SYSTEMATIC CONSERVATION PLANNING IN THE WILD HARTS STUDY AREA

by

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ABSTRACT

The Wild Harts Study Area (WHSA) supports a wide range of ecological diversity and connects a network of protected areas spanning the length of the Rocky Mountain Cordillera. The WHSA occurs within a region of northeastern British Columbia that is poorly represented by protected areas. Industrial expansion threatens to fragment the contiguous habitats found in the WHSA — reducing the ability of the area to perform important landscape functions at local and continental scales. For this research, I employed a systematic conservation planning approach to prioritize lands for conservation action in the WHSA. The software MARXAN with integer linear programming (ILP) was used to produce optimal solutions for conservation, at the lowest cost, and to enforce principles of protected area design. Priority lands for conservation action were those that met the science-based targets for a selection of ecological surrogates, displayed low edge-to-area ratios, and represented intact landscapes outside the influence of resource development. The finalized conservation portfolio produced in this research is meant to inform protected area planning in the WHSA.

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GLOSSARY

These definitions reflect how terms are referred to and applied within the context of this research.

Aichi Target 11: An initiative established by the Convention on Biological Diversity to have 17% of terrestrial and inland waters, and 10% of coastal and marine areas, represented by some form of conservation tenure by 2020.

ArcGIS: A geographic information system used to produce maps and complete geoprocessing tasks (ESRI, 2011).

Avoidance Buffers: Spatial representations of distances at which woodland caribou avoid permanent development.

Biodiversity: Refers to the complete range of species and genetic variation that comprises a biological community, as well as the interactions that take place amongst these variables (Primack, 2010).

Biogeoclimatic Zone: An ecological classification system representing geographic areas with similar patterns of energy flow, vegetation, and soils as a result of a broadly homogenous macroclimate (Province of British Columbia, 1995).

Biophysical Processes: Physical vectors that regulate, organize, and maintain biological communities.

Biodiversity Surrogate: A component of a given ecosystem that is used as a proxy to represent the biodiversity of the whole ecosystem (Grantham et al., 2010).

Climate Change Resilience: The ability of an ecosystem to maintain self-organizing processes and structures in the face of shifting climatological regimes. (Morecroft et al., 2012).

Coarse-filter Conservation Feature: An element within a given planning region that is thought to represent ecological patterns and processes of that region.

Compactness: A dimensionless measure used to describe clusters of selected planning units with low edge-to-area ratios.

Complementarity: The extent to which selecting for one conservation feature results in adequate representation of another by default.

Constraint: Reflective of the combined cost inflicted upon a MARXAN-ILP scenario by user-defined inputs.

Cost Surface: A spatial representation of those elements in a planning region that have been identified as having a negative impact on the conservation features being selected for.

Data-free Conservation Targets: Commonly used targets in systematic conservation planning designed to represent a percentage of a given planning region's overall area. These targets are loosely based on theories of landscape ecology and conservation biology, but are rarely informed by empirical data (Svancara et al., 2005).

Edge-to-area Ratio: The length of boundary surrounding a cluster of selected planning units in relation to the combined surface area of those planning units.

Edge-effects: Ecological impacts that occur along the transitionary boundary between resource development and contiguous habitats. These include barriers to species dispersal, altered temperature regimes within protected area boundaries, and the creation of entry points for invasive species (Primack, 2010).

Fine-filter Conservation Feature: An element that is thought to represent components of a given planning region that are endemic, rare, threatened, or characteristic of multiple other values in that region.

Flagship Species: A species with a high public or political profile (Primack, 2010).

High Conservation Value: Areas containing multiple overlapping values predetermined to be effective surrogates for biotic and abiotic diversity in a planning region.

Integer Linear Programming: Computational algorithm that increases the processing speed of MARXAN and identifies the optimal solution for conservation at the lowest cost.

Integrated Lands: Planning units of disproportionately high conservation value that occur within the integrated resource-use matrix.

Integrated Resource-use Matrix: Transitionary area, containing varying levels of resource development, that occurs between fully-converted landscapes and those placed under protection.

Keystone Species: A species whose presence within a given ecosystem is critical for the ongoing maintenance and function of that ecosystem (Primack, 2010).

Land Facet: An area containing distinct combinations of abiotic variables such as slope, aspect, elevation and landform.

Landscape Function: The ability of a planning region to maintain focal ecosystems, species, and ecological processes within the natural range of variability (Poiani et al., 2000).

MARXAN: Computational software that prioritizes areas for conservation based on user-defined targets and constraints.

Natural Disturbance Regime: An area that has a distinct pattern of both frequency and extent of natural disturbance (e.g. fire, insect epidemics, wind, landslides, flood).

North American Cordillera: A band of contiguous, mountainous landscapes that spans the length of the western portions of the North American Continent.

Permanent Development: Areas in the Wild Harts Study Area where resource use has resulted in complete removal of vegetation, alteration of soil structure, and manipulation of topography. These areas contain little-to-no resemblance of their natural state.

Planning Unit: A parcel of land that is made available for selection by MARXAN-ILP. The user defines the size, shape, and configuration of the unit.

Planning Unit Cost: A penalty metric that is assigned to all planning units and is meant to serve as a baseline acquisition cost that increases efficiency of selection by MARXAN-ILP.

Portfolio: A spatial solution for conservation in a given planning area that is designed to inform decision-making processes relating to protected area creation.

Principles of Good Reserve Design Include, but are not limited to, portfolios exhibiting clusters of planning units that avoid resource development and have low edge-to-area ratios.

Priority Lands: Those planning units of disproportionately high conservation value in comparison to the rest of a given planning region. Also representative of planning units that adhere to principles of good reserve design.

Protected Area: A clearly defined geographical space, recognised, dedicated, and managed, through legal or other effective means, to achieve long term conservation of nature with associated ecosystems services and cultural values (Dudley, 2008).

Protected Area Design: The method of proactively identifying suitable areas for conservation action using spatial tools and the principles of conservation biology and landscape ecology.

Representation: The extent to which the spatial footprint of given conservation feature is captured within the bounds of a protected area.

Resource Development: Refers to the spatial footprint of anthropogenic activity on the land base. This includes both industrial and urban forms of development.

Rocky Mountain Corridor: Contiguous band of high elevation peaks and ridges that run down the center of the WHSA on a southeast-northwest line.

Scenario: An iteration of prioritization completed by MARXAN-ILP that has a distinct combination of user-defined inputs and constraints.

Science-based Conservation Target: Specific representation targets assigned to individual conservation features based on what the scientific literature suggests is necessary to ensure the persistence of those features (Svancara et al., 2005).

Simulated Annealing: Refers to the algorithm at the core of MARXAN that identifies a near optimal solution for conservation at the lowest cost.

Solution Space: Used interchangeably with the term ‘portfolio’.

Special Features: Those ecosystem components that are sensitive, spatially-limited, or of high biodiversity value (Heinemeyer et al, 2004).

Systematic Conservation Planning: A structured approach for identifying candidate protected areas that represent the values, goals, and constraints of a given planning process (Margules & Pressey, 2000).

Temporary Development: The spatial extent of areas in the WHSA that have been logged within the last 20 years.

Traditional Ecological Knowledge: A cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings with one another and with their environment (Berkes, 1993).

User-defined Inputs: Refers to the various mechanisms used to place constraint on a MARXAN-ILP solution to achieve a desired result. These include features, planning units, targets, and cost surfaces.

Umbrella Species: A species whose life history requirements captures the needs of multiple other species (Primack 2010).

Zone of Influence: Areas containing resource-related impacts that extend past the spatial footprint of the development (e.g. noise and light pollution) (Wilson, 2016).

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1.0 INTRODUCTION

1.1 Overview of Protected Areas in Canada

Protected areas (PAs) provide refugia for biotic communities and serve as ecological benchmarks from which rates of ecological change can be measured. These areas also provide ecosystem services that contribute to human health and economic prosperity. Examples of such services include forests that regulate climate through the sequestration and storage of atmospheric carbon or the filtering and purifying of freshwater by wetland areas. PAs provide a setting for people to engage in recreational and tourism pursuits. Benefits that occur when people use these areas to conduct leisure include the generation of tourism revenues, increases in physical wellbeing, and the awakening of an ecological consciousness spurred on by meaningful experiences in nature.

Setting aside natural areas for the purpose of conservation is not a novel concept unique to the western world. PAs are considered to be a cultural artifact with a history dating back two millennia (Holdgate, 1999). The sacred groves of ancient India, for example, were specifically set aside for the protection of natural resources (Eagles et al., 2002). In medieval Europe, vast swaths of land were protected to serve as hunting grounds for the affluent (Eagles et al., 2002). Indigenous societies the world over have, and continue to, engage in the protection of natural areas for a myriad of reasons including providing food and serving as areas for spiritual practice.

The emergence of a contemporary or Western PA movement began in the United States with the establishment of Yellowstone National Park in 1872. The momentum of this movement spread northward to Canada with the creation of Cave and Basin Hot Springs in 1885 — the first manifestation of what would eventually become known as Banff National

Park. Following the establishment of these parks, the importance and associated benefits of PAs materialized within the political and social consciousness of Western society. This resulted in the growth of the PA system within Canada that continues to expand. The Canadian PA system currently encompasses 10.6% of the terrestrial land base (1.05 million km^2) and 0.9% of marine territories (55,000 km^2) (Environment and Climate Change Canada, 2016).

During the early 20th century, PAs were created and managed primarily by the Federal Government. Today, Canada's PA system has diversified to include a multitude of jurisdictions and approaches to management. Types of PAs in Canada include private land trusts, tribal parks, municipal/regional parks, federal national parks, territorial parks and provincial parks, conservancies and ecological reserves. Each jurisdiction operates under its own mandate that outlines a purpose and objectives for the PA.

Private conservation areas, which are owned and operated independent of government, can be effective in satisfying conservation niches such as the preservation of species-at-risk or critical habitats. However, these areas comprise a very small percentage of the overall protected land base and have a limited distribution across the northern latitudes of the country. In Canada, the overwhelming majority of lands set aside for protection are held by the Crown and managed under a mandate rooted both in biodiversity conservation and visitor experiences.

1.2 The Ecology of the Anthropocene

We are currently living in a time of ecological crisis. The present geological period is more biodiverse than any other time in Earth's history — yet the current rate of extinction surpasses that of any era in the past million years (Primack, 2010). Between 1970 and 2012, a time scale which geologists would consider to be infinitesimal in relation to Earth's history, there has been a 58% decline in overall global vertebrate population abundance (World Wildlife Fund for Nature, 2016). The most pronounced declines have occurred in freshwater environs (68–89% reduction in aquatic vertebrate abundance) (World Wildlife Fund for Nature, 2016). As of 2016, 21% of the Earth's biomes have had their natural habitats converted to some degree — a quarter of which have seen over 50% natural habitat conversion (Oakleaf et al., 2015). If current trends continue, by 2020 global vertebrate populations are predicted to have declined by 67% from their 1970 levels (World Wildlife Fund for Nature, 2016).

This unprecedented loss in biodiversity can largely be attributed to the degradation of natural systems that has come at the hands of humans (Dirzo et al., 2014; World Wildlife Fund for Nature, 2016). Since the mid-20th century, human activity and resource consumption have increased exponentially. The demands we have placed on the biosphere have reached such levels that, by 2012, the equivalent of 1.6 Earths was needed to sustain human consumption for a single year. So great has our impact on the natural world become that we have now entered an entirely new geological age known as the Anthropocene — a period during which human activity has been the dominant influence on climate and the environment (Crutzen & Stoermer, 2000; Waters et al., 2016).

Even those areas set aside for protection have been subjected to human-induced stressors. As of 2016, nearly half (46%) of national park ecosystems monitored by Parks Canada were given an ecological integrity rating of fair-to-poor (Parks Canada, 2016). Of particular concern are forest and grassland parks which are experiencing disproportionate declines in biodiversity. These declining trends can largely be attributed to anthropogenic disturbances, such as fire suppression, invasive species introduction, climate change, and overuse of PAs for tourism/recreation (Parks Canada, 2016). In order to counteract these trends, there is a growing need in Canada to improve management strategies and establish additional PAs.

1.3 Commitments and Challenges

In keeping with their mandate of using PAs as tools for biodiversity conservation, the Federal Government has committed, on behalf of the provinces and territories, to an international target of conserving at least 17% of terrestrial and inland waters, and 10% of coastal and marine areas, by the year 2020 (Environment and Climate Change Canada, 2016). This goal of 17%, otherwise known as the *Aichi Target 11* under the Convention on Biological Diversity (Secretariat of the Convention on Biological Diversity & United Nations Environment Programme, 2001), has been criticized as having little grounding in the discipline of conservation biology and is considered to be a politically-derived target (Mackinnon et al., 2016). The conservation community has suggested that a target of 30–70% is required to prevent further loss of global biodiversity and is more in keeping with evidence-based studies (Locke, 2014). The current percentage of protected land in Canada is well under the internationally-agreed upon target of 17%, and the country is faced with the interim challenge of identifying and designating additional lands suitable for conservation prior to 2020.

Adding to this challenge is the fact that Canada's system is currently comprised of relatively small (<10 km^2) and disconnected PAs. Few Canadian PAs satisfy minimum size thresholds (>3000 km^2) deemed necessary for ecological persistence (Wright, 2016). These inadequacies can be attributed to flawed historical approaches to PA design.

In the past, PAs were selected based on opportunity rather than ecological principles. In keeping with the utilitarian mindset of the day, PAs were placed first in those areas deemed undesirable or unprofitable to humans and, therefore, would go unmissed if tenured for conservation purpose. Later strategies targeted areas for protection that would be desirable tourism attractions. In efforts to increase visitation, PAs were established near population centres, or along travel routes, instead of in the most biologically important areas. This approach resulted in the sporadic placement of disjointed PAs in aesthetically-pleasing landscapes that typically contained low levels of biodiversity (i.e., rock and ice parks).

Over time, planning strategies evolved to gradually embrace more ecologically-rooted criteria for identifying PAs. For example, practitioners adopted a 'one and done' approach whereby a single PA representing broad landscape patterns was deemed sufficient protection for an ecoregion (Kavanagh et al., 1995). British Columbia applied ecological representation, but the provincial approach was biased towards selecting for biodiversity hotspots and proved to be insufficient at representing those ecological processes necessary to maintain biodiversity itself (Province of British Columbia, 1993). By focussing on representativeness alone, these approaches failed to fully incorporate principles of landscape ecology and conservation biology that are at the forefront of contemporary approaches to PA design. These rudimentary design criteria have produced a system of isolated PAs, selected to capture standalone values, rather than a network of PAs containing multiple overlapping values.

1.4 The Wild Harts Study Area: An Opportunity for Conservation

When compared to the populated areas that comprise the majority of the Global South, northern Canada serves as a suitable candidate for more advanced conservation planning practices given its low human population density and relatively intact landscapes (Wiersma & Canadian Council on Ecological Areas, 2006). However, the global demand for resources has resulted in increased development of fossil fuels and hydroelectric potential across the northern extent of most provinces in the country (Wiersma & Canadian Council on Ecological Areas, 2006). The Peace Region in northeastern British Columbia, referred to throughout this study as the Peace River Break (PRB), is an example of one such area that has been subjected to intensive resource development to satisfy global demands. A recent analysis of linear disturbances noted that the PRB contains more than 29,000 km of pipelines, 45,000 km of roads, and 117,000 km of seismic lines that, if strung together, would encircle the earth four times (Werring, 2015). Despite this development, a relatively intact band of functioning ecosystems bisect the PRB on a southeast-northwest line. These areas comprise what will hereinafter be referred to as the Wild Harts Study Area (Fig. 1).

The Wild Harts Study Area (WHSA) serves as a corridor joining PA complexes in the Central Rocky Mountains to the large PAs in the Northern Rocky Mountains. In addition to facilitating critical ecological exchanges between these two reserve systems, the WHSA provides refugia for species living in a landscape pressured by competing resource interests. The majority of the WHSA is not protected under any conservation tenure and is, therefore, susceptible to encroaching development (Apps, 2013). The WHSA offers one of the last opportunities to conduct systematic conservation planning (SCP) within the Peace Region. The placement of additional PAs within the WHSA would ensure the North American Cordillera remains a contiguous PA network and would assist Canada in reaching the *Aichi Target 11* before the year 2020.

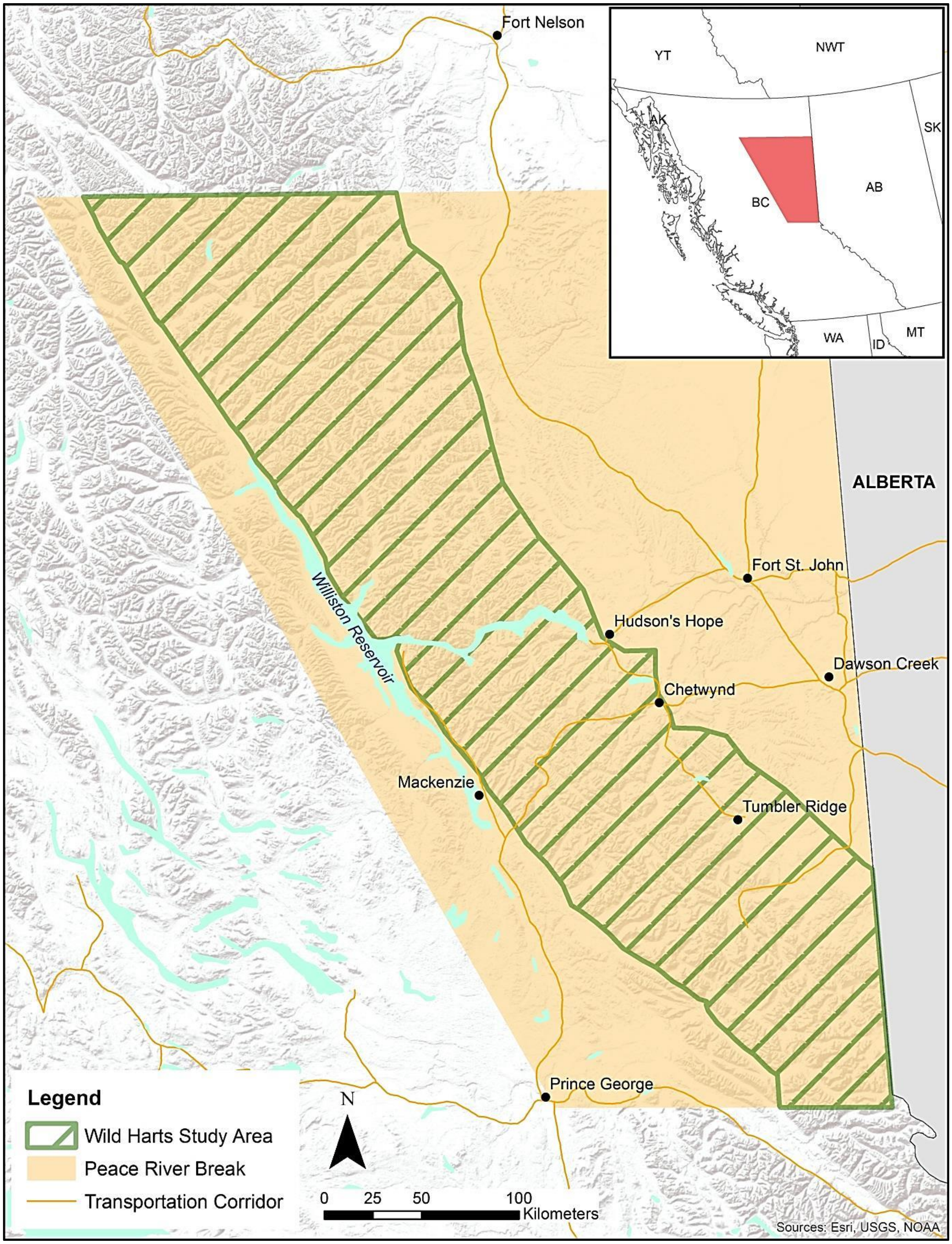

Figure 1. Boundaries of the Peace River Break and Wild Harts Study Area, British Columbia.

1.5 Research Purpose and Associated Questions

The purpose of this research was to prioritize lands for conservation in the WHSA using a systematic conservation planning approach. To achieve this, I was guided by the following 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?

2.0 LITERATURE REVIEW

2.1 From Singles to Systems: A Brief History of Protected Area Design in Canada

In the late 1800s, railway employees stumbled upon a mineral hot spring tucked away in the Canadian Rockies. The Federal Government soon heard about this discovery and the aesthetically-pleasing landscapes that made up the surrounding area. The hot spring was thought to have high potential as a popular tourism and recreation destination. In 1885, the Federal Government acted upon this opportunity and established a 25 km^2 reserve boundary to encompass the hot springs. The area was soon marketed by the Deputy Minister of the Interior as being "the greatest and most successful health resort on the continent" (Lothian, 1976, p. 23). The establishment of this reserve, now known as Banff National Park, marked the beginning of the contemporary PA movement in Canada.

Early motivations for PA establishment in Canada had little to do with conserving areas of inherent ecological value (Dearden & Rollins, 2009). Instead, the tendency was to select areas for protection based on their potential to generate economic stimulus through tourism (Dearden & Rollins, 2009). Much like the creation of Banff National Park, early planners targeted areas that would provide visitors with the opportunity to gaze upon features of the greatest beauty or engage in recreational activities. The utilitarian mindset of the early 1900s was reflected in the creation of national parks like Banff, Yoho, Jasper, Waterton Lakes, and Glacier. Each of these national parks contained world-class scenery, was reasonably proximal to large human settlements, and was accessible by major transportation corridors making them suitable tourism attractions. These early national parks were strictly created out of opportunity and their boundaries were not designed using ecological principles (Dearden & Rollins, 2009).

From 1911–1960, the economic stimulus that could be generated by tourism began to materialize within the minds of bureaucrats in Ottawa and, as a result of this realization, the era saw significant growth in the national parks system (Dearden & Rollins, 2009). The growth of provincial and territorial park systems within Canada mirrored that of national parks during this time. Like the federal system, many of the earliest provincial parks were established primarily out of the opportunity to showcase the natural splendour of the provinces (Stevens & Darling, 2004).

In the west, British Columbia's first provincial parks were established along major railway lines as a means to increase tourism and outdoor recreation (Stevens & Darling, 2004). This was followed by the creation of multiple small roadside provincial parks — each equipped with campsite facilities to address the demand for car-based family recreation opportunities that increased in the province following the Second World War. By the end of the 1950s, British Columbia's PA system was comprised of small, disconnected provincial parks concentrated around southern population centers. In addition, the majority of provincial parks were placed within snow and ice ecosystems that provided visually-appealing scenescapes but contained low biodiversity value (Stevens & Darling, 2004). As was the case with the national park planning process, the majority of these early provincial parks were designed using criteria that had limited or no ecological foundation.

The 1960s saw the emergence of an environmental ethic within the Canadian consciousness (Dearden & Rollins, 2009). As a result of this enlightenment, non-governmental environmental organizations began to place pressure on parliament to expand Canada's PA system. This new paradigm placed an increased emphasis on establishing PAs that would serve as refugia for ecosystems and biotic communities. These pressures incited a shift in policy away from an exclusive focus on tourism and towards targeting those areas higher in conservation value (Hummel, 1989).

In 1964, policy was established that deemed the preservation of significant natural features as being the most fundamental and important obligation to national park designation and management (Dearden & Rollins, 2009). In 1965, the Province of British Columbia developed the first *Park Act* that placed importance on managing provincial PAs for conservation alongside recreation (Stevens & Darling, 2004). These policy shifts coincided with the emergence of conservation sciences — leading to broader understandings of the need for a systematic approach to resource planning and management (Eagles et al., 2002).

Building on this new ecological understanding, PA design in the 1970s began to embrace the concept of planning for representation of biodiversity (Wiersma & Nudds, 2009). For example, national parks were now designed to encapsulate a representative sample of each of Canada's unique landscapes. The nation was divided into national park natural regions (NPNRs) based on prevailing vegetation types and landscape appearance (Government of Canada, 1972). Candidate areas for protection were selected based on how well they represented an NPNR's natural features. The premise of this approach was that the designation of a single national park, within an identified NPNR, would be sufficient to achieve representation of said NPNR (Government of Canada, 1972).

The NPNR approach provided limited direction on where national parks should be placed, how large they should be, or how they should be configured. In addition, the process of delineating NPNRs, based on landscape appearance and prevailing vegetation, was considered too coarse and ecologically inadequate (Noss et al., 1995). Recognizing these shortcomings, non-government environmental organizations developed frameworks for selecting PAs, founded on ecological principles, with hopes that they would be applied in decision making within government.

