PROTECTED AREA SELECTION FOR EFFICIENT AND EQUITABLE BIODIVERSITY CONSERVATION IN BRITISH COLUMBIA

by

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Abstract

Conserving biodiversity is principally achieved through the designation of protected areas, guided by the process of systematic conservation planning (SCP). SCP identifies networks of protected areas that represent regional biodiversity. Ecologists, planners, and decision makers may each use different spatial boundaries, scales, and extents for individual projects; these can be misaligned with the jurisdictional scope and scale of management decisions, impacting the effectiveness of resulting conservation actions. Using British Columbia as a study area, we explore how analysis design effects SCP outputs. Using ILP solvers, we measured concordance, efficiency, and equity between the varying extents (ecological and administrative) and scales (fine, coarse, provincial). Higher efficiency but lower equity results when constraints are lifted. Inversely, higher land requirements with higher equity result when constraints are imposed. We show how initial design decisions influence the priority assigned to conservation areas and find insights for striking a balance between landscape-scale and regional-scale analyses.

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Glossary of Terms and Acronyms

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

BC: British Columbia, a Canadian province.

BCPARF: British Columbia Protected Area Research Forum. A biannual conference of conservation planners and researchers intended to facilitate research and its application to parks and protected areas management.

Biodiversity: the ecological and evolutionary patterns and processes that form the basis of life on Earth.

CAP-BC: Climate-Adaptive Planning for BC's Protected Areas. A web-based, open-access planning tool that will be flexible for diverse user groups, preloaded with data, and updatable for future advances in BC climate change knowledge.

CBD: Convention on Biological Diversity. Originally convened in 1992 following the Rio Earth Summit, the CBD is a global effort with 150 national signatories that is dedicated to sustainable development. It has 3 main objectives: (1) The conservation of biological diversity, (2) the sustainable use of the components of biological diversity, and (3) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

Efficiency: the measurement of how much or little land area is required in a given solution set.

Equity: the proportional availability (or conversely, the relative deprivation) of a resource compared with its availability to others.

Grouping units: classifications of spatial constraints.

Protected area: a clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystems services and cultural values.

Regional biodiversity: the relative uniqueness of local conditions; significant in its distinction from global biodiversity.

SCP: Systematic Conservation Planning. A structured, six-step, systematic approach to conservation planning.

Spatial scale: the geographic size or magnitude of a process (does not refer to resolution or grain size).

Spatial extent: the geographic space enclosing the referenced data.

Spatial constraints: the various differences in scale, size, location, and type of data used to define an SCP problem.

prioritizr: an R package which uses mixed integer linear programming techniques to provide a flexible interface for building and solving conservation planning problems.

1. Introduction

1.1 Background: Conservation Planning for Biodiversity

Biodiversity Conservation in Canada

The term ‘biodiversity’ describes the ecological and evolutionary patterns and processes that form the basis of life on Earth (Noss and Cooperrider, 1994). Global loss of biodiversity has been exacerbated by land use change (Boakes et al., 2010; Jones et al., 2018). Conflict between land-uses is often decided against conservation goals, jeopardizing the success of protection initiatives (Venter et al., 2018). Biodiversity conservation is a practice that aims to protect and manage these values, which are essential to ecosystem function, the global food supply, aesthetics, recreation, and spiritualism (Watson et al., 2005).

Conserving biodiversity is principally achieved through the creation and designation of protected areas (Margules and Pressey, 2000). A “protected area,” as defined by the International Union for Conservation of Nature (IUCN) is “a clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystems services and cultural values (Dearden et al., 2015).” These protected areas are designed to be representative of regional biodiversity and to be resilient to climatic or periodic changes in the ecosystem (Dearden et al., 2015).

Canada is a signatory on Convention on Biological Diversity’s 2011-2020 Strategic Plan for Biodiversity; this plan included targets (the “Aichi Targets”) for its partners to achieve conservation objectives. Aichi Target 11 obligates the signatory countries to protect at least 17% of their terrestrial land and 10% of their marine areas through “effectively and equitably managed, ecologically representative and well-connected systems of protected areas" by 2020 (Convention on Biological Diversity, 2010).

Canada's protected area system currently encompasses 10.5% of the country's terrestrial land base (Climate Change Canada, 2018). Achieving the Aichi Targets requires a rapid and systematic expansion of the protected area network, especially as the 2030 and 2050 protection targets are expected to increase (Convention on Biological Diversity, 2020). British Columbia (BC) is outpacing other provinces, with 15.4% of its land currently in protected areas (Climate Change Canada, 2018). Its high biodiversity, geographic connectivity, and relatively low land use change rates make BC a prime candidate for new protected areas (Austin and Eriksson, 2009). These characteristics also make the province vulnerable to widespread climate-related changes (Woods et al., 2017). Incorporating climate variables is critical to ensuring new protected areas promote the overall adaptive capacity of the total network (Groves et al., 2012; Pressey et al., 2007).

Importantly, the Aichi Target contains a critical mandate that established protected areas be effective, equitable, connective networks selected for their ecological importance. This highlights the importance that true *improvements* to the protected area network must progress the incorporation of these components, ensuring that new protected areas are placed where they will be effective in safeguarding biodiversity (Venter et al., 2018). To successfully improve protected area networks, potential inconsistencies in the conservation planning process must be understood and reconciled.

SYSTEMATIC CONSERVATION PLANNING

Conservation planning aims to systematically identify areas which safeguard biodiversity and ecosystems against loss while still managing land appropriately for human use (Groves et al., 2003). The process of Systematic Conservation Planning (SCP) (Margules and Pressey, 2000) provides a structured approach to the creation of protected areas, and is a key tool for conserving biodiversity. SCP requires (1) considered selection of features of biodiversity, (2) establishment of specific goals and quantitative targets, (3) evaluation of the existing protected area network, (4) complementary design of new reserves, (5) implementation procedures and direction, and (6) management and review to maintain the ecological conditions. SCP is an iterative process, necessitating continual review, additions, and managerial adjustments. Though some variation is to be expected among process results (Wiersma and Sleep, 2016), it is important that SCP is applied consistently to ensure optimal protected areas are created.

In the first step of this process, conservation planners select spatial data that represents relevant conservation features, such as species habitat or forest composition (Margules and Pressey, 2000), to analyze and assign protection priorities across the landscape of interest. These spatial data are used to identify biodiversity conservation priorities and inform landscape-scale decisions. This judicious selection of conservation features is integral to the SCP process.

The second step is to identify representative goals and quantifiable targets for conservation. Using the features identified in step one, relevant numerical targets are assigned to these values as a measure of how much of the feature's spatial range should be conserved. Using a science-based approach, the most appropriate numerical target is determined after a thorough review of the best available ecological and spatial information for each feature (Wiersma and Sleep, 2018). These targets are used to instruct a prioritization algorithm and produce optimal spatial solutions that are representative of the combined spatial requirements of the input features (Svancara et al., 2005).

The third step is to conduct a review of existing conserved areas to identify gaps and key areas for new conservation. The objective of this gap analysis is to evaluate how well existing conservation areas have achieved their goals (Burley, 1988, pp. 227–230) and where there is room for improvement of the network. Protected areas that are not strategically selected can create or exacerbate societal inequity, and are ineffective in protecting biodiversity (Venter et al., 2018). Therefore, this step is important for ensuring that new protected areas are located in the right places to conserve biodiversity effectively.

In the fourth step, the features, targets, and information about the current network of existing protected areas are used to guide the selection of new conservation areas. This selection process is generally conducted using optimization algorithms, which run multiple iterations and produce a range of optimal solution sets. Integer linear programming (ILP) is a commonly used optimization process which uses input data assemblages to iteratively select complementary sites to achieve a solution to a SCP problem (Albuquerque and Beier, 2015). ILP achieves solutions at the lowest cost, which optimizes both conservation and resource opportunity (Beyer et al., 2016). A standard planning unit is employed throughout to delineate the size of each selection (Margules & Pressey, 2000).

Steps five and six (implementation and management, respectively) occur outside the purview of conservation planners, and are implemented by policy makers and land managers. For these actors to succeed, and for resources to be adequately directed towards meaningful conservation, diligent work must be done in the preceding steps. SCP provides structure for evaluating and prioritizing the conservation features, while decision-support technology is used to find optimal solutions for reaching conservation targets. Getting the right data and making informed decisions during the SCP setup is critical to the actualization of conservation goals.

The underlying assumption of SCP is that maximizing species representation within protected areas will ensure their persistence. It follows that the maximum number of protected features represented at the minimum land area should give the most efficient solution to the conservation problem (Ball et al., 2009; Moilanen et al., 2009). However, the process and its outcomes may also be influenced by the spatial constraints that are used to define the area of interest for any SCP exercise.

Spatial Scale and Units for Planning

The spatial scale and extent of a conservation planning project are often determined before the SCP process begins. "Spatial scale," for the purposes of this research, is defined as "the geographic size or magnitude of a process (Dabiri and Blaschke, 2019; O'Sullivan, 2015)," and does not refer to resolution or grain size. "Spatial extent" refers to the geographic space enclosing the referenced data, and is often represented by and referred to as a boundary (National Geographic Society, 2020). The selection of these spatial constraints may be driven by the objective of the project, by available funding, or by specific interests of the researchers, but nonetheless contribute to the process.

Though biodiversity conservation analyses follow a formula, they are often conducted using inconsistent spatial constraints and are frequently misaligned with the jurisdictional boundaries used for management decisions (Warman et al., 2004b). While these may have excellent scientific basis, their results can difficult to implement. For example, the Nature Conservancy Canada Conservation Blueprints, the guiding document for national conservation in Canada, were conducted using spatial regions purpose-designed for the study, and not used anywhere else (Nature Conservancy Canada, 2010).

