protected areas target. This revealed the percent of each conservation feature that was already protected. The percentage of each conservation feature already represented by the existing protected areas network was then subtracted from each of the identified conservation feature targets and set as the MARXAN-ILP target in order to resolve the discrepancy between the target's percent currently achieved and the target's desired percent.

Step 6: Use MARXAN with ILP to Generate a Portfolio of Additional Protected Areas

We used the conservation prioritization software MARXAN to model alternative protected areas network designs based on specified targets and constraints. A MARXAN Model that was previously developed for the WHSA study area by Curtis (2018) was used as a guide in this SCP. The previously developed MARXAN model followed the traditional SCP framework, used binary conservation features, and did not include climate change information aside from the inclusion of land facet diversity as a model variable. In an attempt to overcome the resulting shortcomings and endeavor to achieving outstanding targets/goals for conservation within the WHSA, we enhanced many of the conservation features previously created by Curtis (2018), added additional conservation features and representativeness zones for comparative analyses.

The ArcGIS-based prioritization software MARXAN that operates within an integer linear programming (ILP) framework (Beyer, Dujardin, Watts, & Possingham, 2016) was used to perform conservation prioritization in this SCP. MARXAN with ILP was used to maximize the extent to which targets for conservation were achieved within the planning unit at the lowest cost (with the least amount of area and in areas with the least amount of human modification).

We then assembled a portfolio of recommended protected areas network designs for the WHSA study area that includes both core and corridor areas and meet targets for connectivity, size and representativeness, as well as promote climate change resiliency in the region. The resulting conservation prioritization portfolios were then enhanced through the reintroduction of a conservation value metric identifying the number of targets met per planning cell.

We developed three MARXAN-ILP scenarios to address the research questions. Each scenario, was parametrized to meet conservation targets at the lowest possible cost in order to encourage the selection of areas containing multiple overlapping high value conservation features while avoiding areas with compounding anthropogenic disturbances within or proximal to the planning unit. In scenario A, we set targets on only those static conservation targets identified by Curtis (2018) with the addition of a fisher habitat layer. By doing this, we were able to identify which areas contain the highest "current state" conservation values. This also created a, updated solution comparable to the SCP completed by Curtis (2018). Scenario A identified the minimum area required to achieve the current biodiversity feature targets, as well as how much of the future biodiversity targets could be passively obtained by this scenario. In scenario B, targets were only set on future biodiversity features in order to identify those areas within the WHSA with the most future biodiversity conservation value (Table 3). The percent of each future biodiversity conservation feature that was obtained by Scenario A was evaluated and used to develop the targets for Scenario B. All future conservation features were determined to be satisfactorily represented by Scenario A so the percent of each future biodiversity feature obtained by Scenario A was used as the targets in Scenario B (Table 4). The final scenario; scenario C, incorporated both "current state" and "future state" conservation feature targets in order to most efficiently prioritize planning units have the highest conservation value in areas that meet the needs of "current" and "future" biodiversity while avoiding anthropogenically disturbed lands (Table 5). The targets used in Scenario A and Scenario B were both used in Scenario C. In performing this analysis, MARXAN-ILP was forced to essentially achieve the same targets that were obtained in Solution A but more effectively, by evaluating the unique conservation scores within each current and future biodiversity conservation feature input layer. This ensured the analysis captured the most efficient and effective solution with little to no additional cost.

Scenario	Conservation Feature Inputs
A.	grizzly bear; caribou; fisher; bill trout; special features; forest patterns & processes
B.	land facet diversity & rarity; heat load index diversity; ecotypic diversity; climate diversity; backwards refugia; biotic refugia; novel climates
C.	All of the above

Table 3. Scenario A – Current Biodiversity Feature Targets

Conservation Feature	% Protected	% Target	Additional % Needed
Grizzly Habitat Capability	17	60	43
Grizzly Habitat Suitability	18	60	42
Burnt Pine Caribou Herd	0	90	90
Finlay Caribou Herd	1	90	89
Gataga Caribou Herd	25	90	65
Graham Caribou Herd	14	90	76
Hart Ranges Caribou Herd	16	90	74
Kennedy Caribou Herd	15	90	75
Moberly Caribou Herd	3	90	87
Muskwa Caribou Herd	95	90	0
Narraway Caribou Herd	19	90	71
Pink Mountain Caribou Herd	27	90	63
Quintette Caribou Herd	6	90	84
Scott Caribou Herd	0	90	90
Fisher	8	60	52
Bull Trout	19	60	41
Special Features	22	60	38

NDT1-ESSF-Burned	22	100	78
NDT1-ESSF-Mature/Old	8	74	66
NDT1-ICH-Burned	23	100	77
NDT1-ICH-Mature/Old	30	75	45
NDT2-ESSF-Burned	2	100	98
NDT2-ESSF-Mature/Old	13	75	62
NDT2-SBS-Burned	5	100	95
NDT2-SBS-Mature/Old	5	66	61
NDT2-SWB-Burned	67	100	33
NDT2-SWB-Mature/Old	26	83	57
NDT3-BWBS-Burned	24	100	76
NDT3-BWBS-Mature/Old	10	46	36
NDT3-SBS-Burned	0	100	100
NDT3-SBS-Mature/Old	1	76	75
Climatic Diversity	13	-	NA
Ecotypic Diversity	11	-	NA
Elevation Diversity	26	-	NA
Heat Load Index Diversity	30	-	NA
Land Facet Diversity	16	-	NA
Land Facet Rarity	28	-	NA
Biotic Refugia	41	-	NA
Backwards Velocity Refugia	23	-	NA
Novel Climates 2025	2	-	NA
Novel Climates 2055	21	-	NA
Novel Climates 2085	18	-	NA

Table 4. Scenario B – Future Biodiversity Feature Targets

Conservation Feature	% Protected	% Target	Additional % Needed
Grizzly Habitat Capability	17	-	43
Grizzly Habitat Suitability	18	-	42
Burnt Pine Caribou Herd	0	-	90
Finlay Caribou Herd	1	-	89
Gataga Caribou Herd	25	-	65
Graham Caribou Herd	14	-	76
Hart Ranges Caribou Herd	16	-	74
Kennedy Caribou Herd	15	-	75
Moberly Caribou Herd	3	-	87

Muskwa Caribou Herd	95	-	0
Narraway Caribou Herd	19	-	71
Pink Mountain Caribou Herd	27	-	63
Quintette Caribou Herd	6	-	84
Scott Caribou Herd	0	-	90
Fisher	8	-	52
Bull Trout	19	-	41
Special Features	22	-	38
NDT1-ESSF-Burned	22	-	78
NDT1-ESSF-Mature/Old	8	-	66
NDT1-ICH-Burned	23	-	77
NDT1-ICH-Mature/Old	30	-	45
NDT2-ESSF-Burned	2	-	98
NDT2-ESSF-Mature/Old	13	-	62
NDT2-SBS-Burned	5	-	95
NDT2-SBS-Mature/Old	5	-	61
NDT2-SWB-Burned	67	-	33
NDT2-SWB-Mature/Old	26	-	57
NDT3-BWBS-Burned	24	-	76
NDT3-BWBS-Mature/Old	10	-	36
NDT3-SBS-Burned	0	-	100
NDT3-SBS-Mature/Old	1	-	75
Climatic Diversity	13	67	54
Ecotypic Diversity	11	67	55
Elevation Diversity	26	75	49
Heat Load Index Diversity	30	79	50
Land Facet Diversity	16	65	49
Land Facet Rarity	28	67	38
Biotic Refugia	41	90	49
Backwards Velocity Refugia	23	75	52
Novel Climates 2025	2	31	29
Novel Climates 2055	21	64	42
Novel Climates 2085	18	67	49

Table 5. Scenario C – Current and Future Biodiversity Feature Targets

Conservation Feature	% Protected	% Target	Additional % Needed
Grizzly Habitat Capability	17	60	43
Grizzly Habitat Suitability	18	60	42
Burnt Pine Caribou Herd	0	90	90
Finlay Caribou Herd	1	90	89
Gataga Caribou Herd	25	90	65
Graham Caribou Herd	14	90	76
Hart Ranges Caribou Herd	16	90	74
Kennedy Caribou Herd	15	90	75
Moberly Caribou Herd	3	90	87
Muskwa Caribou Herd	95	90	0
Narraway Caribou Herd	19	90	71
Pink Mountain Caribou Herd	27	90	63
Quintette Caribou Herd	6	90	84
Scott Caribou Herd	0	90	90
Fisher	8	60	52
Bull Trout	19	60	41
Special Features	22	60	38
NDT1-ESSF-Burned	22	100	78
NDT1-ESSF-Mature/Old	8	74	66
NDT1-ICH-Burned	23	100	77
NDT1-ICH-Mature/Old	30	75	45
NDT2-ESSF-Burned	2	100	98
NDT2-ESSF-Mature/Old	13	75	62
NDT2-SBS-Burned	5	100	95
NDT2-SBS-Mature/Old	5	66	61
NDT2-SWB-Burned	67	100	33
NDT2-SWB-Mature/Old	26	83	57
NDT3-BWBS-Burned	24	100	76
NDT3-BWBS-Mature/Old	10	46	36
NDT3-SBS-Burned	0	100	100
NDT3-SBS-Mature/Old	1	76	75
Climatic Diversity	13	67	54
Ecotypic Diversity	11	67	55
Elevation Diversity	26	75	49
Heat Load Index Diversity	30	79	50
Land Facet Diversity	16	65	49

Land Facet Rarity	28	67	38
Biotic Refugia	41	90	49
Backwards Velocity Refugia	23	75	52
Novel Climates 2025	2	31	29
Novel Climates 2055	21	64	42
Novel Climates 2085	18	67	49

Step 7: Perform a Comparative Analysis between the Climate Change Conscious SCP Proposed Protected Areas Network and a Proposed Protected Areas Network Created Using Traditional Static SCP Methods

One of the primary goals of this study was to determine how high-priority sites for landscape-level conservation in the WHSA differ between a static biodiversity-based approach, and a climate resiliency-based approach to conservation area design. To address this goal, we compared the outcomes of scenario 1 (current state), scenario 2 (future state), and the final scenario 3 (inclusive). As all of the analyses were performed on the same study area and used the same cost layer, a comparative analysis allowed us to identify how the incorporation of climate change data for future state planning affected the conservation prioritization results.

Step 8: Analyze Conservation Feature Complementarity and Resultant Representativeness

Using MARXAN-ILP we also analyzed the complementarity (extent to which conservation targets, contributed to other conservation targets) of current and future state conservation planning features. To do this, a MARXAN-ILP analysis was run for each individual conservation feature with a 100% target for only that feature. This revealed, for each conservation feature, how much it that individual conservation feature represents every other conservation feature (what percent) in the analysis. By doing this we were able to determine the ability of each conservation feature to capture other conservation feature targets. This analysis helped to determine whether certain conservation features could reasonably serve as surrogates for other targets.

To further understand how conservation targets and scenario solutions contributed towards representational targets (zones) we reviewed the extent to which the 3 scenario solutions are distributed amongst each of the representational zones within the WHSA. To do this we included the representational features in the MARXAN-ILP analysis but did not set a target on them. When the scenarios were run, the solution metrics revealed the percent of each representativeness zone was achieved by the solution.

Results

A total of 43 conservation feature layers were constructed, overlain across the entire planning region, and made available for selection by MARXAN-ILP. An additional 45 representational zone and 4 connectivity corridor datasets were included in the analysis as supplemental information. Each conservation features was given an equal value of (1) if present within a planning unit.

Coarse-filter Conservation Features

Twenty coarse-filter conservation features were used in this analysis. Coarse-filter features included land facet diversity, land facet rarity, elevational diversity, heatload index diversity, ecotypic diversity, climate diversity and a series of layers displaying an intersection of natural disturbance, biogeoclimatic zone, and forest age (Figures 4-10).

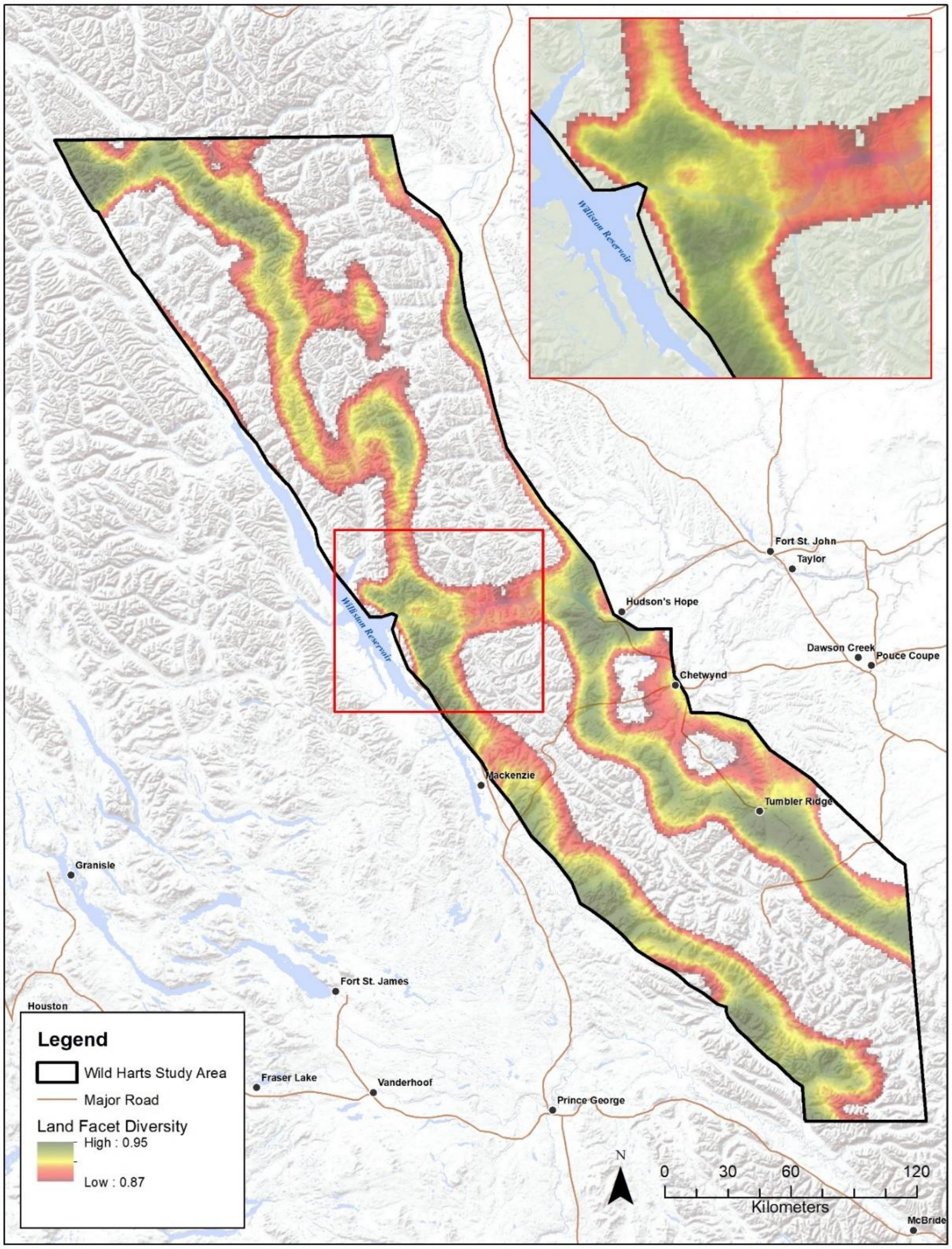


Figure 4. Spatial extent of the land facet diversity layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