An example of such an initiative was the introduction of the gap analysis planning methodology. Developed by the World Wildlife Fund of Canada (WWF), and the Canadian Council on Ecological Areas (CEAA), gap analysis is a method for identifying areas of natural diversity that are not represented by an existing PA system (Kavanagh et al., 1995). This is achieved by overlaying spatial data describing the surficial deposits and quaternary geography of a landscape. Landscape units, known as enduring features, are then selected based on a combination of topography-relief, parent material origin, and parent material texture. The final stage of the method requires the identification of 'gaps', where existing PAs don't represent identified enduring features. Though data on individual species were included when available, the gap analysis methodology was primarily coarse in that enduring features were considered to be foundational elements of ecological diversity (Kavanagh et al., 1995).

This gap analysis approach was the first design methodology aimed at creating an inter-related system of PAs rather than a collection of standalone PAs. Some of the suggestions contained within the WWF/CEAA approach to gap analysis were incorporated into government PA planning processes. For example, the Province of British Columbia's 1993 *Protected Area Strategy* (Stevens & Darling, 2004) drew upon gap analysis as a method for identifying new PAs that would help address underrepresentation of mid-low elevation ecosystems in the province (Province of British Columbia, 1993). Although the planning intent of the *Protected Areas Strategy* was to incorporate a gap analysis approach, established policy targets for conservation, and the existing legacy of PAs that were contrary to representation goals prevented government from fully applying gap analysis methodology. The combination of these factors resulted in limited progress towards building a functioning system of PAs in British Columbia (Doyle & Province of British Columbia, 2010).

Despite the efforts of non-government environmental organizations, the Canadian system remained comprised of small and disjointed PAs at the turn of the 21st century (BEACONS, 2006; Doyle & Province of British Columbia, 2010). It does not resemble a connected network designed to promote biodiversity, maintain biophysical processes, and accommodate shifting ecological communities. Though planning for these values has since become an initiative at the federal and provincial levels (Stevens & Darling, 2004; Parks Canada, 2016), both levels of government continued to employ rudimentary representation approaches for directing PA establishment.

The growing fields of conservation science, and accompanying technological innovations, are ushering in a new era of PA design rooted in ecological principles. The disciplines of landscape ecology, disturbance ecology, and conservation biology have co-evolved with the development of large-scale data visualization, mapping, and management techniques to facilitate the emergence of new planning approaches. With the assistance of radio collars and satellite transmitters, researchers now understand that animals are moving far greater distances than was previously understood (Chadwick et al., 2000). Remotely sensed data, and the ability to process/analyze this information using various spatial tools and metrics, enables researchers to grasp the extent of resource development on the landscape. The advent and accessibility of these data and tools is allowing for more analytical planning processes whereby practitioners model conservation values at multiple spatial scales.

In Canada, First Nation groups and non-government environmental organizations have been leading the alternative PA design movement. For example, in 2003, the Taku River Tlingit (TRT) developed a PA design for their 40,000 km^2 traditional territory in northwestern British Columbia (Province of British Columbia & Taku River Tlinget First Nation, 2011). The design process combined a number of methodologies including: the development of habitat models for several focal species; coarse-filter ecological community classification and representation analysis; regional connectivity analyses; and spatial optimization procedures at multiple scales. Traditional ecological knowledge was used to supplement scientific data and verify computer-generated models. Through a combination of identified core and connectivity areas, the TRT now have 55% of their traditional territory protected under the plan (Province of British Columbia & Taku River Tlinget First Nation, 2011).

Additional examples of contemporary PA designs include the Muskwa-Kechika Management Area (Heinemeyer et al, 2004) and a number of ecoregional assessments conducted by the Nature Conservancy (see for example Horn, 2011). These design approaches, which focus on building an interconnected system of PAs using multiple representation lenses, require careful consideration of a number of key variables. These variables include selection of features, targets, and tools for conservation area design. Each of these PA design elements will be discussed below.

2.2 Deciding What to Conserve

Identifying what to conserve, and how to define it, is one of the first, and most critical decisions in PA planning. Using representation of a single valued ecosystem component as the sole criteria for a design will result in the establishment of PAs that are inadequately equipped to support biodiversity and the biophysical processes needed to maintain it (Noss et al., 1995). Therefore, it is crucial to employ multiple lenses when selecting features for conservation. Hierarchies of conservation features used in a design can range from species-level assemblages to biogeoclimatic landscape units, or the natural disturbance regime of a given planning area (Noss et al., 1995; Margules & Pressey, 2000; Delong & Province of British Columbia, 2011). The use of multiple features, at varying spatial scales, will increase the likelihood of the resultant PA system supporting a broad range of biodiversity and maintaining ecological processes (Noss et al., 1995).

The complexity of ecological systems makes it nearly impossible to quantify all facets of biodiversity within a proposed PA (Margules & Pressey, 2000). Therefore, practitioners must be targeted in their approach and select those features that will best serve as surrogates for biodiversity. Similar to how enduring features are utilized to represent a region's geofeatures, a surrogate is a component of an ecosystem that is used as a proxy to represent the biodiversity of the whole ecosystem (Grantham et al., 2010). Biodiversity surrogates are often categorized as being either taxonomic or environmental (Margules & Pressey, 2000; Groves et al., 2002). Examples of taxonomic surrogates include rare, umbrella, flagship, and keystone species; whereas environmental surrogates include, but are not limited to, watersheds, natural disturbance regimes, land facets, or climatic zones (Margules & Pressey, 2000).

The use of surrogates carries with it the assumption that one component of biodiversity can be considered to be representative of another — an assumption criticized by many as being an oversimplification of complex natural systems (Lambeck, 1997; Simberloff, 1998; Molles, 1999; Margules & Pressey, 2000; Carroll et al., 2001; Bonn et al., 2002; Lindenmayer et al., 2002). Therefore, a comprehensive PA design would include a number of surrogates, selected from both taxonomic and environmental categories, in order to account for the limitations and assumptions behind single surrogate use. Surrogate selection is largely dictated by data availability and comprehensiveness, as well as the specified objectives for a given planning process (Margules & Pressey, 2000). For the purposes of this study, environmental and taxonomic surrogates are referred to as coarse- and fine-filter conservation features respectively.

2.3 Deciding How Much to Conserve

Once the suite of conservation features has been selected, the next step is determining how much of each feature should be protected. Typically, this target is expressed quantitatively for use at the operational level (Margules & Pressey, 2000). Canada has a long history of setting quantitative targets to help drive progress towards expanding the country's PA system. In 1992, Canada was a signatory of the *UN Convention on Biological Diversity* (CBD), and through this agreement committed to expand the Canadian PA system to encompass 12% of the nation's terrestrial ecosystems (Canadian Parks and Wilderness Society, 2016). This action came after the *World Commission on Sustainable Development* (i.e., Bruntland Commission) called for a tripling of PAs globally. In 2010, the CBD determined the target of 12% had not reduced declines in global biodiversity. Based on this analysis, the CBD recommended countries commit to protecting at least 17% of terrestrial and inland water areas by the year 2020 (i.e., *Aichi Target 11*). In 2015, the Canadian government committed to achieving *Aichi Target 11* in the report *2020 Biodiversity Goals and Targets for Canada* (Canadian Parks and Wilderness Society, 2016).

Though based on good intentions, global targets for biodiversity conservation are criticized as being political abstractions, or data-free initiatives with little scientific foundation (Schmiegelow et al., 2006; Locke, 2014; Wiersma & Sleep, 2018). The 12% target, recommended by the Bruntland Commission, is considered by the conservation community to be grossly inadequate and it is predicted that 50% of all species would be committed to extinction if PA expansion was restricted to this target (Schmiegelow et al., 2006; Locke, 2014). It has been argued that more realistic targets of 30–70% protection of terrestrial environs are necessary to prevent further losses in biodiversity (Margules et al. 1988; Saetersdal et al. 1993; Soulé and Sanjayan 1998; Warman 2001; Rumsey et al. 2003; Venter et al., 2014).

The policy-based targets described above are premised on the assumption that selecting for a fixed percentage of a given planning region's total area will effectively represent the ecology of that region. In a review of 159 studies on conservation targets, Svancara et al. (2005) found that the simplistic approach of targeting x% of a planning region often leads to inadequate representation of individual species and their respective habitats. Instead of blanketing entire planning regions with a single data-free target, it has been suggested that a more effective approach is to employ a range of science-based targets in SCP processes (Wiersma & Sleep, 2018). Under a science-based approach, each conservation feature should be assigned an individualized target that is the product of an in-depth understanding of the ecology and spatial extent of that feature within the context of a given planning region. In this way, the overall percentage of a planning region's total area needed to achieve conservation is representative of the combined spatial requirements of individual conservation features (Svancara et al., 2005).

Irrespective of the approach, the setting of conservation targets is plagued by assumption and uncertainty (Schmiegelow et al., 2006). To ensure best practices when selecting targets for a PA design, Margules and Pressey (2000: 246) suggest planners do the following: "focus on scales that are much finer than whole countries or regions; deal with natural processes as well as biodiversity patterns; reflect the relative needs of species and landscapes for protection; recognize that reserves must be complemented by off-reserve management; and leave options open for revision as social and economic conditions change". In order to achieve these requirements, planners must have an understanding of the ecological and social dimensions of their planning area prior to establishing targets. However, possessing knowledge alone will not result in the design of a PA system that is effective at ensuring the preservation of biodiversity. Planners need to employ tools that allow them to manipulate targets and assess possible solutions for conservation at multiple scales.

2.4 The Right Tool for the Job

Given the complexity attendant to a system with multiple conservation features and varying targets, optimization tools are increasingly employed by conservation planners to assist in PA selection (Schuster et al., 2016). Through the use of these tools, planners are able to explore the extent to which varying PA configurations achieve conservation targets and minimize cost. Optimization software identifies a portfolio of high-value conservation lands that can contribute to a transparent, inclusive, and defensible decision-making process relating to PA creation (Schuster et al., 2016). The majority of these optimization tools are strictly computational and have no graphical interface. The outputs of these programs can be uploaded into ArcGIS (Environmental Systems Research Institute, 2011) to be viewed spatially (Morrell et al., 2015).

To date, the most commonly used decision support software for conservation planning is MARXAN (Ball et al., 2009). MARXAN is designed to select planning units based on the presence/absence of identified conservation features (Morrell et al., 2015). The user can manipulate how aggressively MARXAN works to select conservation features by adjusting each feature's associated target. Planners can also adjust the software to align with additional goals for the PA design. For example, MARXAN can be manipulated to minimize boundaries (edge) or avoid highly fragmented portions of the planning landscape — as these would be considered as being costs to the overall effectiveness of the PA design. The software is designed to maximise targets for conservation while minimizing costs (Morrell et al., 2015).

The traditional MARXAN platform uses the heuristic method of simulated annealing (SA) to produce portfolios of conservation lands (Morrell et al., 2015). SA is simply an algorithm that produces 'near optimal solutions' for a problem given user-defined parameters (i.e., planning units, features, targets, and costs) (Morrell et al., 2015). Planners have recognized the problem-solving abilities of this software and, as a result, MARXAN has been employed in multiple contemporary PA designs (Airamé et al., 2003; Evans, 2003; Leslie et al., 2003; Stewart et al., 2003; Banks et al., 2005; Geselbracht & Torres, 2005, Loos & Canessa, 2006; Horn, 2011; Venter et al., 2014). However, the traditional MARXAN model has recently come under criticism for producing solutions of questionable quality (Beyer et al., 2016). This is because the heuristic method of SA is limited to selecting PA designs that are near optimal and, thus, may exclude important features from a prioritization. In addition, SA can take hours/days to calculate a solution and processing time increases with the complexity of datasets used and the size of a reserve planning area (Beyer et al., 2016).

Recent advances in algorithms and computing power have now increased the capabilities of decision support software (Beyer et al., 2016). Integer linear programming (ILP) is an example of a state-of-the art approach to optimization problems that has superseded simulated annealing (Schuster et al., 2016). When used in conjunction with MARXAN, ILP is capable of analyzing large, complex datasets to find an 'optimal solution' to identified biodiversity goals based on user-defined parameters (Schuster et al., 2016). ILP is superior to SA in computational speed (seconds-minutes vs hours-day) and solution quality (optimal vs near-optimal) (Beyer et al., 2016). These advantages allow planners to explore trade-offs, assess the complementarity of selected surrogates, and evaluate effectiveness of targets in near real time. When compared to the static portfolio of hypothetical PA designs produced by MARXAN with SA, MARXAN with ILP offers an interactive platform that can facilitate conversations with stakeholders and decision makers regarding the establishment of PAs (Beyer et al., 2016; Schuster et al., 2016).

3.0 CASE STUDY

3.1 Overview of the Peace River Break

The Peace River Break (PRB) is a geographic designation coined by the Yellowstone to Yukon Conservation Initiative to describe a 135,400 km^2 section of the North American Cordillera that straddles the Peace River in northeastern British Columbia (Fig. 1) (Apps, 2013). Ten ecoregions merge here to create a hotspot of biotic and abiotic diversity. The Peace River itself has the unique distinction of being one of the only watercourses in Canada that travels eastward through the Rocky Mountains. Where arctic air typically dominates this region, the Peace River provides a channel for warm Pacific air to flow through, resulting in a moderated climate and unique ecological conditions (Apps, 2013).

This west-east pathway, and the temperate climate it provides, made the PRB a logical area for multiple First Nations groups to inhabit (Apps, 2013). The arable soils of the Peace River valley later drew agricultural interests to the region at the turn of the 20th century. By the 1950s, two major transportation corridors (i.e., Alaska Highway and John Hart Highway) had been constructed, providing access to what was previously a remote and isolated area. This led to the development of a natural resource industry in the area 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 most prominent regions for resource-related industry and extraction (Apps, 2013).With construction of the Site C Dam underway, and other large-scale development proposals pending approval, such as TransCanada's Prince Rupert Gas Transmission Project, the area could see considerable growth in population and resource-related infrastructure. Considering the PRB is currently underrepresented by PAs (approximately 9% of the land base is conserved), landscape connectivity and associated biodiversity values in the area are quickly becoming vulnerable to the cumulative effects of industrial expansion (Apps, 2013).

3.2 The Wild Harts Study Area

A preliminary analysis of industrial activity in the PRB revealed the spatial footprint of linear development on the land base (Fig. 2). Industrial expansion has formed an ecological bottleneck in the region — whereby the mountain ranges that bisect the PRB on a southeast-northwest line represent the only ecologically functional landscapes within this section of the North American Cordillera. When compared to the rest of the PRB, these areas remain relatively intact and form a natural corridor for species moving amongst existing PAs (Fig. 2).

Given their ecological significance within local and regional contexts, the lands that comprise the abovementioned corridor were selected to be the focus of this research. The borders of the Eastern System Physiographic Region capture the corridor and, thus, served as a logical reference from which to delineate longitudinal study area boundaries. Horizontal boundaries were established in areas where lands beyond were thought to have sufficient representation by existing PAs. All lands that fell within the finalized boundary comprised what was referred to in this study as the Wild Harts Study Area (WHSA) (Fig. 2).

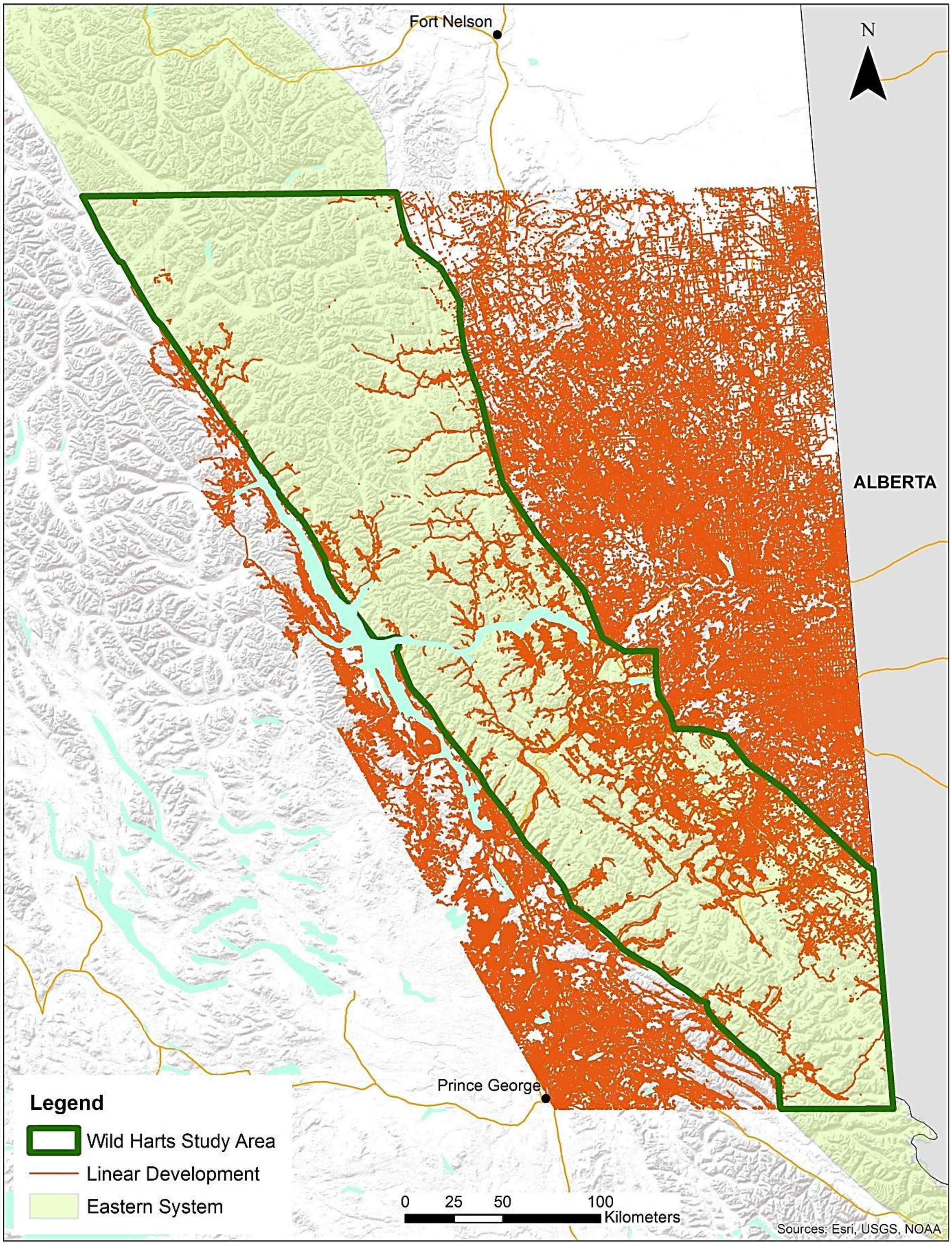

Figure 2. The Wild Harts Study Area juxtaposed against the Eastern System Physiographic Region and linear development in the Peace River Break.

3.2.1 Geography & Natural History

The lands that make up the WHSA occupy 70,000 km^2 of the Eastern System Physiographic Region. This section of the Eastern System is predominately comprised of the Northern and Central Canadian Rocky Mountain ecoregions — with small portions of the Eastern Continental Ranges and Southern Alberta Upland ecoregions occupying the southeastern corner (Demarchi, 2011). Elevation in the WHSA increases in a southerly to northerly direction and decreases from west to east (Demarchi, 2011).

At the ecosection scale, the portions of the WHSA that fall below the Peace River are largely characterized by the steep-sided, round-topped mountains of the Hart Ranges (Demarchi, 2011). Moving eastward, the Hart Ranges subside into the low, rounded mountains and wide valleys that make up the Hart Foothills. The remaining southeasterly portions are comprised of the ridges and valleys of the Front Ranges and rolling uplands of the Kiskatinaw Plateau (Demarchi, 2011).

The central portions of the WHSA contain rounded mountains characteristic of the Peace Foothills and Misinchinka Ranges ecosection (Demarchi, 2011). Moving northward, above the Peace River, these rounded mountains are disrupted by the deep valleys and rugged peaks of the Muskwa Ranges which represent the highest mountains in the WHSA. The Muskwa Foothills make up the remaining northeastern portion of the study area and are characterized by rounded mountains and wide valleys (Demarchi, 2011).

The climate in the WHSA consists of cold winters and warm summers (Demarchi, 2011). Extreme cold events are frequent during winter and early spring when Arctic air moves unhindered from north to south across the area. The rugged topography of the WHSA results in unique patterns of surface heating at high-elevation slopes and cold-air drainage in low valleys. Precipitation is strongly influenced by warm Pacific air that is brought across the central interior by prevailing westerly winds. The Rocky Mountains serve as a barrier that causes said warm air to rise, resulting in high precipitation in windward areas and the occurrence of rain shadows in leeward areas. In general, precipitation levels are relatively constant throughout the year (Demarchi, 2011).

The WHSA is unique in that its boundary captures portions of ten major watersheds that serve as tributaries to both the Pacific and Arctic oceans (Demarchi, 2011). From north to south, these include the Kechika, Fort Nelson, Finlay, Halfway, Peace, Pine, Parsnip, Smokey, Kiskatinaw, and McGregor watersheds (Demarchi, 2011; Apps, 2013). The complex relief of the WHSA causes drainage to radiate out in all directions. However, the majority of streams are relatively short in length and either flow westward into the Parsnip/Fraser watersheds, or eastward into the Peace (Demarchi, 2011).

The area's disturbance regime is predominately comprised of stand-replacing fire events and insect epidemics (Delong & Province of British Columbia, 2011). Vegetation pattern in the WHSA is defined by six prevailing biogeoclimatic zones (Demarchi, 2011). These include the Sub-boreal Spruce, Englemann Spruce – Subalpine Fir, Boreal Altai Fescue Alpine, Interior Cedar – Hemlock, Boreal White and Black Spruce; and Spruce – Willow – Birch zones (Demarchi, 2011; Apps, 2013).

The unique combination of topography, climate, hydrology, disturbance, and vegetation pattern enables the WHSA to support a high diversity of native wildlife and fish species. Characteristic mammalian species include wolverine, moose, caribou, mountain goat, mule deer, elk, lynx, marten, black bear, Stone's sheep, and grizzly bear (Demarchi, 2011; Apps, 2013). The area is said to support 57% of all avifauna known to occur in British

Columbia. Bull trout and Arctic grayling are the dominant fish species (Demarchi, 2011; Apps, 2013).

3.2.2 The Human Element

The WHSA boundary captures traditional territories of the Halfway River First Nation, McLeod Lake Indian Band, West Moberly First Nation, Saulteau First Nation, Simpcw First Nation, Blueberry River First Nation, Horse Lake First Nation, and Lheidli T'enneh First Nation. Four significant urban settlements (i.e., population > 1000) are within, or directly proximal to, the study area. These include the towns of Mackenzie, Tumbler Ridge, Chetwynd, and Hudson's Hope. Residents of these communities rely heavily upon natural resources for recreation and employment. The WHSA boasts some of the best hunting, fishing and snowmobiling opportunities in British Columbia. Main employers in the area include the oil, natural gas, coal, hydro-electric, forest, and resource-related-tourism industries (Apps, 2013).

3.2.3 Resource Development

Where oil and gas dominate in the larger PRB area, forestry is the most prolific resource-based industry in the WHSA (Apps, 2013). Harvesting activities within the WHSA supply major pulp, lumber, and particle board mills situated in the communities of Chetwynd and Prince George. The study area captures the majority of TFL 48 — a 640,000 ha tree farm licence managed by Canadian Forest Products Limited that has an allowable annual cut of 1,550,000 m^3 (Province of British Columbia, 2015a).

Mining is another major industry in this area. There are two major coal mines (i.e., Sukunka and Murray River) that occur within the bounds of the WHSA along with multiple small placer and aggregate operations. There is some agricultural activity in the far southwest and northeast portions of the study area. Several wind power proposals occur within the area but remain in the investigative phase due to the potential energy surplus that the Site C Clean Energy Project is expected to create. The WHSA is also bisected by John Hart Highway, two railroads, and a myriad of access roads that are associated with the abovementioned industries.

When compared to the rest of the Peace River Break, there is limited oil and natural gas extraction/infrastructure in the WHSA. However, TransCanada's Prince Rupert Gas Transmission proposal is currently under review. If approved, this initiative would increase the rate of natural gas extraction from the Peace River Break which would then be sent overland by pipeline to Prince Rupert. There is a high likelihood that, in order to keep up with increasing demands associated with this project, and others like it, natural gas exploration and development will encroach upon the WHSA in the near future.