It is the nature of land conservation that different organizations and operators have differing geographic priorities. Effective and consistent conservation planning should be conducted at consistent scales and congruous extents, or provide justification for the constraints used, as ecological relevance may not always translate well to jurisdictional applications (Huber et al., 2010). It is possible that the constraints chosen cause evaluations to over- or under-emphasize the ecological significance of areas relative to the distribution of the features in the larger landscape. However, there is currently no way to measure the effect of geographic scale and extent of SCP evaluations on the ability of models to accurately represent ecologically significant areas.

Table 1. 1
Definitions and examples of the spatial constraint terms used in this analysis.

Term	Use	Example
Spatial Scale	The relative size of a process or area	(Huber et al., 2010)
Spatial Extent	The geographic coverage of a process or area	(Saura and Martinez-Millan, 2001)
Grouping Unit	The classification of a given spatial scale and/or extent	(Selig et al., 2012)

SPATIAL CONSTRAINTS COMMONLY USED IN THE STUDY AREA

The Canadian province of British Columbia (BC) serves as the study areas for this research. BC is home to more biodiversity than any other place in North America, including over 75% of Canada's mammals, the majority of the global range for 99 species, high genetic diversity between species, and a relatively short history of large-scale land use change (Austin et al., 2008). Terrestrial protected areas total 15.4% of the province's land area, higher than any other province in Canada (Environment and Climate Change Canada, 2018; Environmental Reporting BC, 2016). Biodiversity in BC is vulnerable to the effects of climate change, which are projected to intensify in the coming decades (Bellard et al., 2012; Woods et al., 2017). Combined, these factors make BC a candidate site for impactful SCP. However, to ensure meaningful conservation, it is important to consider the role of spatial scale and extent in the SCP processes which occur in the province. The current state of SCP in BC reveals disparity between the spatial scales and extents used in planning and those used in administration.

There is disparity across the geographic extent groupings used by various provincial actors. BC's Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD) use an administrative unit to define its operations. The administrative unit employed is not consistent; Land Use Plan boundaries, for example, have been established through a collaborative process involving Regional Districts, municipalities, government agencies, and First Nations, and often do not reflect any distinct administrative boundary. By contrast, many conservation studies are conducted using ecological groupings. Global ecoregions (Olson et al., 2001) are one such grouping which gives a biogeographical framework to large-scale conservation strategies. The global ecoregions are employed commonly, as evidenced by their 5,500+ citations. In BC, an analog dataset of provincial ecoregions is often used.

Regarding spatial scale, studies conducted in BC are generally inconsistent (Warman et al., 2004b). Some analyses are meant to represent the full province; however, sampling is carried out by region, and do not deliberate on the effect of this artificial apportionment on the study results (Guerrero et al., 2013). The major guiding documents for private land conservation in the southern ecoregions of Canada, Nature Conservancy Canada's Conservation Blueprints, are conducted in this manner. Additionally, the scale of Old-growth Management Areas are chosen based on provincial harvesting rates and limits, and are generally scattered and small in size compared to the geographic distribution of BEC zones that would support contiguous old-growth forests (Environmental Law Centre, 2013). Studies such as these which arbitrarily stratify data based on artificially-constructed regions jeopardize the legitimacy of their own conservation efforts.

The impact of spatial constraints on SCP research design is an important one. However, this relationship is not often explicitly explored. Many recent studies suggest that multi-scale studies collectively yield more informative results than any singular spatial scale. In conservation biology, it can be difficult to determine the most appropriate or ecologically relevant scale for management of a species of interest, even though multiscale studies are employed to study selection patterns (Johnson et al., 2004). While Johnson's work focuses on the patterns of habitat selection of caribou, the argument is equally applicable to protected area selection, as it raises the issue of processes which operate at multiple scales. SCP efforts which are limited to any single spatial scale will neglect biodiversity patterns and ecological processes that are important at other scales (Huber et al., 2010). These inconsistencies can result in largely disparate spatial optimization results. Conservation is hindered by the spatial scale of global climate change and the difficulty in reconciling its regionalized impact, and this mismatch may cause incomplete or inaccurate SCP optimization results (Cadotte et al., 2017). Carroll et al. (2017) similarly identify that the results for priority areas differ with ecological context and spatial scale. These results collectively suggest a need for balanced integration of broad-scale ecosystems planning with regionalized considerations for specific ecological processes. It is therefore evident that SCP should be conducted complementarily, spanning several spatial scales and extents to emulate the variation in ecological and physical processes which comprise biodiversity.

Conservation Data Limitations and Opportunities

Conservation planners have historically employed spatial data representing biodiversity to instruct SCP optimizations (Margules and Pressey, 2000). However, it is nearly impossible to represent the diversity of life within any single SCP problem (Lambeck, 1997; Margules et al., 2002). Furthermore, data approximations are ubiquitous (Langford et al., 2011), contain commission and omission errors, and are subject to sampling bias (Rondinini et al., 2006).

Because the full biotic composition of a landscape is too complex to be useful for systematic conservation planning, surrogates are selected to represent the biodiversity of the ecosystem (Caro and O'Doherty, 1999). Coarse-filter surrogates represent ecological patterns and processes, such as biogeoclimatic zone, land facets, and/or disturbance regimes. Fine-filter surrogates represent individual habitat requirements of species that are endemic, threatened, and/or representative of the ecosystem (Carroll et al., 2017). Choosing the right suite of features to represent biodiversity is still plagued with uncertainty, and there is disagreement among practitioners as to the best approach (Pressey, 2004; Rodrigues and Brooks, 2007)

The accuracy of SCP is limited by the quality of the obtainable data (Hermoso et al., 2013b). Accurate datasets are necessary both at the planning stage of SCP, and as a baseline for long-term monitoring and stewardship (Margules and Pressey, 2000). Accurate and/or high resolution biodiversity data are infrequently and inconsistently available, creating a data availability gap which hinders conservation efforts (Cadotte et al., 2017). Comprehensive surveys of entire taxa are expensive and time-consuming endeavors (Ricketts et al., 1999). Even so, the most robust surrogate datasets are subject to data approximation biases (Langford et al., 2011; Pressey, 2004). Datasets derived from species point localities are subject to sampling bias as well as misclassification (Pressey, 2004). The geographic range of a species can be used, but these ranges often over-generalize, and only convey the presence or absence of a species, as opposed to its abundance (Gaston and Rodrigues, 2003). Using the predicted distributions of a species carries similar risk, as these distributions are inferred from environmental conditions and are not verified on the ground (Rondinini et al., 2006).

Additionally, no single surrogate can represent the whole of ecological diversity (Lambeck, 1997). Given the limitations of individual surrogate datasets, the use of several carefully-chosen surrogates together can give a clearer picture (Pressey, 2004). Muti-taxa surrogate sets (Monroy-

Gamboa et al., 2019) and composite datasets (Hermoso et al., 2013a) have proven successful in overcoming some of the limitations of biological surrogate data.

In recent years, computer modelling has advanced, global climate models have become more accurate, and range estimates have become more precise (Conlisk et al., 2013; McKenney et al., 2011). Recent data advances have fostered the development of improved biodiversity datasets for entire taxa in some regions (McKenney et al., 2011; Stralberg et al., 2018; Wilsey et al., 2019). There is evidence to support that the minimum set of data selected to represent well-documented taxa perform well at representing other taxa ("incidental representation") (Warman et al., 2004a). The improved accuracy of these new datasets presents an opportunity to reevaluate the effectiveness of surrogate data and perhaps improve upon the criticisms of the practice.

CLIMATE CHANGE AND CLIMATE-ADAPTIVE CONSERVATION PLANNING

Global climate change presents a major threat to the persistence of biodiversity. In the coming decades, climate change is likely to overtake habitat destruction as the greatest threat to global biodiversity (Leadley et al., 2010). It is now well-known that climate change will exacerbate and accelerate species extinctions, changes in species' distributions, and habitat loss. It will also cause changes in the distributions of natural habitat and of entire biota (Leadley et al., 2010). As global mean temperatures reach 2-3°C above pre-industrial levels, 10-40% of all species on Earth face high risk of extinction (Pachauri and Reisinger, 2008). Further indirect consequences will follow as the global cascade of species interactions is disrupted (Gilman et al., 2010).

In British Columbia and all of northwestern North America, where changes are projected to occur faster and be more pronounced than the global average, it is apparent that significant warming has already taken place (Fields et al., 2007). Climate-driven changes are expected to exceed biological tolerances for many species and ecosystems in BC (Hamann and Wang, 2006; Hebda, 1997).

Vulnerable ecosystems that are well represented in the province, such as boreal forests and alpine mountains, are at high risk (Fields et al., 2007; Wilson and Hebda, 2008). Four of the province's broad biogeoclimatic zones, or 5% of the land area, are considered under conservation concern, while most the alpine regions of the province are expected to disappear entirely (Austin et al., 2008). At the finer scale, vulnerable ecological communities are present across every one of BC's biogeoclimatic zones (Austin et al., 2008).