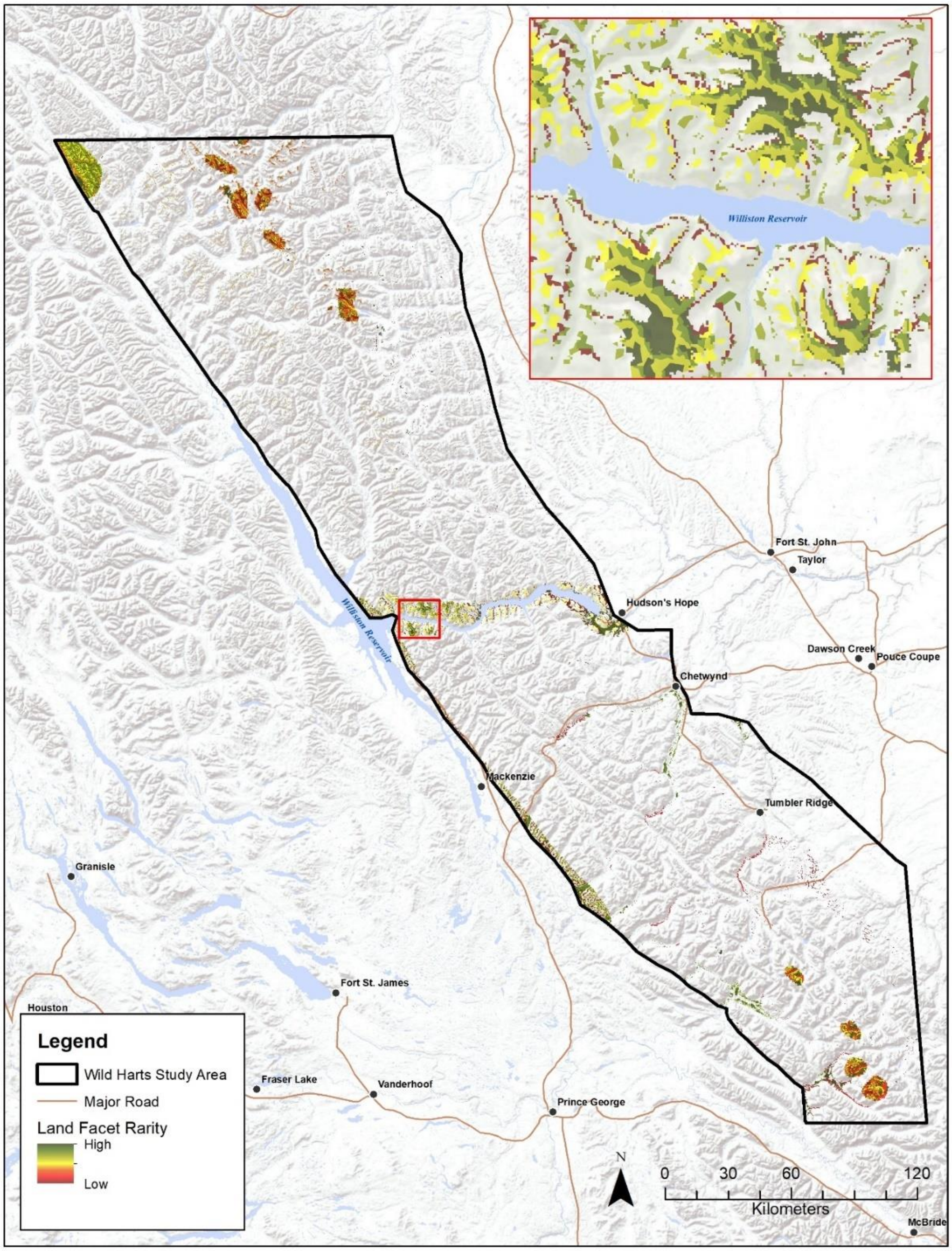


Figure 5. Spatial extent of the land facet rarity layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

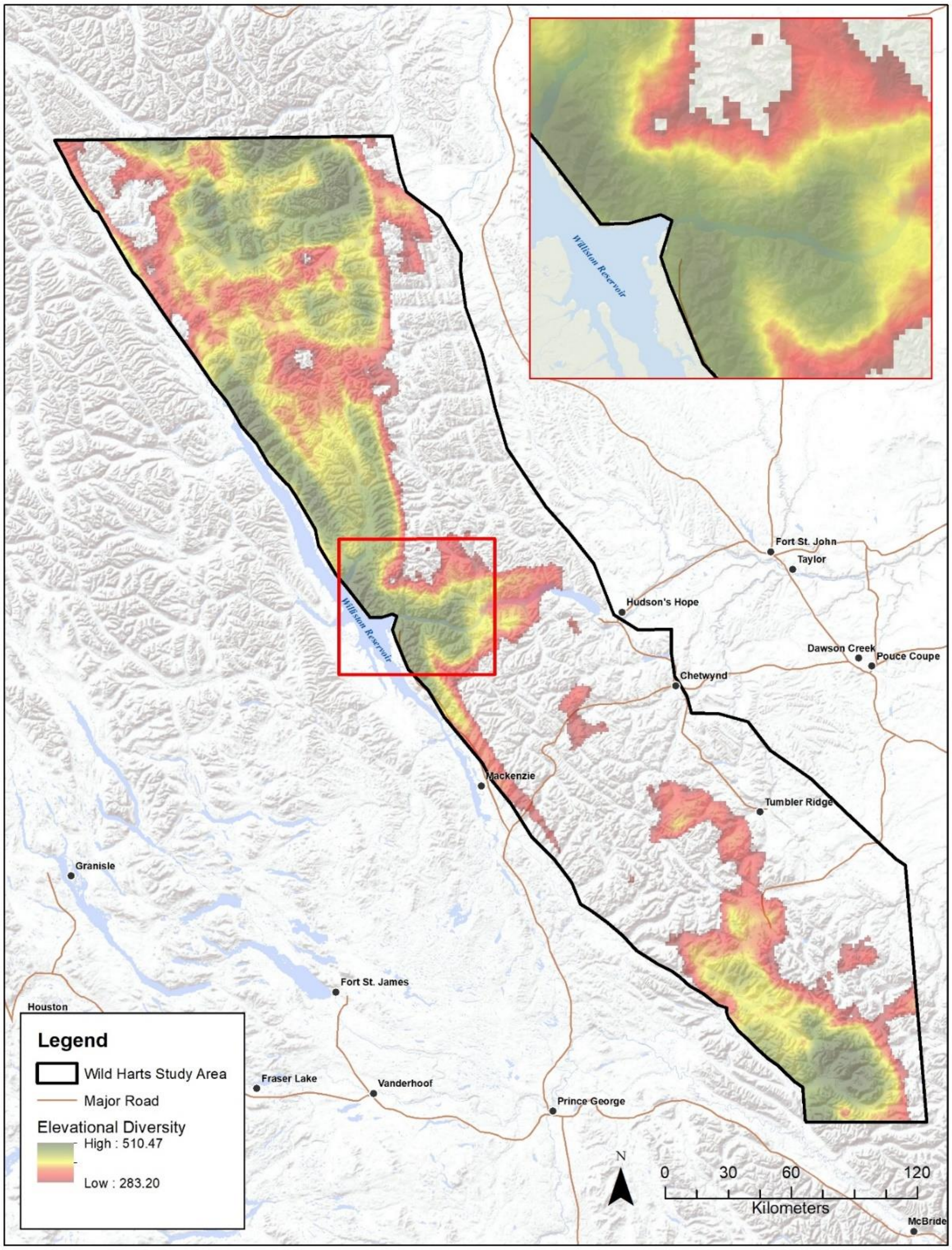


Figure 6. Spatial extent of the elevational diversity layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

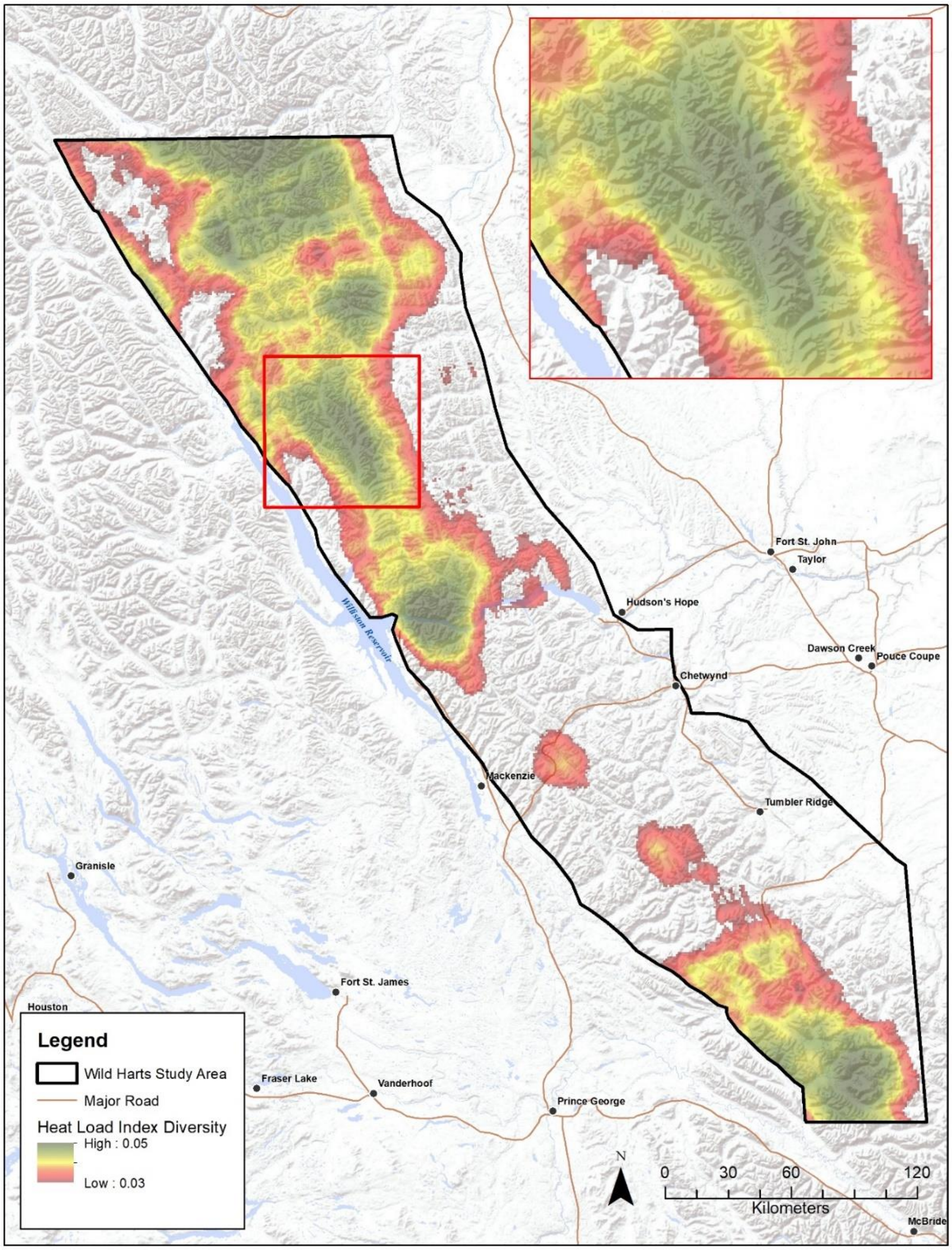


Figure 7. Spatial extent of the heat load index diversity layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

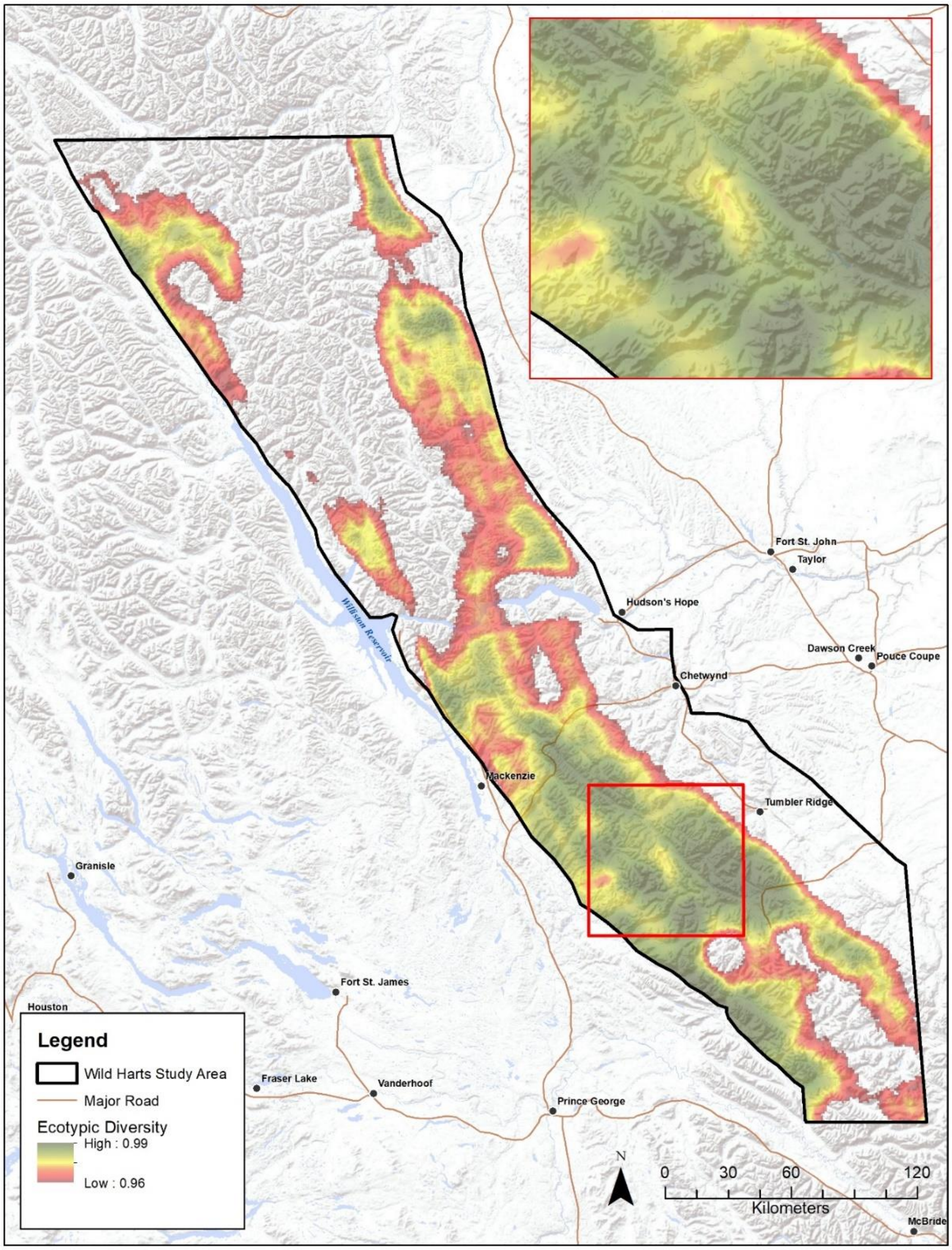


Figure 8. Spatial extent of the ecotypic diversity layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

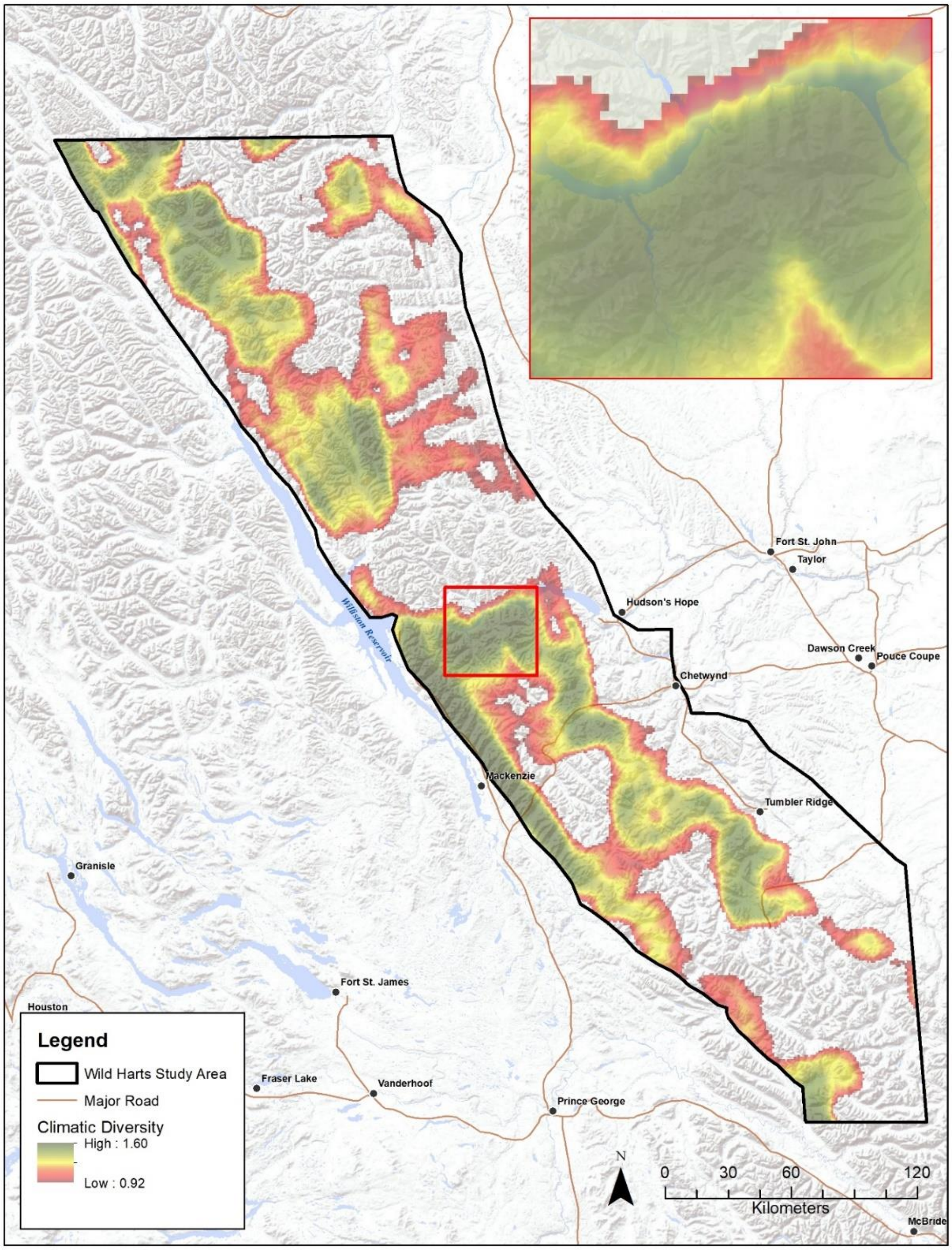


Figure 9. Spatial extent of the climatic diversity layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