3.2.4 Conservation in the Wild Harts Study Area

At the North American scale, the WHSA joins large PA systems in the Central Rocky Mountains to the Muskwa-Kechika Management Area (M-KMA) and territorial parks in the north. In this way, the WHSA serves as an integral section of the Yellowstone to Yukon corridor — an initiative centered on establishing a contiguous PA network stretching from Wyoming to the Yukon Territory (Fig. 3). Fragmentation of the WHSA may create barriers to species movements and effectively split the trans-continental corridor into two ecologically disjointed PA networks. This limits the ability of biological communities to adapt to shifting climate regimes by migrating along latitudinal gradients. It may also isolate

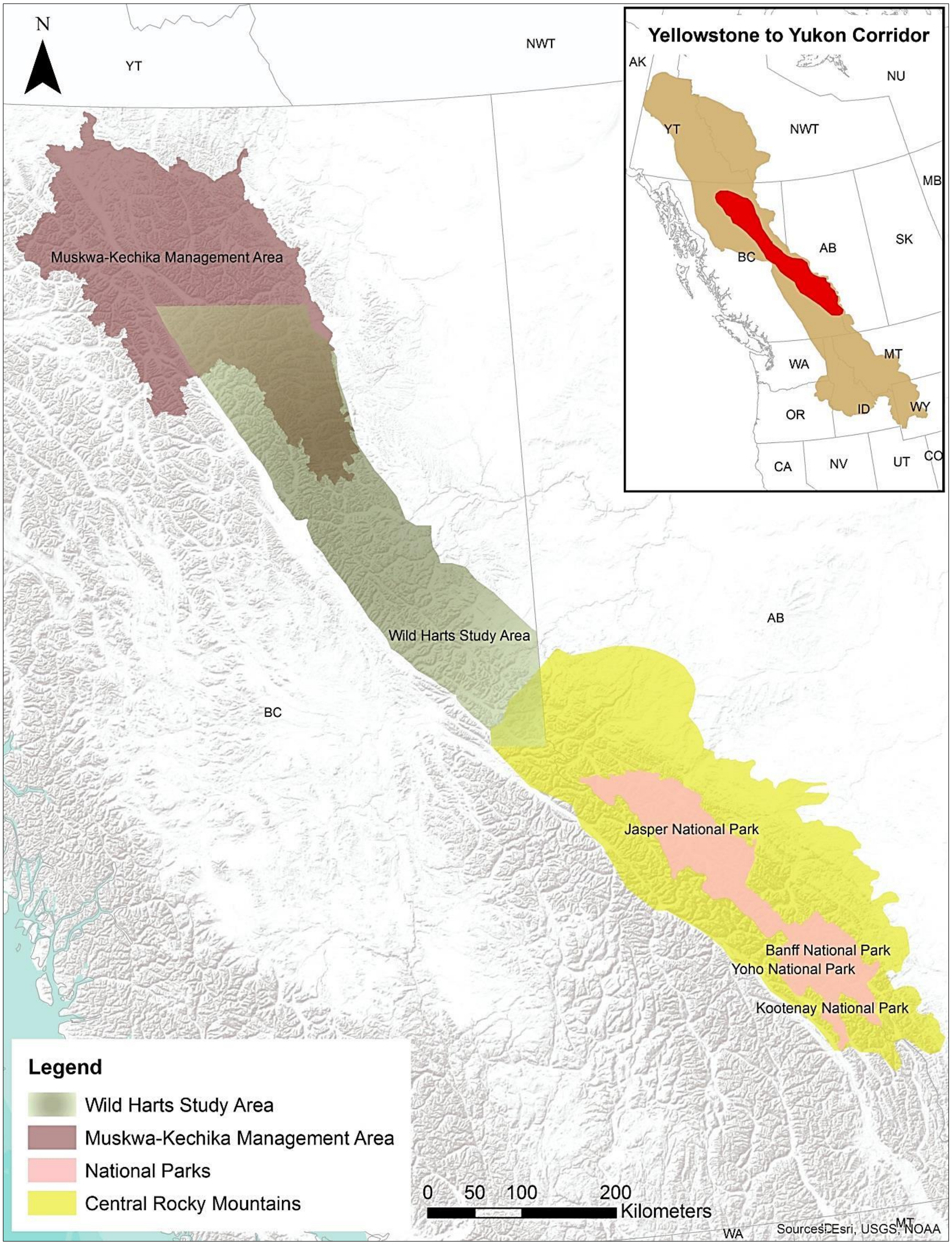

Figure 3. The position of the Wild Harts Study Area in relation to the Muskwa-Kechika Management Area, Central Rocky Mountains, and Yellowstone to Yukon Corridor.

populations and reduce the amount of biological/genetic exchange occurring along the North American Cordillera.

Similar to the Peace River Break, there is relatively little PA representation within the WHSA (Fig. 4).Total PA coverage equals approximately 1,067,000 ha or 17.4% of the WHSA's total area. Northern Rocky Mountains Provincial Park and Kakwa Provincial Park occupy the terminal ends of the study area and comprise approximately half of the total area under protection in the WHSA. The remaining half is comprised of small and disjointed PAs (Fig. 4). The creation of new PAs within these poorly-represented sections would limit fragmentation of the WHSA and facilitate connectivity across the northern portion of the North American Cordillera. In addition, PA creation in the WHSA could assist Canada in achieving its international agreement of protecting 17% of the nation's terrestrial land base by 2020.

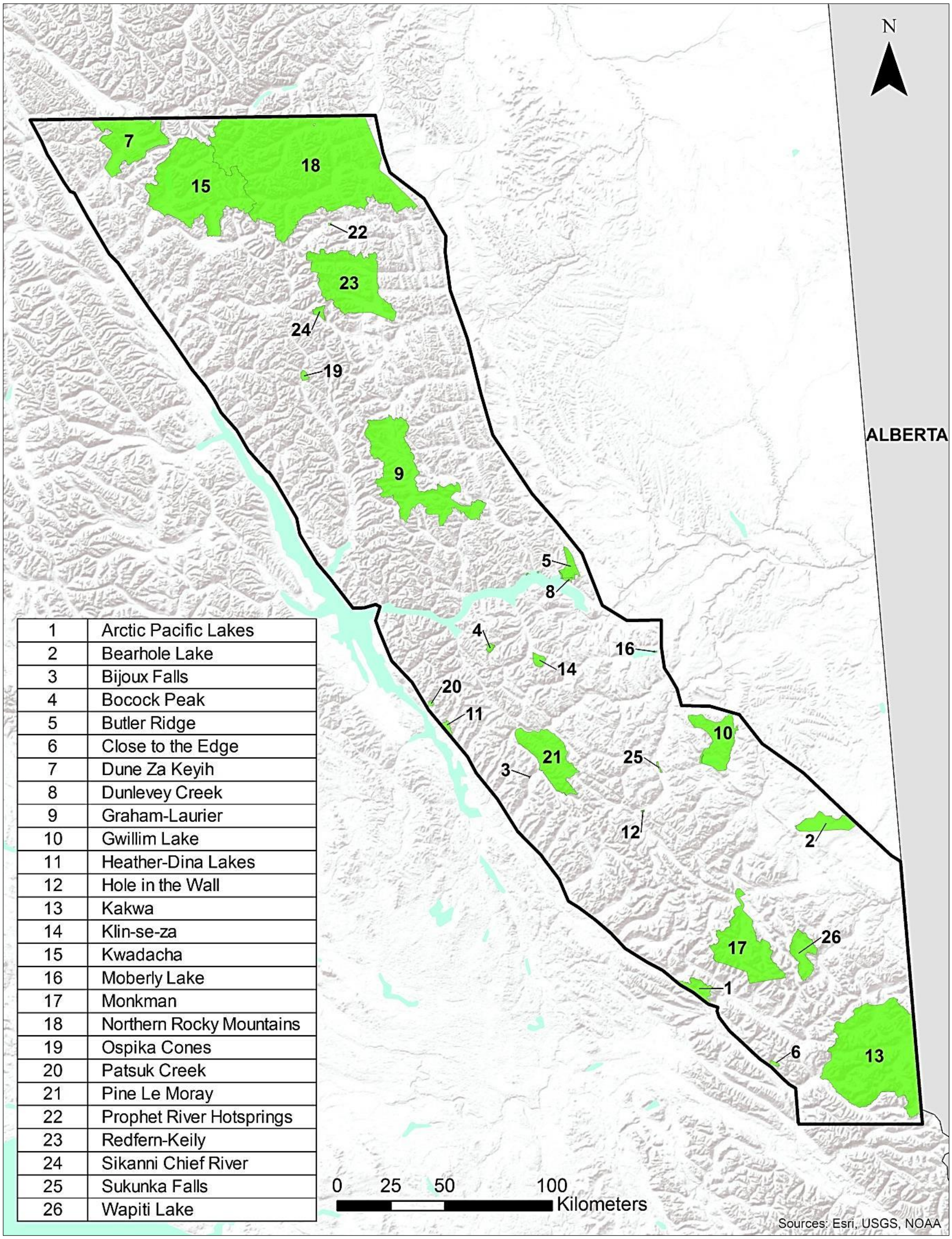

Figure 4. Existing protected area representation in the Wild Harts Study Area.

4.0 METHODS

To address each of my research questions, I used a variation of the methods for conservation area design described in Margules and Pressey's (2000) *systematic conservation planning* (Table 1). The four steps involved in my SCP methods were: (1) select and develop conservation features; (2) identify conservation goals and targets for the WHSA; (3) review existing conservation areas; and (4) use MARXAN-ILP to identify lands suitable for protection in the WHSA.

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

1. Select and Develop Conservation Features
• Review literature and existing data to identify multi-spatial surrogates for biodiversity in the WHSA. • Select those datasets that have sufficient rigor and consistency to support the construction of spatial layers for the WHSA. • Develop spatial layers in ArcGIS that represent each conservation feature's extent across the WHSA.
2. Identify Conservation Goals and Targets
• Employ knowledge gained in the literature review to set goals for conservation in the WHSA centered on promoting biodiversity, maintaining natural disturbance regimes, and increasing resilience to climate change. • Translate goals into a series of quantifiable targets for operational use.
3. Review Existing Protected Areas
• Determine the extent to which existing protected areas achieve my targets for conservation in the WHSA. • Identify gaps in the current WHSA protected areas system.
4. Use MARXAN-ILP to Identify Lands Suitable for Protection in the WHSA
• Apply the conservation software MARXAN with ILP to identify gaps in the current protected areas system in order to spatially prioritize lands for conservation in the WHSA. • Select a portfolio of priority lands that achieve optimal targets for conservation while minimizing user-defined costs.

4.2 Step 1 Selection and Development of Conservation Features

I conducted a review of existing literature on the biodiversity and biophysical processes present in the WHSA in order to identify a suite of possible surrogates for use in the SCP process. Expert opinion was drawn upon informally to assess the extent to which select surrogates represented other facets of biodiversity in WHSA. I analyzed databases to identify which surrogates had geospatial layers that were most available, reliable, and consistent across the WHSA (Appendix 1). Multiple datasets were combined, using geospatial analysis in ArcGIS to create full layers for surrogates.

The combination of literature, expert opinion, and data availability resulted in the selection of coarse-filter and fine-filter surrogates, hereinafter referred to as conservation features, for use in the subsequent ILP scenarios. The conservation feature layers described below were developed in binary form (0, 1). There is no continuous gradient that would suggest one portion of a conservation feature is of higher value than another.

4.2.1 Coarse-filter Conservation Features

In SCP, coarse-filter conservation features are typically representative of ecological patterns and the biophysical processes that define those patterns (Schneider et al., 2011). The coarse-filter approach is grounded in the assumption that, by representing a wide array of ecosystems and their constituent processes, the habitat needs of multiple species will be accommodated in a resultant PA design (Schneider et al., 2011). In this way, coarse-filter conservation features are an efficient means by which to compensate for a lack of data on the ecology of individual species when prioritizing lands for conservation across a large region such as the WHSA. Coarse-filter conservation features used in this study included land facet diversity, land facet rarity, and a set of features displaying an intersection of natural disturbance, biogeoclimatic zone, and forest age.

4.2.1.1 Land Facets

Ecological pattern and process is largely determined by underlying abiotic variables such as slope, aspect, elevation, and landform (Beier & Brost, 2010). A land facet is a recurring landscape unit with uniform combinations of these abiotic variables. In contemporary conservation planning, land facets are used as a coarse-filter conservation feature to build climate change resilience into PA designs. This is because topography and geology represent those components of an ecosystem that are relatively stable and unlikely to undergo abrupt reorganization in response to a shifting climate regime. Essentially, land facets serve as the static stage for temporary biological assemblages to pass across and for evolutionary processes to play out upon (Beier & Brost, 2010).

I used datasets developed by Michalak et al. (2015) and Carroll et al. (2017) to construct a land facet diversity (LFD) and land facet rarity (LFR) layer for application in MARXAN-ILP. Land facets were defined in these datasets as raster cells containing unique combinations of 4 abiotic variables: elevation, landform, modified heat load index (HLI), and soil order. Landform was referred to as coarse topographic features such as headwaters, hilltops, ridges, valleys, and canyons. Modified heat load index was a measure of radiation exposure relative to aspect and slope. Soil order was described as patterns in surficial deposits at a scale of 1 km^2. Michalak et al. (2015) and Carroll et al. (2017) delineated individual land facets by categorizing the four abiotic variables into discrete classes for application in the following equation:

$$\text{Land Facet ID} = (\text{Landform} + \text{HLI} + \text{Elevation})*100 + \text{Soil Order}$$

4.2.1.1.1 Land Facet Diversity

Areas of high diversity occurred where clusters of land facet cells had dissimilar combinations of abiotic variables relative to neighboring cells. Details on the formulas used to generate diversity metrics can be found in the R script of the land facet diversity dataset (see Carroll et al., 2017). In ArcGIS, I scaled the dataset produced by Carroll et al. (2017) to the WHSA and ranked diversity on a scale of 1 (high LFD) to 10 (low LFD). The mountainous terrain of the WHSA made it so that the majority of the area received a diversity value of ≤ 3. Therefore, only those areas containing a diversity value of 1 were selected to serve as a surrogate for LFD — as these areas represented the most diverse combinations of abiotic variables in an already highly diverse landscape.

4.2.1.1.2 Land Facet Rarity

Using the dataset produced by Michalak et al. (2015), I assessed rarity based on the total area that each land facet covered in the WHSA. The data were scaled to the WHSA and each land facet type was assigned a value from 1 (low area) to 10 (high area). Those land facets assigned a value of 1 occupied <1000 ha of the WHSA total area and were considered to have a rare distribution. Accordingly, the LFR layer reflects those cells containing unique combinations of elevation, landform, and HLI that occupy <1000 ha of the WHSA area.

4.2.1.2 Forest Pattern and Process

As previously stated, coarse-filter conservation features should represent the full array of ecosystems that occur within a given planning region, as well as the biophysical processes which create the conditions necessary for the persistence of those ecosystems. To satisfy those criteria, I constructed a series of layers that incorporated data on vegetation types, forest age, wildfire occurrence, and climatological patterns in the WHSA. Information on vegetation types was included to ensure adequate representation of dominant tree species. Old forests were included in the selection as these areas are synonymous with high-value habitat features (e.g., coarse-woody debris, wildlife trees, stratified canopy, shrubs, etc.). Recently burned areas (≤40 years) were selected as they represent suitable habitat for those species that are heavily dependent upon burned, standing forests. Lastly, natural disturbance regimes were drawn upon because of their ability to reorganize biological communities and initiate ecological succession.

Provincial datasets from DataBC were used to construct the multiple layers representing forest pattern and process in the WHSA (Appendix 1). In ArcGIS, I intersected data describing natural disturbance type (NDT), biogeoclimatic ecosystem classification (BEC) zone, and stand age to create polygons that represented unique combinations of these three input datasets (Table 2). I used the seral stage definitions by NDT/BEC, as described in the *Biodiversity Guidebook* (Province of British Columbia, 1995), to select for mature-old stands. Additional datasets describing historical wildfire and harvesting activity were used to select stands within each NDT/BEC that were recently burned and free of any harvest activity since time of disturbance.

Table 2. Nomenclature of the forest pattern and process conservation features used in the MARXAN-ILP analysis to prioritize areas for conservation in the Wild Harts Study Area.

Label*	Description
NDT3-SBS-Mature/Old	NDT3: ecosystems with frequent stand initiating events SBS: Sub-boreal Spruce biogeoclimatic zone Mature/Old: stand age >100 years
NDT3-SBS-Burned	NDT3: ecosystems with frequent stand-initiating events SBS: Sub-boreal Spruce biogeoclimatic zone Burned: exposed to wildfire within last 40 years
NDT3-BWBS-Mature/Old	NDT3: ecosystems with frequent stand-initiating events BWBS: Boreal White and Black Spruce biogeoclimatic zone Mature/Old: stand age >80 years
NDT3-BWBS-Burned	NDT3: ecosystems with frequent stand-initiating events BWBS: Boreal White and Black Spruce biogeoclimatic zone Burned: exposed to wildfire within last 40 years
NDT2-SWB-Mature/Old	NDT2: ecosystems with infrequent stand-initating events SWB: Spruce - Willow - Birch biogeoclimatic zone Mature/Old: stand age >120 years
NDT2-SWB-Burned	NDT2: ecosystems with infrequent stand-initating events SWB: Spruce - Willow - Birch biogeoclimatic zone Burned: exposed to wildfire within last 40 years
NDT2-SBS-Mature/Old	NDT2: ecosystems with infrequent stand-initiating events SBS: Sub-boreal Spruce biogeoclimatic zone MO: stand age >100 years
NDT2-SBS-Burned	NDT2: ecosystems with infrequent stand-initiating events SBS: Sub-boreal Spruce biogeoclimatic zone Burned: exposed to wildfire within last 40 years
NDT2-ESSF-Mature/Old	NDT2: ecosystems with infrequent stand-initiating events ESSF: Englemeann Spruce - Subalpine Fir biogeoclimatic zone Mature/Old: stand age >120 years
NDT2-ESSF-Burned	NDT2: ecosystems with infrequent stand-initiating events ESSF: Englemeann Spruce - Subalpine Fir biogeoclimatic zone Burned: exposed to wildfire within last 40 years
NDT1-ESSF-Mature/Old	NDT1: ecosystems with rare stand-initiating events; ESSF: Engelmann Spruce - Subalpine Fir biogeoclimatic zone Mature/Old: stand age ≥120 years
NDT1-ESSF-Burned	NDT1: ecosystems with rare stand-initiating events ESSF: Engelmann Spruce - Subalpine Fir biogeoclimatic zone Burned: exposed to wildfire within last 40 years
NDT1-ICH-Mature/Old	NDT1: ecosystems with rare stand-initiating events; ICH: Interior Cedar - Hemlock biogeoclimatic zone Mature/Old: stand age >100 years
NDT1-ICH-Burned	NDT1: ecosystems with rare stand-initiating events ICH: Interior Cedar - Hemlock biogeoclimatic zone Burned: exposed to wildfire within last 40 years

**NDT: natural disturbance type; mean disturbance intervals described in Province of British Columbia (1995)*

4.2.2 Fine-Filter Conservation Features

A coarse-filter SCP approach will likely identify lands that meet the habitat requirements of the majority of species present in a planning region; however, it is inevitable that the needs of some species will be missed and excluded from a given portfolio (Tingley et al., 2014). To account for those species that pass through the wide mesh of the coarse-filter, it is good practice to also incorporate fine-filter conservation features (Tingley et al., 2014). The fine-filter approach addresses the individual habitat requirements of those species considered to be endemic, threatened, or representative of multiple organisms in a planning region (i.e., umbrella). Habitats that are unique, or rarely distributed across a planning region, can also be used as fine-filter conservation features. I selected 4 fine-filter conservation features to complement the previously discussed coarse-filter features. These included grizzly bear, bull trout, woodland caribou, and a special features layer.

4.2.2.1 Grizzly bear

I selected grizzly bear to serve as a fine-filter conservation feature because they are a wide-ranging omnivore that utilizes a number of different food sources and habitat types (Apps, 2013). Grizzly bears that inhabit mountainous terrain of the WHSA have home ranges of approximately 300 km^2 and are capable of travelling ±10 km/day (Ciarniello, 2006). It is because of these generalist life-history traits that grizzly bear is often referred to as an umbrella species whose habitat requirements cover the needs of multiple other species by default (Noss and Cooperrider, 1994; Noss et al., 1996; Apps, 2013). Accordingly, I mapped and selected for suitable grizzly bear habitat in an effort to capture large, intact landscapes that represented a multitude of ecosystems.

Grizzly bears are blue-listed as a ‘species of special concern’ in British Columbia. Population declines are the result of low fecundity rates and direct/indirect mortality caused by habitat fragmentation (Apps, 2013). Aside from capitalizing on their utility as an umbrella species, seeking to capture large portions of grizzly bear habitat in this prioritization exercise would help to promote the persistence of this species.

I used methodology described in the *Draft Cumulative Effects Framework Grizzly Bear Value Summary* (Province of British Columbia, 2015b) as a baseline to construct a grizzly bear layer for use in MARXAN-ILP. In ArcGIS, datasets describing BEC zone and stand age/composition (Appendix 1) were used to remove mid-seral, conifer-dominated forests, with $\geq$30% closed canopy as these stand characteristics are not ideal for grizzly bear forage production. Of the remaining stands, only those identified in the Broad Ecosystem Inventory (Appendix 1) as ‘capable/suitable’ grizzly habitat were selected for inclusion in the layer and all others deleted. To refine the layer further, I only included those areas with >10 km^2 of roadless habitat to accommodate the daily range of an adult female grizzly bear (Province of British Columbia, 2015b). Lastly, I added all Wildlife Habitat Areas (Appendix 1) set aside for grizzly bears in the WHSA to the finalized layer.

4.2.2.2 Bull Trout

Bull trout was selected for use as a fine-filter conservation feature that represented a broad diversity of aquatic values across the WHSA. These fish are associated with cold, high-elevation streams that have clean gravel beds and undisturbed riparian vegetation. Mapping the known extent of the species across the WHSA allowed me to select for large, healthy watersheds that contained relatively little fragmentation.

At the provincial scale, suitable habitat has been reduced by large-scale hydroelectric projects and forestry-related riparian degradation. These forms of development have contributed to bull trout being blue-listed as a ‘species of special concern’. The recent approval of the Site C Dam Clean Energy Project may perpetuate bull trout declines within the WHSA and provided further justification for prioritizing the habitat needs of this species.

I developed a bull trout layer for the WHSA using 1:50,000 watersheds as selectable units (Appendix 1). To be included in this layer, watersheds were required to satisfy one of the following criteria: overlap with a Fisheries Sensitive Watershed – Bull Trout (legal or proposed), overlap with Wildlife Habitat Area – Bull Trout (legal or proposed), identified by experts as critical rearing habitat (Williamson 2017, pers. comm), or identified in Appendix 4 of Hagen and Decker (2011) as being a tributary large enough to support local populations. Provincial bull trout specialists provided supplemental information on which watersheds should be included and/or excluded from the resultant layer (Williamson & Peck 2017, pers. comm).

4.2.2.3 Caribou

Woodland caribou were selected to serve as a fine-filter conservation feature because of their association with alpine and subalpine parkland habitats. These two habitat types were not represented by any of the other conservation features used in this study. Caribou also utilize old, mid-elevation stands containing arboreal lichens (Johnson et al., 2004). Therefore, mapping and selecting for caribou habitat would not only capture high-elevation habitats, but also provide redundant representation of old-forest alongside the forest pattern and process layers.

The WHSA contains portions of Southern, Central, and Northern Mountain caribou populations — 3 Designatable Units[1] identified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and recognized under the federal *Species-at-Risk Act* (SARA). The Northern Mountain population is currently blue-listed as a 'species of special concern' in the province. Those animals which comprise the Central and Southern Mountain populations are red-listed (i.e., threatened or endangered). The status of these animals provided further justification for their inclusion in this conservation planning exercise.

I used a core habitat dataset, developed by Jones (2008) to represent mountain caribou herds occurring in areas of the WHSA that fell within the South Peace region (i.e., Central and Southern Mountain populations). Jones (2008) identified suitable summer/winter habitats using resource selection functions (RSFs) and ranked habitat quality based on probability of selection from 1 (very low) to 5 (very high). Those areas with a 'very high' probability of selection were considered to be core habitat. Point locations of GPS-collared animals were used to further refine the core habitat polygons and recognise the recent distribution of caribou — potentially excluding those high-value habitats that were not occupied. For this reason, I decided to merge core habitat polygons, reflective of 'very high' selection probability and recent telemetry, with those polygons assigned a 'high' probability of selection. In this way, the overall selection area for South Peace herds was increased and represented those habitats currently occupied by caribou, as well as those areas that are unoccupied but contain high-value habitat features.

[1] The term Designatable Unit (DU) is described by COSEWIC as a significant unit of a taxonomic species that is important to the evolutionary legacy of the species as a whole and, if lost, would likely not be replaced through natural dispersion.

A similar approach to that employed in the South Peace was used by Gustine and Parker (2008) to delineate suitable habitat for herds occurring in the northern portions of the WHSA (i.e., Northern Mountain population). Gustine and Parker (2008) completed RSFs across all seasons and assigned a quality rank by binning probability of selection into deciles (1 = low; 10 = high). Where Jones (2008) used telemetry points to refine core polygons, Gustine and Parker (2008) used telemetry points to test the predictive capacity of the RSF modelling. They found the modelling did well in predicting the habitat selection of collared animals across seasons but that increasing the bin size to quintiles would absorb some of the error present in RSFs (Gustine & Parker, 2008). Based on this observation, I rescaled Gustine and Parker's (2008) RSF dataset into quintile bins and extracted those habitats given a ranking ≥4. The extracted selections from each season were then merged to create a single layer representing the full range of year-round habitats selected by woodland caribou in the northern portions of the WHSA.