Given BC's high susceptibility to climate change impacts, it is critical that SCP across the province recognizes and adapts to these vulnerabilities. Traditional conservation strategies are predicated upon the assumption that current species distributions are sufficient to represent the future. These strategies are insufficient to tackle the challenge of conservation planning within climate change (Belote et al., 2017; Groves et al., 2012; Hannah et al., 2002). Climate change effects will cross protected area boundaries indiscriminately and alter the landscapes otherwise preserved there (Belote et al., 2017). With the knowledge of anthropogenic climate change came the call for new conservation tools to integrate climate-driven changes in the biota to the mission of SCP (Hannah et al., 2002). To address the reality of a shifting biota, conservationists began to advance new frameworks for considering climate change in the course of SCP, including conserving the geophysical setting that supports biodiversity and prioritizing protecting unique land facets (Groves et al., 2012; Jones et al., 2016; Schmitz et al., 2015), as well as incorporating climate-adaptive approaches such as prioritizing connectivity corridors, protecting future climate space, and protecting climate refugia (Belote et al., 2017; Carroll et al., 2018; Keppel and Wardell-Johnson, 2012; Schmitz et al., 2015).

Climate impacts will exacerbate non-climate stressors related to human activity, such as land-use changes, pollution and resource use (Austin et al., 2008). Human activity disrupts the natural forest and watercourse processes and reduces ecosystem resilience through development and agriculture (Austin et al., 2008). As climate change affects land use opportunities and community access to resources, equity considerations are an important factor in climate-adaptive conservation planning. Climate-adaptive conservation planning should mitigate these land-use conflicts (Halpern et al., 2013).

Climate-Adaptive Planning for British Columbia (CAP-BC) Tool

The SCP process is time- and resource-intensive, and the data needs and technical skill requirements for conservation practitioners are burdensome (Wiersma and Sleep, 2016). Using multiple features and targets quickly makes the SCP problem complex (Wiersma and Sleep, 2018). As climate change hastens the pace at which SCP must be executed and implemented (Pressey et al., 2007), the complexity of the problem and challenge for conservation planners increases. These limitations hinder scientifically-sound conservation decision making. New frameworks for incorporating climate change data have been put forth (Belote et al., 2017; Groves et al., 2012; Schmitz et al., 2015). However, there is still a need for more accessible tools with improved functionality for solving climate-adaptive SCP problems (Moilanen et al., 2009; Runge et al., 2016).

Large-scale mapping, data visualization, and decision-support advances allow conservation planners to analyze these processes more quickly and effectively. Recent advances in computing make these selection software packages readily available and flexible (Wiersma and Sleep, 2016). These technological innovations have greatly increased capacity for tackling these multifaceted problems (Ball et al., 2009).

To address these needs for BC practitioners, data from this study will be used to assist the development of a fully-contained, open access planning tool for climate-adaptive SCP. The

Climate-Adaptive Planning for British Columbia (CAP-BC) web tool brings together recent advancements in computing to address these problem (Pacific Institute for Climate Solutions, 2020). It will provide a common basis of pre-loaded data, removing the need to search for and transform spatial data from numerous sources. It will be flexible and accessible to users without specialized training and democratize the process by being online and open access. The tool will be province-wide, facilitating use by ministries, NGOs, and other planners at all scales.

SCP work is complicated and time-consuming, and doing so necessitates better, more accessible tools for landscape-scale planning. To best facilitate the practice, it is necessary to ensure the data and process are democratized and readily available. It is critical to ensure that SCP is an adaptive process, and conducted in a manner which can mitigate the effects of climate change in the province.

To ensure this research would meet actual conservation data needs, I engaged conservation planners from across the province and derived a list of priority biodiversity datasets. With this input, I chose a suite of biodiversity data to be used in the following analyses. Additionally, I used this list to compile all of datasets that these practitioners requested to be pre-loaded into the web tool. All of these datasets will be supplemented with sourcing and citation data, as well as requested information about the best uses of each spatial layer. The results of these analyses will be written up and included as supplemental materials for web tool users.

1.2 Research Objectives

Scale, Extents, and Units for Planning

Conserving biodiversity is principally achieved through the designation of protected areas, guided by the process of systematic conservation planning (SCP) (Margules and Pressey, 2000). Decision-support systems are used together with the SCP process to guide conservation planning. Despite having the structure of the SCP process, ecologists, planners, and decision makers may each employ different spatial constraints to individual projects. The choices made to delineate these projects can be misaligned with the jurisdictional scope and scale of management decisions (Huber et al., 2010).

Getting the right spatial scale is a challenge for conservation planning. Planning at too small a scale overlooks regional conservation needs, creating a 'tyranny of the local' in terms of conservation priorities (Groves et al., 2003). Fine-scale analyses can miss the importance of regional-scale factors, and do not account for connectivity with neighboring or overlapping grouping units (Huber et al., 2010). On the other hand, conservation plans that evaluate needs at a coarse spatial scale fail to capture features of local importance (Hermoso and Kennard, 2012). Variation is as important as any single feature, and may not be adequately accounted for in a coarse-scale analysis (Groves et al., 2002). Coarse-scale planning also carries the risk of disproportionately allocating conservation priority to one or few localities, placing the burden of conservation unevenly across communities (Halpern et al., 2013). Conservation planning should be conducted consistently, at a carefully considered spatial scale, and provide justification for the spatial scale used, as ecological relevance alone may not coincide with jurisdictional application.

It is in the nature of land conservation that different organizations and operators have differing geographic priorities, so choosing an appropriate project boundary, or extent, is also a challenge. While there are plenty of good reasons to have these divergent priorities, using non-standard spatial constraints can make SCP prioritization outcomes difficult to compare to one another. Three types of spatial constraints for planning are generally used: ecological boundaries, administrative boundaries, and purpose-fit, or custom, boundaries. These different extent categories are sometimes referred to as “grouping units.”

Conservation studies are often conducted using ecological boundaries, while management actions are regularly planned using administrative boundaries. An ecological boundary is a surface or patch associated with an ecological system, which are composed of and included in other systems, and which enclose discernible processes (Yarrow and Salthe, 2008). Administrative boundaries capture the hierarchical structure of multilevel government entities (Kurian and Kojima, 2021). This mismatch between planning and implementation can impact the resulting conservation actions (Guerrero et al., 2013). Further, the ecosystem being studied does not adhere to the spatial boundaries employed, nor does it behave subject to them (Huber et al., 2010). There is currently no way to measure whether the spatial constraints used in SCP evaluations affect the ability of models to accurately represent ecologically significant areas.

Conservation studies are most often conducted using several different types of ecological groupings. The provincial Biogeoclimatic Ecosystem Classification (BEC) System (Krajina, 1959) is often (though not always) used. The province is apportioned into these ecosystem zones containing similar ecological processes and broadly homogenous macroclimates, which in turn contain sub-zones describing the condition of the local ecosystem (Forests and Environment, 1995). BEC zones are valuable for summarizing the natural abiotic and biotic components of the landscape, but they do not align with the boundaries of any administrative unit used by the province. Other ecological studies use the provincially-defined ecoprovinces, ecoregions, and ecosections; others use the national ecoregions established by Environment Canada; still others use global terrestrial ecoregions established by World Wildlife Fund. Each of these groupings is valuable for summarizing the landscape, but they do not align with the boundaries of any administrative unit used by the province.

In BC, management organizations often use administrative boundaries to guide decision-making. Natural Resource Areas, Regions, and Districts (GeoBC, 2018) are a set of hierarchical geographic boundaries established by BC's Ministry of Forests, Lands, Natural Resource Operations & Rural Development (MFLNRORD). NR District boundaries are designated by the Lieutenant Governor in council and published as regulations, which establish the Ministry's management areas (B.C. Reg. 137/2014, 2014). MFLNRORD sometimes uses a conglomerate unit known as Land Use Plan boundaries (B.C. Reg. 137/2014, 2014). These spatial grouping units were defined through a collaborative process involving Regional Districts, municipalities, government agencies and First Nations. Because these planning extents and grouping units do not reflect any distinct administrative boundary, nor do they align with any ecological grouping, they can also be difficult to understand when applied inconsistently.

Within conservation organizations, the early-stage decisions about what spatial constraints to use for a study are inconsistently made. Though many use existing groupings, such as those described above, sometimes purpose-fit boundaries are used. Studies done this way are difficult to compare accurately with the results of other conservation plans. Conservation organizations often work collaboratively; to do so, they need to know where their priorities align. For example, Nature Conservancy Canada's (NCC) Conservation Blueprints are the major guiding documents for private land conservation in the southern ecoregions of Canada. In its assessment of BC's "Central Interior" region, NCC notes that "the study area boundary corresponds with that of the Montane Cordillera Ecoregion as originally delineated…and then modified by [The Nature Conservancy] and NCC for use in their Ecoregional assessments in…Canada (Nature Conservancy Canada, 2010).” By using uniquely designed spatial constraints, the priorities identified in NCC’s Blueprints are made harder to use alongside priorities identified by other analyses.

There have been few studies explicitly investigating the influence of spatial constraints on conservation outcomes across large regions (Saura and Martinez-Millan, 2001), and relatively few on the influence of spatial scale (Erasmus et al., 1999; Huber et al., 2010). The results of multi-scale analyses conducted within the province highlight a lack of guidance on the effect of spatial scale on SCP (Johnson et al., 2004; Wade et al., 2011), but draw no conclusions about its effect. Our understanding of the magnitude of biodiversity loss depends on the scale at which it is measured (McGill et al., 2015). Therefore, understanding the relationship between these spatial variables and SCP is critical to the success of biodiversity conservation (Levin et al., 2016).

Efficient & Equitable Conservation

The urgent need for conservation comes into conflict with competing interested on the land base. Resource-dependent communities, such as those that rely on timber harvest, agriculture, fisheries, etc, can be put at a disadvantage when land is slated into conservation. For this reason, as well as those outlined in the previous section, there is a profound lack of clarity for conservation planners on the optimal planning scale.