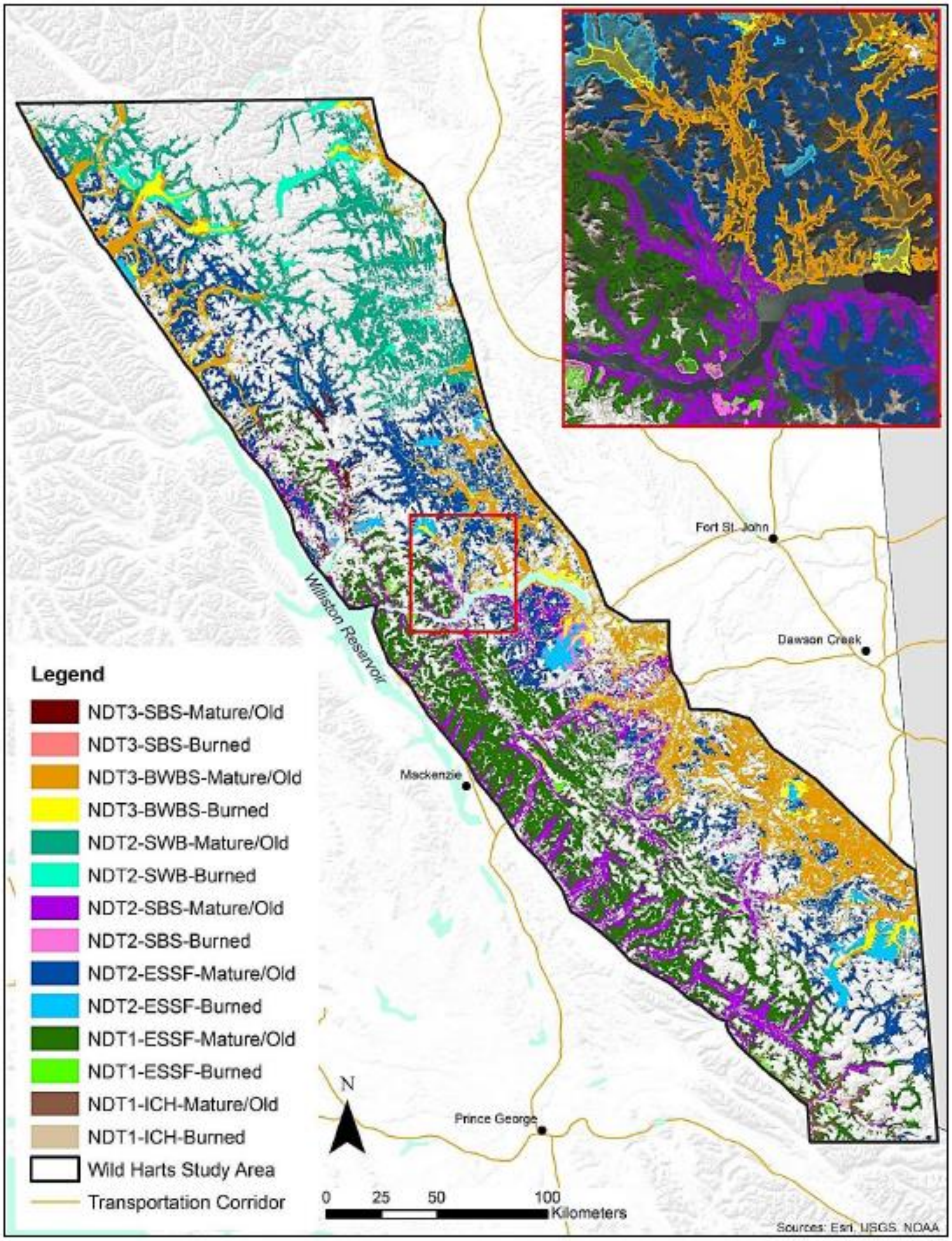


Figure 10. Spatial extent of all forest pattern and process layers used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame (Curtis 2018)

Fine-filter Conservation Features

In an attempt to adapt conservation planning for climate change, conservation scientists have begun to complement the coarse-filter conservation features with additional fine-filter conservation features. This hybrid approach allows this SCP to hedge against uncertainty, take advantage of new information and methods, and customize planning to the unique needs and limitations of planning areas, thereby improving biodiversity conservation outcomes. We created an additional 17 layers showing the spatial extent and conservation value of select fine-filter conservation features across the WHSA (Figures 11-15).

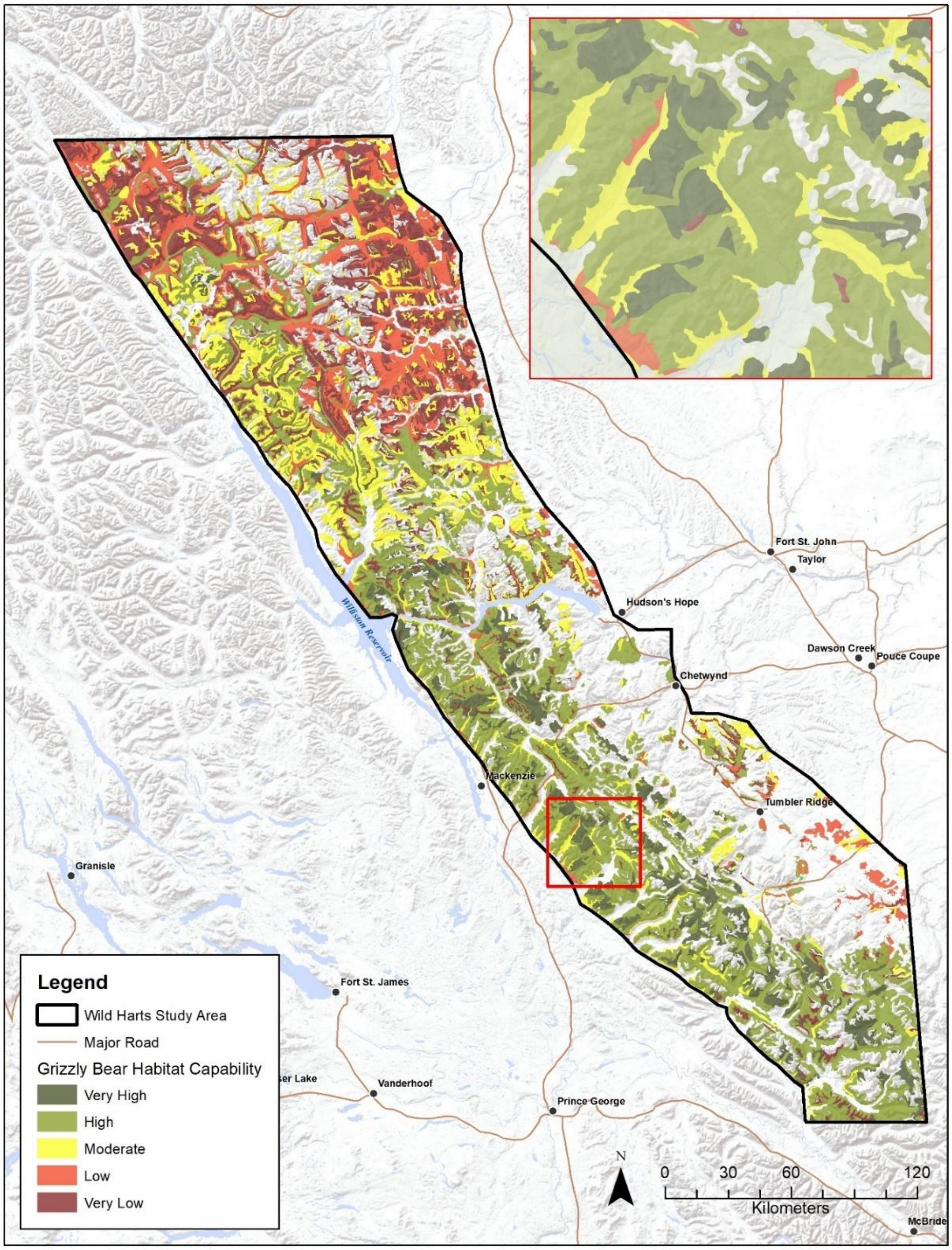


Figure 11. Spatial extent of the grizzly bear habitat capability layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

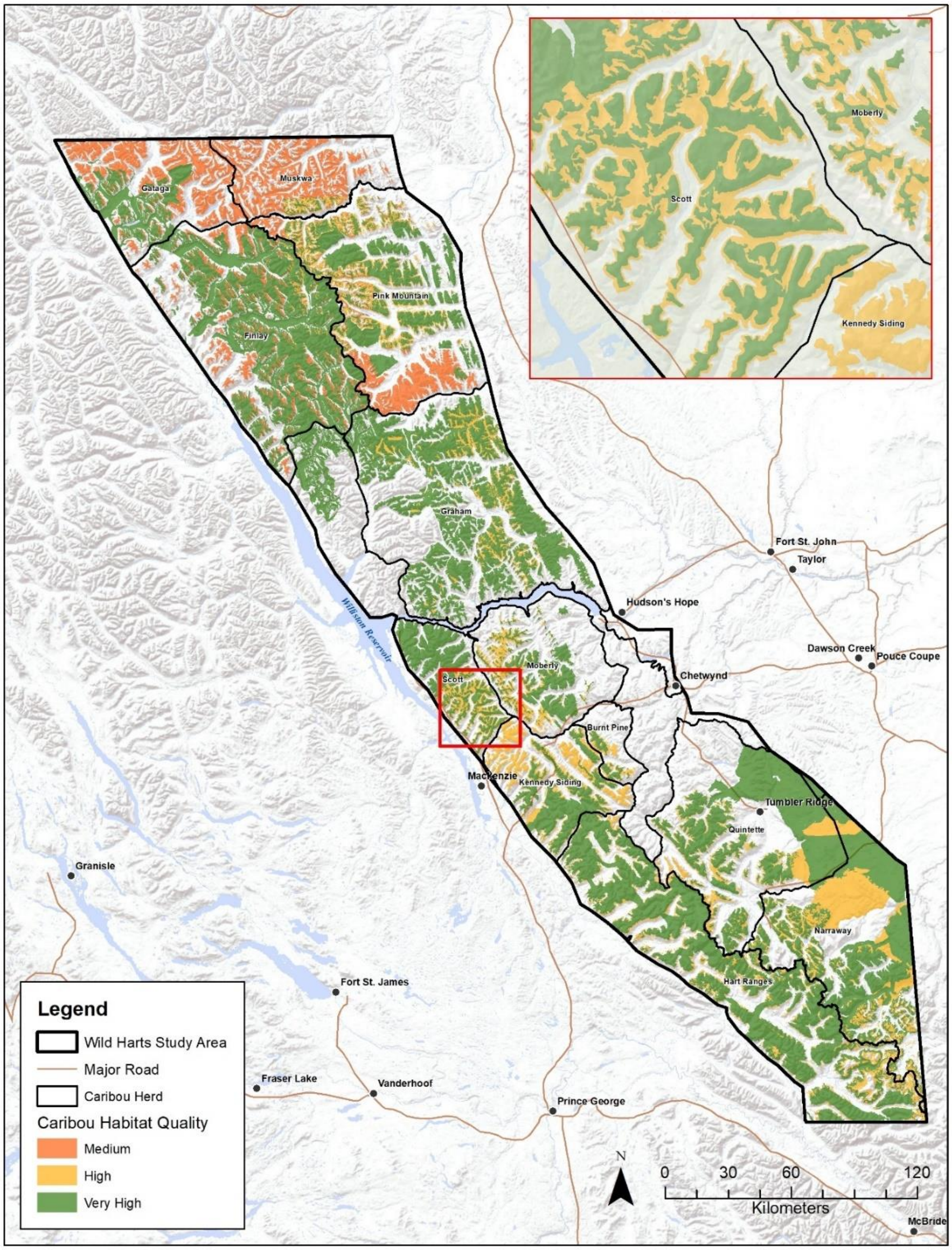


Figure 12. Spatial extent of the woodland caribou layers used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

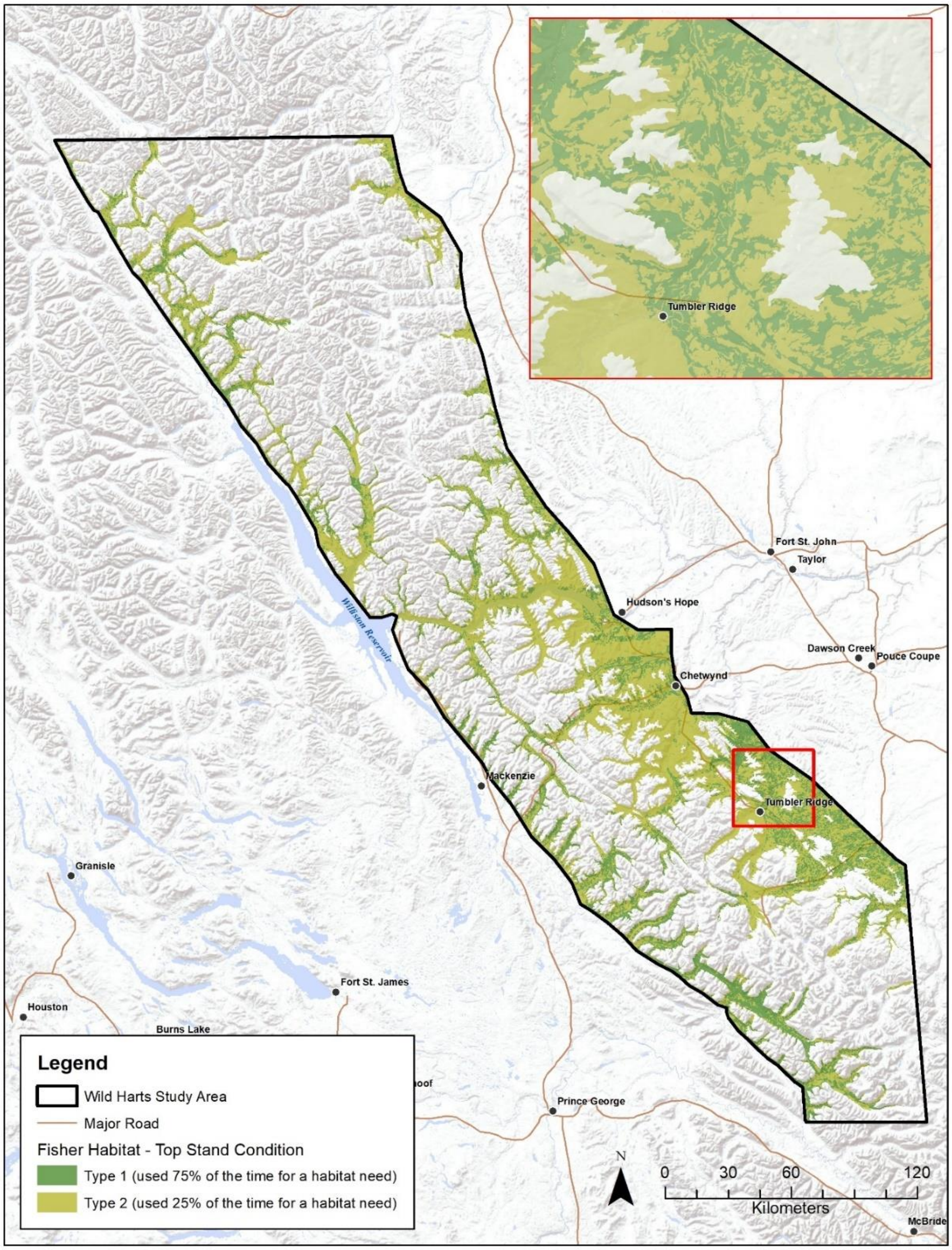


Figure 13. Spatial extent of the fisher layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