I used an RSF model produced by Johnson et al. (2004) to represent those animals in the Southern Mountain Population that were not captured by the Jones (2008) data (e.g., Hart Range herd). The RSF produced by Johnson et al. (2004) differed from the abovementioned datasets in that it only represented winter habitats. The RSF displayed probability of occurrence based on observed distribution of caribou (i.e., survey data) relative to vegetation and topography. Johnson et al. (2004) scaled probability of occurrence into four broad classes of 1 (rare) to 4 (high). For consistency, I rescaled RSF dataset into quintile bins and extracted those habitats given a ranking ≥4.

The multi-year collaring programs and RSF modelling described above were relatively consistent in methodology and assisted in the development of a robust layer depicting caribou habitat across the majority of the WHSA. There remained some gaps in the layer where caribou were known to occur but for which a comparable level of analysis on habitat quality and point locations had not been completed. Rather than attempt to extrapolate local RSF modelling to herds with potentially dissimilar ecology, it was suggested that Ungulate Winter Ranges 7-003 and 7-025 be used to fill these gaps in the layer. These special management areas are relatively compatible with the mapping done by Jones (2008) and are largely representative of high-elevation summer range as well (Seip 2017, pers. comm). In addition to filling in gaps, these data would represent summer habitats utilized by the Hart Range herd that were not captured in the RSF produced by Johnson et al. (2004).

All components described in this section were merged into a single dataset and the resultant layer divided into individual herds based on a provincial layer describing legal herd boundaries (Appendix 1). The finalized woodland caribou layer thus represented year-round habitats that are currently occupied, as well as those areas that are unoccupied but contain high-value habitat features. Before being applied in this study, the layer was validated by the researchers whose data contributed to its creation (Seip & Parker 2017, pers. comm.).

4.2.2.4 Special Features

In SCP, a fine-filter conservation feature layer is usually developed to represent the extent of special features across a given planning region. Special features are described as those ecosystem components that are sensitive, spatially-limited, or of high biodiversity value (Heinemeyer et al, 2004). For this study, I developed a single layer that represented wetlands, karst deposits, and mineral licks across the WHSA.

Wetlands were included because they are an aquatic value in the WHSA whose full distribution may not be adequately represented by the bull trout layer as wetlands are not necessarily associated with high-elevation watersheds. Wetlands also provide habitat for migratory waterfowl and perform valued ecosystem functions such as water filtration. Karst formations were targeted as these ecosystems provide habitat for plant and animal species that utilize caves for some portion of their life history. Mineral licks were incorporated as they are an important nutrient source for ungulates and serve as hunting areas for carnivores.

Minimal geoprocessing was needed to construct the special features layer. Complete and reliable datasets were available for each of the elements described above. In ArcGIS, I merged datasets depicting karst deposits, mineral lick locations, and wetlands to produce a consolidated layer for use in MARXAN-ILP (Appendix 1).

4.3 Step 2 Identify Conservation Goals and Targets for the WHSA

The overarching goal of this study was to prioritize lands for conservation in the WHSA that were effective at promoting biodiversity, maintaining disturbance regimes, and increasing climate change resilience. The conservation features described in the previous section were intentionally selected to serve as mechanisms for meeting this goal. For example, land facets build resilience by representing those abiotic elements that are unaffected by a shifting climate and provide a foundation for evolutionary processes. The forest pattern and process layers represent three distinct disturbance regimes in combination with forest types containing high levels of biodiversity. The individual species used for fine-filter conservation features each represent a wide array of ecosystems and the habitat needs of species-at-risk making them effective surrogates for promoting biodiversity across the WHSA.

Though integral to the SCP process, simply identifying these conservation features on the landscape would not allow me to achieve the study goal. When conducting SCP in areas such as the WHSA, there is an increased emphasis on using the area efficiently to achieve desired conservation outcomes so that opportunities for resource use are maintained (Wiersma & Sleep, 2018). With this in mind, I identified a suite of targets for use in this study that were informed by relevant literature. These targets were meant to be uncompromising in capturing the amount of area needed to achieve desired conservation outcomes, but also efficient in that they would reach these outcomes while still allowing some lands to be used for non-conservation purposes.

I drew upon the best available knowledge to assign each conservation feature with a target that was reflective of that feature's ecology and spatial extent within the WHSA (Table 3). These targets instructed MARXAN-ILP on how much area to include for each conservation feature when conducting prioritizations. For example, if a conservation feature was assigned a target of 10%, MARXAN-ILP would capture 10% of that feature's spatial extent across the WHSA in the resultant solution space. Effort was made to select those targets that would provide each conservation feature enough area to effectively fulfill the purpose for which it was designed (see Section 4.2 for purpose descriptions).

Of note, these targets were drawn from studies whose planning region(s) differed in area from that of the WHSA. The percentage of area required for a feature to be adequately represented at the scale of one study area may not constitute proportionate representation at the scale of another. However, when conducting SCP it is often the case that targets specific to a given study area are unavailable and practitioners must extrapolate from those used in comparable research. The research used to inform target selection was conducted within, or directly adjacent to, the WHSA and represented the best-available data at the time of this study.

Table 3. Targets assigned to each conservation feature for application in MARXAN-ILP scenarios.

Coarse-filter	Target (%)	Fine-filter	Target (%)
Land Facet Diversity	50	Burnt Pine Caribou Herd	90
Land Facet Rarity	50	Finlay Caribou Herd	90
NDT3-SBS-Mature/Old	76	Gataga Caribou Herd	90
NDT3-SBS-Burned	100	Graham Caribou Herd	90
NDT3-BWBS-Mature/Old	46	Hart Ranges Caribou Herd	90
NDT3-BWBS-Burned	100	Kennedy Siding Caribou Herd	90
NDT2-SWB-Mature/Old	83	Moberly Caribou Herd	90
NDT2-SWB-Burned	100	Muskwa Caribou Herd	90
NDT2-SBS-Mature/Old	66	Narraway Caribou Herd	90
NDT2-SBS-Burned	100	Pink Mountain Caribou Herd	90
NDT2-ESSF-Mature/Old	75	Quintette Caribou Herd	90
NDT2-ESSF-Burned	100	Scott Caribou Herd	90
NDT1-ESSF-Mature/Old	74	Grizzly Bear	60
NDT1-ESSF-Burned	100	Bull Trout	60
NDT1-ICH-Mature/Old	75	Special Features	60
NDT1-ICH-Burned	100		

In efforts to optimize conservation outcomes, targets assigned to individual woodland caribou herds (i.e., retention of 90% of preferred habitats) met those objectives outlined in *Implementation Plan for the Ongoing Management of South Peace Northern Caribou in British Columbia* (Ministry of Environment, 2013). The Quinette Caribou Herd is assigned an 80% target under the implementation plan but was increased up to 90% for purposes of this study. The target of 50% assigned to land facet diversity/rarity was consistent with that used to represent physical variety/rarity in the *Muskwa-Kechika Management Area Biodiversity Conservation and Climate Change Assessment* (Yellowstone to Yukon Conservation Initiative, 2012). I used the 'higher biodiversity emphasis' values, described in the *Biodiversity Guidebook* (Province of British Columbia, 1995), to define targets for each forest pattern and process layer. For bull trout, I used the aquatic focal species representation target of 60% outlined in *Conservation Area Design for the MKMA* (Heinemeyer et al, 2004). When no consistently referenced target was available, a conservative default target of >60% of the feature's extent was assigned (i.e., grizzly bear, special features).

4.4 Step 3 Review Existing Protected Areas within the WHSA

I combined all PAs within the WHSA into a single polygon to serve as a conservation feature in MARXAN-ILP. I then ran a scenario where 100% of the existing PAs were selected and all other conservation features left without a target. The result of this scenario revealed the extent to which existing PAs in the WHSA contributed towards achieving targets for conservation and assisted in identifying gaps within the existing system. The percentage of each conservation feature's total area represented by existing PAs was then subtracted from each of the target used in this study. For example, if 10% of the bull trout layer fell within existing PAs, an adjusted target would be 50% to achieve a sum total 60% of bull trout representation in the WHSA.

4.5 Step 4 Use MARXAN-ILP to Generate a Portfolio of Priority Lands for Conservation

I used MARXAN-ILP to prioritize lands for conservation in the WHSA. The tool allowed me to assess the adequacy of the existing PA system across the WHSA, observe the impact of resource development on conservation features, and identify portfolios of candidate lands for protection that met the targets and goals of this study.

4.5.1 Defining MARXAN-ILP Inputs

In order for MARXAN-ILP to operate, the user must first define a number of inputs that reflect the overall purpose of a given SCP process. Inputs typically required for

MARXAN-ILP include a definition of planning units and costs. All inputs used for this study are described in the following sections.

4.5.1.1 Planning Units

Prior to running MARXAN-ILP, I divided the WHSA into planning units. A planning unit is a parcel of land made available for selection by MARXAN-ILP. The size and shape of a planning unit is user-defined. Commonly used planning units in SCP include uniform grids, surveyed land parcels, administrative boundaries, and those units defined by various ecological classification systems (e.g., watersheds, wildlife management units, biogeoclimatic zones, etc.). Given the large area of the WHSA, I opted to use 1 km^2 planning units in this analysis. This was determined after observing that 1 ha planning units used in earlier versions of MARXAN-ILP developed for this study made for longer computing times and produced a solution space not superior in quality to that produced by the larger 1 km^2 planning units.

4.5.1.2 Planning Unit Costs

Once planning unit size and shape has been established, MARXAN-ILP requires a cost metric for all units in a planning region. Planning unit cost is representative of the expense associated with including a given planning unit in a selection. In this way, planning unit cost can reflect property values (acquisition cost), resource potential (opportunity cost), or an arbitrary number designed to place constraints on the selection. Whatever the metric, planning unit cost forces the tool to be efficient and select high-value areas because the acquisition of planning units is expensive. There are minimal private holdings in the WHSA that would have an assigned market value, and the available data on resource potential in the region was inconsistent and forestry-centric; therefore, an arbitrary planning unit cost of 1 was assigned to all planning units in the WHSA. This would force the tool to be economical in its selection and target those planning units containing multiple, overlapping conservation features as inefficient selection would absorb unnecessary planning unit cost.

4.5.1.3 Cost Surfaces

In addition to basic planning unit cost, MARXAN-ILP allows the user to exert further constraint on selection through the use of cost surfaces. A cost surface is a spatial representation of those elements in a planning region that have been identified as having a negative impact on the conservation features being selected for. A cost surface is mapped across the landscape and any planning unit that contains a portion of that surface is given a user-defined penalty. This penalty is typically weighted based on the extent to which the form of land-use represented in the cost surface degrades the values that make up a conservation feature. In this way, the use of a cost surface dissuades the tool from selecting those planning units containing elements that may jeopardize the goals of a given SCP process. I developed three separate cost surfaces in order to explore the influence that varying levels of resource development had on the selection of priority lands for conservation in the WHSA.

4.5.1.3.1 High-Sensitivity

Of the three cost surfaces produced for this study, the high-sensitivity cost surface was designed to be the most conservation-oriented. The intent of this cost surface was to make MARXAN-ILP ‘highly sensitive’ to resource development when prioritizing areas for conservation in the WHSA. To build the layer, I first mapped the spatial extent of permanent development in the WHSA using the layers described in Appendix 1 and the geoprocessing steps outlined in Appendix 2. I defined ‘permanent development’ as areas where human-use had resulted in complete landscape conversion that would require substantial restoration effort to be returned to a natural state.

Using ArcGIS, I placed buffers on the various forms of development based on distances described in Dyer et al. (2001) and Polfus et al. (2011). The distances were a reflection of the extent to which woodland caribou avoid the respective forms of permanent development at the foundation for the high-sensitivity cost surface (Table 4). Given their large size, these avoidance buffers not only addressed the needs of that species, but also increased the likelihood of accommodating the needs of species that exhibited less sensitivity to resource development.

Table 4. Buffer distances used for the construction of the high-sensitivity cost surface to represent the zone of influence in the Wild Harts Study Area.

Development	Buffer*
Roads (paved)	2 km from centerline
Roads (rough)	1 km from centerline
Seismic Lines	250 m from centerline
Urban/Agriculture	9 km radius
Mines	2 km radius
Outfitter Cabins	1.5 km radius
Gas Wells	1 km radius

**Buffer distances represent woodland caribou avoidance of resource development described in Dyer et al. (2001) and Polfus et al. (2011).*

Planning units containing the high-sensitivity cost surface were assigned a large penalty of 10, making it 10x as costly to select a planning unit containing the high-sensitivity cost surface than one where the surface was absent. The rationale behind the large penalty and avoidance buffers was to dissuade the MARXAN-ILP from selecting planning units within, or proximal to, any form of resource development. Accordingly, the high-sensitivity cost surface would be used in scenarios to prioritize those high-value conservation lands occurring outside the 'zone of influence' in the WHSA. The term zone of influence (ZOI) is used in this context to describe the ability of industry to create impacts that extend past the spatial footprint of development.

4.5.1.3.2 Medium-Sensitivity

The intent of this cost surface was to make MARXAN-ILP exhibit a 'medium-sensitivity' to resource development when prioritizing areas for conservation. The medium-sensitivity cost surface was built to represent the spatial extent of both permanent and temporary development in the WHSA. For the purposes of this study, I defined temporary development as harvested areas ≤20 years old, as this is a threshold commonly used by forest managers in British Columbia to identify areas that haven't recovered fully from harvesting activities (Ministry of Sustainable Resource Management, 2005). The surface was constructed by merging the data described in Appendix 1 with the permanent development layer used in the high-sensitivity cost surface.

All planning units containing portions of the medium-sensitivity cost surface were given a moderate penalty of 5. No avoidance buffers were placed on temporary or permanent development. Similar to the high-sensitivity cost surface, the medium-sensitivity cost surface would encourage MARXAN-ILP to select non-developed areas in efforts to produce the optimal solution for conservation at the lowest cost. However, in medium-sensitivity scenarios, the reduced penalty and absence of buffers would make available for selection those high-value planning units that occur proximal to temporary and permanent development. These are planning units that would have been avoided in scenarios where the high-sensitivity cost surface was used on account of them falling within avoidance buffers and carrying high costs. In this way, the medium-sensitivity cost surface would assist in locating areas of high conservation value that fell within the ZOI, but outside the physical footprint of development where possible.

4.5.1.3.3 Low-Sensitivity

The intent of this cost surface was to force MARXAN-ILP exhibit a 'low-sensitivity' to resource development when prioritizing areas for conservation in the WHSA. The low-sensitivity cost surface only represented the spatial extent of permanent development in the WHSA. I built the low-sensitivity cost surface using the layers described in Appendix 1 and geoprocessing steps outlined in Appendix 2. When constructing the low-sensitivity cost surface I did not include spatial representations of temporary disturbance or avoidance buffers. All planning units containing portions of the low-sensitivity cost surface were given a menial penalty of 2.

Similar to the two cost surfaces described above, the low-sensitivity cost surface would encourage MARXAN-ILP to select non-developed areas in efforts to produce the optimal solution for conservation at the lowest cost. However, the minimal penalty, absence of buffers, and omission of forestry data in low-sensitivity scenarios would make those high-value planning units that occur within temporary and permanent development available for selection. These are planning units that would have been avoided in high-to-medium sensitivity scenarios as they occur within avoidance buffers, recently logged areas, or fully converted landscapes. Accordingly, the low-sensitivity cost surface was intended to assist in identifying those areas of the WHSA that retained conservation value despite having undergone extensive resource development.

4.5.1.5 Protected Areas

I used the ‘locked out’ option to make existing PAs unavailable for selection when running MARXAN-ILP. The contributions of existing PAs were incorporated through the completion of Step 3 in the SCP process. Targets had been adjusted based on the extent to which existing PAs already achieved them and scenarios run to prioritize remaining percentages. The ‘locked out’ option simply ensured that MARXAN-ILP selected planning units based on their conservation value and not primarily based on their adjacency to PAs.

4.6 Running MARXAN-ILP

Once all of the user-defined inputs had been selected, the model was run using MARXAN-ILP software. MARXAN-ILP uses integer linear programming to spatially identify a configuration of planning units that represent the optimal solution to the objective function:

$$\textbf{Minimize} \sum Costs_{\ selected\ planning\ units};$$

$$\textbf{Given that} \sum Conservation\ features_{\ selected\ planning\ units} \geq user\ defined\ targets;$$

$$\textbf{and}\ selected\ planning\ units = (0,1)$$

Prior to running MARXAN-ILP, the extents of all conservation features in the area were mapped across the landscape. The cost surface and conservation features were then blanketed by a planning unit grid that contained a planning unit cost for each cell (Fig. 5).

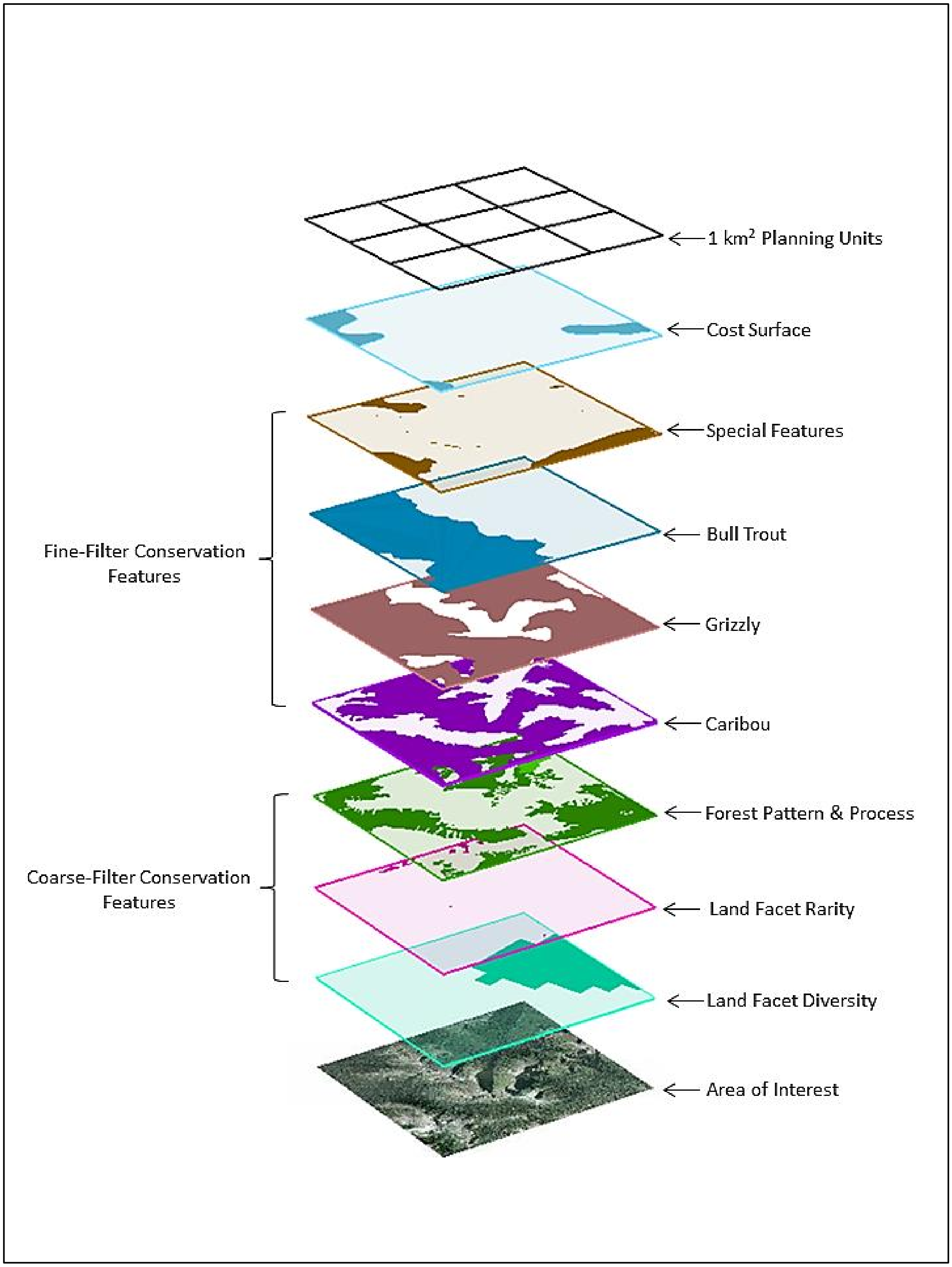

Figure 5. Cross-section of the MARXAN-ILP model used to prioritize lands for conservation in the Wild Harts Study Area.

Figure 6 provides a reductionist model showing the mechanics of MARXAN-ILP. When a scenario is initiated, MARXAN-ILP hovers over each planning unit, drills down through the layers present, and calculates the overall value of that planning unit. If a conservation feature is present with the planning unit, it is assigned a value of (1). If the planning unit contains no conservation features, it is given a score of (0). If a planning unit contains a cost surface, it is assigned whatever penalty the user has determined is in line with the objectives of the study. For the purposes of this example, an arbitrary penalty of 5 was assigned to all planning units containing a cost surface (Fig. 6).

In fulfilling its objective function, MARXAN-ILP attempts to meet conservation targets by amassing those planning units that avoid cost surfaces and have the highest amount of overlapping conservation features. The fact that each planning unit has an acquisition cost of 1 places even further emphasis on efficiency of selection and cost reduction. With this in mind, the selected cell in example A has a higher likelihood of being included in a prioritization output than does the cell selected in B (Fig. 6).

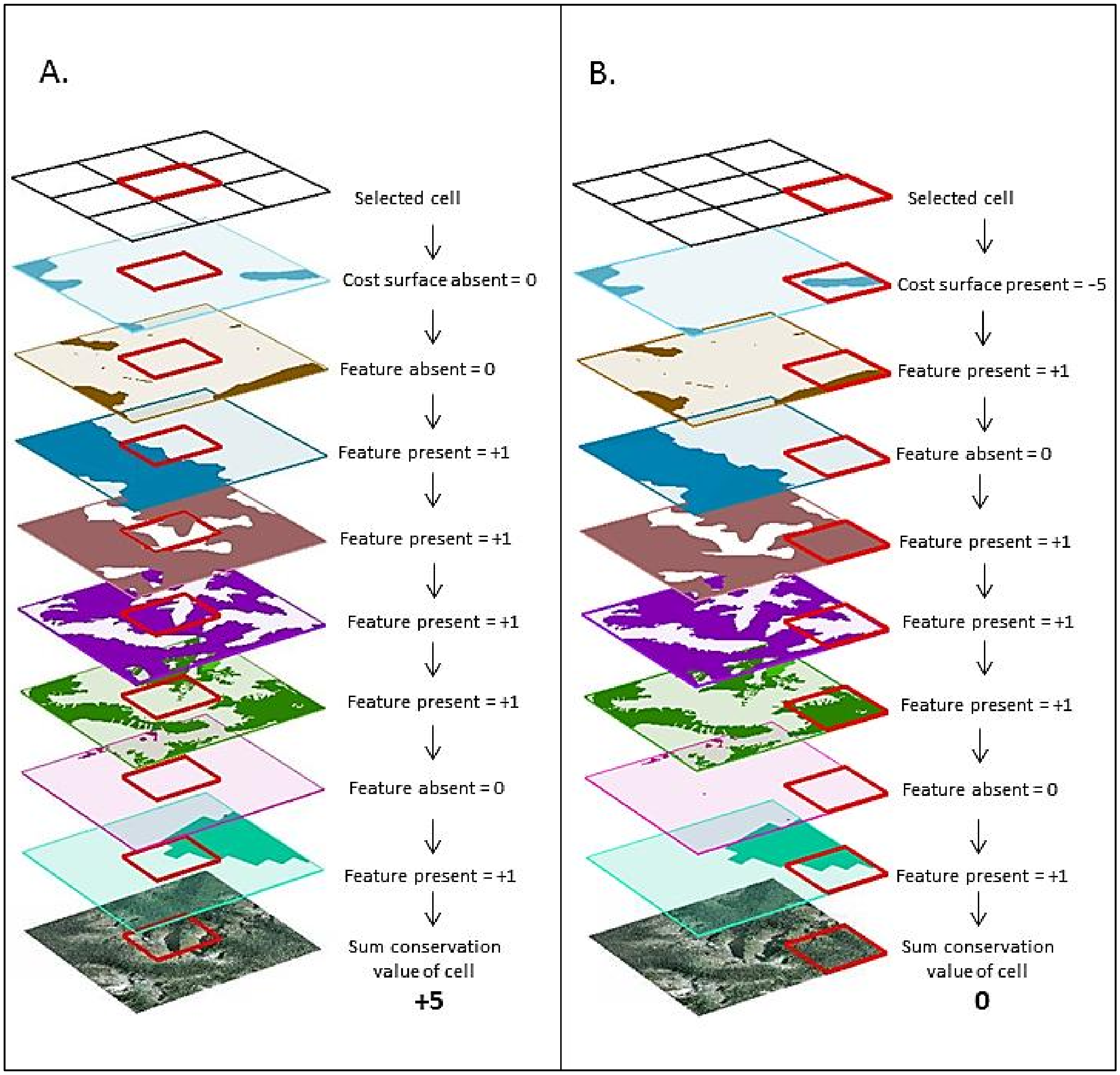

Figure 6. Cross-section of the MARXAN-ILP conservation value calculations used to prioritize lands for conservation in the Wild Harts Study Area.