One way that conservation planners attempt to grapple with this issue is by pursuing maximum efficiency through the SCP process. Site-selection algorithms used to perform SCP identify highly efficient protected area solutions through complementarity (Kukkala and Moilanen, 2013). In most cases, the term “efficiency” implies cost-efficiency. Therefore, efficiency is high when the conservation features of interest can be covered by a small number of sites, or more accurately, the minimum necessary land area. Conservation efforts that are highly efficient tend to be more socially popular, and therefore have greater chance of implementation (Game et al., 2011). Efficient protected area networks are viewed as less costly, as they typically have lower overall acquisition costs, have lower management costs (in terms of the number of land managers needed, hours necessary to monitor land, access and road maintenance, etc), and reduce economic loss from other land use interests (Possingham et al., 2006).

It is however possible to be overly focused on the algorithmic results and neglect the social context on the land. Though biodiversity loss and the eradication of poverty are considered integrated problems, historical conservation efforts have often come in direct conflict with economic opportunity, exacerbating disenfranchisement (Adams et al., 2004; Miller et al., 2012). In many cases, strict protectionism, where land is managed in isolation from human activity, has proven futile and counterproductive (Adams et al., 2004; Roe, 2008; Wells and McShane, 2004). As human and social factors greatly impact conservation success, it is important to quantify the equity implications of conservation planning. In order to achieve the "equitably managed" mandate of Aichi Target 11, protected area designation should recognize these effects, limit the procedural harm, and accordingly distribute protected areas and enact any necessary mitigation. Conservation outcomes "can be made much more durable with even modest consideration of equity effects (Kark et al., 2015)." Community support greatly increases success in achieving conservation objectives; it is therefore critical to weigh the potential positive (ecosystem services, reduced human-wildlife conflict, employment) and negative (reduced access to resources, management costs) social impacts created by designating a protected area (Franks et al., 2018).

It is clear that planning at too broad a scale can sacrifice equity for the sake of efficiency. It is also probable that planning at small scales carries a risk that a large amount of low conservation value land will be selected to meet targets. This research investigates the intersection of equity:efficiency tradeoffs and how they interact with scale and grouping unit type.

HYPOTHESIS

My research aims to explore: 1) How spatial constraints affect the outputs of algorithmic optimization in systematic conservation planning, 2) What implications exist for human equity, and for efficiency in biodiversity conservation, and 3) Whether there is there a balance of spatial scale and extent that is best at achieving both equity and efficiency.

In this study, I analyze the spatial concordance, total area protected, and distribution of priority areas between systematic conservation plans produced using administrative and ecological boundaries as grouping units. I expect to find that there are tradeoffs between these measures associated with the different spatial constraints. I hypothesize that there will be higher efficiency but lower equity when spatial constraints are relaxed. Inversely, there will be higher land requirements with higher equity when constraints are imposed. I further hypothesize that while administrative units will contain clustered pockets of biodiversity, ecological units will be more comprehensive in terms of capturing biodiversity.

RESEARCH DESIGN

The questions which guided the design of this MNRES research project research are: (1) Do the boundaries employed in systematic conservation planning affect the areas selected for conservation? (2) How could these difference affect the efficiency of conservation planning? (3) How might these differences affect the equity in resource-dependent communities across the province? And, (4) What insights can be gleaned from these analyses for CAP-BC users and other conservation planners?

To answer the first question, I researched the existing literature around multi-scale analyses, and the effects of spatial scale and extent on conservation planning. Having found little consensus on the matter, I designed an analysis which varies the size and type of grouping unit for optimizations in BC, and measures the efficiency and equity of the solutions to address the second and third questions. The results of the second analysis will provide CAP-BC users with best-use information for those datasets.

Thus, the main objectives of this MNRES research project research are to; (1) demonstrate the potential incongruences of SCP planning conducted with inconsistent spatial boundaries, (2) quantify the land use efficiency resulting from different spatial designs, (3) qualify the equity effects of assigning heavier conservation priorities to fewer communities, and (4) make this information readily available to users of these datasets through CAP-BC.

Table 1. 2
Questions, objectives, and methods for achieving them in this research, by chapter.

Description	Question	Objective	Method
Analysis where the size and type of grouping unit is varied for SCP optimizations in BC.	Do the spatial constraints employed in SCP affect the areas selected for conservation?	Demonstrate the potential incongruences of SCP conducted with varying spatial constraints.	Measured the overlap of the solutions to quantify congruence.
	How could these affect the efficiency of SCP?	Quantify the land use efficiency resulting from different spatial designs.	Measured and compared the land area required by each of the solutions.
	How might these differences affect the equity in resource-dependent	Qualify the equity effects of assigning heavier conservation priorities to fewer communities.	Measured and compared the relative land area required by each of the solutions per political / community unit.

	communities across BC?		
	What insights can be gleaned from these analyses for CAP-BC users and other conservation planners?	Make this information readily available to users of these datasets through CAP-BC.	Include the results in the documentation of each dataset when they are incorporated into CAP-BC.

2. Impact of Spatial Constraints on Systematic Conservation Planning Outcomes

2.1. Introduction

This analysis uses SCP to explore the relationship between spatial scale and extent on the efficiency and equity of protected area selection in British Columbia. I employ ecological and administrative boundaries, each at a fine and coarse spatial scale, in five scenarios. I measure efficiency as the land-use requirement to meet targets, and equity as the relative distribution of potential land-use restrictions on communities. By varying the spatial constraints, I quantify the effect of these factors on the efficiency and equity of the solutions while meeting conservation targets. I analyze the results relative to each other and against a baseline solution for the full province.

2.2. Methods

Overview

To identify the spatial data needs of conservation planners in BC, I engaged 42 stakeholders from the conservation community at the British Columbia Protected Areas Research Forum in December 2018. In a guided workshop, the stakeholders derived a list of biodiversity data which they felt were essential for doing meaningful conservation work in the province. This list was then used to guide the selection of datasets for the CAP-BC web tool. From this stakeholder-identified list, I additionally identified and compiled those datasets for which province-wide data could feasibly be rendered for this analysis.

The analyses for this study were done using the *prioritizr* R-package decision-support technology (Hanson et al., 2020). *prioritizr* uses ILP (Beyer et al., 2016) and cloud-based solvers, which outperform previously-used simulated annealing techniques (Schuster et al., 2020, 2019) .

My aim is to identify efficiency in terms of conserving features; therefore, I employed feature-based conservation targets. These targets instructed *prioritizr* on the percentage of area to select for each conservation feature when running scenario optimizations. As this study is not intended as an operational conservation plan for BC, the targets used here are illustrational and do not reflect actionable targets for the individual species used as features.

This analysis was conducted using three nested scales, utilizing two contrasting grouping units (Table 1). The targets are constant across these scenarios, and all solutions must meet or exceed the targets for all features. In scenarios that use multiple grouping units, the features are treated as sub-features and the feature targets must be met within every grouping unit. Repeating the same target-based analyses, subject to these spatial constraint variables, allowed me to identify how initial extent and scaling decisions influence the relative priority assigned to conservation areas.

Table 2. 1
Spatial constraint for scenario analysis. The labels at the intersection of scale and grouping unit are the extents used.

Scale	**Grouping Units**	
	Administrative	Ecological
Provincial	BC Provincial Boundary	
Coarse	Natural Resource Regions	BC Ecoprovinces
Fine	Natural Resource Districts	BC Ecoregions

The resulting solutions were analyzed for three elements. First, measuring how the differing grouping units affect the selection of land areas in the solutions provides a metric of spatial congruence between solutions. Second, measuring the amount of land area required by the larger-scale solutions informs how fine-scale planning affects comparative land use efficiency. Third, measuring how unevenly the burden of conservation may be distributed across communities shows how social equity is affected by land use decisions.

Study Area

I used BC as a case study to explore the effects of the spatial constraints on the outputs of SCP optimization, employing provincially-relevant biodiversity features and targets. BC is an ecologically diverse province (relative to other North American jurisdictions), influenced by the coastal landscape to the west and the mountainous terrain traversing most of its landscape. It contains Canada's only inland temperate rainforest, wide-ranging carnivores and ungulates, unique populations of fish, and numerous mesocarnivores (Austin and Eriksson, 2009). In particular, BC is globally significant for its richness in large carnivore and ungulate species (Austin and Eriksson, 2009). Each of these factors make important biological, cultural, and economic contributions to the province. BC is considered a relatively undisturbed landscape; 15.4% of the land area of the province has been gazetted in protected areas ("Protected Lands & Waters - Environmental Reporting BC," 2016).

Conservation planning in BC is the purview of several NGOs, provincial ministries, local agencies, and funding bodies. Each of these actors has their own mission and conservation priorities. For these organizations to work collaboratively, it is important to understand how they can achieve complementary objectives.

Selection and Development of Conservation Feature Data

The majority of the datasets used were retrieved from BC Data Catalogue and from the BC Ministry of Forests, Lands, Natural Resource Operations & Rural Development. Songbird suitability distribution data was retrieved from Audubon (Wilsey et al., 2019) and tree distribution models from Natural Resources Canada (McKenney et al., 2011). A full table of data and sources is listed in Appendix A.

Geospatial data was prepared in ESRI ArcMap 10.5.1, and the optimizations were scripted in the R programming language and executed using the *prioritizr* script. All data used in this analysis were set to a 1000m BC Albers (ESPG: 3005) planning unit grid. The spatial datasets for each feature were clipped to the grouping units to create one feature data sub-set per grouping unit (e.g., one grizzly bear (*Ursus arctos horribilis*) layer for each ecoregion). The targets for each feature data sub-set were set the same across all grouping units, and the *prioritizr* scenarios were run treating each feature data sub-set as a unique feature. *Prioritizr* was instructed to meet all sub-feature targets within each grouping unit. This method simultaneously optimizes each of the grouping units, with identical feature data and targets.