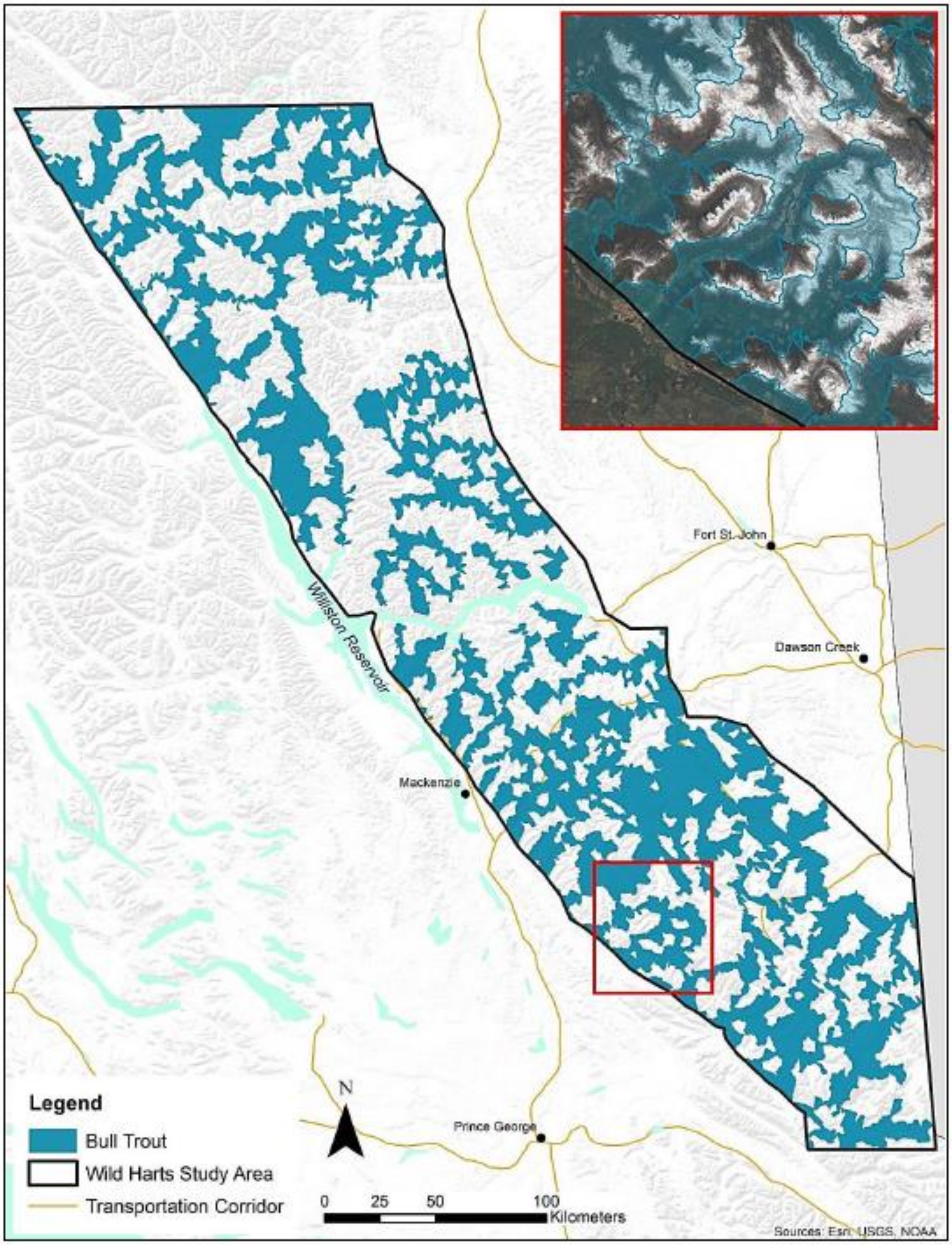


Figure 14. Spatial extent of the bull trout layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame. (Curtis, 2018)

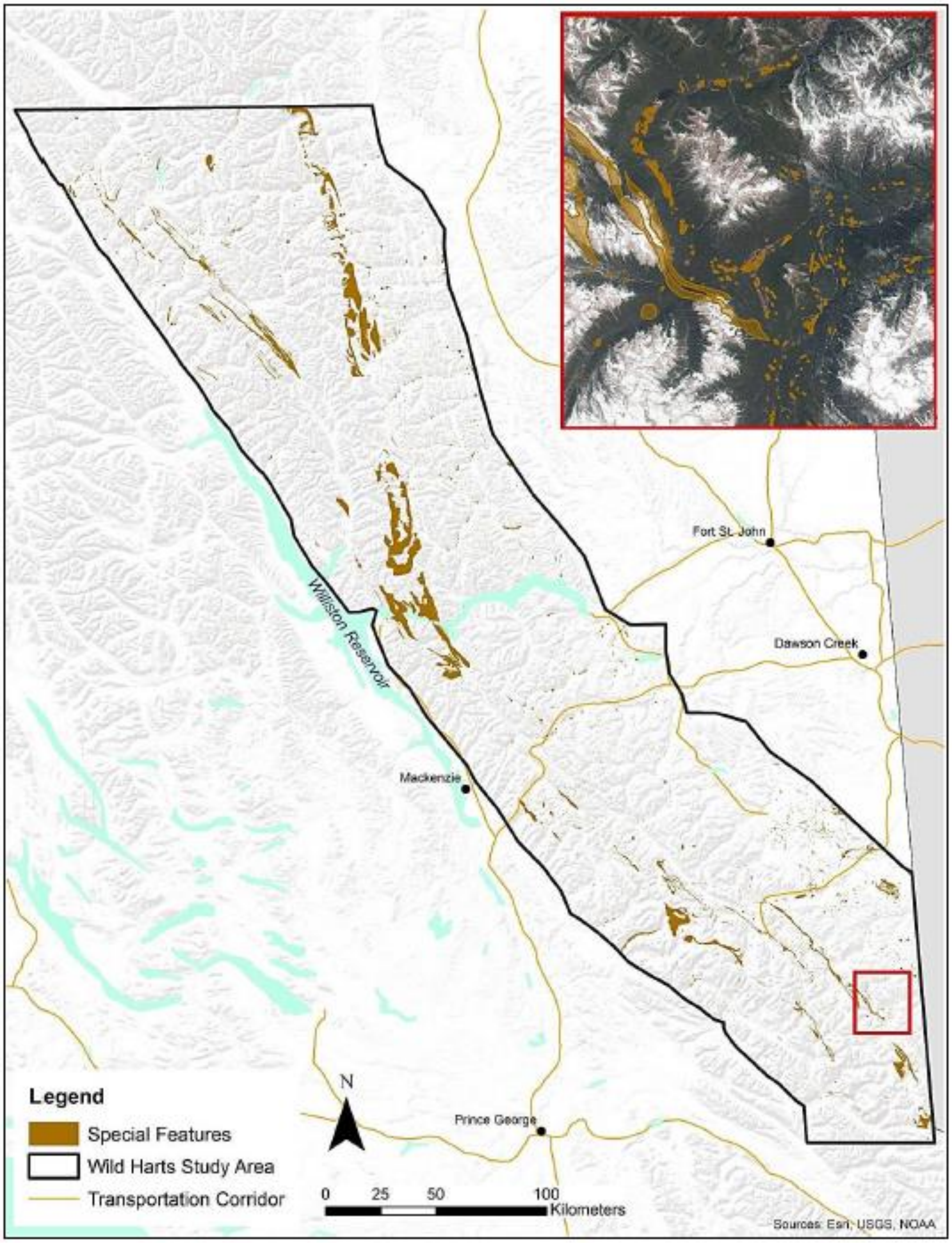


Figure 15. Spatial extent of the special features layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame. (Curtis, 2018)

Climate Change Conservation Features

In addition to the protection of coarse and file-filter conservation features, we included climate change conservation features as another approach to climate change-conscious conservation. We created 5 climate change conservation layers to incorporate areas resilient to climate change, areas identified as important biotic refugia, and areas projected to experience novel climatic regimes in the future. Given the unique focus of this project a summary of these features is provided here with full details provided in J. Mann's thesis.

Backward Velocity Refugia

The backward velocity refugia potential layer occupies 51% of the total WHSA's area and is already 23% protected by the existing protected areas network (Fig. 16). The areas of highest backward velocity refugia occur in the northern half of the WHSA at the highest elevations of the mountainous terrain. These areas exhibiting high backward velocity refugia potential demonstrate a clear association with elevation within the WHSA (19% = Low, 34% = Medium and 47% = High).

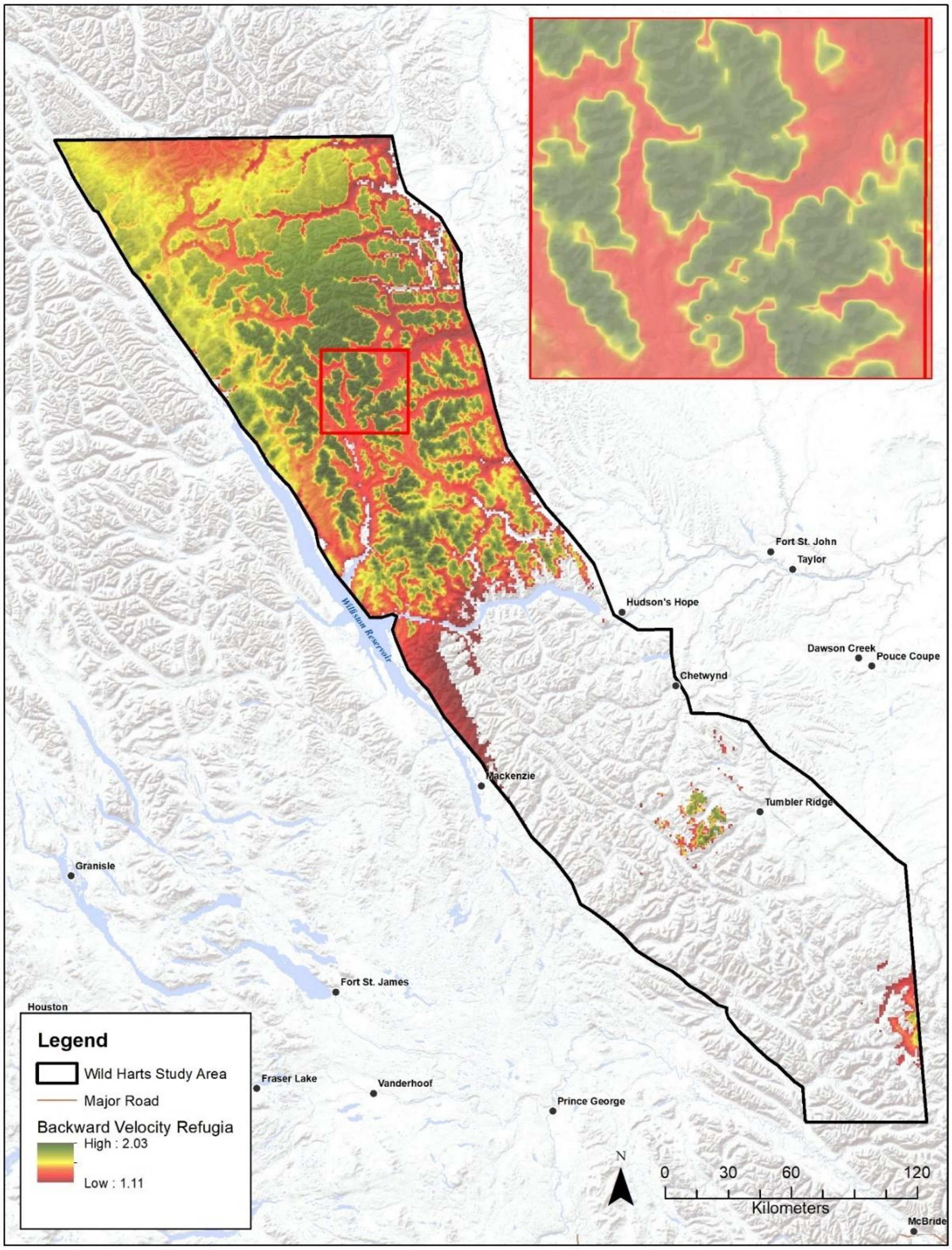


Figure 16. Spatial extent of the backward velocity refugia layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

Novel Climates

Three novel climate layers were created for 2025, 2055 and 2085. The 2025, 2055 and 2085 novel climate data layers occupy 1.8%, 20.7% and 74.9% of the total WHSA area, and are 2.2%, 21.2% and 17.8% currently protected, respectively (Fig. 17-19). The novel climate data is largely located within valley bottoms that may lack nearby climate analogs, resulting in longer migration distances to colonize these locally new habitat/climate conditions. In 2025 novel climates are restricted to low elevation areas, largely to the southwest of Hudson's, by 2055 they spread to the majority of the valley bottoms on the eastern side of the WHSA and appear in some of the northwest and southwest quadrants of the WHSA, and by 2085 novel climates emerge across the vast majority of the WHSA with the exception of the area to the north of the Peace Arm Peace Arm of the Williston Reservoir along the western boarder of the WHSA (Fig. 17-19).

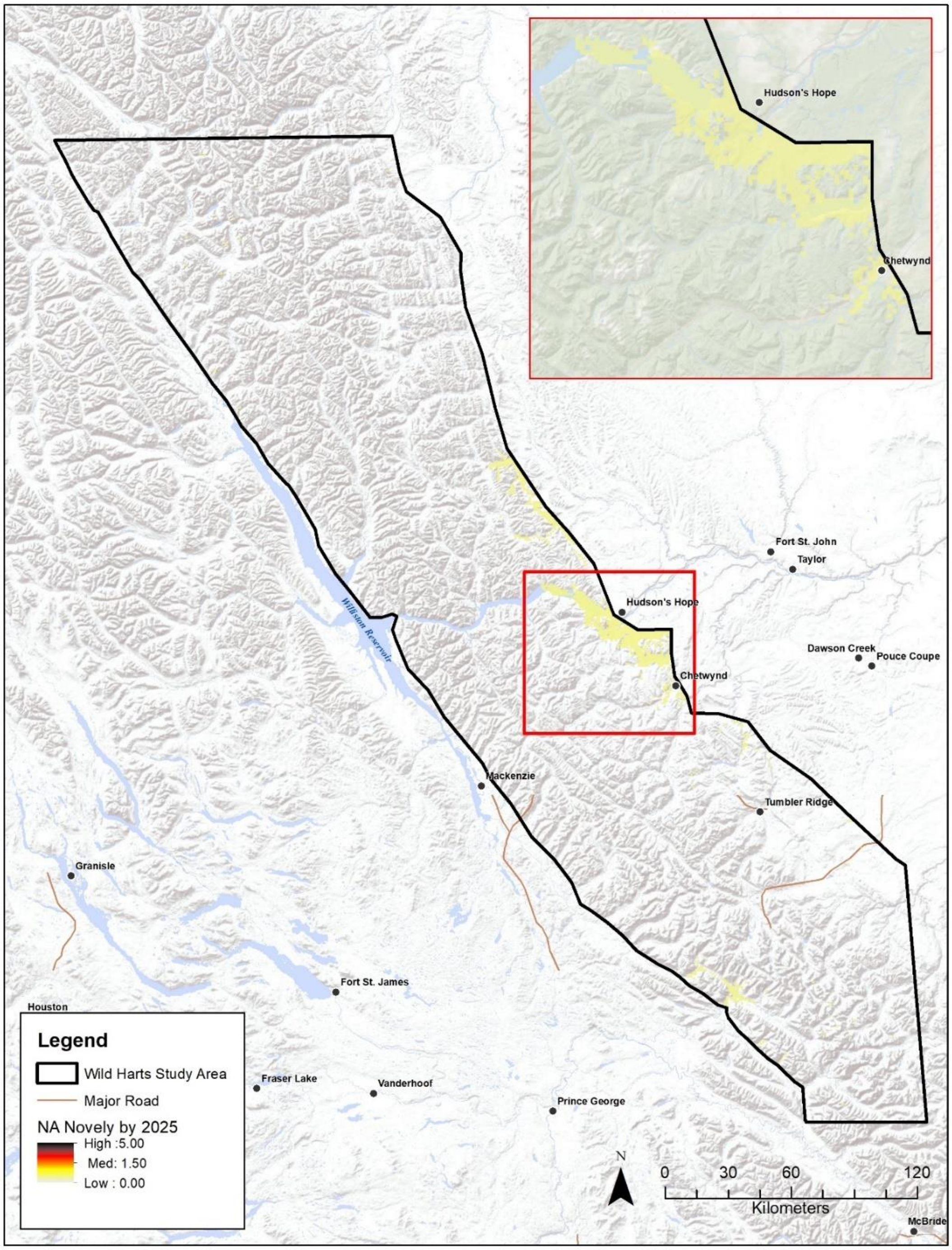


Figure 17. Spatial extent of the 2025 novel climate layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