4.7 Scenario Development

I developed four MARXAN-ILP scenarios to address each of my research questions (Table 5). Across all scenarios, MARXAN-ILP was instructed to meet conservation targets at the lowest cost possible. This was meant to encourage the selection of areas containing multiple overlapping features. In doing so, the resultant portfolios would address the first research question (i.e., what areas contain high conservation value?)

Table 5. Description of the MARXAN-ILP scenario inputs used to prioritize lands for conservation in the Wild Harts Study Area.

Scenario	Cost Surface	Constraint
A.	High-sensitivity	High ⇩ Low
B.	Medium-sensitivity	
C.	Low-sensitivity	
D.	None	

Cost surfaces were used to help identify areas of the WHSA that retained conservation value despite the presence of resource development (i.e., research question 2). Scenario A was designed to produce a portfolio of high-value lands unaffected by resource development. This was meant to provide a benchmark of intactness from which I could observe deviations made by MARXAN-ILP in subsequent scenarios. Scenario B was designed to increase selection of high-value planning units in the ZOI. Scenario C was meant to increase selection in temporarily developed landscapes. Scenario D was designed to increase selection of permanently developed landscapes. When overlaid, these portfolios would provide zonation from which to base management objectives.

In addition to the avoidance of development, cost surfaces were expected to place constraint on MARXAN-ILP by reducing the amount of penalty-free area available to the tool for selection. I predicted that the more constrained a scenario became, the greater the emphasis would be on achieving targets with compact clusters of high-value planning units to reduce costs. Within the context of this study, a compact portfolio containing low levels of resource development was thought to exhibit principles of good PA design. The portfolio that met targets and best emulated those principles would be used to address the third research question (i.e., what is an optimal conservation portfolio to direct planning processes?).

4.8 Statistical Analysis

Using the ArcGIS Patch Analyst tool, I examined the extent to which common landscape ecology fragmentation statistics varied across scenario results. Statistics used to compare portfolios included total number of patches, maximum patch area (km^2), average patch area (km^2), average patch perimeter (km), mean shape index, and total core area index. Mean shape index (MSI) was used to measure the relative edge-to-area relationship of patches that comprised a given solution space. As MSI decreases, so too does the shape complexity of a given solution space.

Total core area index (TCAI%) measures the percentage of core area present within a solution space based on user-defined buffers. I calculated TCAI% at 200 m (2x average tree height) to determine the percentage of core area unaffected by altered temperature regimes along patch edges. A TCAI% was also calculated at 500m from edge as this is a general core requirement for wildlife that prefer interior habitats. The purpose of applying these buffers was less to determine whether solutions met ‘core criteria’ for any specific value so much as it was to assess the extent to which compactness of solution space differed across scenarios A–D.

5.0 RESULTS

This section reviews the results of completing the 4 steps of SCP (Table 1). These steps included (1) the selection and development of conservation features; (2) the identification of conservation goals and targets; (3) a review of existing PAs; (4) and the use of MARXAN-ILP to identify lands suitable for protection in the WHSA. Inset maps have been included for some figures and are not intended to highlight any specific result so much as they are in place to provide the reader with an understanding of fine-scale details.

5.1 Conservation Feature Layers

A total of 31 conservation feature layers were constructed, overlain across the entire planning region, and made available for selection by MARXAN-ILP. All conservation features were given an equal value of (1) if present within a planning unit.

5.1.1 Coarse-filter Conservation Features

I developed 16 coarse-filter conservation features for this study. These features included land facet diversity, land facet rarity, and a series of layers displaying an intersection of natural disturbance, biogeoclimatic zone, and forest age.

5.1.1.1 Land Facet Diversity

The land facet diversity layer occupies 9.6% of the WHSA total area and is distributed relatively evenly across the planning region (Fig. 7). Of particular note is the extent to which areas containing high abiotic diversity have a tendency to straddle the band of mountainous terrain that bisects the WHSA on a southeast-northwest line (Fig. 7). Aside from a few exceptions, the peak-and-ridge dominated landscape that comprises the center of that band is low in abiotic diversity when compared to the transitional landscapes that occur along the outer edges of the Rocky Mountain corridor (Fig. 7).

5.1.1.2 Land Facet Rarity

Land Facet Rarity occupies 0.5% of the WHSA. An observable pattern in this layer is the tendency of areas with rare abiotic attributes to occur in river valley bottoms (Fig. 8). In keeping with this observation, there appears to a disproportionate amount of rare land facets bordering the Peace Arm of the Williston Reservoir (see inset map) (Fig. 8). This is likely due to the fact that the Peace River is the only eastwardly flowing river through the Rocky Mountains in the WHSA — a distinction that carries with it unique geological history and climatic conditions that have created the rare abiotic features present there.

5.1.1.3 Forest Pattern and Process:

Table 6 describes the distribution and amount of area in the WHSA occupied by 14 forest pattern and process layers shown in Figure 9. The inset map provides insights on the scale and detail at which these features were typed out across the landscape (Fig. 9). Alpine areas have been excluded as these layers were intended to only capture forested areas. It must be noted that although the following figure show layers for mature/old and burned forest on the same map, these layers were used as standalone conservation features in all MARXAN-ILP scenarios. They have only been combined in this figure for efficiency's sake.

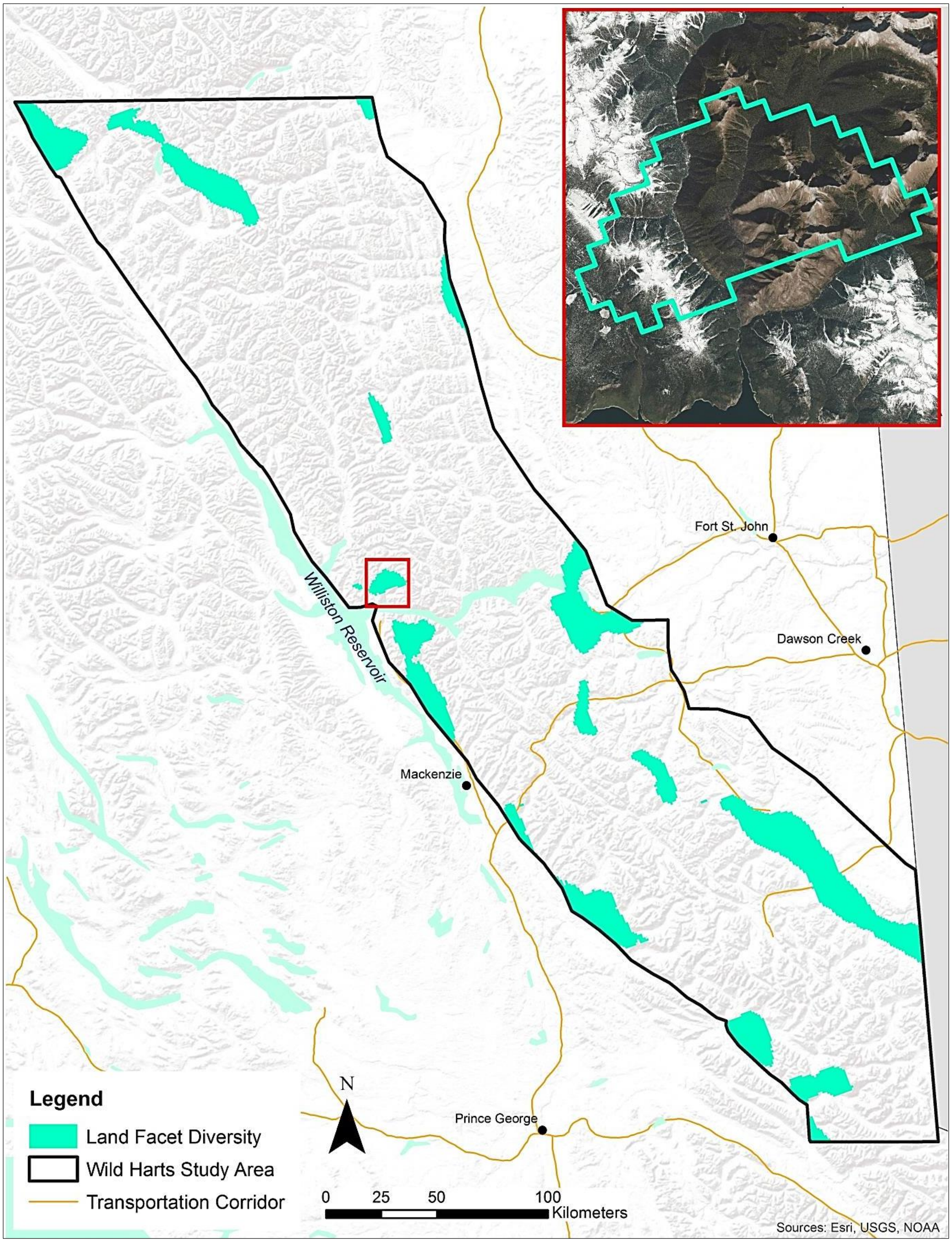

Figure 7. Spatial extent of the land facet diversity layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

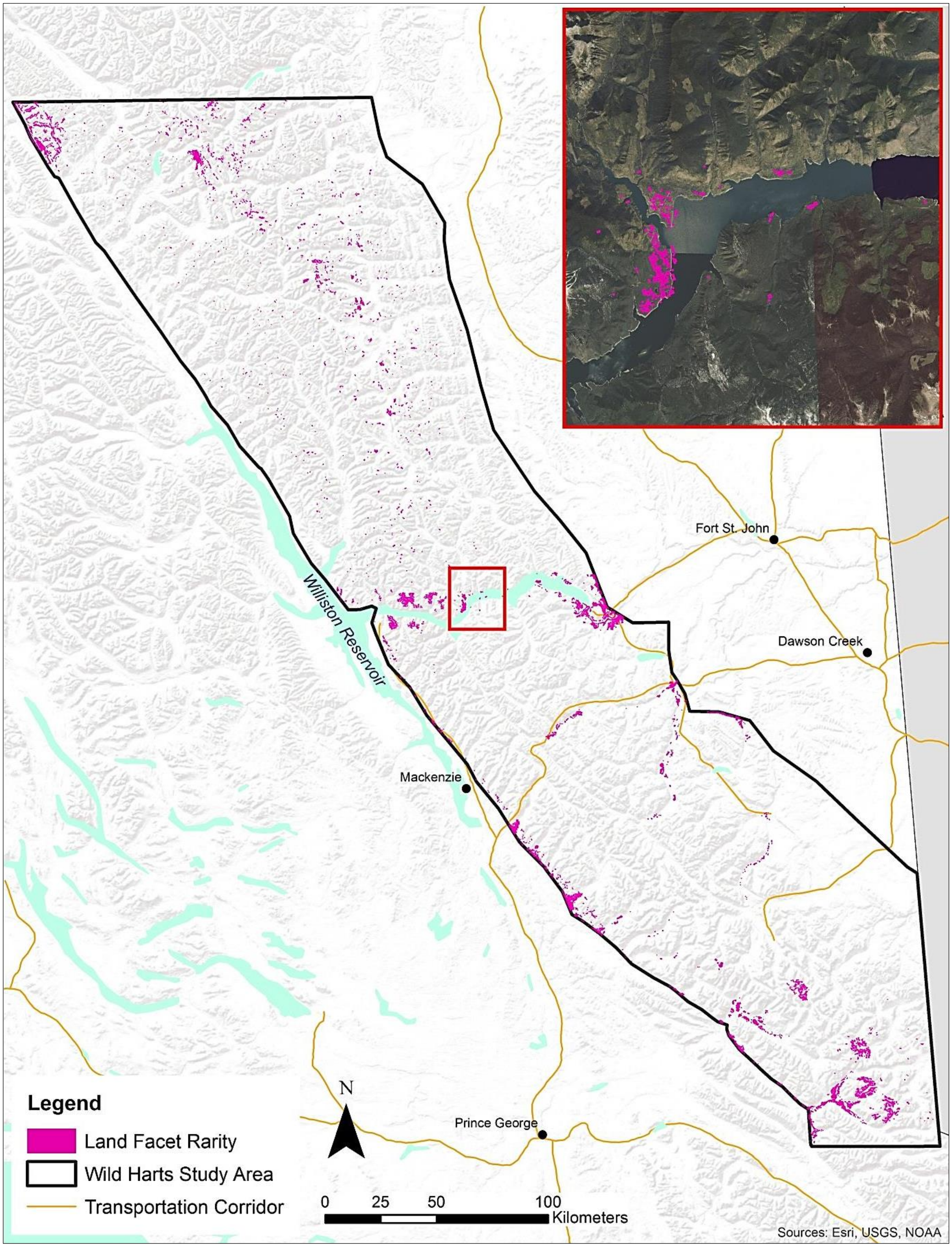

Figure 8. Spatial extent of the land facet rarity layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

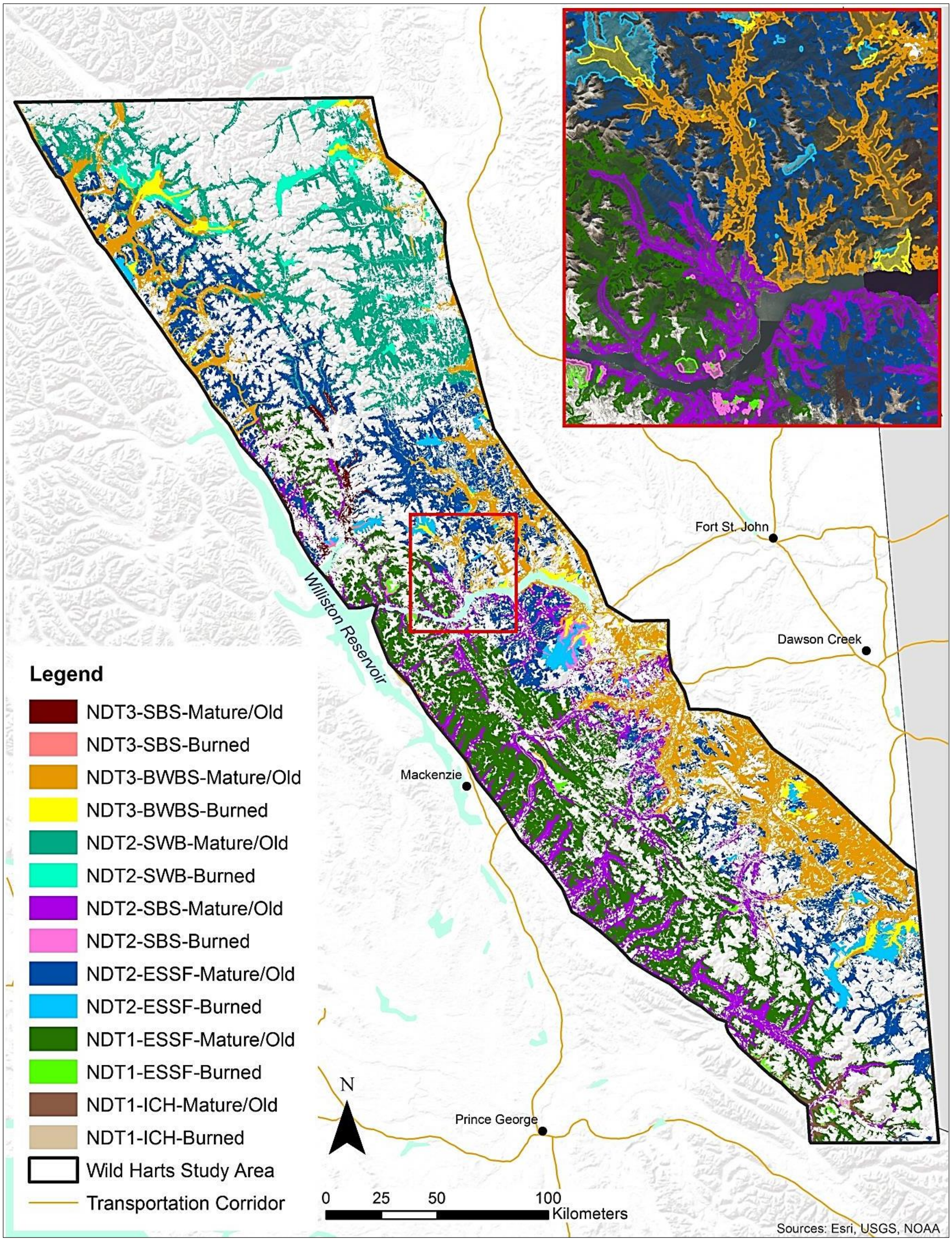

Figure 9. Spatial extent of all forest pattern and process layers used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

Table 6. Location and size of each forest pattern and process layer in relation to the Wild Harts Study Area (WHSA).

Label	Distribution	Percent (%) of total area
NDT3-SBS-Mature/Old	Confined to riparian areas and watersheds in the northwestern quarter of the WHSA	0.4
NDT3-SBS-Burned	Confined to riparian areas and watersheds in the northwestern quarter of the WHSA	0.02*
NDT3-BWBS-Mature/Old	Occupies low-elevation valleys and riparian areas that straddle the Rocky Mountain corridor	10
NDT3-BWBS-Burned	Occupies low-elevation valleys and riparian areas occurring along the outer extents of the WHSA	1*
NDT2-SWB-Mature/Old	Occupies high-elevation valleys and riparian areas within northeastern quarter of the WHSA	7
NDT2-SWB-Burned	Comprised of a few large burned watersheds in the northeastern quarter of the WHSA	0.2*
NDT2-SBS-Mature/Old	Occurs in low-elevation valley bottoms containing streams in the southern half of the WHSA	6
NDT2-SBS-Burned	Occurs sporadically throughout the central sections of the WHSA at low elevations	0.2*
NDT2-ESSF-Mature/Old	Occurs at mid-elevation across the entire WHSA and is densely concentrated in sections that occur above the Peace Arm of the Willison Reservoir	11
NDT2-ESSF-Burned	Primarily confined to the mid-lower elevations on the eastern side of the Rocky Mountain corridor	1.4*
NDT1-ESSF-Mature/Old	Dominates the forested area on the western slopes of the Rocky Mountain corridor at mid-high elevation	12
NDT1-ESSF-Burned	Occurs sporadically along the western slopes of the Rocky Mountain corridor at mid-high elevation	0.2*
NDT1-ICH-Mature/Old	Poorly distributed and confined to mid-high elevation landscapes at the most southern extents of the WHSA	0.3
NDT1-ICH-Burned	Poorly distributed and confined to mid-high elevation landscapes at the most southern extents of the WHSA	0.1*

**Below the area required to meet high biodiversity target described in Province of British Columbia (1995)*

5.1.2 Fine-filter Conservation Features

To complement the coarse-filter conservation features, an additional 15 layers were built that displayed the spatial extent of select fine-filter conservation features across the WHSA. Fine-filter conservation features used in this study included woodland caribou, bull trout, grizzly bear, and a special features layer displaying a mixture of unique habitats in the WHSA.

5.1.2.1 Woodland Caribou

With all herds consolidated, the woodland caribou layer occupies 45% of the WHSA total area and is distributed across the majority of the planning region (Fig. 10). The layer is confined to high-elevation alpine areas and is largely absent from valley bottoms (see inset map) (Fig. 10). There is no woodland caribou representation in the upper-half of the planning region's southeastern quarter and the lower-half of the northwestern quarter as herds have been extirpated from both these areas (Fig. 10). It must be noted that although woodland caribou herds in the WHSA are being presented in the same figure, each herd was used as a standalone conservation feature and made available for selection by MARXAN-ILP in all scenarios. They have only been combined in this figure for efficiency's sake.

5.1.2.2 Bull Trout

The bull trout layer is evenly distributed across the entire planning region and occupies approximately 44% of the WHSA total area (Fig. 11). The majority of major watersheds and rivers present in the WHSA are represented by this layer. Of particular note is the exclusion of a major drainage at the center of the northeast quarter of the WHSA (Fig. 11). This blank space represents the Sikanni Chief River headwaters — a section of river where bull trout are absent due to a downstream obstacle outside the bounds of the WHSA (i.e., Sikanni Chief Falls). The Peace Arm of the Williston Reservoir supports bull trout populations but was excluded from this layer on account of being a manmade structure that represents sub-optimal habitat.

5.1.2.3 Grizzly Bear

The grizzly bear layer dominates the majority of the planning region — occupying 61% of the WHSA total area. The wide distribution of this fine-scale conservation feature is likely due to grizzly bear being a generalist species that is able to inhabit a vast array of ecosystems and habit types. Despite the wide distribution, the grizzly bear layer is largely absent from the southeastern quarter of the WHSA (Fig. 12). The disproportionate levels of resource-related disturbance that occur within that section of the WHSA would have prevented these areas from being included on account of their inability to accommodate the daily range of an adult female grizzly.

5.1.2.4 Special Features

The special features layer displays the spatial extent of karst deposits, wetlands, and mineral licks across the WHSA. This fine-filter conservation feature occupies approximately 4% of the WHSA total area. Karst deposits occur in narrow striations within the Rocky Mountain corridor and are most abundant in the mid-upper half of the planning region (Fig. 13). Wetlands are distributed evenly across the WHSA and become most concentrated in those low-elevation areas and alongside streams (Fig. 13). Mineral licks have a scattered distribution with no noticeable pattern (Fig. 13). In efforts to mask sensitive datasets, all three layers were merged into a single, homogenous layer.