The key biodiversity datasets used for this analysis include the spatial range of several species. Most of the selected species have experienced >20% contractions of their historic range: bighorn sheep (*Ovis canadensis*), woodland caribou (*Rangifer tarandis caribou*), elk, or wapiti (*Cervus canadensis*), fisher (*Martes pennanti*), mountain goat (*Oreamnos americanus*), and grizzly bear (*Ursus arctos horribilis*). These charismatic mammalian fauna are flagship species for different ecosystems in the province; their inclusion helps select for ecological diversity (Olson et al., 2001; Laliberte and Ripple, 2004). I developed and used spatial layers for Bull trout- (*Salvelinus confluentus*) and Sockeye salmon- (*Oncorhynchus nerka*) bearing waterways. The species included are all significant to First Nations whose traditional territories lie within BC (Austin et al., 2008). I also used spatial data for BEC zones, songbirds, and tree species distributions in this analysis. Each of these layers is described in detail below.

Grouping Unit Boundaries

The ecological grouping units used in this study are the BC Ecoregions and Ecoprovinces (Figure 2.1, left). The coarse-scale ecological grouping units used for this analysis are the BC

Ecoprovinces. This is the parent unit of the fine-scale BC Ecoregions; one Ecoprovince contains multiple Ecoregions (Figure 1; Appendix B, Map 1). Ecoregions are the fine-spatial scale grouping unit. They contain strong interactions of biodiversity and ecological processes. These Ecoregions are a significant unit because they group biodiversity regionally rather than globally, and therefore represent unique local conditions more accurately (Olson et al., 2001). Biodiverse regions of Canada, for example, are generally species-poor compared to global biodiversity hotspots, but are species-rich compared to neighboring areas. These ecological boundaries are commonly used in conservation studies (Dinerstein et al., 2017; Fleishman, 2017; Woolmer et al., 2008).

The administrative grouping units are the provincial Natural Resource (NR) Districts and Regions (Figure 2.1, right). The coarse-scale administrative grouping units used for this analysis are BC NR Regions. These are the parent unit of the fine-scale NR Districts; one NR Region contains multiple NR Districts (Figure 2; Appendix B) (GeoBC, 2018). I use NR Districts as the fine spatial-scale administrative grouping units for this analysis. These are administrative areas established by the Ministry of FLNRORD. NR District boundaries are designated by the Lieutenant Governor in council and published as regulations, which establish the Ministry's management areas. These administrative boundaries are one of several different grouping units used to make planning decisions in the province.

To further consider the impact of scale, this study applied the BC provincial boundary as another administrative boundary. This absolute unit provides a baseline for comparison with the grouping unit scenarios.

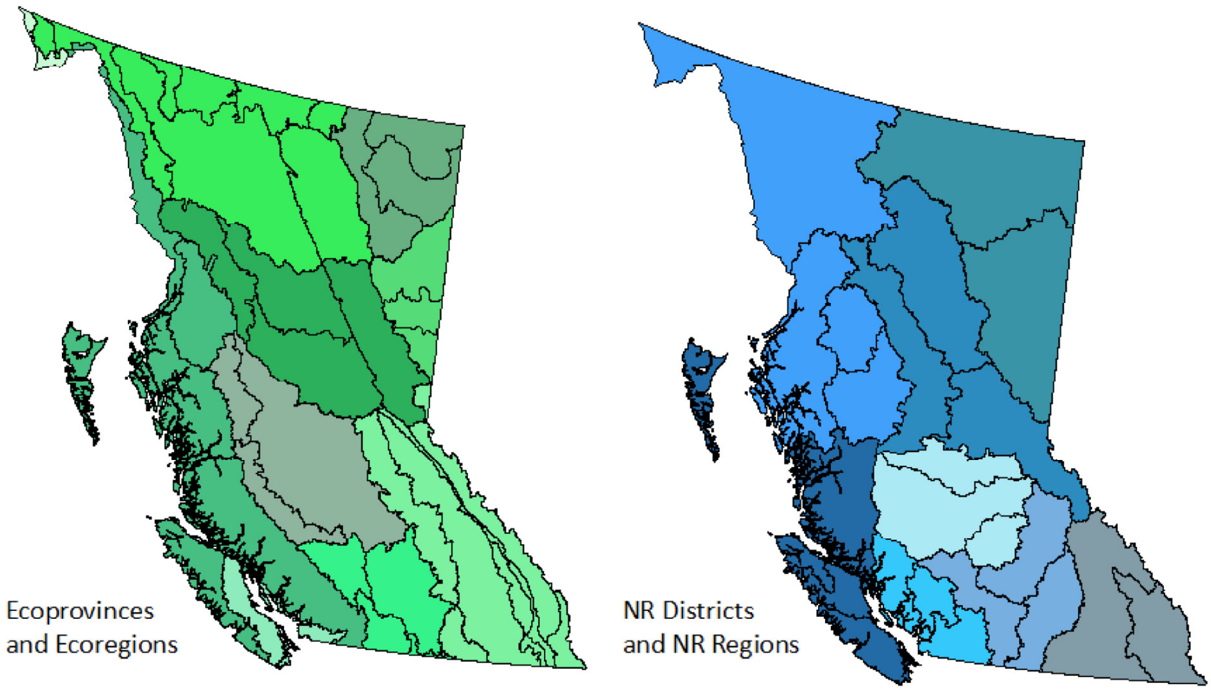


Figure 2. 1 Ecological grouping units (left) including Ecoprovinces (outlined) and Ecoregions (green tones), and administrative grouping units (right) including NR Districts (outlined) and NR Regions (blue tones).

Coarse-Scale Biodiversity Features

Vegetation

The provincial Biogeoclimatic Ecosystem Classification (BEC) zones (Krajina, 1959) were used as a vegetation feature. The province is apportioned into these assemblages which contain similar ecological processes and a broadly homogenous macroclimate (Forests and Environment, 1995). The BEC system comprehensively captures the vegetation potential ("bio"), soils and geology ("geo"), and climate conditions ("climatic") in each of 14 classifications. This layer incorporates spatially-contiguous ecological assemblages into this analysis, which is advantageous for achieving targets. Including such elements of the physical landscape, which change slowly over time, improves protected areas' long-term persistence against biodiversity loss (Margules and Pressey, 2000). The BEC System utilizes four levels of classification: zones, subzones, variants, and phases. Zones are the highest level, representing the broad macroclimate and named for the dominant tree species. Subzones are the mid-division, further delineating the zones by climate and precipitation. Variants are further divisions of subzones, describing localized conditions that may be wetter, cooler, drier, or hotter than other areas of the subzone. Phases describe changes in variants that occur based on topography, such as grasslands or rain shadows (Pojar et al., 1987). Zones are the only level used in this analysis, as they are most appropriate for the large extent of the province.

Fine-Scale Biodiversity Features

Bighorn Sheep

The species range of Bighorn sheep in BC spans several ecosystems. I included their distribution in this analysis to facilitate selection for multiple habitats: temperate coniferous forests; temperate grasslands, savannas, and shrublands; and deserts and xeric shrublands. Bighorn populations have contracted toward the center of their historic range (Laliberte and Ripple, 2004). Due to previous species declines and habitat fragmentation, this species is recovering, yet potentially vulnerable.

The bighorn sheep layer was developed by extracting the species habitat data from BC Wild Mountain Sheep Registry – Distribution (FLNRORD, 2019) and verified against the current range for the species (Shackelford et al., 2018).

BULL TROUT-BEARING WATERWAYS

Bull trout are associated with high-elevation streams; as these fish are highly sensitive to riparian disturbance and pollution, their inclusion aids in prioritizing healthy watersheds. The distribution of this fish also overlaps with the habitat of Arctic grayling (*Thymallus arcticus*) and Brook trout (*Salvelinus fontinalis*) (Hagen and Decker, 2011). Cold-water fish such as these are identified as key indicator species for areas resilient to climate change (Isaak et al., 2015).

I developed a layer for Bull trout-bearing waterways using BC lakes and rivers as selectable features. To be included in this layer, these water layers were required to satisfy one of the following criteria: overlap with Wildlife Habitat Area – Bull trout (legal or proposed); overlap with Fisheries Sensitive Watershed – Bull trout (legal or proposed); be within 1km (selected by location) of Known BC Fish Observations and BC Fish Distributions – Bull trout. The final layer was produced using these points to create line segments that run from the ocean to the maximum extent of fish distribution on each river or lake where the fish have been inventoried (Mason, 2019, pers. comm).

Caribou

Woodland caribou are highly associated with alpine and subalpine habitats, as well as old, mid-elevation forest stands containing arboreal lichen communities (Johnson et al., 2004). I included woodland caribou because it is a highly threatened ungulate, and its inclusion helps prioritize selection of forest habitats with ecologically significant attributes.

I developed the caribou layer using the publicly-available Caribou Herd Locations for BC dataset. I separated the species' range into its four populations (Boreal, Northern Mountain, Central Mountain, and Southern Mountain populations) present in BC, which range in conservation concern from vulnerable to critically imperiled, and have been identified as a high conservation priority within the province. These herds were grouped into four population-based "Designatable Units" identified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and recognized under the federal *Species-at-Risk Act (SARA)*.