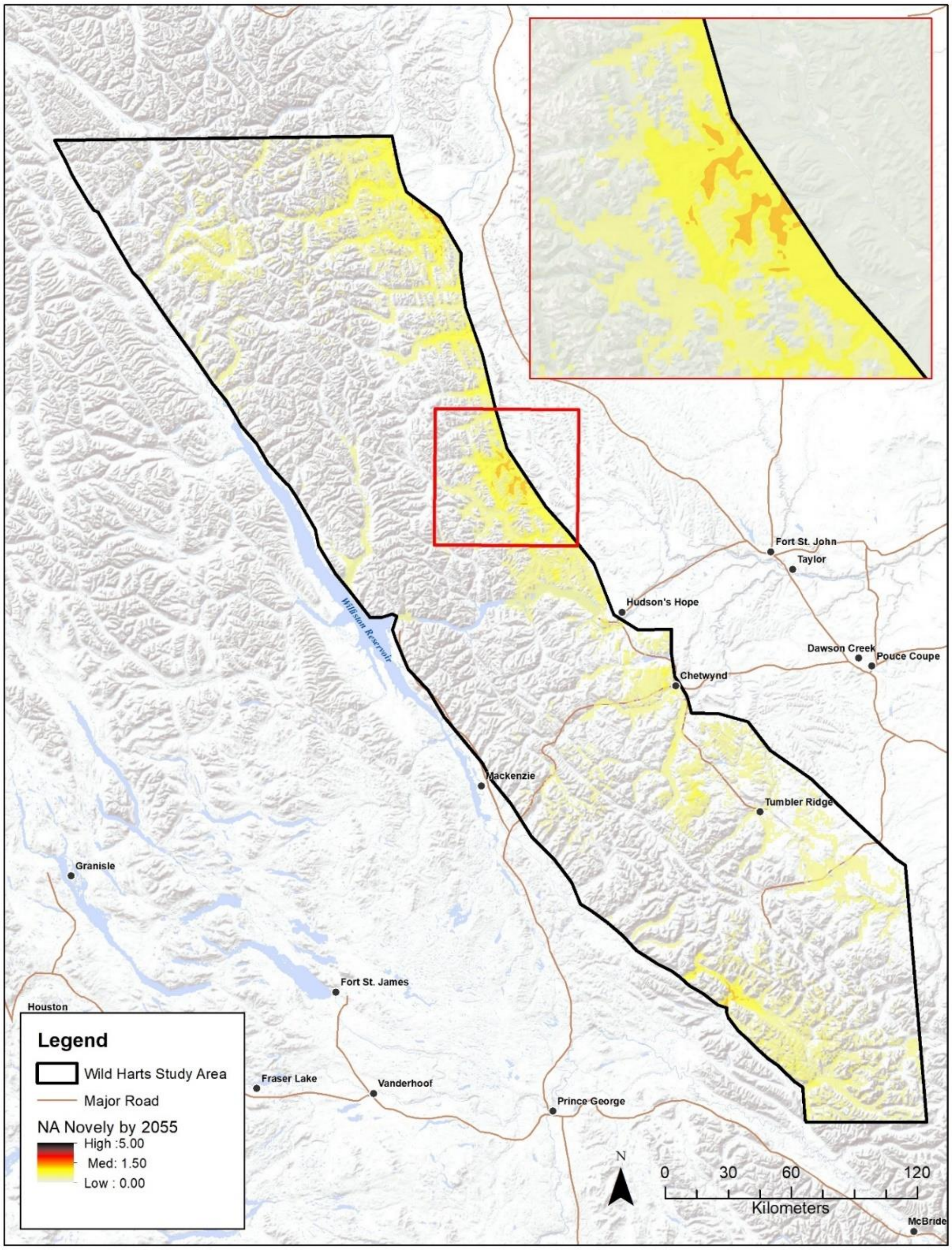


Figure 18. Spatial extent of the 2055 novel climate layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

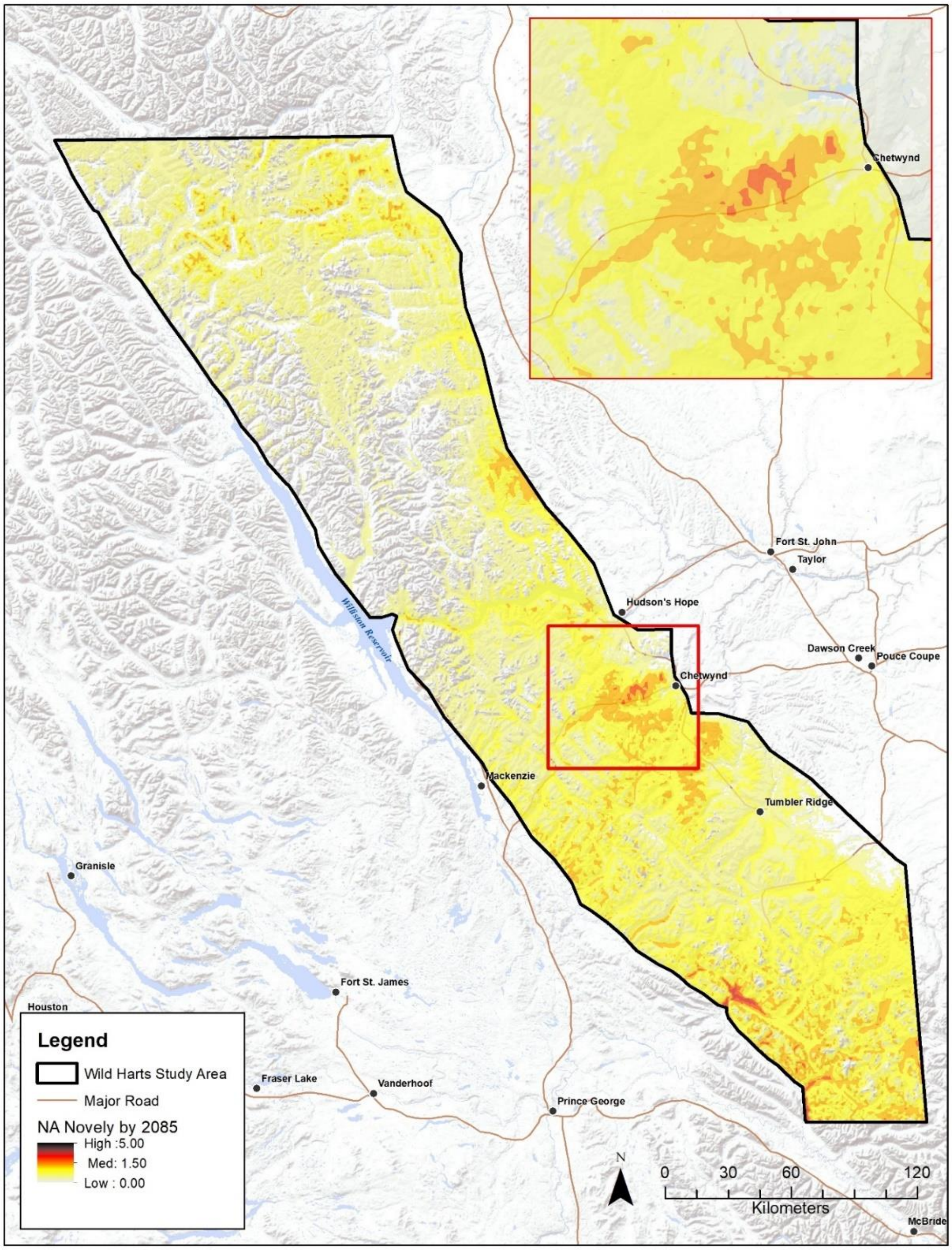


Figure 19. Spatial extent of the 2085 novel climate layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

Disappearing Climates / Biotic Refugia

The biotic refugia layer occupies approximately 23% of the WHSA total area and is currently 40.7% protected by the existing protected areas network in the planning region (Fig. 20). The areas of biotic refugia are distributed along the mountainous spine of the WHSA (Fig. 20). These areas of biotic refugia demonstrate a surprisingly strong association with elevation within the WHSA (1% = Low, 18% = Medium and 45% = High).

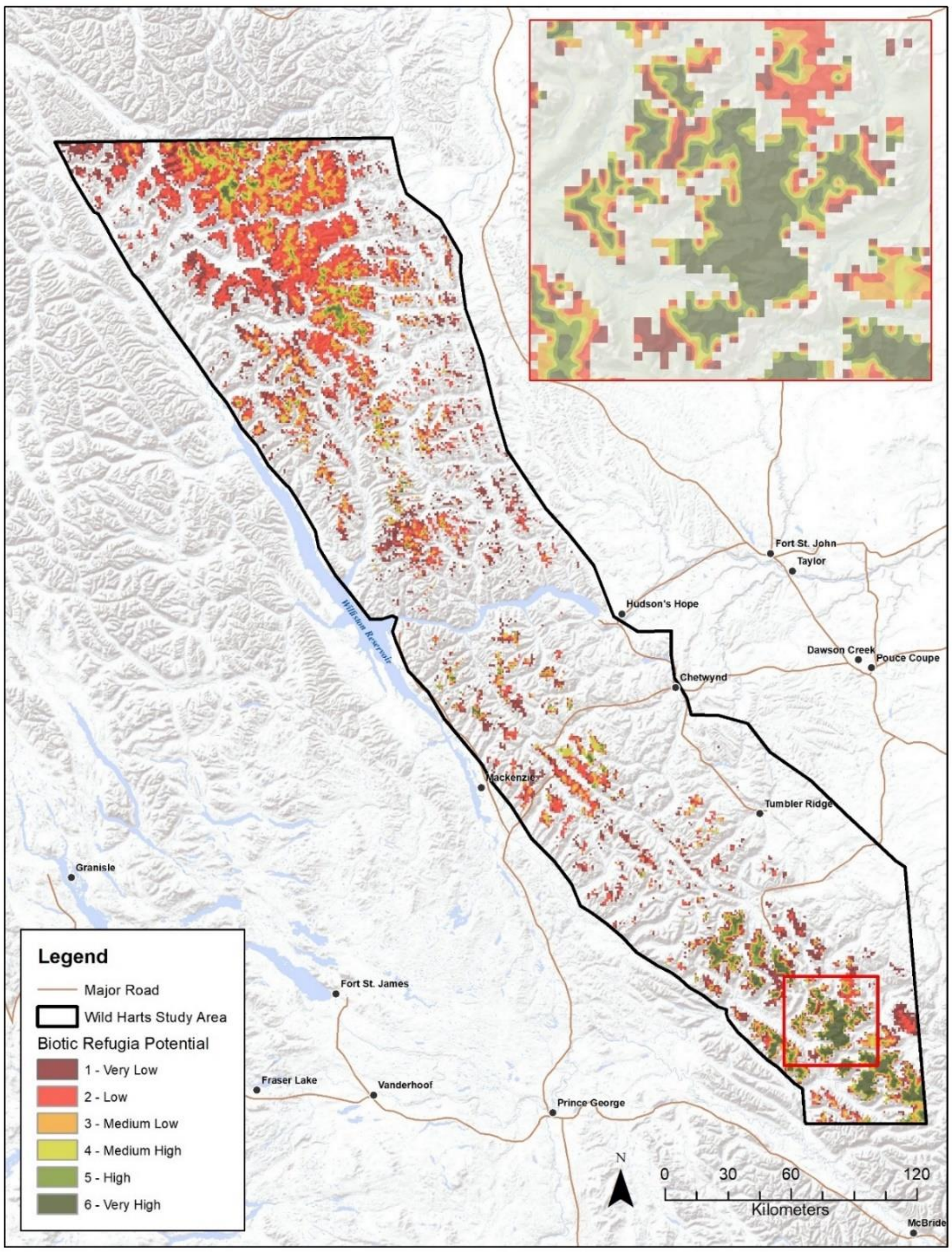


Figure 20. Spatial extent of the biotic refugia layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

Climate Change and Connectivity as Supplemental Planning Information

In addition to the MARXAN-ILP conservation features and representational zones, climate corridor data was use to provide insights into which areas may serve as important corridors for species tracking shifting climates. Within the WHSA, forward shortest-path centrality corridors, which represent the number of dispersal paths that overlap along the shortest paths from current (1981-2010 period) to future (2071-2100 period) climate locations, are prominent within the WHSA and run the length of the WHSA corridor with the exception of the northwest and southwest portions of the study area (Figure. 21). Backward shortest-path centrality corridors, which represent the number of dispersal paths that overlap from future to current climate analogs are more prominent in the northeastern portion of the WHSA. In addition, the shortest-path centrality layer displays important connections between current and future locations of climate types by or the net flow of dispersers through a site which is highest along the mountainous spine of the WHSA (Figures. 22-23).

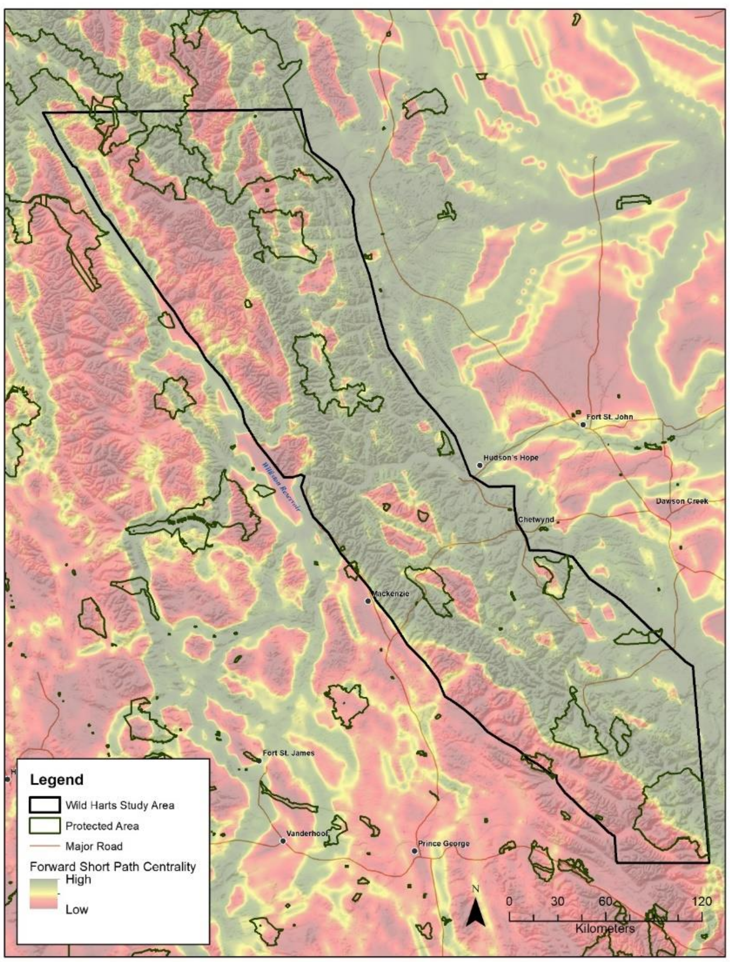


Figure 21. Spatial extent of the Forward Short Path Centrality layer used to assess MARXAN-ILP solutions in the Wild Harts Study Area.