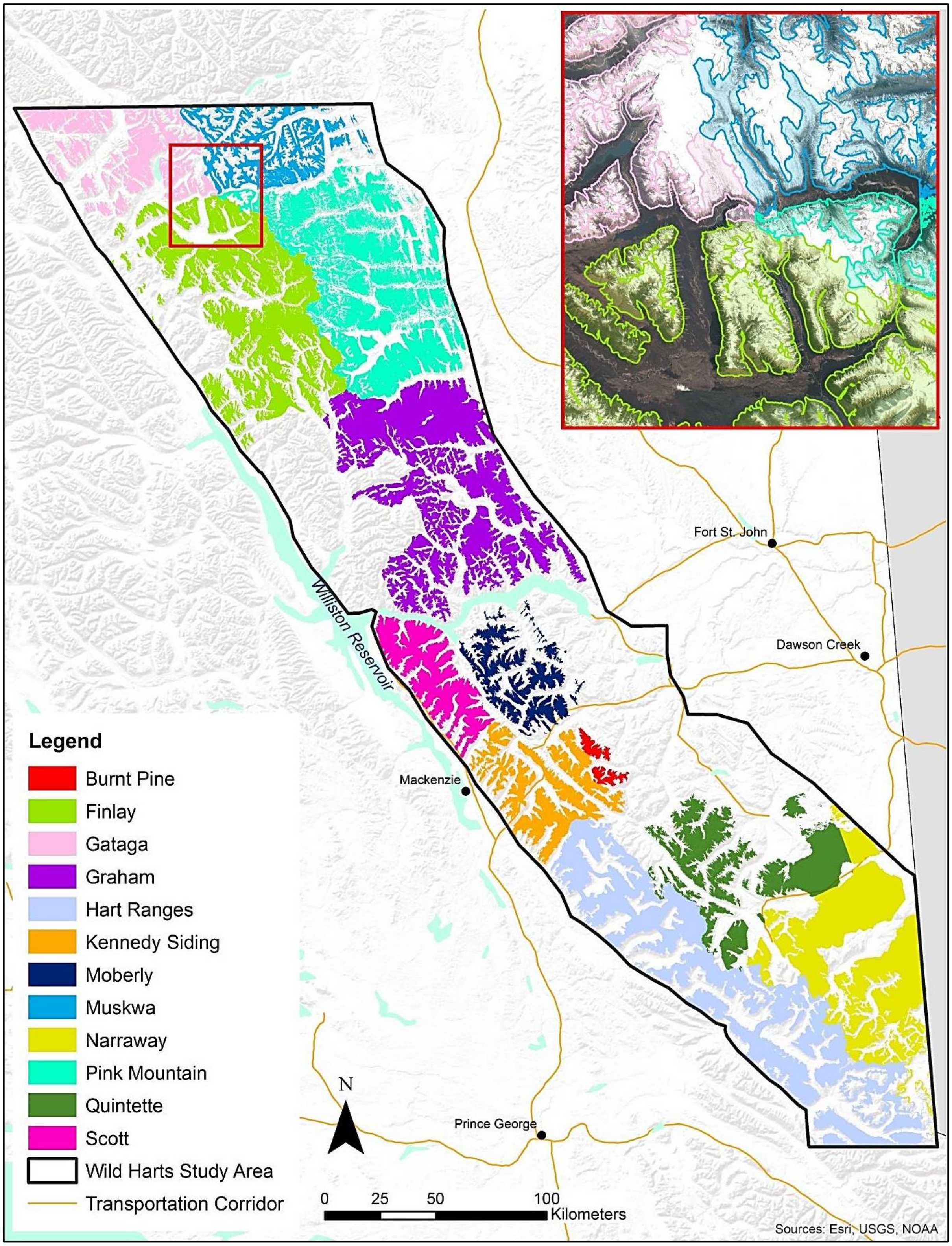

Figure 10. Spatial extent of the woodland caribou layers used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

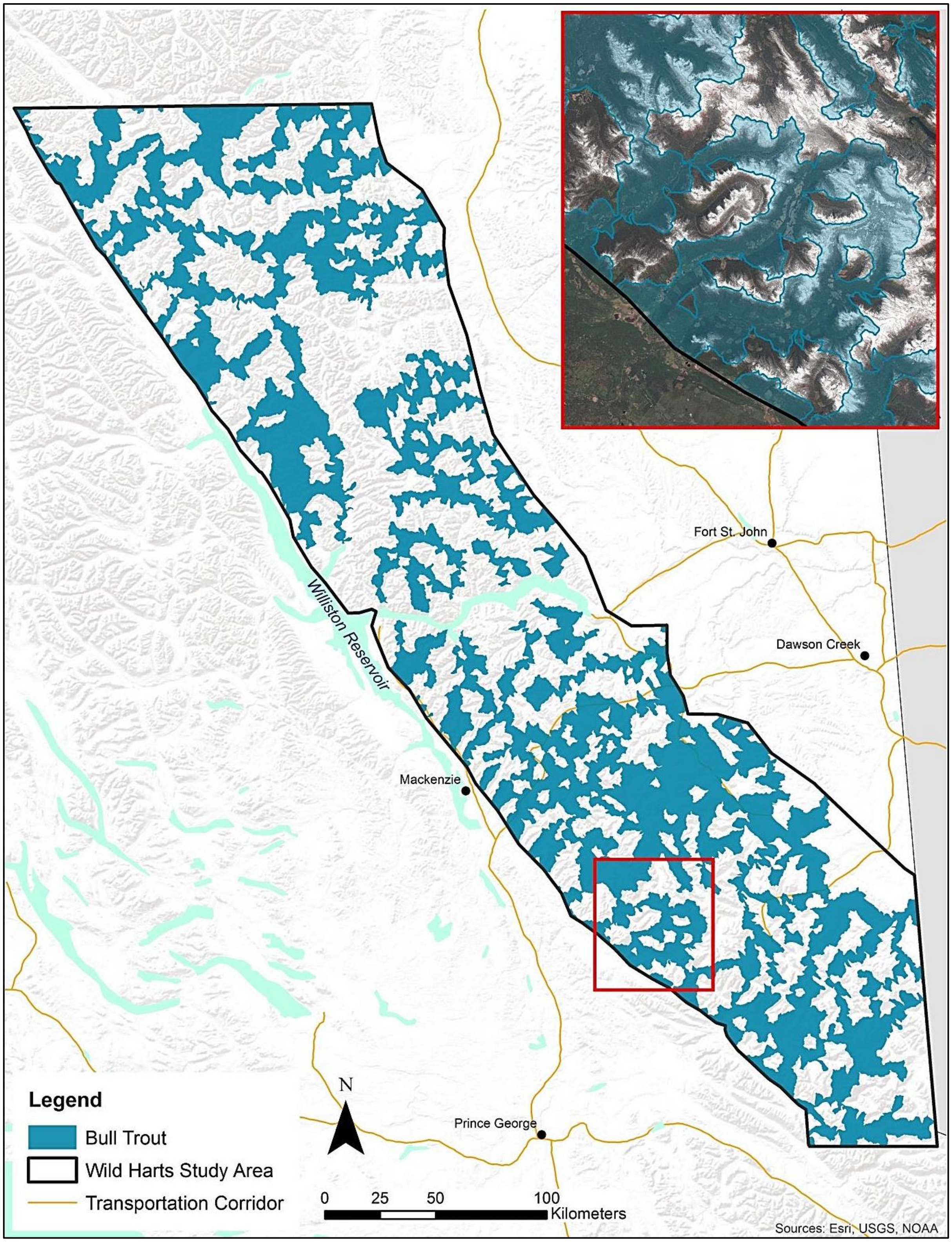

Figure 11. Spatial extent of the bull trout layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

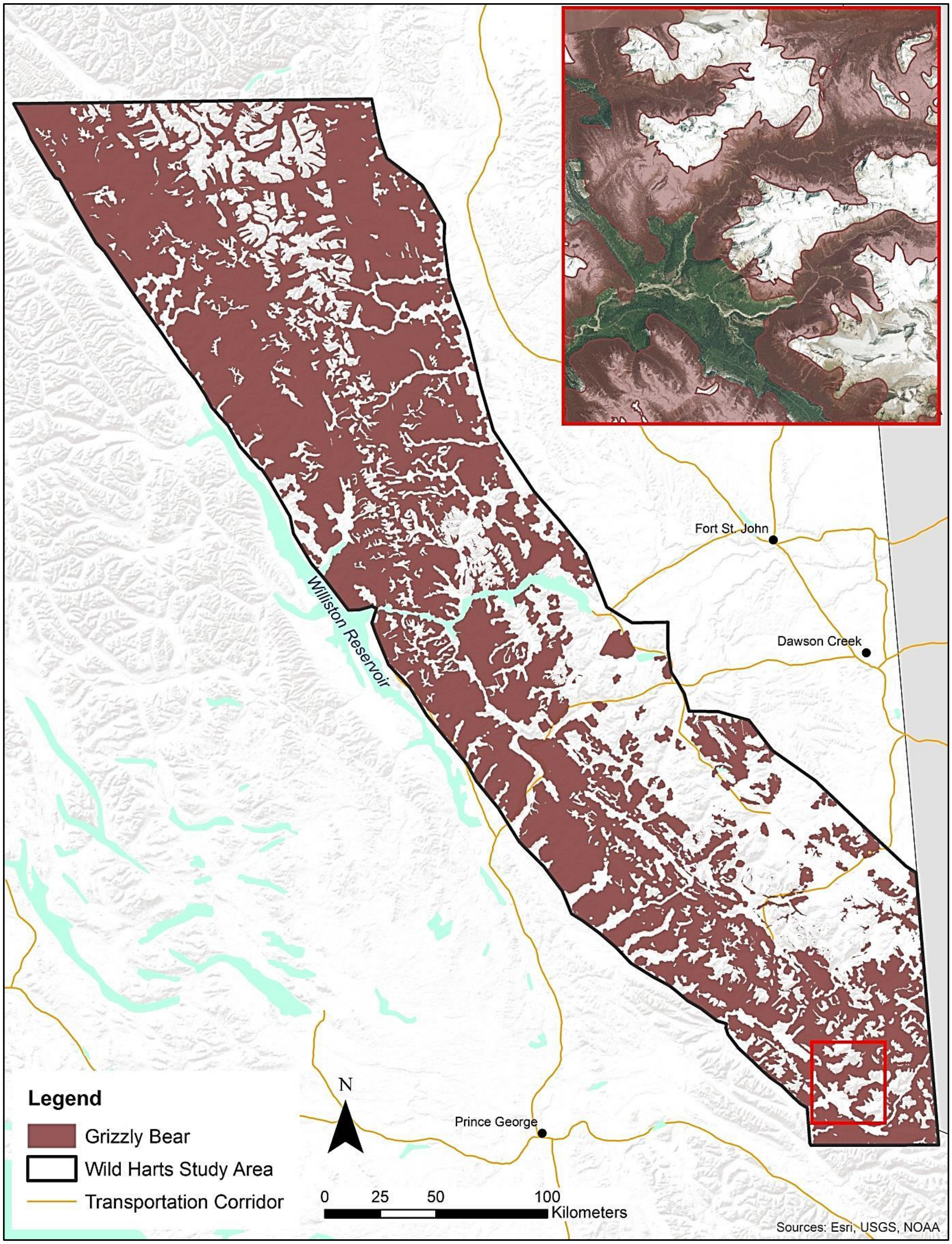

Figure 12. Spatial extent of the grizzly bear layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

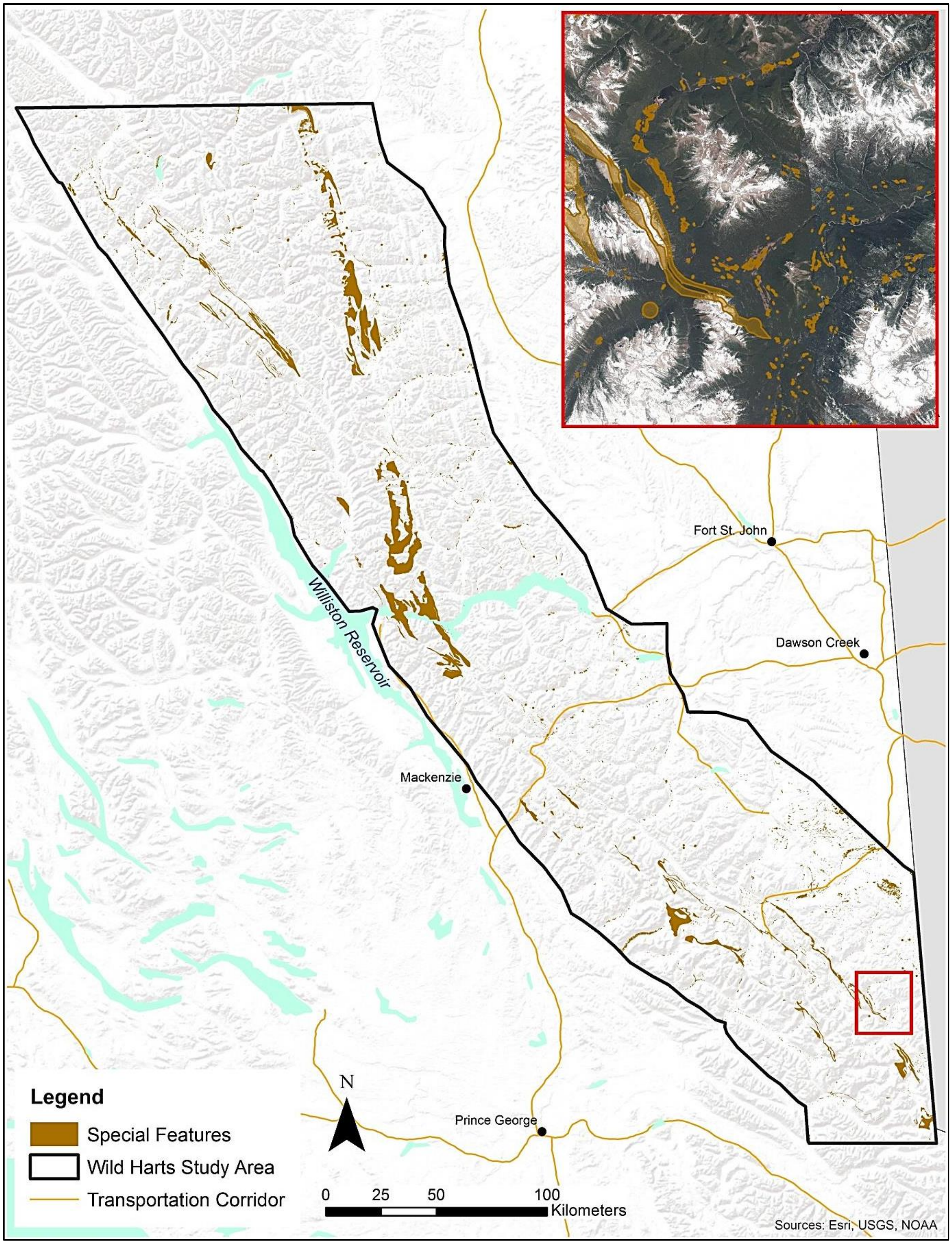

Figure 13. Spatial extent of the special features layer used by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by red frame.

5.2 Gap Analysis

Representation of conservation features within PAs in the WHSA was highly variable (Table 7). Conservation features that were well represented (>50%) within PAs included the Muskwa Caribou Herd and recently burned areas within the Spruce-Willow-Birch biogeoclimatic zone, natural disturbance type 2 (NDT2-SWB-Burned). The majority of remaining conservation features had mid-to-low levels of representation within existing PAs (5–50%). Of particular note are those conservation features with little-to-no (≤1%) representation. These include the Scott Caribou Herd, Burnt Pine Caribou Herd, and those areas in the Sub-boreal Spruce biogeoclimatic zone and natural disturbance type 3 that contain late-seral or recently burned stands (NDT3-SBS-Mature/Old & NDT3-SBS-Burned).

Table 7. Representation of conservation features achieved by existing protected areas in the Wild Harts Study Area.

Coarse-filter	% Protected	Fine-filter	% Protected
Land Facet Diversity	14	Burnt Pine Caribou Herd	0
Land Facet Rarity	28	Finlay Caribou Herd	3
NDT3-SBS-Mature/Old	0.86	Gataga Caribou Herd	42
NDT3-SBS-Burned	0	Graham Caribou Herd	14
NDT3-BWBS-Mature/Old	10	Hart Ranges Caribou Herd	14
NDT3-BWBS-Burned	24	Kennedy Siding Caribou Herd	16
NDT2-SWB-Mature/Old	26	Moberly Caribou Herd	4
NDT2-SWB-Burned	67	Muskwa Caribou Herd	96
NDT2-SBS-Mature/Old	5	Narraway Caribou Herd	21
NDT2-SBS-Burned	5	Pink Mountain Caribou Herd	26
NDT2-ESSF-Mature/Old	13	Quintette Caribou Herd	10
NDT-ESSF-Burned	2	Scott Caribou Herd	0.35
NDT1-ESSF-Mature/Old	8	Grizzly Bear	19
NDT1-ESSF-Burned	22	Bull Trout	19
NDT1-ICH-Mature/Old	30	Special Features	22
NDT1-ICH-Burned	23		

5.3 Cost Surfaces

High, medium, and low-sensitivity cost surfaces placed differential constraints on the MARXAN-ILP tool to identify high-value conservation lands within varying intensities of resource development.

5.3.1 High-Sensitivity

The high-sensitivity cost surface was the largest used in this study, occupying 44% of the WHSA total area. The layer dominated the majority of the planning region's southeastern quarter — an area containing extensive oil and gas infrastructure (Fig. 14). The western portions of the layer occupy those valleys and river bottoms that provide access for various forms of resource extraction within an otherwise impassible and mountainous landscape (Fig. 14).

In general, the layer is more concentrated towards the lower half of the WHSA as these areas are closer to population centers containing those resources needed to sustain extraction activities (i.e., labour, equipment, mill sites, etc.) (Fig. 14). Of particular note is the band of relatively intact landscapes running down the center of the WHSA on a northwest-southeast line that are not covered by the high-sensitivity cost surface (Fig. 14). The absence of the high-sensitivity cost surface in these areas is likely due to the rugged topography and the challenges such landscapes create for industry in terms of access.

5.3.2 Medium-Sensitivity

The medium-sensitivity layer occupies approximately 3.8% of the study area and, like the high-sensitivity layer, dominates the majority of landscapes in the southeastern quarter (Fig. 15). Most of the watersheds in the planning region show evidence of harvesting and associated road infrastructure (Fig. 15). The band of relatively intact landscapes mentioned in the high-sensitivity results is even more noticeable with the absence of avoidance buffers (Fig. 15). The northernmost portions of the WHSA are almost entirely void of resource development save for what appears to be a small number of roads confined to the outer bounds of the planning region (Fig. 15).

5.3.3 Low-Sensitivity

The low-sensitivity cost surface occupies approximately 2% of the WHSA total area. Despite the reduction in area, the low-sensitivity cost surface still dominates the majority of landscapes present in the southeastern corner of the planning region (Fig. 16). The presence of all three cost surfaces here suggests the area is highly compromised and would require substantial restoration effort to return to a natural state. Where the medium-sensitivity layer occupied large portions of watersheds in the WHSA, the absence of forestry data in the low-sensitivity cost surface made it so that the only disturbance in these watersheds was the spatial footprint of access roads. The band of intact landscapes down the center of the WHSA remains noticeable and the northernmost extents are virtually free of this cost surface (Fig. 16).

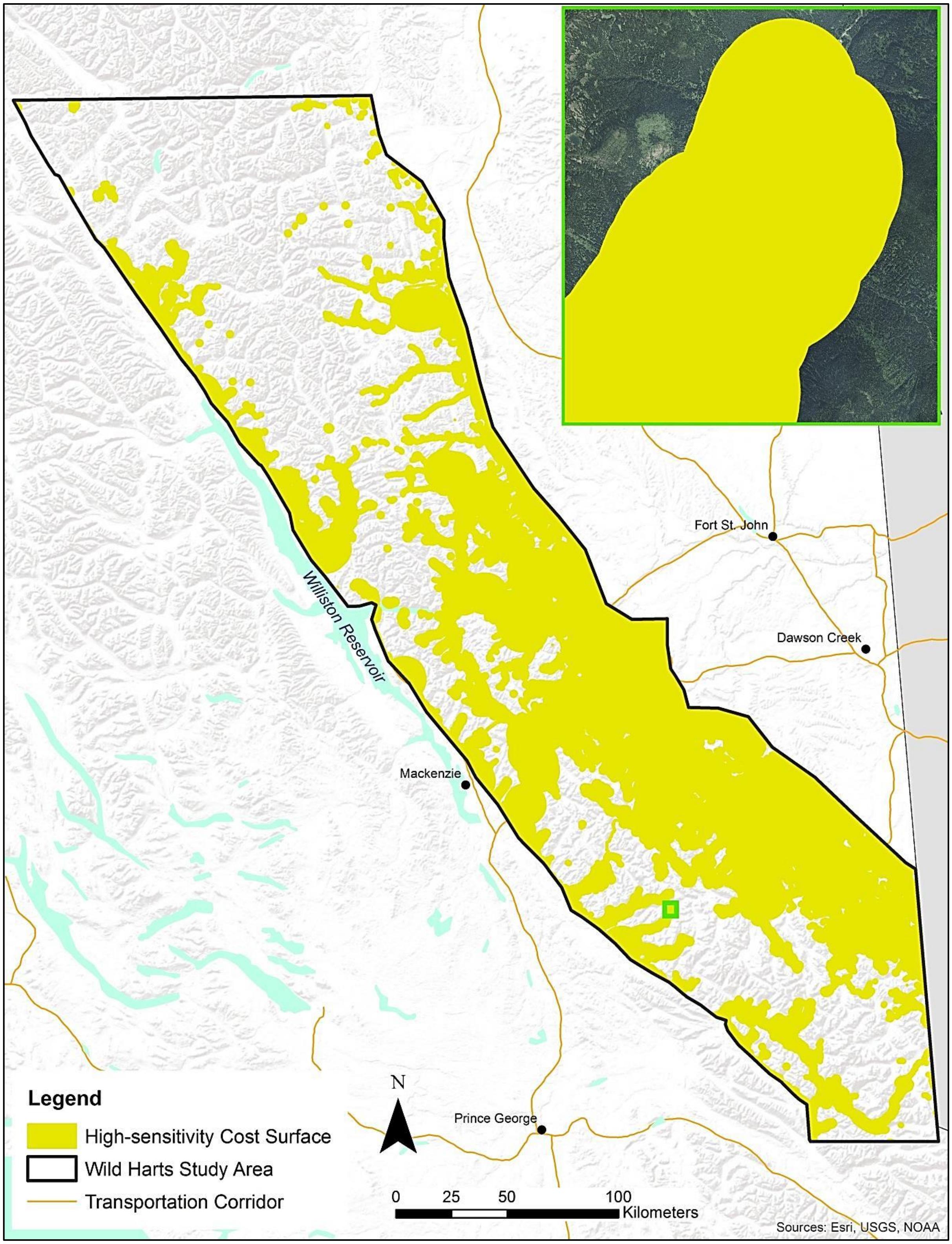

Figure 14. Spatial extent of the high-sensitivity cost surface used to constrain MARXAN-ILP when prioritizing lands for conservation in the Wild Harts Study Area; inset represented by green frame.

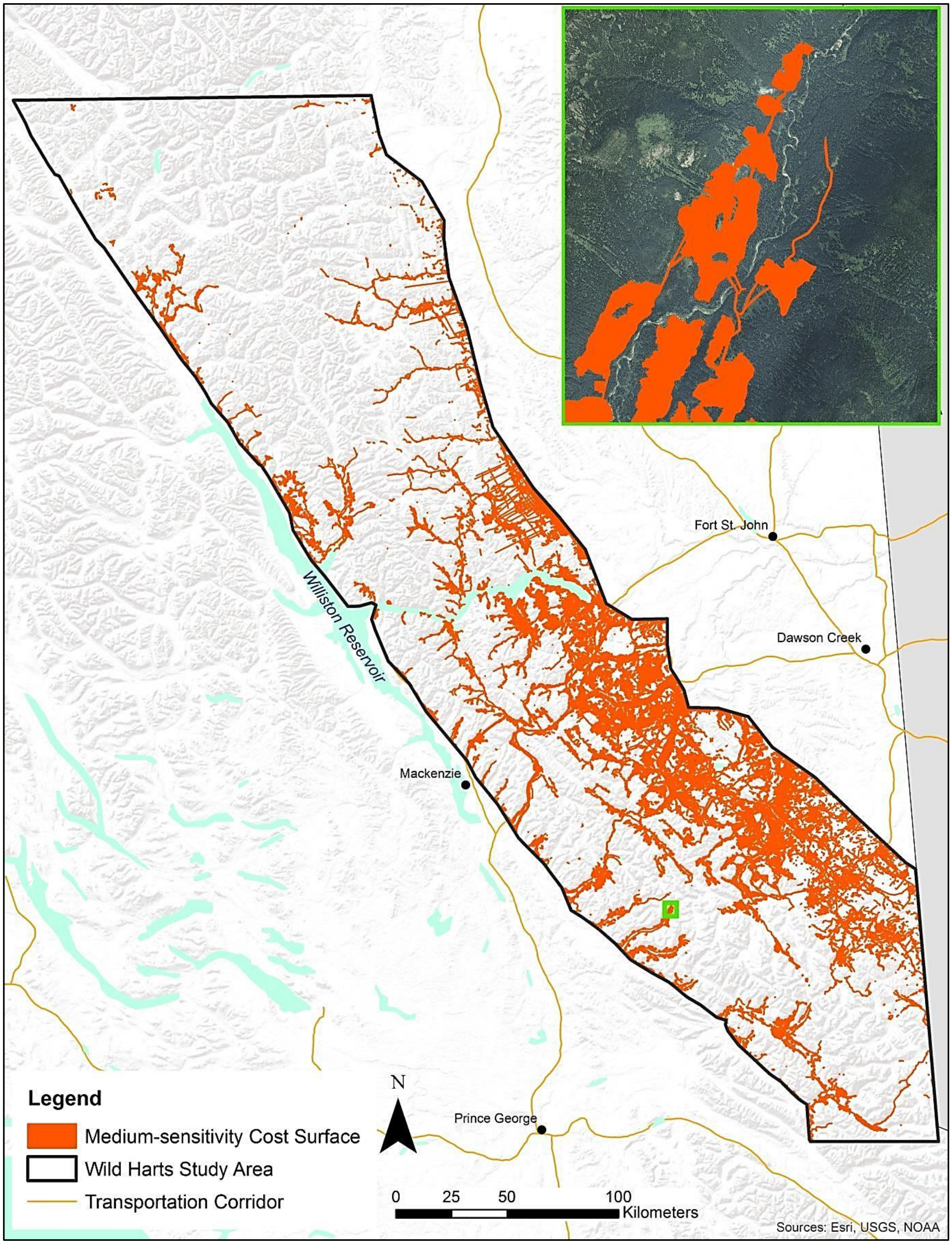

Figure 15. Spatial extent of the medium-sensitivity cost surface used to constrain MARXAN-ILP when prioritizing lands for conservation in the Wild Harts Study Area; inset represented by green frame.