Elk

The persistence of elk in BC contributes to the province's globally-significant richness in ungulates (Ministry of Environment, Lands and Parks, 2000). Elk have lost a large portion of their range in regions of high human influence (Laliberte and Ripple, 2004). Decline in this species exacerbates loss of predatory species, especially wolves and grizzly bears (Laliberte and Ripple, 2004). Elk occupy a variety of habitats, though they are generally constrained to areas with shallow snow pack. Two of the four subspecies of North American elk (Rocky Mountain and Roosevelt elk) occur in BC.

The elk range layer is a generalized distribution area polygon developed from the species' current range in North America (Shackelford et al., 2018). This layer was selected due to the lack of higher-resolution data of their distribution.

Fisher

Fisher is a widespread but low-density species, and the only mesocarnivore included in this analysis. Fisher avoid open areas and rely on structural elements of mature and old forests to meet several of their life history requirements: mainly reproduction and natal denning. Thus, fisher are vulnerable to land use changes, and their inclusion in conservation planning provides a measure of sensitivity to disturbance as well as surrogate for the elements of mature and old forest structure (Laliberte and Ripple, 2004).

The fisher range layer is an area polygon representing generalized distribution developed from the species' current North American range (Shackelford et al., 2018). This layer was selected due to a lack of higher-resolution distribution data for this species.

Mountain Goat

Mountain Goats have most of their global range in BC, and therefore have global importance within their provincial context. Mountain Goat range was included as a fine-filter conservation target because of their high-elevation range and provincial status as a vulnerable (S3) species. Mapping the extent of this species helps guide selection in temperate coniferous forests, boreal forests and taiga, and tundra biomes (Laliberte and Ripple, 2004).

I developed two Mountain Goat layers using the current North American range (Shackelford et al., 2018) for this species. The first layer uses the full distribution of the species as represented by this range. The second layer represents the vulnerable, high-elevation reaches of this species' range.

Most of their habitat is above the tree line, identified at the mid-latitude of the province (51°N) as being at 2,400m / 7,900ft. Therefore, I used latitude-adjusted elevation classes corresponding with elevation classes 9 (6000-7000ft) and 10 (7000-13000ft) (Michalak et al., 2018) as a mask to extract a more accurate range for this species. Both layers are used to prioritize land selection for mountain goat; the inclusion of the specific high-elevation range ensured that some of that vulnerable range must be selected in order to meet the feature target meaningfully.

GRIZZLY BEAR

Grizzly bear was selected as a fine-filter conservation target mainly due to its broad range. Grizzly bears have omnivorous diets which require several differing habitat types, and therefore can function as an umbrella species (Noss et al., 1996). “Umbrella species” are those whose habitat overlaps with a large number of co-occurring species; it is expected that the conservation of an umbrella species also confers protection to these other species (Lambeck, 1997). Mapping the extent of this species captures large, intact landscapes in several diverse ecosystems. Grizzly bears have seen some population decline due to habitat conversion (Laliberte and Ripple, 2004) and are provincially considered potentially vulnerable.

The grizzly bear layer was developed using the publicly available BC Grizzly Bear Habitat Classification and Rating dataset (Hamilton et al., 2018), a measure of the availability of vegetation habitat. The habitat suitability rakings 1-3 (“very high,” “high,” “moderate”) were extracted to a classified density layer to represent suitable grizzly bear habitat for this analysis.

SOCKEYE SALMON- BEARING WATERWAYS

Sockeye salmon are a widely-distributed and provincially important species. Despite being a marine species, Sockeye salmon are useful for the selection of healthy terrestrial ecosystems.

These migratory fish are associated with both upstream and downstream ecological processes, and are recognized as providing vital ecosystem services in the marine and riparian nutrient cycles (Darimont et al., 2010).

I developed the layer for sockeye salmon-bearing waterways using BC lakes and rivers as selectable features (Appendix 1). To be included in this layer, these water layers were required to satisfy one of the following criteria: be contained within a watershed identified in Provincial Fish Ranges – Sockeye Salmon; be within 1km (selected by location) of a Known BC Fish Observations and BC Fish Distributions – Sockeye Salmon. The final layer was produced using these points to create line segments that run from the maximum extent of fish distribution (on each river or lake where the fish have been inventoried) to the ocean (Mason, 2019, pers. comm).

SONGBIRD DISTRIBUTION

The current distributions of 242 species of songbirds (Wilsey et al., 2019) with suitable breeding-bird habitat in BC were included to account for the relative importance of species where the extent of their suitable habitat exceeds that of the study area. By incorporating these ranges, I can analyze where areas may be over-emphasized as important because a proportionally small piece of their range crosses into the study area.

These layers were extracted from a dataset of 389 North American bird species, with both breeding- and nonbreeding- range and suitability. Only those with breeding-bird suitability occurring within British Columbia were included from that larger set.

TREE SPECIES DISTRIBUTION

The distributions of 233 tree species (McKenney et al., 2011) with ranges in British Columbia were also included to represent extended ranges. Projected climate change scenarios suggest these species will experience poleward and up-slope shifts within the century; prioritizing these species for conservation helps inform forward-looking forest management and protection actions.

These layers were extracted from a dataset of 325 North American tree species to include only those with present-day ranges in British Columbia.

Setting Conservation Targets

This analysis employs target-based (as opposed to area-based) conservation, as this approach is often taken by conservation planners in BC. As conservation targets are numerical goals that quantify the minimum amount of a particular biodiversity feature sought to be conserved (Possingham et al., 2006), target-based conservation is a reserve-selection strategy that aims to protect enough habitat for a suite of target species, vegetation types, and landforms (Carwardine et al., 2009). The most common objective of target-based SCP is to solve a minimum-set problem, in which an area is selected that meets all of the conservation targets in the fewest number of sites (Margules and Pressey, 2000). Target-based conservation problems are designed to maximize efficiency while meeting all set targets (Albuquerque and Beier, 2015). The ILP *prioritizr* R-package (Hanson et al., 2020) is used to solve minimum-set problems within individual grouping units, described below (Scenario Analysis Structure).

Generally, the targets for each feature are assigned according to the most appropriate guidance from the contemporary literature. For example, BC has set a 90% target for most herds of southern mountain caribou (Ministry of Environment, 2013). Protection of 60% of bull trout range has been used for bull trout populations at smaller scales, as it was identified as a target for aquatic focal species representation in the Muskwa-Kechika Management Area, where the species is abundant (Heinemeyer, 2004). However, these targets were derived to achieve habitat retention, and not for ongoing management of protected areas. It would therefore by inappropriate to directly adopt them for this analysis. Therefore, an adjusted target-setting method was employed to achieve representation. These datasets and conservation targets are described below in Table 2.

A target for each feature was assigned based on a scale derived from the BC Conservation Status rankings. The minimum terrestrial area target values of 10, 17, and 30% mirror the progression of Convention on Biological Diversity (CBD)'s global conservation targets. In the Convention's initial inception, the signing parties committed to securing 10% of the global land in protected areas by 2010. The CBD's renewal increased that target to 17% of global land by 2020 (Aichi Target 11) (Convention on Biological Diversity, 2011, 2014). For the next set of global targets, presently in review, an increase to 30% by 2030 has been established (Convention on Biological Diversity, 2021). [1]

Table 2. 2
Targets assigned to conservation features based on provincial conservation status.

Coarse-filter Feature	Status	Target
BEC Zone: Boreal Altai Fescue Alpine	S5	10
BEC Zone: Bunchgrass	S2	30
BEC Zone: Boreal White and Black Spruce	S5	10
BEC Zone: Coastal Douglas fir	S2	30
BEC Zone: Coastal Mountain-heather Alpine	S5	10
BEC Zone: Coastal Western Hemlock	S5	10
BEC Zone: Engelmann Spruce -- Subalpine fir	S5	10
BEC Zone: Interior Cedar -- Hemlock	S5	10
BEC Zone: Interior Douglas fir	S3	17
BEC Zone: Interior Mountain-heather Alpine	S5	10
BEC Zone: Mountain Hemlock	S5	10
BEC Zone: Montane Spruce	S5	10
BEC Zone: Ponderosa Pine	S2S3	30
BEC Zone: Sub-Boreal Pine -- Spruce	S5	10
BEC Zone: Sub-Boreal Spruce	S5	10
BEC Zone: Spruce -- Willow -- Birch	S5	10
Fine-filter Feature	**Status**	**Target**
Caribou - Southern Mountain Population	S1	30
Caribou - Central Mountain Population	S1S2	30

[1] Achieving the 10%, 17%, or 30% target for features does not constitute the Aichi targets being met in BC, as the Aichi targets are area-based, and this study utilizes feature-based conservation targets.

Caribou - Boreal	S2?	30
Caribou - Northern Mountain Population	S3	17
Bighorn Sheep	S3?	17
Bull Trout	S3S4	17
Elk	S5	10
Fisher	S3	17
Grizzly Bear	S3?	17
Mountain Goat	S3	17
Mountain Goat: Threatened Range	S3	17
Sockeye	S4	17
Birds		10
Trees		10

"Critically Imperiled" (S1) and "Imperiled" (S2) features were assigned the high 30% target. "Vulnerable" (S3) and "Apparently Secure" (S4) features were given the moderate 17% target. Features which were provincially ranked as "secure" (S5) were given a target of 10% to reflect the minimum terrestrial area target proposed by the CBD. Features with overlapping status assignments (i.e., Bull Trout at S3S4) or which were denoted as uncertain (?) were adjusted accordingly.

Scenario Analysis Structure

Fine-Scale Scenario

At the fine spatial scale, the BC Ecoregion and Natural Resource District grouping units were used as spatial constraints. There are forty-six (46) BC Ecoregions compared to twenty-three (23) NR Districts used in this scenario (Figure 2.2). A complete list of these grouping units is in Appendix B. This fine-scale scenario resembles the landscape-scale considered by managers and conservation practitioners, such as NTBC, BCPF, and CPAWS.