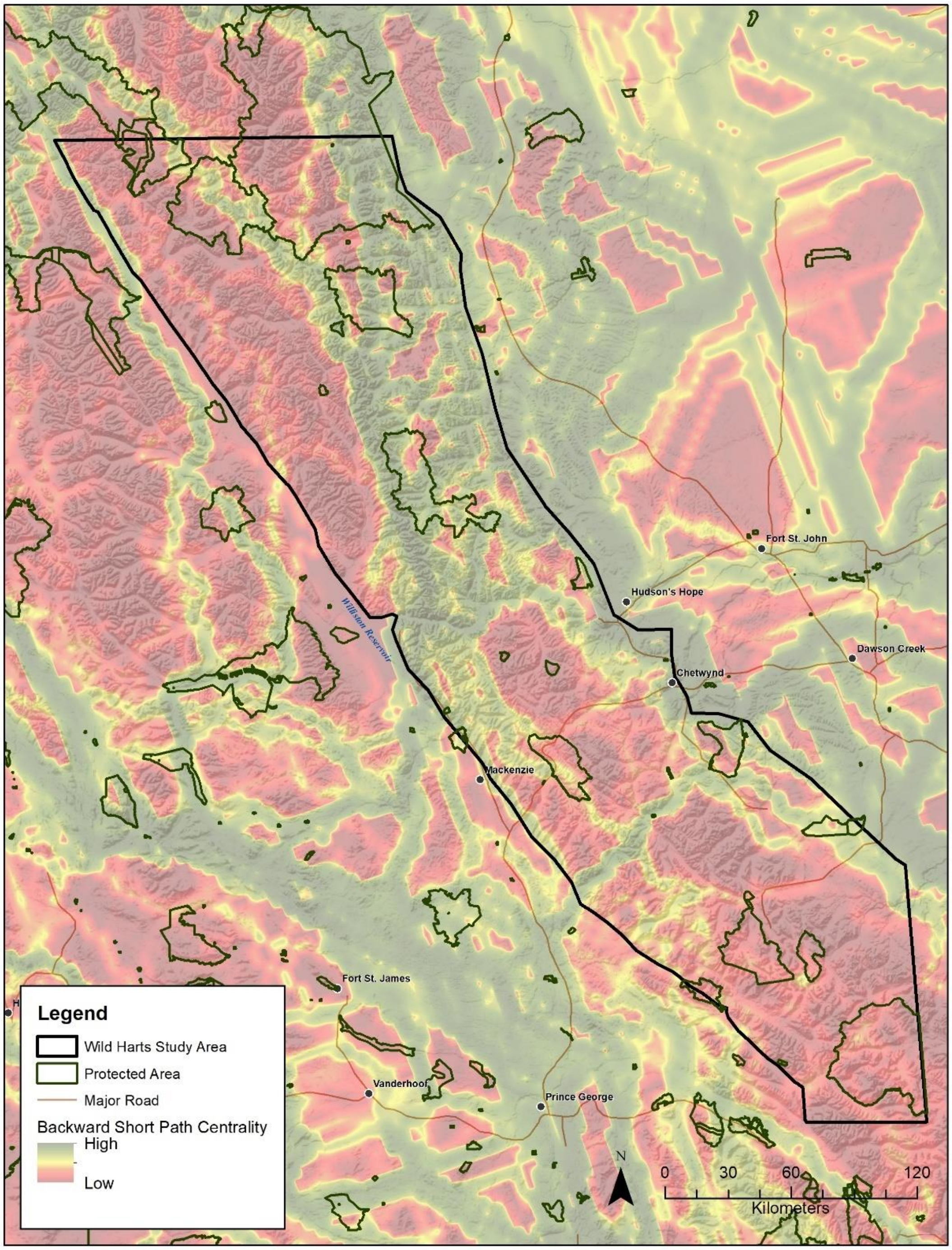


Figure 22. Spatial extent of the Backward Short Path Centrality layer used to assess MARXAN-ILP solutions in the Wild Harts Study Area.

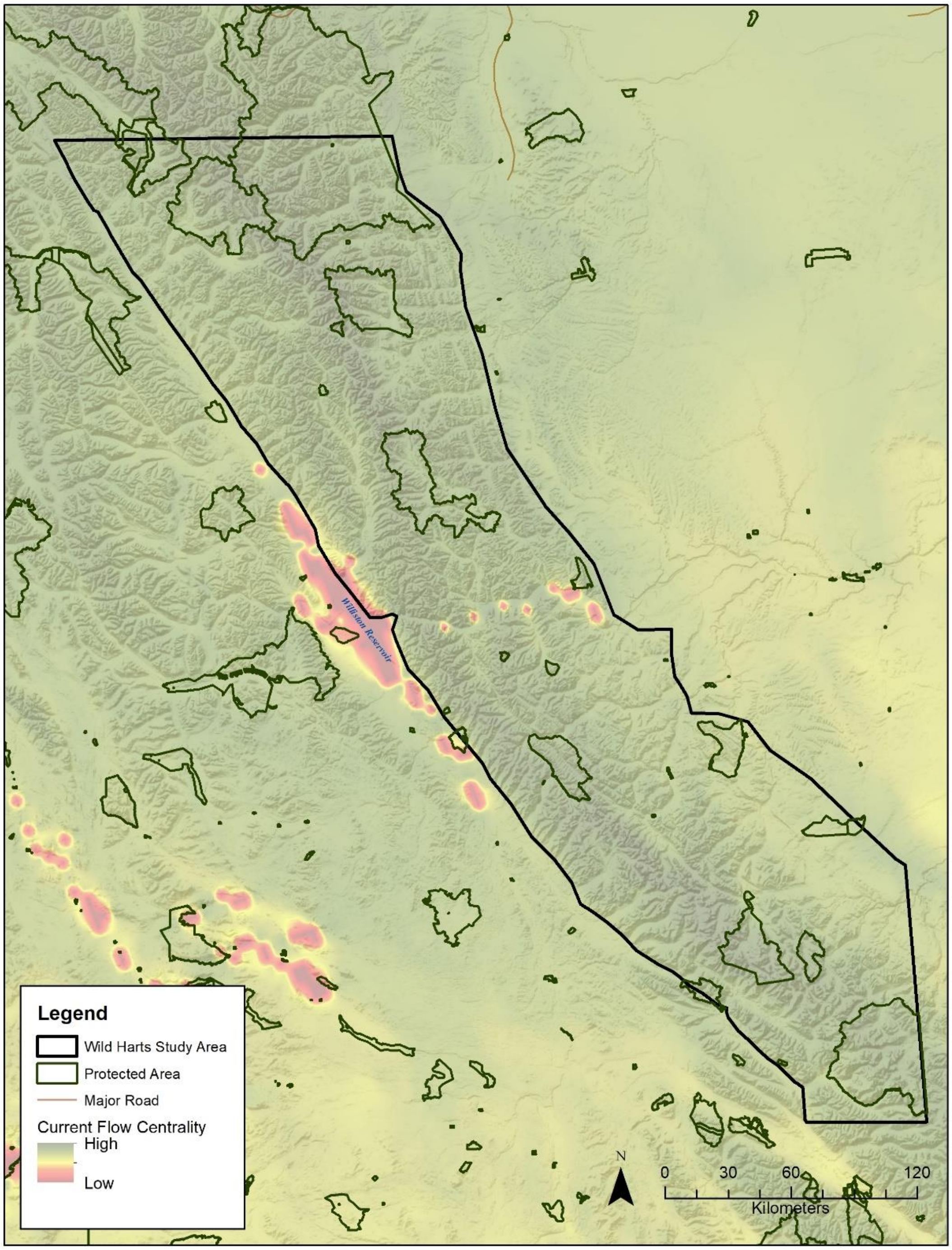


Figure 23. Spatial extent of the Current Flow Centrality layer used to assess MARXAN-ILP solutions in the Wild Harts Study Area.

Landscape Resistance and Connectivity

The landscape resistance/permeability analysis covers 100% of the WHSA and displays landscape resistance as determined by land cover, slope, anthropogenic disturbance and caribou avoidance buffers. High landscape resistance areas occupy the landscapes to the east and west of the WHSA and permeate into the WHSA along low elevation valleys characterized by low to medium slopes. These areas of low topographic resistance are characterized by high resistances due to compounding anthropogenic disturbances such roads, powerlines, transmission lines and pipelines. The high landscape resistance values are found in the southeastern quarter of the WHSA where numerous anthropogenic disturbances associated with natural resources extraction are densest. While high landscape resistance values are widespread in the WHSA, a large area of low landscape resistance/disturbance occupies the northern half of the WHSA and funnels into a band of low resistance that follows the mountainous terrain of the WHSA in a northwest-southeast line (Figure. 24).

The landscape connectivity layer created using the landscape resistance/permeability data can be interpreted as movement probabilities of organisms between protected areas in the broader Peace River Break which encompasses the WHSA (Figure. #). Sparse and narrow corridors of high movement probability occur to the west and east outside of the WHSA with the majority of the high probability movement corridor area occurring within the WHSA. The narrow corridors that connect protected areas outside the WHSA connect with a wider movement corridor that runs the length of the WHSA in a northwest-southeast line. Within the WHSA, corridors of high movement probability are largely absent in the southeastern quarter of the WHSA where compounding anthropogenic disturbances result in high landscapes resistances and wide and dispersed throughout the northern third of the WHSA (Figure. 25).

The results show a measures of current (or movement of organisms) and resistance (or opposition to movement) between habitat patches which can be interpreted as movement probabilities of organisms across a landscape.

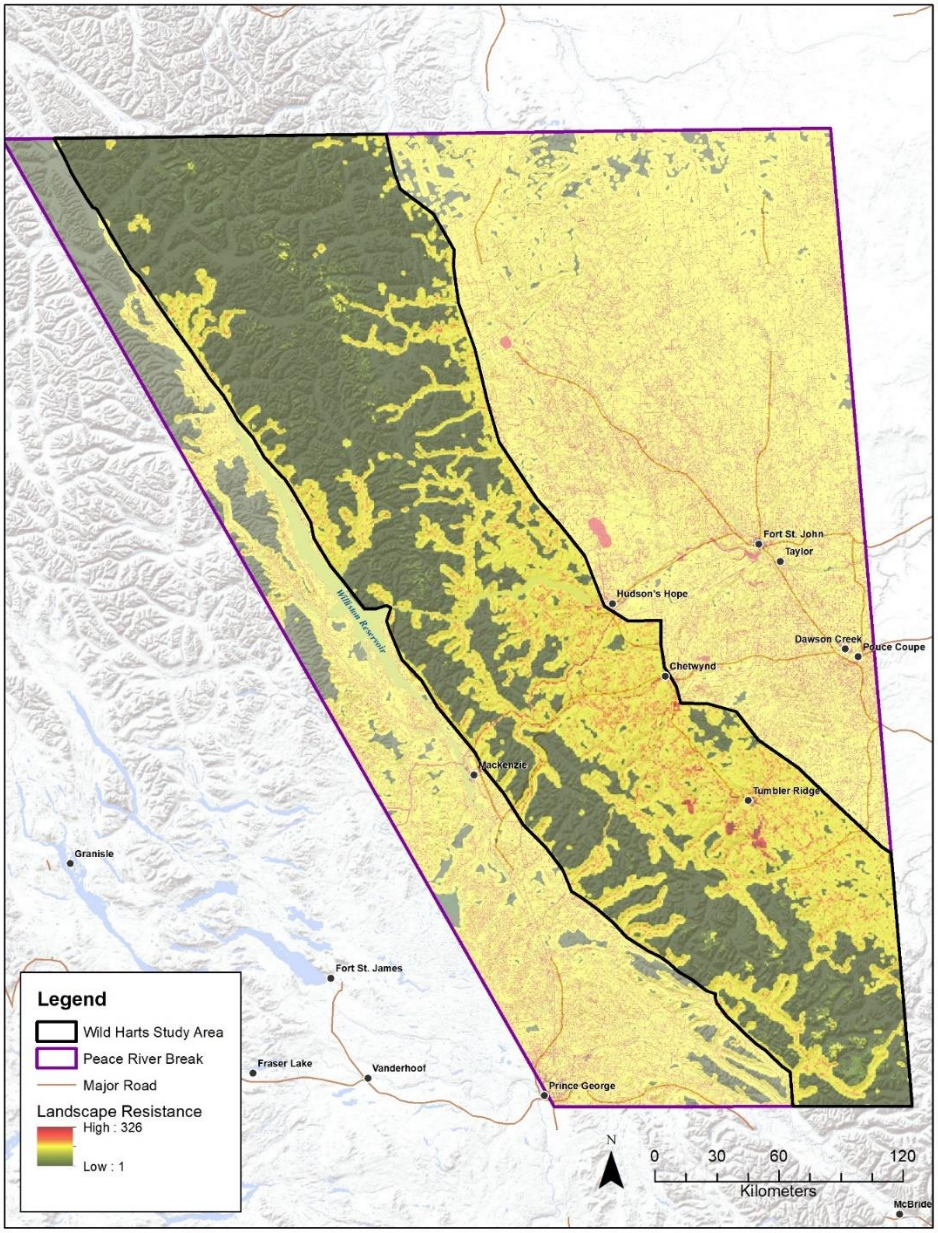


Figure 24. Spatial extent of Landscape Resistance layer used to create the Landscape Connectivity Model for the Wild Harts Study Area.

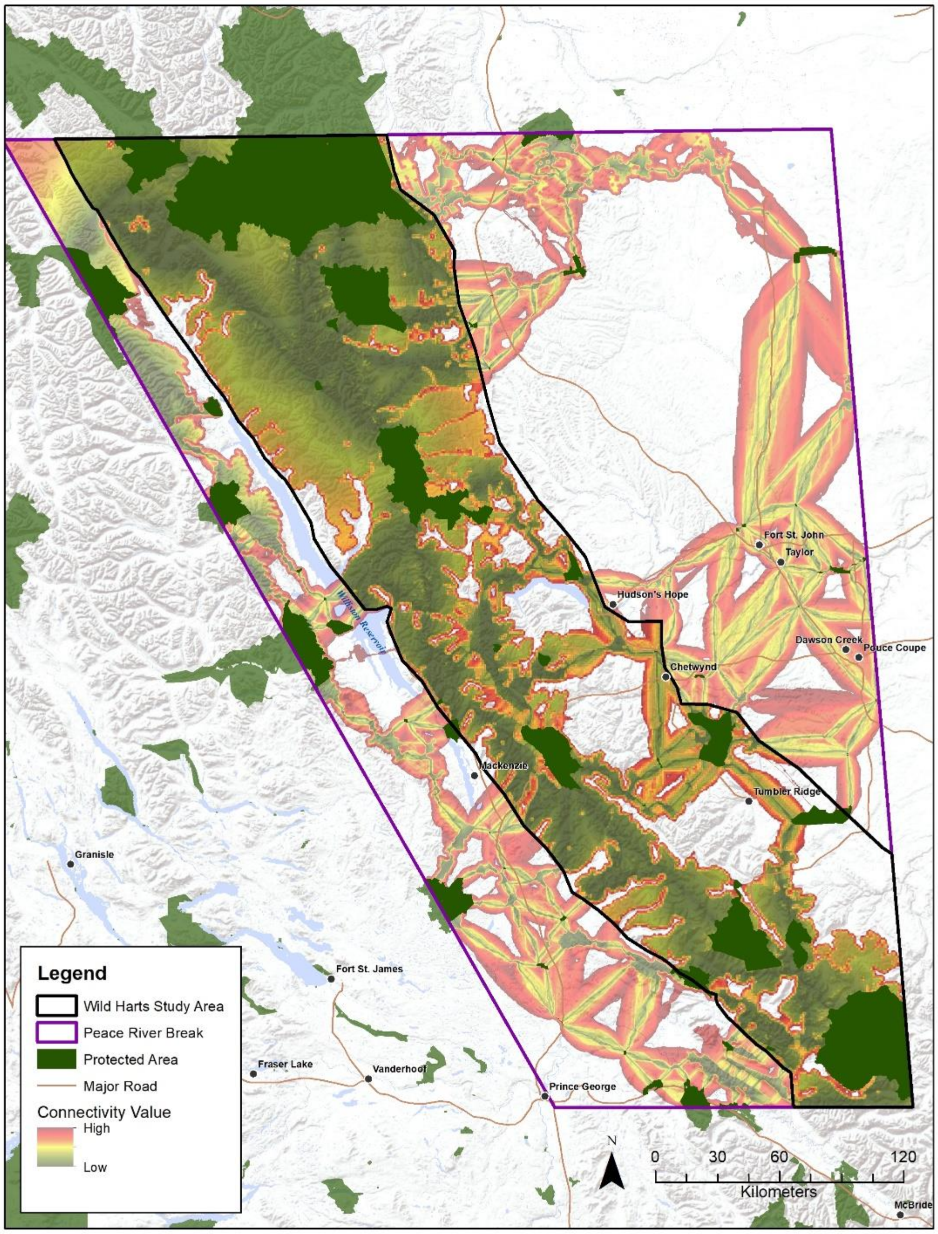


Figure 25. Spatial extent of the Landscape Connectivity layer used to assess MARXAN-ILP solutions in the Wild Harts Study Area.

Cost Surface

One cost surface was developed and used to apply varying constraints on the MARXAN-ILP tool while identifying high-value conservation lands within a landscape of varying intensities of anthropogenic disturbances.

The cost surface layer occupies 40 % of the WHSA total area. The cost layer occurs primarily in the southern half of the WHSA where population centers source natural resource extraction sites. Within the southern half of the WHSA, the majority of the cost surface and highest penalties are located in the eastern quarter which contains extensive resource development (Figure. 26). In the western portions of the WHSA, the cost layer is located within valleys and river bottoms that provide road, transmission line and pipeline access within an otherwise largely impassible mountainous landscape (Figure. #). Despite the widespread disturbance in the WHSA, a relatively intact band of non-to-lightly disturbed landscapes forms a northwest-southeast line down the mountainous center of the WHSA (Figure. 26).