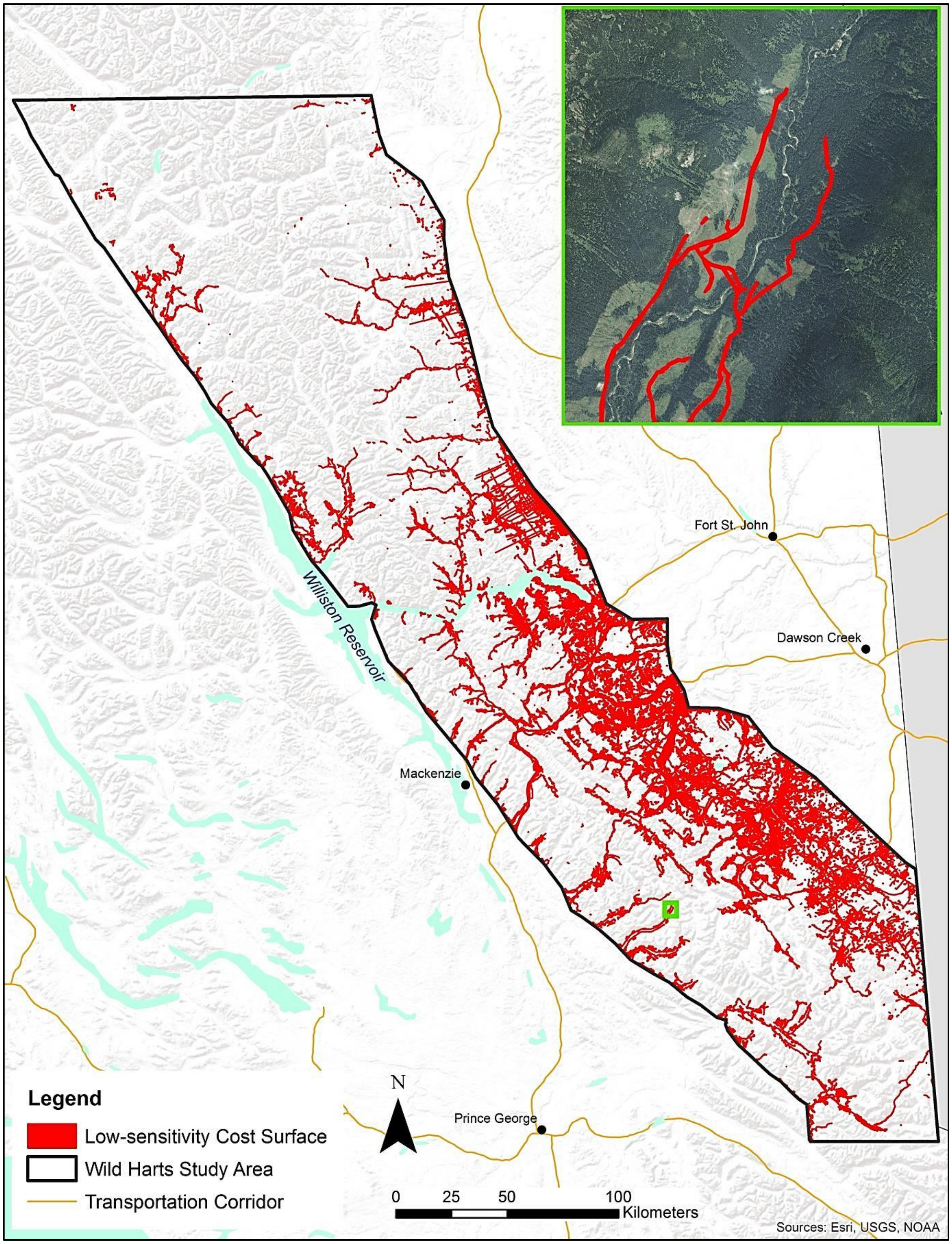

Figure 16. Spatial extent of the low-sensitivity cost surface used to constrain MARXAN-ILP when prioritizing lands for conservation in the Wild Harts Study Area; inset represented by green frame.

5.4 MARXAN-ILP Scenario Outputs

The following sections describe the results of the 4 MARXAN-ILP scenarios developed to prioritize high-value areas for conservation in the WHSA (Table 5).

5.4.1 Observable Patterns

For each scenario, MARXAN-ILP selected the configuration of planning units that met conservation targets at the lowest cost. A noticeable pattern across all portfolios is the pronounced corridor of selected lands that stretches from the southwestern extent of the planning region to Northern Rocky Mountains Provincial Park in the northeast (Figs. 4 and 17). Below the Peace Arm, selection is largely concentrated to the western half of the Rocky Mountains (Fig. 17). The opposite occurs above the Peace Arm where prioritization has a tendency to concentrate in the eastern portion of the Rocky Mountains (Fig. 17).

Of particular note is the almost complete absence of selected planning units along the western boundary of the WHSA above the Peace Arm (Fig. 17). A similar pattern is observable in those blank spaces occurring along the easternmost extent of the WHSA below the Peace Arm (Fig. 17). The lack of selection here is likely due to the absence of the woodland caribou conservation feature and the ability of large conservation features to meet targets for small conservation features through complementarity elsewhere.

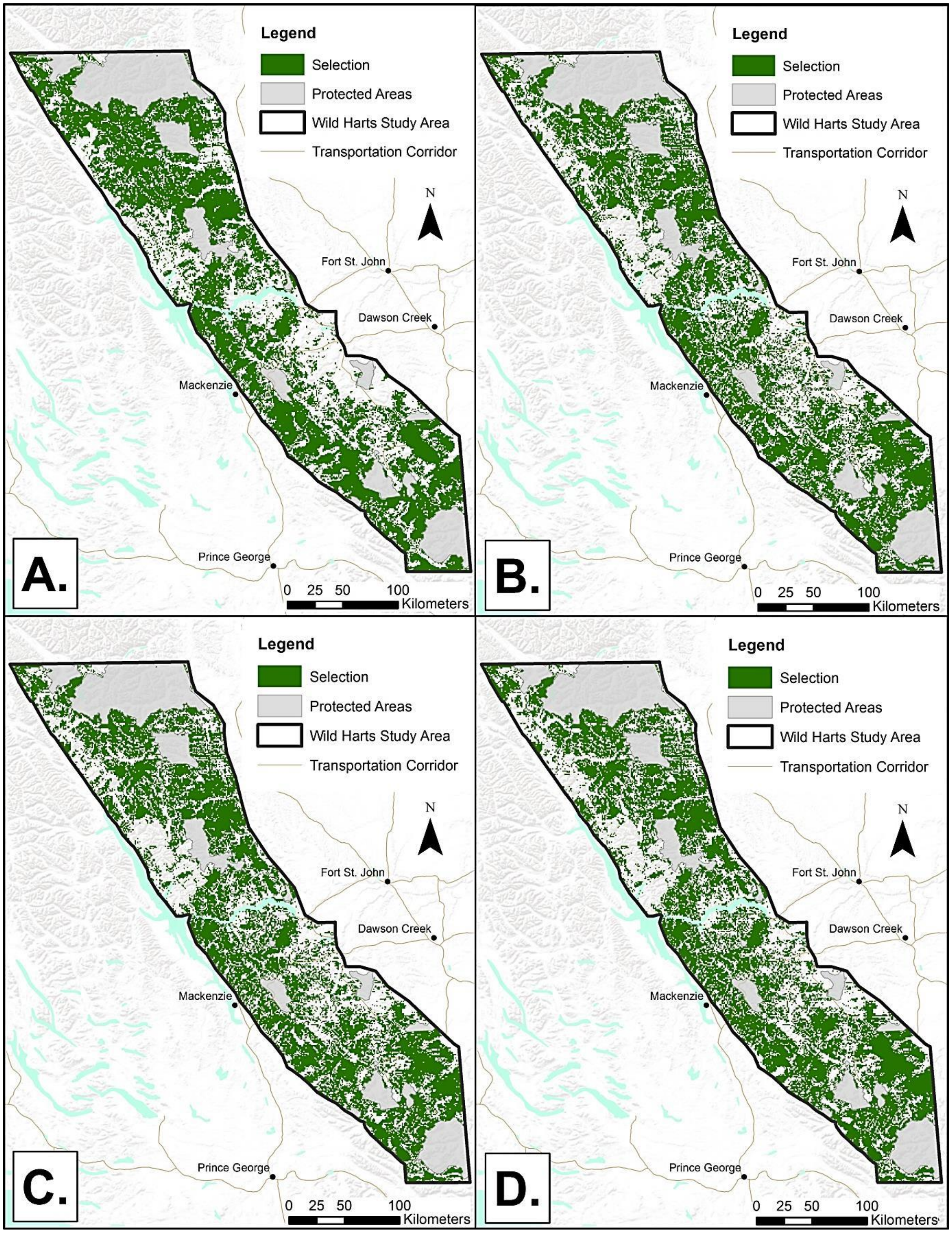

Figure 17. Four portfolios produced by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; **A**: high-sensitivity cost surface used; **B**: medium-sensitivity cost surface used; **C**: low-sensitivity cost surface used; **D**: no cost surface used.

5.4.2 Influence of Cost Surface:

Overlaying the four portfolios produced in this study highlights the influence of each cost surface (Fig. 18). Portfolio A was placed at the top of this overlay to serve as a benchmark of intactness. The high-sensitivity cost surface forced MARXAN-ILP to avoid the southeastern quarter of the WHSA and heavily-developed watersheds (Fig. 18). The portfolio is comprised of 28,018 km^2 of intact planning units. However, the large conservation targets resulted in 30% of that area falling within the ZOI (Fig. 18).

Portfolio B was placed underneath A to observe which planning units became selected when the level of constraint on MARXAN-ILP was lowered. The medium-sensitivity cost surface produced a portfolio similar to A in that the southeastern quarter of the WHSA and heavily-logged watersheds were avoided (Fig. 18). The reduced sensitivity to industrial activities resulted in 3892 km^2 of high-value planning units being selected in the ZOI that were avoided in scenario A (Fig. 18).

Portfolio C was placed underneath B to observe the effect of the low-sensitivity cost surface on selection. Low-elevation valleys containing high road density were avoided in this scenario (Fig. 18). The lack of sensitivity to recent timber harvesting resulted in 81 km^2 of high-value planning units being selected in temporarily disturbed landscapes that were avoided in scenario B.

The results of scenario D were placed at the bottom of the overlay to observe which planning units were selected when no constraints were placed on MARXAN-ILP. The absence of a cost surface resulted in Portfolio D capturing 175 km^2 of high-value planning units that were avoided in more constrained scenarios (Fig. 18). This is evident by the increased selection of planning units within the southeastern quarter of the WHSA (Fig. 18).

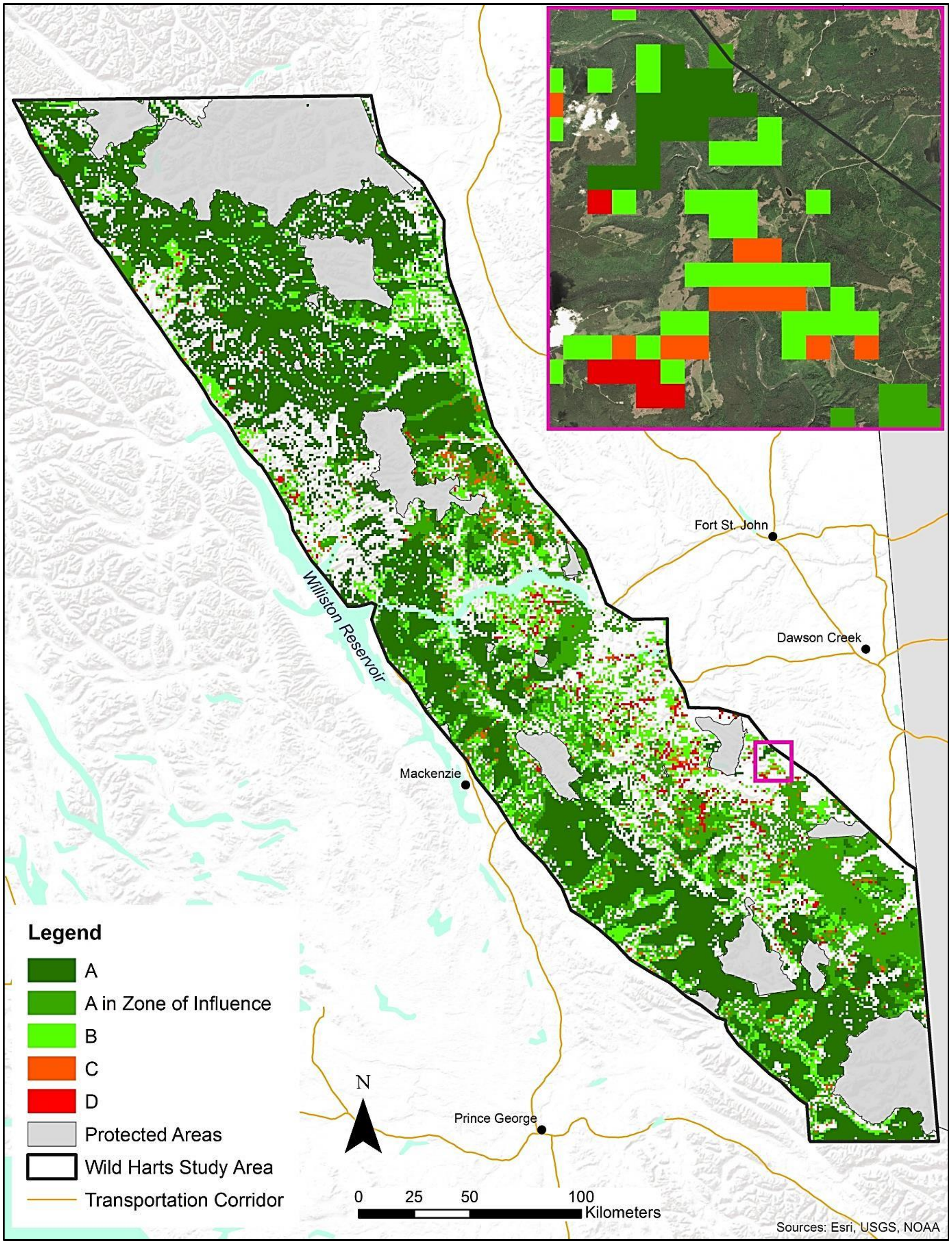

Figure 18. Overlay of four portfolios produced by MARXAN-ILP to prioritize lands for conservation in the Wild Harts Study Area; inset represented by pink frame.

5.4.3 Patch Statistics

As predicted, the level of constraint placed on the scenarios controlled the extent to which compactness amongst selected planning units was achieved in the resultant portfolios. Of the four scenarios, A was most constrained because of the reduction in penalty-free area inflicted by the high-sensitivity cost surface. As a result, Portfolio A met targets with the fewest patches and the largest average patch area of any scenario (Table 8). The patches that comprised Portfolio A were the least-convoluted of any produced in this study as is made evident by the low mean shape index and high total core area (Table 8).

The results of scenarios B through D were relatively uniform statistically (Table 8). When compared to A, these portfolios were comprised of more small patches of planning units which resulted in less core area and higher edge-to-area ratios (Table 8). Of particular note is the extent to which the patches that comprised Portfolio D were less-convoluted than those that made up B and C (Table 8). The increase in shape complexity displayed in Portfolio B and C was likely the result of MARXAN-ILP selecting narrow bands of high-value in-between linear developments that were demarcated by the low and medium-sensitivity cost surfaces (Fig. 17).

Table 8. Patch statistics of four MARXAN-ILP scenarios used to prioritize lands for conservation in the Wild Harts Study Area.

Variable	Portfolio A	Portfolio B	Portfolio C	Portfolio D
Total Area (km^2)	28018	27555	27577	27533
Number of Patches	1140	1477	1471	1349
Maximum Patch Area (km^2)	10077	6594	5499	5001
Average Patch Area (km^2)	25	19	19	20
Average Patch Perimeter (km)	22	21	21	22
Mean Shape Index (MSI)	1.30	1.32	1.32	1.32
Total Core Area Index @ 150m (%)	83	78	78	79
Total Core Area Index @ 500m (%)	59	49	49	51

6.0 DISCUSSION

The WHSA in northeastern British Columbia is an area of high ecological importance that is currently underrepresented by protected areas (PAs). The underlying purpose of this research was to prioritize lands for conservation in the WHSA using a systematic conservation planning (SCP) approach. This proved to be a complex exercise as the WHSA is a large planning region with multiple biotic and abiotic values. The challenge was increased further by the presence of competing land interests that threatened those values being targeted for conservation. Employing the four steps of SCP allowed me to address those challenges systematically and answer my three research questions.

6.1 What Areas Contain High Conservation Value for Select Coarse- and Fine-filter Features?

In a multi-use landscape like the WHSA, planners must use area efficiently to achieve conservation objectives so that opportunities for resource development are maintained (Wiersma & Sleep, 2018). Recognizing this, I set out to identify sections of the WHSA that were disproportionately high in conservation value. To be considered high in conservation value, a planning unit needed to contain multiple values predetermined to be effective surrogates for biotic and abiotic diversity. Assembling high-value planning units allowed MARXAN-ILP to achieve conservation targets at the lowest cost. In meeting targets, each portfolio captures the infrastructure that comprises and regulates natural systems in the WHSA.

Each portfolio captures 50% of both the land facet diversity and land facet rarity layers. These areas can provide a stable platform for evolutionary processes to play out as biological communities reorganize in response to climate change in the WHSA (Beier and

Brost, 2010). The abiotic elements that comprise land facets also govern variation in local temperature, precipitation, and disturbance regimes (Beier and Brost, 2010). Accordingly, each portfolio captures a diversity of physical environments to maintain the processes that shape current patterns of biodiversity in the WHSA.

All four MARXAN-ILP portfolios met the targets assigned to individual forest pattern and process features. Sufficient late-seral forest was captured within each landscape unit (i.e., NDT-BEC) to withstand the average fire size for that unit without experiencing a collapse in biodiversity (Province of British Columbia, 1995). Although there was not enough young natural forest to meet biodiversity objectives for early successional stands, each portfolio contained all of the recently burned areas in the WHSA that have not undergone salvage operations. As such, the portfolios accommodate habitat requirements of fire-obligate species and contain unique features not found in young managed stands (i.e., burned snags) (Province of British Columbia, 1995).

All portfolios capture 90% of year-round habitat for each woodland caribou herd in the WHSA. These areas are primarily comprised of intact alpine forests that provide refuge from predators and a year-round food source in arboreal lichens. Conserving the majority of caribou habitat in the WHSA may assist in the recovery of the species and, in turn, prevent the extirpation of a valued component of biodiversity in the WHSA. Selecting for woodland caribou habitat also resulted in large portions of the alpine and subalpine parkland ecosystems being represented in each portfolio. These areas are not captured by any of the other features used in this study and provide suitable habitat for Rocky Mountain bighorn sheep, Stone’s sheep, and wolverine among other species.

The four MARXAN-ILP portfolios each contain 60% of suitable grizzly bear habitat in the WHSA. This resulted in the prioritization of intact landscapes containing low road density. Open canopy forests have been included in each portfolio because of their association with *Vaccinium* spp. fruits — an important food source for grizzly bears in the summer and fall (Apps, 2013). Similarly, avalanche chutes are captured in each portfolio as these areas provide a spring food source in the form of emerging vegetation (Apps, 2013). Accommodating the habitat requirements of this generalist species (i.e., contiguous landscapes with high productivity rates) not only promotes the persistence of grizzly bears but also addresses the needs of multiple species at lower trophic levels such as songbirds, furbearers, and ungulates.

The portfolios each contain 60% of identified bull trout habitat in the WHSA. This resulted in the inclusion of healthy watersheds as bull trout are highly sensitive to riparian disturbance and pollution (Hagen & Decker, 2011). Streams identified as suitable bull trout habitat contain cold water, clean gravels, natural flows, and stable banks with large amounts of cover. Conserving streams with these characteristics not only favours the persistence of bull trout, but also accommodates the needs of other valued aquatic species in the WHSA such as Dolly Varden and brook trout (Hagen & Decker, 2011). Similarly, the inclusion of intact watersheds can benefit those non-aquatic species that make use of riparian and floodplain habitats in the WHSA (e.g., fisher).

MARXAN-ILP included 60% of the special features layer in each portfolio. This captured karst ecosystems containing cavities that are utilized by multitude of wildlife for nesting and hibernation. Also represented in each portfolio are wetland ecosystems that accommodate the needs of migratory waterfowl and perform important ecosystem services such as carbon sequestration and water filtration. Lastly, achieving conservation targets for the special features layer resulted in the inclusion of mineral licks within each portfolio. The supplementary nutrition provided by these areas can contribute to the persistence of elk, moose, mountain goats, and Stone's sheep, and Rocky Mountain bighorn sheep (Rea et al, 2004).

6.2 What Areas Retain Conservation Value Despite the Presence of Resource Development?

For the purposes of this study, a portfolio containing low levels of resource development was thought to display principles of good PA design. However, to suggest undeveloped landscapes were the only option for conservation would create the impression that all other areas of the WHSA could be written off as sacrifice zones. In SCP, sacrifice zones are those areas that, due to their modified state, are surrendered to accommodate natural resource development (Pressey, 1999). In reality, there exist multiple areas in the WHSA that retain high conservation value despite the presence of industrial activity. With this in mind, I intentionally designed scenarios that would visualize conservation targets being met across different landscape types in the WHSA — ranging from untouched wilderness areas, to those situated within the integrated resource-use matrix, to areas heavily modified by industrial and urban development.

Figure 18 shows high-value planning units in permanently developed landscapes that were selected in scenario D. Within the context of future conservation planning in the WHSA, planners could target these areas to assess whether the identified conservation values are at risk of being lessened or lost should resource development continue. If a planning unit is nearing a threshold where value may be lost, it may be a suitable candidate for restoration efforts. If the values present are relatively stable, stewardship agreements with stakeholders could be put in place so that conservation value can continue to persist alongside industry.

The low-sensitivity cost surface used in scenario C helped identify pockets of high conservation value within landscapes recently affected by forest harvesting (Fig. 18). Given their high conservation value, and temporarily disturbed state, these areas could be considered suitable candidates for removal from the integrated resource matrix. Protection of these areas would allow succession to occur naturally without active restoration. This may result in the eventual recruitment of conservation features that are currently absent because of habitat degradation from logging activity (e.g., bull trout). In addition to allowing for recovery, this would prevent the authorization of conflicting land-use that may further degrade the already disturbed landscape and result in the present value being lost.

Portfolio B identified areas where human activity, industrial light, and noise pollution is likely present but the landscape remains virtually void of fragmentation (Fig. 18). In their current state, these landscapes can accommodate those conservation features (e.g., land facets, forest pattern and process layers) whose ecology is such that they remain largely unaffected by stressors present in the ZOI. Given that these stressors are often short-lived, such as the noise created by a passing vehicle or seasonal construction, high-value lands in the ZOI may represent suitable habitat throughout the majority of the year for species that exhibit a high sensitivity to industrial activity (e.g., woodland caribou) (Wilson, 2016). Because of their intactness, these areas should be treated as buffers for high-value lands outside the ZOI.

The high-sensitivity cost surface applied to scenario A identified high-value areas containing little-to-no resource development. The results of this scenario are best suited to anchor a finalized conservation portfolio. The attributes of this portfolio and the associated management implications are discussed in the following section.

6.3 What is an optimal portfolio from which to direct conservation planning efforts?

High-value planning units in fully-converted or recently-logged landscapes contain attributes that limit their utility in planning initiatives aimed at immediate protection measures. These areas have sharp edges between ecotones, increased occurrences of invasive species, and are often comprised of young managed stands that are low in biodiversity (Bannerman & Province of British Columbia, 1998; Delong & Province of British Columbia, 2011). Identifying high-value sections of these landscapes helped answer the second research question and prevent condoning sacrifice zones. However, I wanted to avoid only suggesting long-term options for conservation that were predicated on restoration effort, special management, or surrender of existing tenures. Conservation initiatives often lack the resources needed to perform such interventions.

Part of the rationale for enforcing principles of good protected area PA design on MARXAN-ILP was to identify lands that achieved conservation objectives in their current state and provided space on the landscape for other uses. Aside from some areas that fell within the ZOI, the majority of lands that make up Portfolio A exist in complete isolation from resource development and are free of any land-use conflicts. These areas would require the least amount of intervention prior to PA creation and were thus considered to be best suited for immediate application in planning processes.

In addition to administrative utility, Portfolio A displayed desirable patch characteristics that were consistent with principles of good PA design. Of all the scenarios, Portfolio A had the highest percentage of core area and the lowest mean shape index (Table

8). This was likely due to the fact that the portfolio was comprised of few, large patches that were the least-convoluted of any produced in this study (Table 8). The high percentage of interior forested habitat makes Portfolio A the most compatible with conservation features that are sensitive to fragmentation (e.g., woodland caribou, bull trout, grizzly bear). A low mean shape index also minimizes the amount of transitionary area between patches where harmful edge-effects can occur. Examples of edge-effects include barriers to species dispersal, altered temperature regimes within PA boundaries, and the creation of entry points for invasive species (Bannerman & Province of British Columbia, 1998).