For this and all scenarios, the conservation targets were held constant (described in Table 2.2, above) as the grouping units varied. For each scenario, the feature datasets were geospatially apportioned into the corresponding spatial constraint units (here: each of the BC Ecoregions and each of the Natural Resource Districts), allowing *prioritizr* to achieve the targets within each of the grouping units. By utilizing a spatial constraint, the targets for each feature had to be met within the grouping unit, e.g., 17% of range must be protected within each unit.

Coarse-Scale Scenario

At the coarse spatial scale, the BC Ecoprovinces and Natural Resource Region grouping units were used as spatial constraints. Ten (10) BC Ecoprovinces are compared to eight (8) NR Regions in this scenario (Figure 2.2). See Appendix B for the complete list of these grouping units. This coarse-scale scenario allowed me to compare the fine-scale results against the kind of broader analyses used by national NGOs and conservation planning initiatives.

The conservation targets were again held constant while the grouping units vary. The feature datasets were correspondingly apportioned into each of the BC Ecoprovinces and Natural Resource Regions, again allowing *prioritizr* to achieve the targets within each of the grouping units.

Provincial Scenario

At the provincial scale, I lifted all spatial constraints, and the *prioritizr* optimization ran across the full extent of all the features to achieve the targets (Figure 2.2). The solution set from this analysis provides a baseline for analysis of the fine- and coarse-scale scenarios. Additionally, the provincial boundary is truly a larger administrative boundary, and there will be room for future discussion regarding the implications of this constraint.

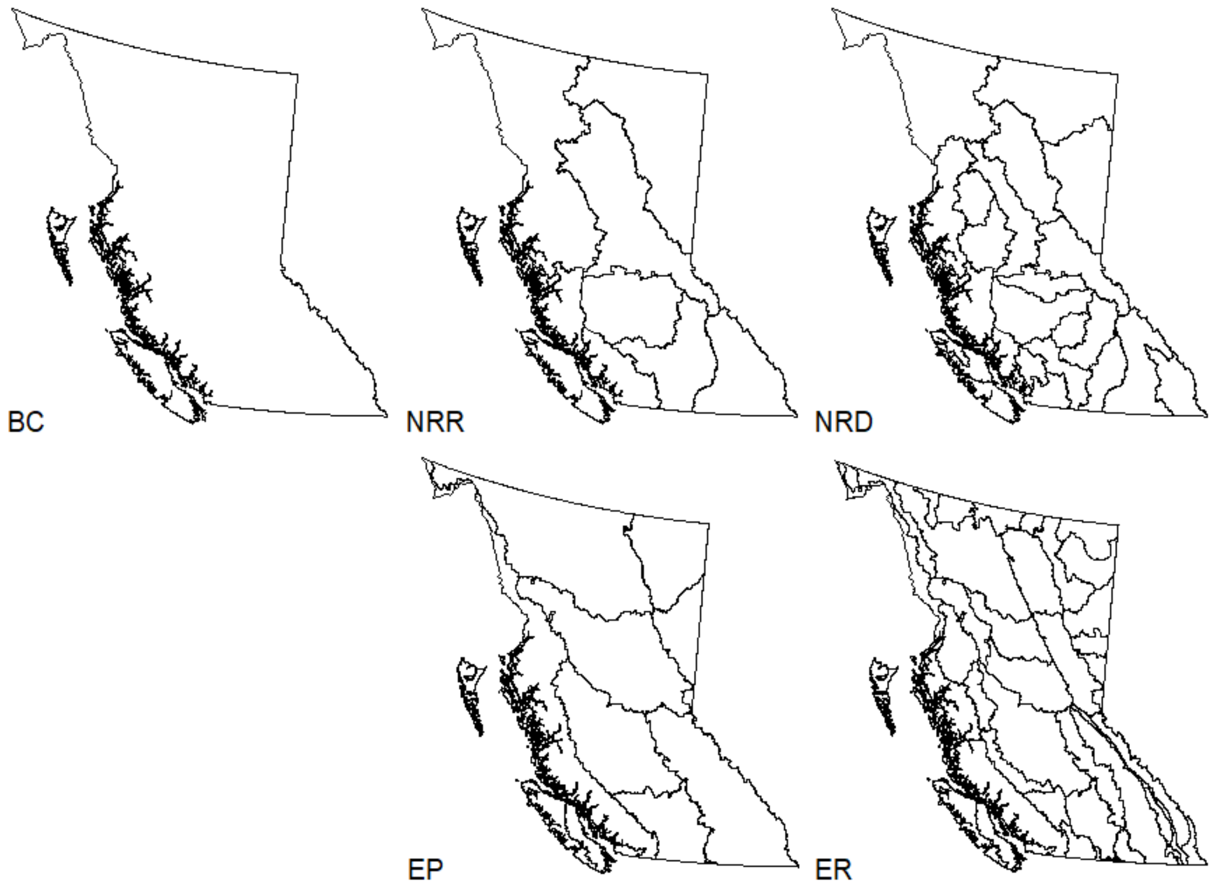


Figure 2. 2 Geographical grouping units for all 5 scenarios.

MEASURING EQUITY AND EFFICIENCY

For each scenario, I conducted a *prioritizr* optimization where the input data were separated by grouping unit and treated as though they were individual features. The *prioritizr* algorithm then solved to meet the targets for each feature iteratively within each grouping unit. The total area needed to achieve conservation targets in each scenario is meant to be representative of the combined spatial needs of the individual features (Svancara et al., 2005), but the priorities identified in each solution set should differ. I used efficiency and equity as response variables. I measured the efficiency of each scenario as the land area required to capture the conservation features. I measured the equity of each scenarios as the comparative percentage of land area that the conservation solution would remove from other possible land uses, within their respective communities.

The three nested scales for scenario analysis allowed me to determine whether the system gains efficiency as the constraints are released. “Efficiency” is defined as the measurement of how close a given solution set comes to meeting the optimal solution (Wiersma and Sleep, 2018). In this case, highly efficient solution sets will meet the conservation targets with the lowest possible land use requirement. In this way, greater efficiency may mean less area is removed from the timber harvest land base or from other land uses; it also generally assumes a lower acquisition and management cost. I measured efficiency as the percentage of the land area required (relative to total area per grouping unit) to meet the set conservation targets.

Measuring equity is a method of recognizing on whom the burden of conservation falls. “Equity” refers to the proportional availability (or conversely, the relative deprivation) of a resource compared with its availability to others (Halpern et al., 2013). Areas with higher concentrations of conservation priority areas are subject to the tradeoffs associated with restricting other land uses. Communities within high priority conservation areas are subject to these restrictions and any associated losses (commercial, cultural, etc).

To analyze equity, I began by overlaying the provincial Regional Districts (n = 61) (Figure 2.3), the administrative boundary most closely associated with local communities in BC, over the results of each scenario. Within each Regional District, I calculated the land area requirement by summing the binary scenario solutions with Zonal Statistics in ESRI ArcMap. I used the resulting values to calculate the percentage of the land area required within each Regional District, took that percentage in each solution to create a histogram, and binned by 5% increments.

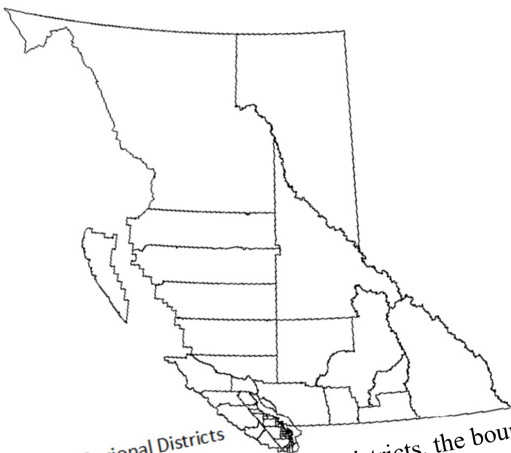


Figure 2. 3 BC Regional Districts, the boundary used to calculate the equity of scenario results.

2.3. Results

Spatial Congruence

The results of the five scenarios (Appendix B, Maps 3 – 7) show little spatial overlap between the resulting solution sets. Of BC's 964,490 km^2, only 5,186 km^2 (0.54%) were selected in all five scenarios. Those cells which were selected more times tended to cluster spatially, suggesting significant areas for conservation under a range of prioritization settings. 555,429 km^2 (57.59%) of the province was not selected in any scenario. The degree of overlap decreased exponentially (Figure 3, 4; Appendix B, Map 8) with the number of optimization scenarios ($R^2 = 0.9897$, $p = 0.0113$).