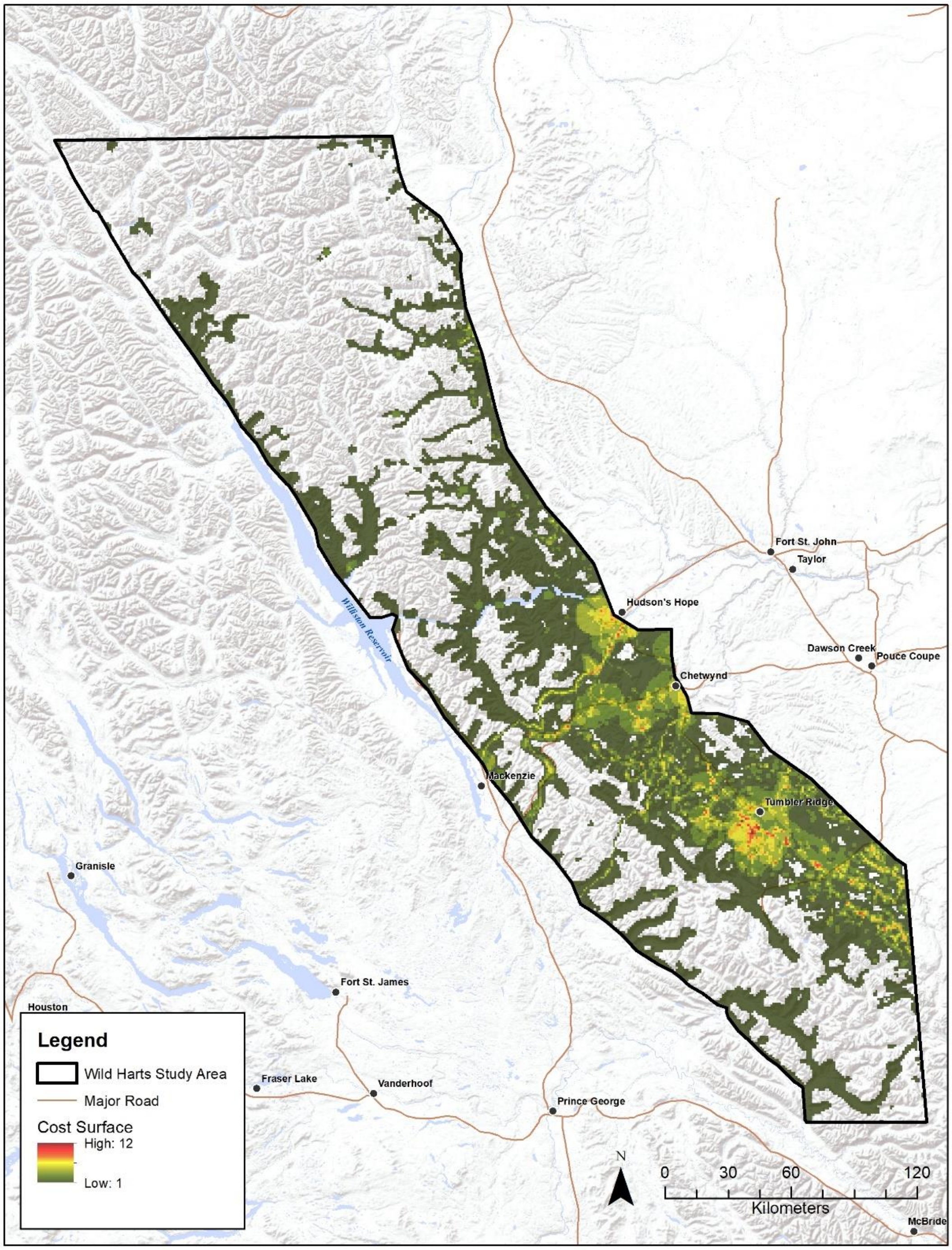


Figure 26. Spatial extent of the Cost layer used to assess MARXAN-ILP solutions in the Wild Harts Study Area.

MARXAN-ILP Scenario Outputs

The following sections describe the results of the 3 MARXAN-ILP scenarios developed to prioritize high-value areas for conservation in the WHSA (Table 6). For each of the three scenarios, MARXAN-ILP produced a solution by selecting those planning units that met conservation targets, had the highest individual and cumulative conservation value and the lowest cost.

Scenario A - Current Conservation Features

Scenario A's solution covers approximately 68% of the WHSA's total area. The solution highlights a corridor of high conservation value lands that stretch from the southwest of the planning region to Northern Rocky Mountains Provincial Park in the northeast (Figure 27-1). In the bottom half of the WHSA, below the Peace Arm, the solution is largely concentrated to the western side of the Rocky Mountains (Figure #). Conversely, north of the Peace Arm, the solution curves to the eastern portion of the Rocky Mountains around Graham Laurier Provincial Park (Figure 27-1) then back to the western side of Redfern-Keily before occupying the majority of the northern portion of the top of the WHSA.

Solution A is largely absent from on the eastern boundary below Hudson's Hope down to Monkman Provincial Park where numerous overlapping natural resource developments correspond in the Tumbler Ridge area (Figure 27-2). This area also lacks woodland caribou conservation feature and thus, was likely not selected due to its high cost, lack of conservation features, and the ability to meet targets in alternative areas within the WHSA. A similar yet less drastic void in solution A is visible along the western boundary of the WHSA north of the Peace Arm. As this area contains low, to no cost, a lack of conservation features, or lower individual conservation values, likely encouraged the model to meet targets conservation features with complementarity elsewhere.

Figure 27-1 displays the number of conservation features captured per planning unit. The maximum number of overlapping conservation features that Solution A was able to capture was 14. The highest values are located in the northeast, south of Kwadacha and the Northern Rocky Mountains Provincial Parks, and east of Redfern-Keily Provincial Park. High values also occur south of the Peace Arm along the western boarder of the WHSA. This pattern occurred when looking at current biodiversity features only, future biodiversity values only, as well as all conservation features combined.

Solution A was successful in achieving targets for both current and future biodiversity (Table 6) and selected those planning units with the highest individual current biodiversity values and collective values. In doing so, the scenario resulted in a solution with a clear bias toward high elevation areas with 85%, 67% and 53% of the high, medium, and low elevation zones being captured, respectively. Despite the elevational bias, solution A captures over 50% of 9 of the 13 climate zones within the WHSA, with only 1 climate zone receiving less than 30% representation. Solution A adequately (obtaining at least 50% of the representational BEC zone represents all the BEC zones within the WHSA with the exception of the current SBS distribution (48%) and the 2050's IDF distribution (13%).

Table 6. Scenario A – Current Biodiversity Targets Solution Results

Conservation Feature	% of WHSA	% Protected	% Target	Additional % Needed	Additional % Acquired	% Captured
Grizzly Habitat Capability	66	17	60	43	61	78
Grizzly Habitat Suitability	65	18	60	42	61	79
Burnt Pine Caribou Herd	0	0	90	90	90	90
Finlay Caribou Herd	1	1	90	89	89	90
Gataga Caribou Herd	6	25	90	65	65	90
Graham Caribou Herd	6	14	90	76	76	90
Hart Ranges Caribou Herd	7	16	90	74	74	90
Kennedy Caribou Herd	2	15	90	75	75	90
Moberly Caribou Herd	0	3	90	87	87	90
Muskwa Caribou Herd	11	95	90	0	0	95
Narraway Caribou Herd	7	19	90	71	71	90
Pink Mountain Caribou Herd	9	27	90	63	63	90
Quintette Caribou Herd	2	6	90	84	84	90
Scott Caribou Herd	0	0	90	90	90	90
Fisher	11	8	60	52	52	60
Bull Trout	47	19	60	41	48	67
Special_Features	5	22	60	38	48	70
NDT1-ESSF-Burned	0	22	100	78	78	100
NDT1-ESSF-Mature/Old	12	8	74	66	66	74
NDT1-ICH-Burned	0	23	100	77	77	100
NDT1-ICH-Mature/Old	0	30	75	45	45	75
NDT2-ESSF-Burned	1	2	100	98	98	100
NDT2-ESSF-Mature/Old	11	13	75	62	62	75
NDT2-SBS-Burned	0	5	100	95	95	100
NDT2-SBS-Mature/Old	6	5	66	61	61	66
NDT2-SWB-Burned	1	67	100	33	33	100
NDT2-SWB-Mature/Old	7	26	83	57	57	83
NDT3-BWBS-Burned	1	24	100	76	76	100
NDT3-BWBS-Mature/Old	10	10	46	36	47	57
NDT3-SBS-Burned	0	0	100	100	100	100
NDT3-SBS-Mature/Old	0	1	76	75	75	76
Climatic Diversity	50	13	-	NA	54	67
Ecotypic Diversity	51	11	-	NA	55	67
Elevation Diversity	51	26	-	NA	49	75
Heat Load Index Diversity	51	30	-	NA	50	79
Land Facet Diversity	50	16	-	NA	49	65
Land Facet Rarity	5	28	-	NA	38	67
Biotic Refugia	23	41	-	NA	49	90
Backwards Velocity Refugia	51	23	-	NA	52	75
Novel Climates 2025	2	2	-	NA	29	31
Novel Climates 2055	21	21	-	NA	42	64
Novel Climates 2085	75	18	-	NA	49	67

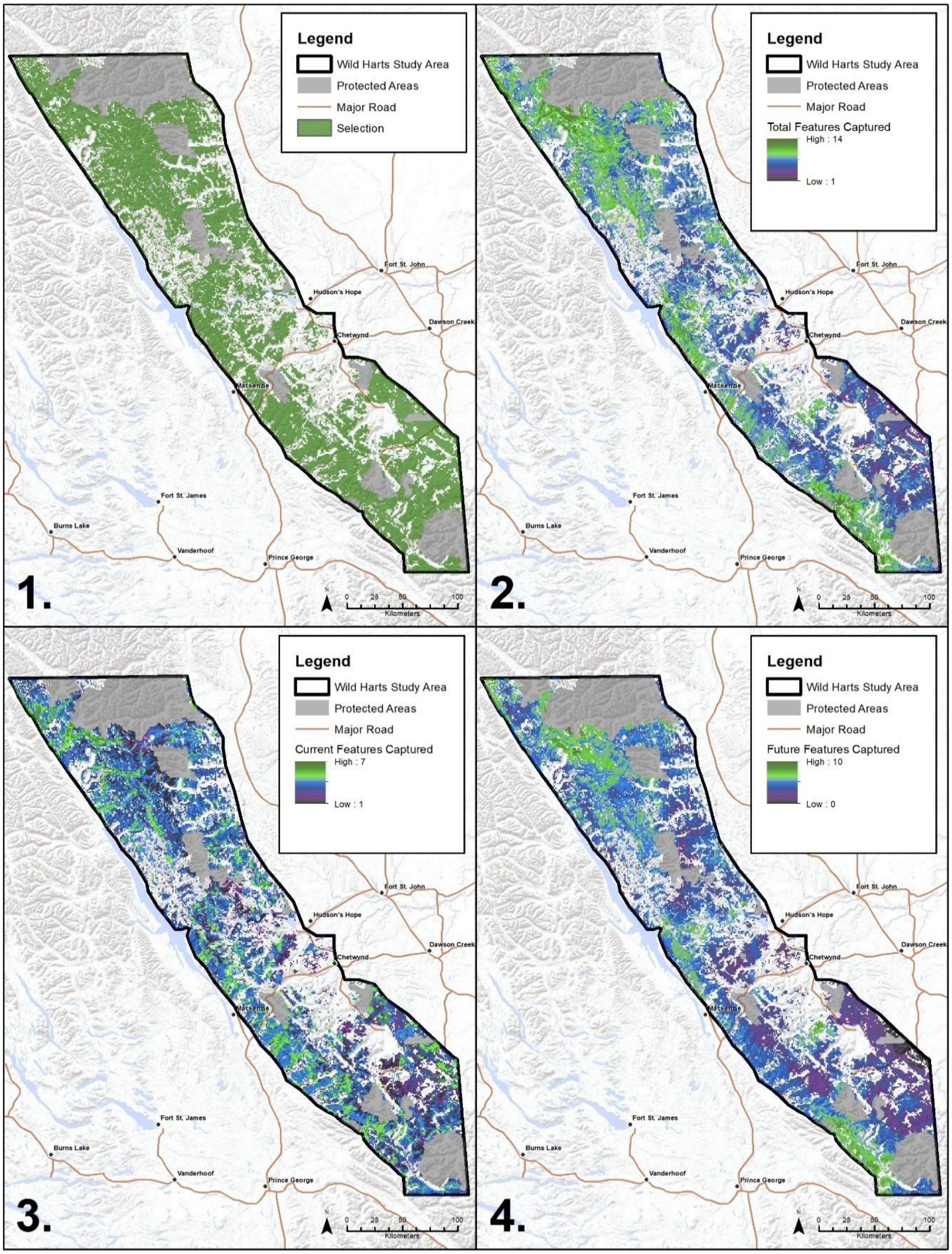


Figure 27. Scenario A Current Conservation Feature Analysis

Scenario B - Future Conservation Features

Scenario B's solution covers approximately 65% of the WHSA's total area. The solution followed the same observable pattern as solution A but with a more condensed spatial distribution (Figures 28). Solution B highlights a corridor of high conservation lands that stretch from the southwest of the planning region to Northern Rocky Mountains Provincial Park in the northeast. South of the Peace Arm, the solution is largely concentrated to the western side of the Rocky Mountains whereas north of the Peace Arm, the solution broadens to the mid and eastern portions of the WHSA until Redfern-Keily Provincial Park, after which the solution occupies the full northern extent of the study area.

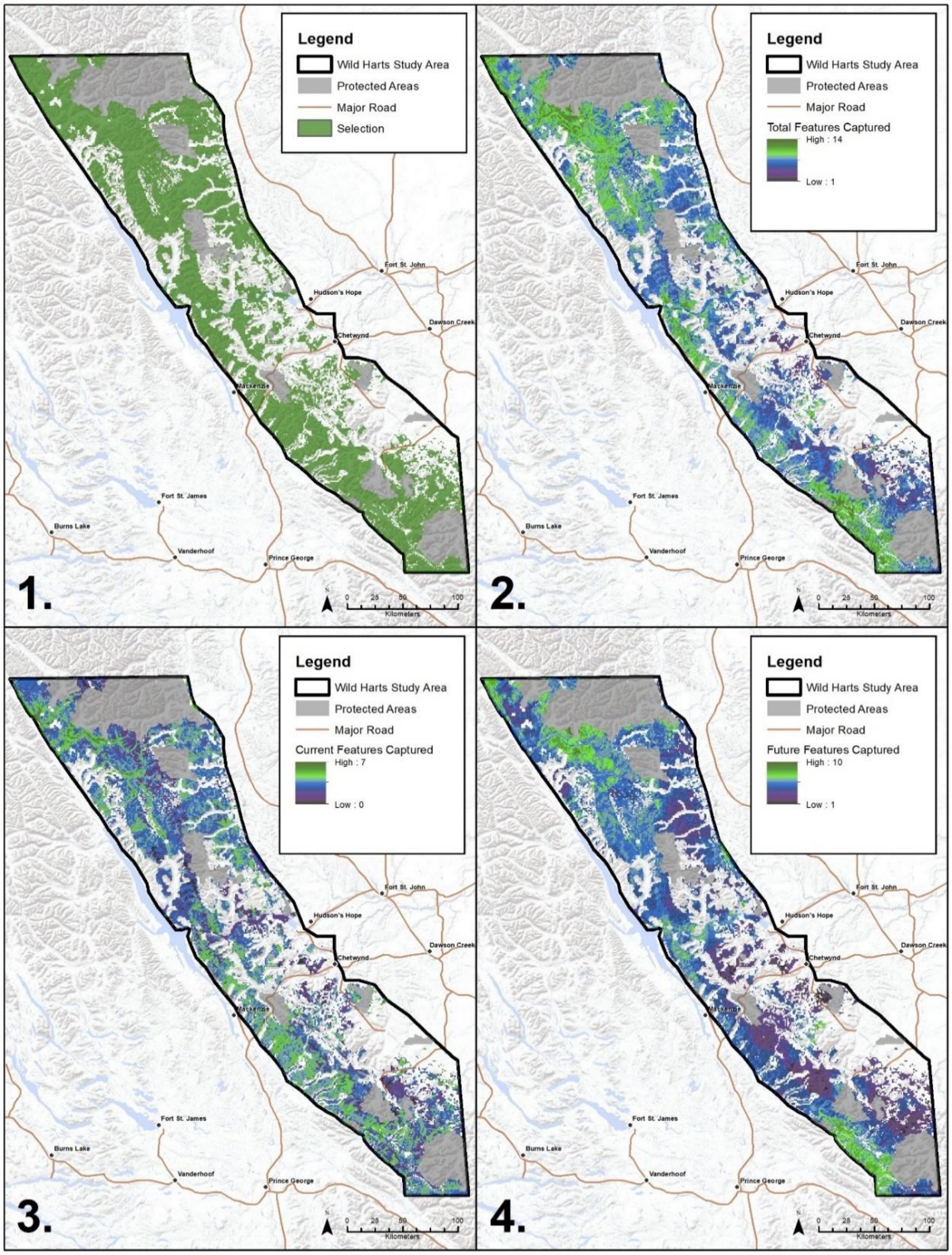


Figure 28. Scenario B Current Conservation Feature Analysis

Scenario C – Current and Future Conservation Features

Scenario C's solution covers approximately 68% of the WHSA's total area - the same amount of area as solution A. Solution C followed the same observable pattern as solution A but with a few differences (Figures 29). Similar to solution A, solution C is spatially distributed along a corridor of high conservation value lands that stretch from the southwest of the planning region to Northern Rocky Mountains Provincial Park in the northeast. In the bottom half of the WHSA, below the Peace Arm, the solution is largely concentrated to the western side of the Rocky Mountains, whereas north of the Peace Arm, the solution curves to the western boarder of the WHSA before occupying the majority of the northern portion of the top of the WHSA.