The large area requirement of the conservation targets, combined with the reduction in penalty-free area induced by the high-sensitivity cost surface, caused a natural corridor of prioritized lands to form in Portfolio A. This corridor can be seen across all portfolios but is most intact and pronounced in Portfolio A (Fig. 17). The corridor spans the entire length of the WHSA on a southeast-northwest line and shows a network of high-value lands prioritized amongst existing PAs (Fig. 4 and 17). Achieving connectivity amongst PAs in the WHSA has important implications for those species migrating along latitudinal gradients in response to shifting climate regimes and could prevent the isolation of populations within the planning region.

In summary, Portfolio A not only achieves the goal of this study by meeting targets for all features, but does so with a corridor of contiguous landscapes that contain little-to-no conflicting land-use. As outlined above, these characteristics are thought to complement the biology of select conservation features and reduce the amount of resources required to establish PAs. It is because of these attributes that the lands identified in Portfolio A are considered to be ‘priority lands’ for protection and have been placed at the center of a finalized portfolio to direct conservation efforts in the WHSA (Fig. 19).

If all priority lands were to be conserved, and consolidated with the 17% representation achieved by existing PAs, the result would be a network of protected lands covering 63% of the WHSA. This scale of representation is consistent with emergent concepts that suggest protecting over half of terrestrial environs is necessary to address the current inadequacy of Canada’s PA system and prevent the collapse of global biodiversity (Locke, 2014). Though it exceeds political targets, it could be argued that this scale of PA representation is what is realistically required to ensure the persistence of conservation features and maintenance of landscape function along the North American Cordillera.

Figure 19 shows a diffuse buffer on the outside of priority lands labelled ‘integrated lands’. Integrated lands are an amalgamation of those areas that were selected in scenarios B through D (Fig. 17). Integrated lands should not be written off as sacrifice zones because of their compromised state, but rather be considered as high-value areas that soften the transition zone between heavily developed landscapes and priority lands. Integrated lands also increase connectivity amongst priority lands and existing PAs in the WHSA (Fig. 19).

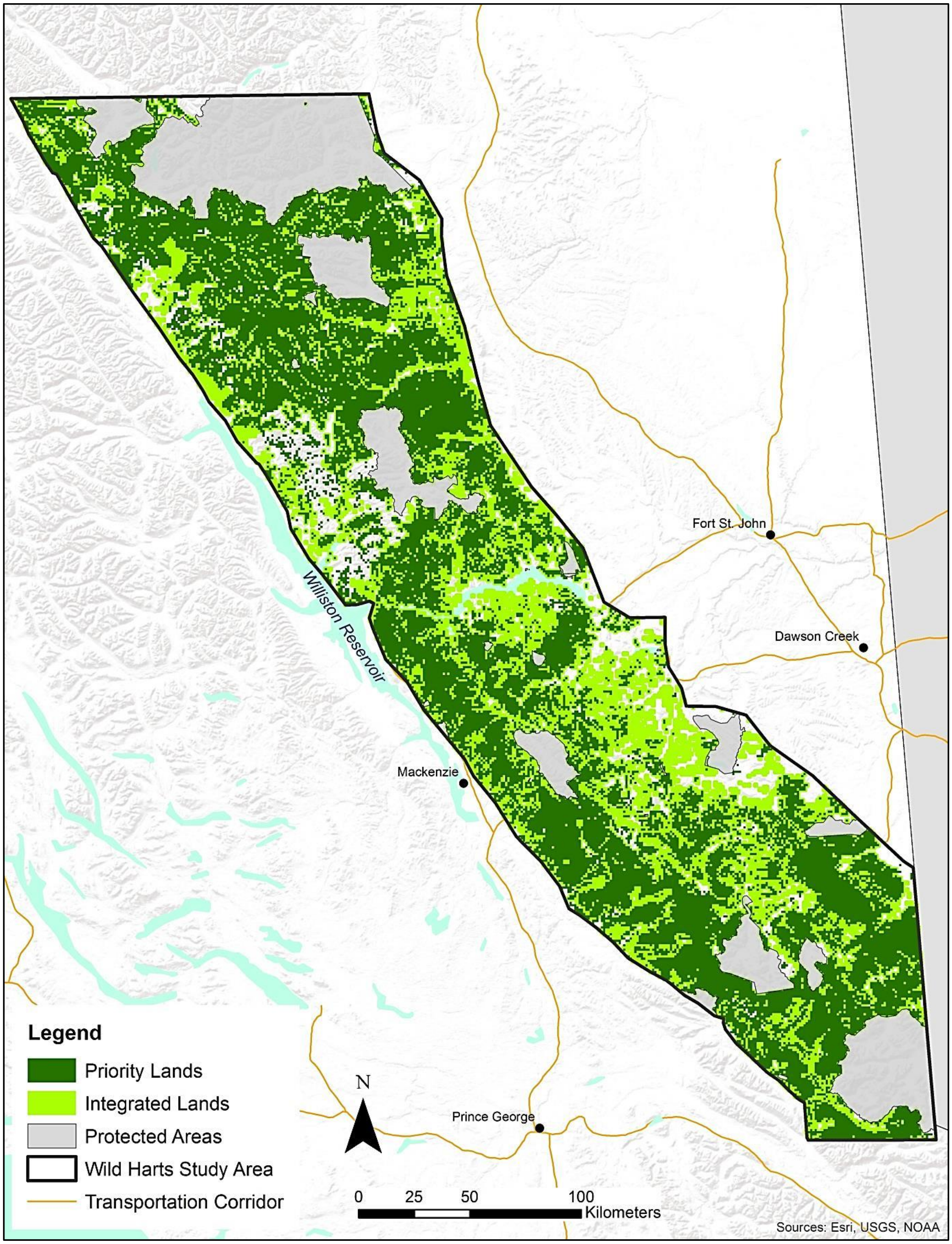

Figure 19. Finalized portfolio for conservation planning in the Wild Harts Study Area.

6.4 Next Steps

The next steps in the SCP process would be to identify suitable PA boundaries in the WHSA using the finalized conservation portfolio produced in this research. The portfolio was designed to serve as a coarse-scale reference of priority lands from which finer-scale analyses could be directed. The MARXAN-ILP model used to produce the portfolio is a live interface that can be scaled-down and applied to specific areas of interest. Decision makers could use the final portfolio to locate areas best suited for immediate conservation action and conduct a downscaled MARXAN-ILP analysis within those areas to delineate PA boundaries. A downscaled analysis would not need to adopt the MARXAN-ILP inputs applied in this model, but rather could apply a different set of user-defined constraints that are reflective of the goals for that revised planning region.

Integrated lands require further analysis to gauge whether the current conservation value present is at risk of succumbing to resource development. The zonation achieved by the various cost surfaces displayed in Figure 18 can assist in targeting areas most at risk. The results of such an assessment would inform whether special management is required to sustain conservation value in these areas. Areas most at risk might be best served by a strong form of protection; whereas, those low-risk areas could be managed in such a way that accommodates other forms of land-use (i.e., recreation, low impact resource extraction, etc.).

Equally important is the step of completing a fine-scale connectivity analysis to complement the happenstance connectivity achieved by the WHSA conservation portfolio. Further investigation is required to determine whether the connectivity achieved within the priority lands is reflective of that which actually occurs on the land base. Of additional interest is whether the resource development present within the integrated lands degrades the ability of these areas to facilitate movement of species.

7.0 LIMITATIONS

There were several limitations that emerged during the course of this research. These included limitations associated with applying systematic conservation planning to the WHSA and limitations built into the MARXAN-ILP model used in this study.

7.1 Limitations of Conducting Systematic Conservation Planning in the Wild Harts Study Area

Many of the limitations involved in the SCP process existed in the form of the assumptions required to complete the process itself. Principle amongst these was the selection of surrogates. I employed surrogates assuming that one component of biodiversity was representative of another — an approach that could be criticized as being an oversimplification of ecological complexity present in the WHSA. I attempted to address that assumption through the use of multiple surrogates at varying spatial scales. However, it is still possible that the conservation features did not constitute adequate representation of those biological elements being selected for through surrogacy.

Other limitations arose in the form of data availability, or lack thereof, when building the conservation feature layers to drive MARXAN-ILP. The WHSA is of such a large scale that consistent and reliable spatial data for the entire area were difficult to obtain or generate. Oftentimes those datasets that were available had a commercial element to them or were used by licensees and the provincial government to measure the impact of resource use. For example, the layers used to build the forest pattern and process layers have a primary purpose of analysing timber supply. Similarly, much of the bull trout layer was constructed using datasets that were built to measure the impacts of harvesting on riparian areas and watershed quality. There were very few datasets available that were produced solely for conservation or ecological research sake. In this way, the selection of conservation features was somewhat biased to those elements valued by the natural resource sector and less a reflection of the most efficient surrogates for abiotic/biotic diversity.

An additional limitation of the SCP process involved translating the goals for conservation into quantifiable targets. The goal of this study was to prioritize lands that, if protected, would complement existing PAs in promoting biodiversity, maintaining natural disturbance regimes, and building climate change resilience within the WHSA. The criteria that make up this goal are based on large-scale biophysical patterns and processes. Attempting to quantify how much area was needed to account for climatological variables, stochastic disturbance events, geomorphological processes, and interactions between biological communities proved to be a challenging task. There remains the potential that, even if all lands prioritized by conservation targets were protected, the resultant PA network would still fall short of achieving all components of the study goal.

Another limitation was the extent to which the large woodland caribou targets masked the full capabilities of MARXAN-ILP. Meaning, the spatial footprint of 90% representation for each of the woodland caribou herds resulted in many of the other targets being met within that footprint through complementarity. In addition, the woodland caribou conservation feature layer had a comparatively low edge-to-area ratio and a tendency to occur outside of resource development — both characteristics that lessened the influence of cost surfaces. This made for relatively uniform results across all scenarios when compared to some of the trial runs conducted in the early stages of this research, at lower representation targets, with the same user-defined constraints (Appendix 3). This result was not ideal given the resources expended on scenario development, but was welcomed because it highlighted the effectiveness of woodland caribou as a surrogate for other conservation features in the WHSA.

There is potential that I have been overly generous in describing the distribution of select conservation features across the WHSA. Given the scale of this analysis, I drew upon methodologies that could be applied across the entire planning region when constructing conservation feature layers. This resulted in some layers being built using rudimentary selection criteria for what was considered suitable habitat (e.g., bull trout and grizzly bear). These layers might have resulted in an over-estimation of the amount of area needed to ensure the persistence of select conservation features. The inclusion of surplus area could have implications if these portfolios are used to delineate administrative boundaries for PAs. These implications would come in the form of unnecessary opportunity and acquisition cost that occurs when area is used inefficiently to achieve conservation.

7.2 Limitations of the MARXAN-ILP Model

One of the major limitations involved in the construction of the MARXAN-ILP model was the WHSA boundary itself, specifically the northern and southern extents. In hindsight, Northern Rocky Mountains and Kakwa Provincial Parks should have been excluded from the boundary as they are not representative of the WHSA. Northern Rocky Mountains Provincial Park is part of the Muskwa-Kechika Management Area and Kakwa Provincial Park is more closely associated with the Central Rocky Mountains PA complex than with the WHSA. The rationale for their initial inclusion was to assess the extent to which selected planning units interacted with borders of these PAs and whether any connectivity was achieved naturally. However, including these large PAs created an inaccurate representation of how much area in the WHSA is actually protected. In reality, the core sections of the WHSA are poorly represented with only 4.8% falling within PAs once Northern Rocky Mountains Provincial Park and Kakwa Provincial Park are removed.

The inclusion of these large PAs also raised issues when completing step 3 in the SCP process (review existing PAs in the WHSA). These PAs captured large portions of many conservation feature’s total area, thus reducing the amount of outstanding area needed to achieve the various conservation targets for each feature respectively. Essentially, those large parks created the impression that some features were well-represented by PAs when, in fact, the actual representation of these features was poor within the core portions of the WHSA. Accordingly, MARXAN-ILP would not have selected additional area to accommodate those features thus leaving them vulnerable to resource development.

Another limitation that arose when running scenarios in MARXAN-ILP was the similarity in portfolios produced by scenarios using medium and low-sensitivity cost surfaces. This was likely due to the large planning unit size of 1 km^2. The planning units were too coarse a scale for MARXAN-ILP to make the distinction between temporary and permanent development as these forms of land use were commonly in close proximity to one another. Meaning, the same planning units that were avoided due to cutblocks in the medium-sensitivity scenarios would also have been avoided in the low-sensitivity scenarios because of the road used for access. Smaller planning unit size would result in differentiation between cutblocks and permanent landscape conversion and produce solution spaces whose perimeters exhibit greater sensitivity to these different levels of land use.

8.0 RECOMMENDATIONS

This research helped to identify coarse-scale priority areas for conservation action in the WHSA. The finalized conservation portfolio can be used to direct the establishment of PA boundaries. It can also be used for the assessment of risk to conservation value, and the completion of a fine scale connectivity analysis.

As noted above, the MARXAN-ILP model is a live interface that can be manipulated to achieve alternative solution spaces. With this in mind, a way to improve the current model would be to include a conservation feature representing a mid-trophic level carnivore such as a furbearing mammal (e.g., fisher, American marten). Small, carnivorous mammals are commonly included in conservation planning process as they are often heavily harvested and are representative of late-seral stage forests (Apps, 2013).

The working model would also benefit from research conducted in partnership with First Nations whose traditional territories overlap the WHSA. The incorporation of traditional ecological knowledge would complement the empirically-based data used in this study and would be invaluable for addressing some of the gaps present in those datasets. Aside from the ecological contribution, First Nations involvement would add a cultural element to the conservation efforts taking place in the WHSA. Additional conservation features could be developed that encapsulate areas being used by First Nations within contemporary contexts for exercising their constitutional rights of hunting, fishing, and gathering. Such research would ensure that inclusivity is built into any portfolio meant to inform decision-making processes regarding PA creation in the WHSA.

Another avenue for future research would be to explore the extent to which shifting climate regimes will interact with lands prioritized for conservation under current state conditions. Many of the values targeted in this study have the potential to display latitudinal migration in response to changes in temperature and precipitation (e.g., forest pattern and process features). Research aimed at predicting these movements, and where climate velocity might be most pronounced in the WHSA, would lend insights into which lands should be proactively selected to accommodate novel assemblages of species — regardless of whether those areas contain high conservation value under current state conditions (Brito-Morales et al., 2018). Similarly, this research would also help to identify areas unlikely to retain their conservation value.

9.0 CONCLUSION

At the local scale, the WHSA supports a wide range of ecological diversity and represents some of the last remaining intact landscapes in northeastern British Columbia. At the continental scale, the WHSA serves as a vital corridor connecting networks of PAs in the south to large PAs in the north. To lose landscape function in the WHSA would effectively sever the band of contiguous habitats spanning the length of the North American Cordillera and create two isolated PA complexes. This has implications for those biological communities that migrate along latitudinal gradients and could result in the isolation of populations. The WHSA is currently underrepresented by existing PAs and competing resource interests from the surrounding Peace River Region threaten to encroach upon the ecological values present there. This research was aimed at producing a suite of possible options for conservation in the WHSA that could be used to inform decision-making processes concerning future PA creation in the area.

The SCP approach was effective for conducting a prioritization exercise at the scale of the WHSA. The MARXAN-ILP software allowed me to identify areas of high conservation value and explore the extent to which varying intensities of resource use influenced prioritization. The software performed large computations at high speed and consistently achieved the optimal solution at the lowest cost. The results of this research represent a wide range of options for conservation in the WHSA and present additional research questions.

The final conservation portfolio shows priority lands (i.e., Portfolio A) that are best suited for immediate protection measures. These areas met targets for all conservation features and best displayed principles of good PA design. Complementing priority areas are integrated lands (i.e., Portfolio B, C, and D) that retain high conservation value despite containing varying levels of resource development. The integrated lands serve as a transitionary buffer between heavily-developed landscapes and the values present within priority lands. These areas offer an opportunity to prescribe restorative efforts or special management strategies to achieve conservation alongside other forms of land-use in the WHSA.

The results of this research are not meant to serve as legal boundaries for future PAs. More research is required to further refine the selected areas and explore solutions that take into account First Nations interests or different climate scenarios. What this research does provide is a decision-support portfolio that is repeatable, transparent, and scientifically-defensible. Land planners can be sure that the areas prioritized in this research represent the foundational and mechanistic elements that comprise the ecology of the WHSA on the whole. The final portfolio is meant to inform the discussion surrounding protected area creation in the WHSA and contribute to the preservation of one of British Columbia's last true wildernesses.

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APPENDIX 1: Spatial information used for MARXAN-ILP model

LAYER	LAYER NAME	SOURCE
Land Facet Diversity and Rarity	Land Facets Incorporating Latitude-adjusted Elevation	Adaptwest
Forest Pattern and Process	Vegetation Resource Inventory	Data BC
	Biogeoclimatic Zones	Data BC
	Natural Disturbance Zones	MFLNRORD - Geospatial Services Team Omineca Region
Woodland Caribou	Core Habitat Mapping South Peace	MFLNRORD - Ecosystems Branch Prince George
	Resource Selection Function Northern Mountain	parker@unbc.ca
	Resource Selection Function Southern Mountain	johnsoch@unbc.ca
	Ungulate Winter Range Proposed and Approved	Data BC
	Legal Herd Boundaries	Data BC
Grizzly Bear	Biogeoclimatic Zones	Data BC
	Broad Ecosystem Inventory	Data BC
	Wildlife Habitat Areas Proposed and Approved	Data BC
Bull Trout	Third-order and Greater Watersheds (50,000)	Data BC
	Fisheries Sensitive Watersheds Proposed and Approved	Data BC
	Critical Rearing Habitat	MFLNRORD - Ecosystems Branch Prince George
	Wildlife Habitat Areas Proposed and Approved	Data BC
Special Features	Reconnaissance Karst Potential Mapping	DataBC
	Freshwater Atlas Wetlands	Data BC
	Mineral Licks	MFLNRORD - Ecosystems Branch Prince George
	Baseline Thematic Mapping Urban	Data BC
	TANTALIS - Residential Leases	Data BC
	TRIM Enhanced Base Map Urban	Data BC
	Digital Road Atlas	Data BC
	Forest Tenure Road Sections	Data BC
	TRIM Transportation Lines	Data BC

Cost Surfaces	Petroleum Development Roads	Data BC
	Petroleum Access Road	Data BC
	Crown Tenures Pipelines and Processing	Data BC
	Oil and Gas Right-of-way	Data BC
	Oil and Gas Facility	Data BC
	Oil and Gas Ancillary	Data BC
	Oil and Gas Well Sites	Data BC
	Oil and Gas Surface Hole	Data BC
	TRIM Well Sites	Data BC
	TRIM Pipelines	Data BC
	TRIM Seismic Lines	Data BC
	OGC 2003-2012, 2002-2006, 1996-2004 Seismic Lines	Data BC
	TANTALIS Quarrying Licence	Data BC
	TANTALIS Quarrying Lease	Data BC
	TANTALIS Right-of-way Mineral Production	Data BC
	Baseline Thematic Mapping Mining	Data BC
	TANTALIS Industrial Licence	Data BC
	TANTALIS Industrial Lease	Data BC
	TANTALIS Industrial Right-of-way	Data BC
	Baseline Thematic Mapping Agriculture	Data BC
	Agricultural Land Reserve	Data BC
	Consolidated Cutblocks	Data BC

APPENDIX 2: Cost Surface Geoprocessing Steps

Step 1.	Merge all datasets depicting roads described in Appendix 1.
Step 2.	Buffer road polylines based on surface type: paved = 15 m from centerline; FSR = 10 m from centerline; secondary unpaved road = 7.5 m from centerline; trail = 3.5 m from centerline
Step 3.	Dissolve buffered roads on a single attribute field to reduce the amount of data in the layer
Step 4.	Merge all datasets depicting seismic lines described in Appendix 1
Step 5.	Buffer seismic polylines 6 m from centerline
Step 6.	Dissolve buffered seismic lines on a single attribute field to reduce the amount of data in the layer
Step 7.	Merge all datasets depicting oil and gas development described in Appendix 1 and dissolve on single attribute field
Step 8.	Merge all datasets depicting industrial development described in Appendix 1 and dissolve on single attribute field
Step 9.	Merge all datasets depicting quarrying/mineral/mining development described in Appendix 1 and dissolve on single attribute field
Step 10.	Merge all datasets depicting urban/residential development described in Appendix 1 and dissolve on single attribute field
Step 11.	Merge all datasets depicting agricultural development described in Appendix 1 and dissolve on single attribute field
Step 12.	Merge all dissolved layers into a single polygon and dissolve on single attribute field to produce low-sensitivity cost surface
Option A	Prior to completing step 12, add consolidated cutblocks $\leq$20 years old to produce medium-sensitivity cost surface
Option B	Prior to completing step 12, buffer forms of development based on avoidance distances described in Table 4 to produce high-sensitivity cost surface

APPENDIX 3: Solution spaces produced in trial scenarios prioritizing areas for conservation in the Wild Harts Study Area.

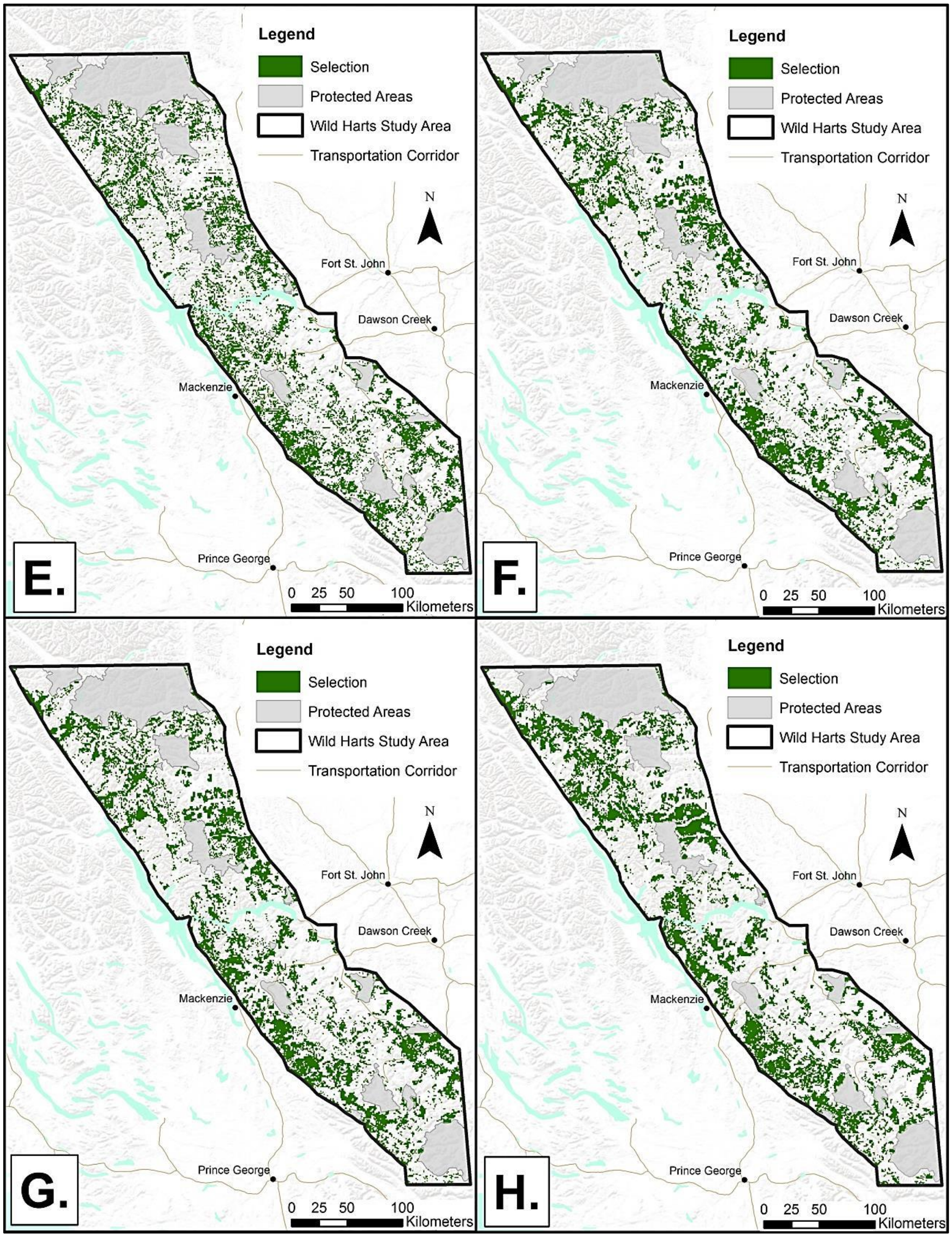

Figure 20. Trial scenarios at 50% target for all conservation features; **E**. no cost surface used; **F**. low-sensitivity cost surface used; **G**. medium-sensitivity cost surface used; **H**. high-sensitivity cost surface used.