Similar to Solution A and B, solution C is largely absent from on the eastern boundary below Hudson's Hope down to Monkman Provincial Park where numerous overlapping natural resource developments coincide in the Tumbler Ridge area. A similar yet less drastic void in solution C is visible along the western boundary of the WHSA north of the Peace Arm.

Figure 29-2 displays the number of conservation features captured per planning unit. The maximum number of overlapping conservation features that Solution A was able to capture was 14. The same planning units with the highest values located in the northeast, south of Kwadacha and the Northern Rocky Mountains Provincial Parks, and east of Redfern-Keily Provincial Park that were selected by scenarios A and B were also selected by scenario C. High values areas were also selected south of the Peace Arm along the western boarder of the WHSA. Figure 29-3 demonstrates that this pattern occurred when looking at current biodiversity features only, future biodiversity values only (Figure 29-4), as well as all conservation features combined.

Solution C was successful in achieving targets for both current and future biodiversity (Table 7) and selected those planning units with the highest individual and collective values, taking into consideration both current and future biodiversity conservation feature values. Scenario C resulted in a solution with a clear bias toward high elevation areas with 85%, 67% and 53% of the high, medium, and low elevation zones being captured, respectively. Despite this, solution C captures over 50% of 9 of the 13 climate zones within the WHSA, with only 1 climate zone receiving less than 30% representation (one 1 receiving exactly 30% representation). Solution C adequately (obtaining at least 50% of the representational BEC zone) represents all the BEC zones within the WHSA with the exception of the current SBS distribution (49%) and the 2050's IDF distribution (13%) (Table 7).

Table 7. Scenario C – Current and Future Biodiversity Targets Solution Results

Conservation Feature	% of WHSA	% Protected	% Target	Additional % Needed	Additional % Acquired	% Captured
Grizzly Habitat Capability	66	17	60	43	60	77
Grizzly Habitat Suitability	65	18	60	42	60	78
Burnt Pine Caribou Herd	0	0	90	90	90	90
Finlay Caribou Herd	1	1	90	89	89	90
Gataga Caribou Herd	6	25	90	65	65	90
Graham Caribou Herd	6	14	90	76	76	90
Hart Ranges Caribou Herd	7	16	90	74	74	90
Kennedy Caribou Herd	2	15	90	75	75	90
Moberly Caribou Herd	0	3	90	87	87	90
Muskwa Caribou Herd	11	95	90	0	0	95
Narraway Caribou Herd	7	19	90	71	71	90
Pink Mountain Caribou Herd	9	27	90	63	63	90
Quintette Caribou Herd	2	6	90	84	84	90
Scott Caribou Herd	0	0	90	90	90	90
Fisher	11	8	60	52	52	60
Bull Trout	47	19	60	41	48	67
Special_Features	5	22	60	38	51	73
NDT1-ESSF-Burned	0	22	100	78	78	100
NDT1-ESSF-Mature/Old	12	8	74	66	66	74
NDT1-ICH-Burned	0	23	100	77	77	100
NDT1-ICH-Mature/Old	0	30	75	45	60	90
NDT2-ESSF-Burned	1	2	100	98	98	100
NDT2-ESSF-Mature/Old	11	13	75	62	62	75
NDT2-SBS-Burned	0	5	100	95	95	100
NDT2-SBS-Mature/Old	6	5	66	61	61	66
NDT2-SWB-Burned	1	67	100	33	33	100
NDT2-SWB-Mature/Old	7	26	83	57	57	83
NDT3-BWBS-Burned	1	24	100	76	76	100
NDT3-BWBS-Mature/Old	10	10	46	36	46	55
NDT3-SBS-Burned	0	0	100	100	100	100
NDT3-SBS-Mature/Old	0	1	76	75	75	76
Climatic Diversity	50	13	67	54	55	68
Ecotypic Diversity	51	11	67	55	55	67
Elevation Diversity	51	26	75	49	49	75
Heat Load Index Diversity	51	30	79	50	50	79
Land Facet Diversity	50	16	65	49	50	66
Land Facet Rarity	5	28	67	38	40	69
Biotic Refugia	23	41	90	49	49	90
Backwards Velovity Refugia	51	23	75	52	53	76
Novel Climates 2025	2	2	31	29	29	31
Novel Climates 2055	21	21	64	42	42	64
Novel Climates 2085	75	18	67	49	49	67

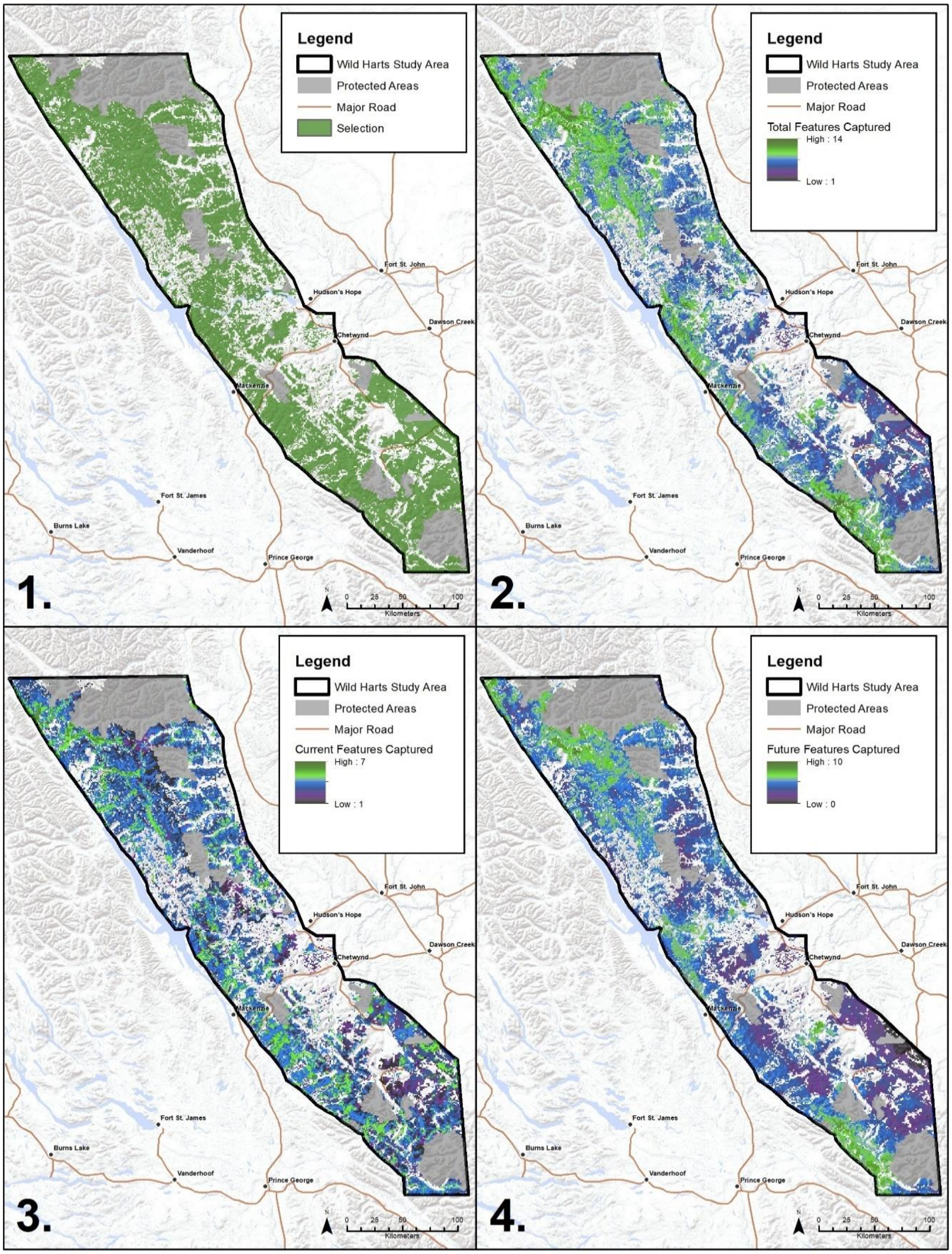


Figure 29. Scenario C Current Conservation Feature Analysis

Scenario Comparison

In all three solutions, a noticeable spatial pattern exists along a corridor of selected lands that stretches from the southwestern extent of the WHSA to Northern Rocky Mountains Provincial Park in the northeast (Figure 30). Below the Peace Arm, the selections are largely concentrated to the western half of the Rocky Mountains. Conversely, north of the Peace Arm, the solutions curves to the eastern portion of the Rocky Mountains around Graham Laurier Provincial Park (Figure #) then back to the western side of Redfern-Keily before occupying the majority of the northern portion of the top of the WHSA. The solutions are largely absent from on the eastern boundary below Hudson's Hope down to Monkman Provincial Park and along the western boundary of the WHSA north of the Peace Arm.

While solution A required 68% of the WHSA to be selected in order to achieve conservation targets for current biodiversity, solution B only required 65% of the WHSA to meet it's targets for future biodiversity. Accordingly, an additional 3% of the WHSA's total area is required to meet current biodiversity targets. Of particular note is that solution A was capable of adequately representing future biodiversity conservation features (Table 8) whereas solution B was not able to adequately represent the current biodiversity features (Table 8). When solution A and solution B are merged, their combined area overlaps by 61%. Seventy-three percent of solution A was also captured by solution B while 27% of solution A was not also captured by solution B. Conversely, 79% of solution B was also captured by solution A while 21% of solution B was not also captured by solution A.

Solution C was successful in achieving targets for both current and future biodiversity and selected the same amount of area (68% of the WHSA) as solution A. Accordingly, solution C required no additional area (cost). Although solutions A and C achieved the exact same targets, solution C was able to make a "smarter" solution by selecting those planning units with the highest individual and collective values, taking into consideration both current and future biodiversity conservation feature values. In doing so, scenario C was forced to make compromises and weigh the cost of current and future biodiversity values in each planning unit in order to select planning units that were the most complementary for all of the conservation features. Consequently, solution C forfeited certain planning units that were captured in solution A in order to selected certain areas that contained higher overall scores. When solution A and solution C are merged, their combined area overlaps by 93%. Ninety-six percent of solution A was also captured by solution C and vice versa.

Figure # (4.) displays the discrepancies between solutions A and C. Low elevation valleys between the Norther Rocky Mountains and Graham-Laurier Provincial Parks that were selected in solution A were forfeited by solution C and replaced with mid elevation patches between

Redfern-Keily and Graham-Laurier Provincial Parks (Figure #. Similarly, small patches of planning cells to the north and south of the Peace Arm were forfeited and replaced by alternative planning cells with higher overall scores when both current and future biodiversity feature values were taken into consideration.

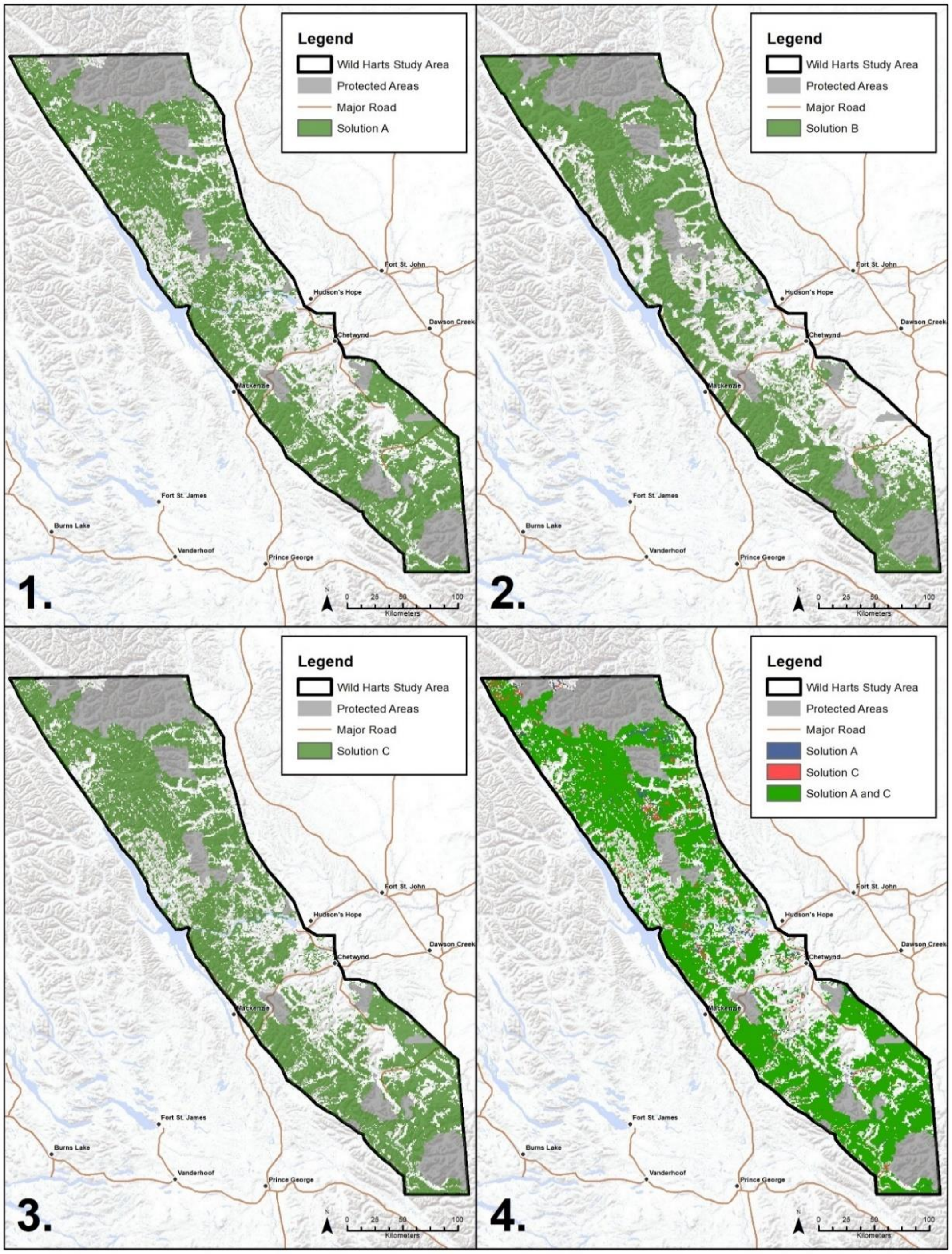


Figure 30. Scenario C Current Conservation Feature Analysis

Table 8. Scenario Comparisons over Time

BEC Zone	Current				2050s				2080s			
	PAs	Scenario A	Scenario B	Scenario C	PAs	Scenario A	Scenario B	Scenario C	PAs	Scenario A	Scenario B	Scenario C
BAFA	40	88	92	88	63	89	95	89	67	88	95	88
BWBS	9	53	33	53	11	52	45	51	12	54	53	53
CMA	0*	0*	0*	0*	62	100	93	100	65	100	92	100
CWH	0*	0*	0*	0*	16	83	71	83	25	89	90	89
ESSF	11	69	66	69	21	82	82	82	29	85	87	85
ICH	31	71	85	80	9	60	52	61	9	59	52	60
IDF	0*	0*	0*	0*	0	13	0	13	1	55	8	54
IMA	21	95	100	100	0*	0*	0*	0*	0*	0*	0*	0*
MH	0*	0*	0*	0*	47	100	100	100	43	96	97	96
MS	0*	0*	0*	0*	0	100	100	100	4	68	93	78
SBS	4	48	41	49	6	55	49	55	7	66	53	67
SWB	34	78	86	78	57	94	96	94	37	93	95	93

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