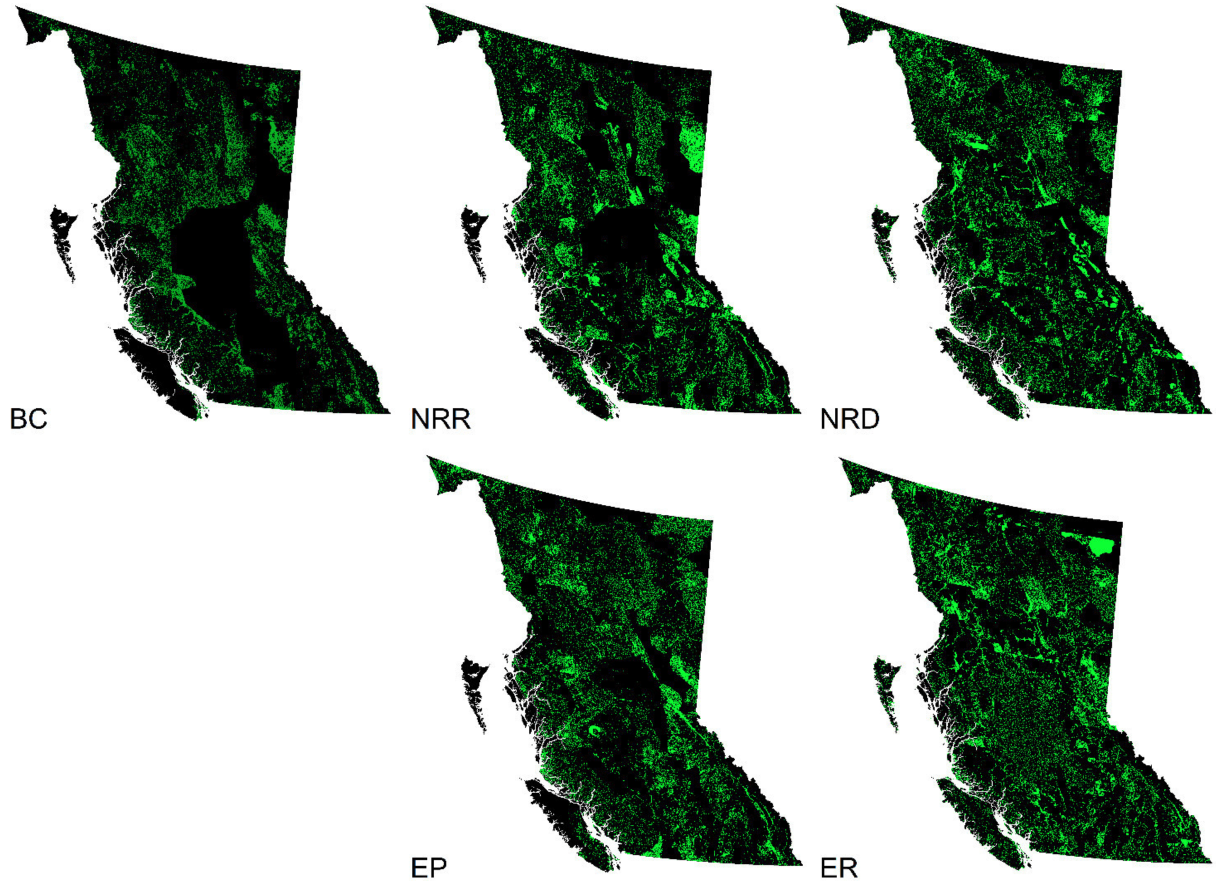


Figure 2. 4 Optimization results for all 5 scenarios, showing dissimilarity between results derived from the different grouping units.

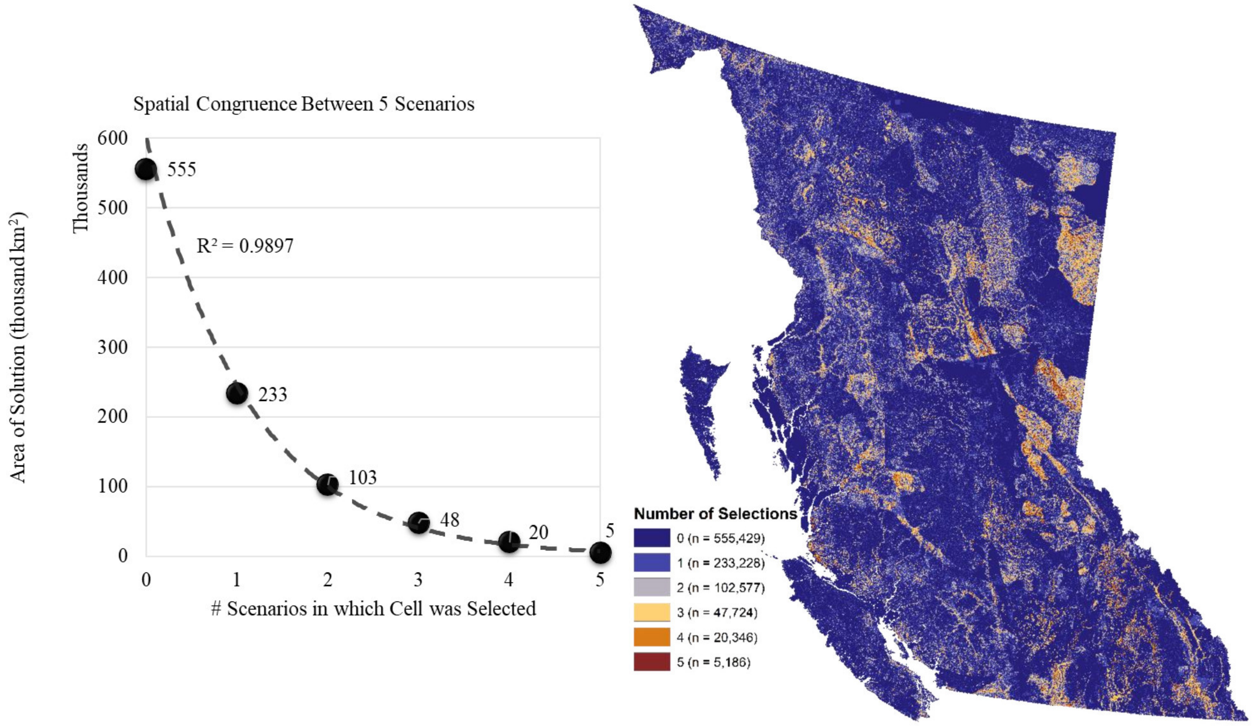


Figure 2. 5 (left) Plotting the number of cells selected against the number of scenarios those cells were selected in shows an exponential decrease in overlap as the number of scenarios increases. (right) Mapping the gradient of cells by number of scenarios in which they were selected shows proportional selection concordance, as well as groupings of significant areas.

Effect of Grouping Unit Type

Ecological grouping units gave more evenly distributed solutions, which is consistent with the hypothesis, but required more cells than their respective administrative counterparts. Solutions generated using administrative grouping units had denser clustering and required fewer cells. This difference in area requirement is significant, as the solutions vary by thousands of square kilometers. The efficiency-equity tradeoff is also apparent here; planning conducted using administrative grouping units will require a lower percentage of land area, but the burden of conservation is unevenly distributed. Resource-dependent communities in areas that are located in the clustered solution areas may face difficulties under traditional, restrictive conservation management plans.

EFFICIENCY

The land area requirement of each scenario, determined by the number of cells required to meet the targets, increased as the scenarios became finer in scale. This confirms the hypothesis that efficiency decreases as the number of grouping units increases (Table 2.3; Figure 2.6). There is a clear relationship (R^2 = 0.9658, p = 0.0002) between land area requirement and planning scale.

Notably, there is a relatively large (13.3%) increase in land area requirement between the coarsest scale (1 grouping unit) when compared with the increase (6.3%) between the next three scales (8, 10, 23 grouping units). Further analysis may be able to determine an optimal number of planning units for efficient conservation in BC.

Table 2. 3
Planning scenario outputs and total land area requirements.

Scenario	# Grouping Units	Solution Area (km^2)	% Total Area
BC	1	117,992	12.23%
NRR	8	133,637	13.86%
EP	10	138,829	14.39%
NRD	23	142,052	14.73%
ER	46	156,252	16.20%

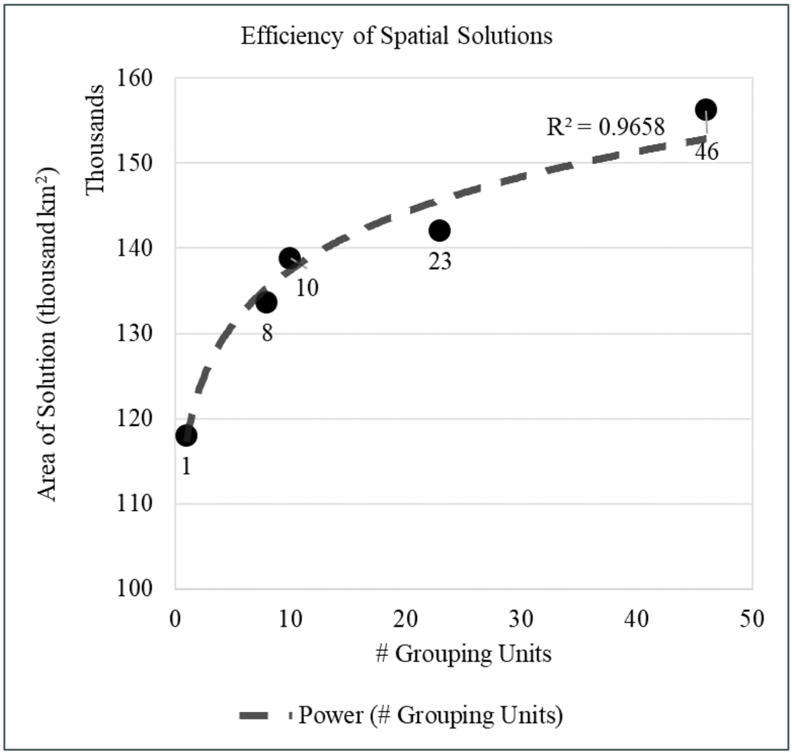


Figure 2. 6 Plotting the number of 1km^2 cells required in each scenario solution against the number of grouping units in their associated scenario shows that planning at smaller scales yields less efficient solutions in terms of land area.

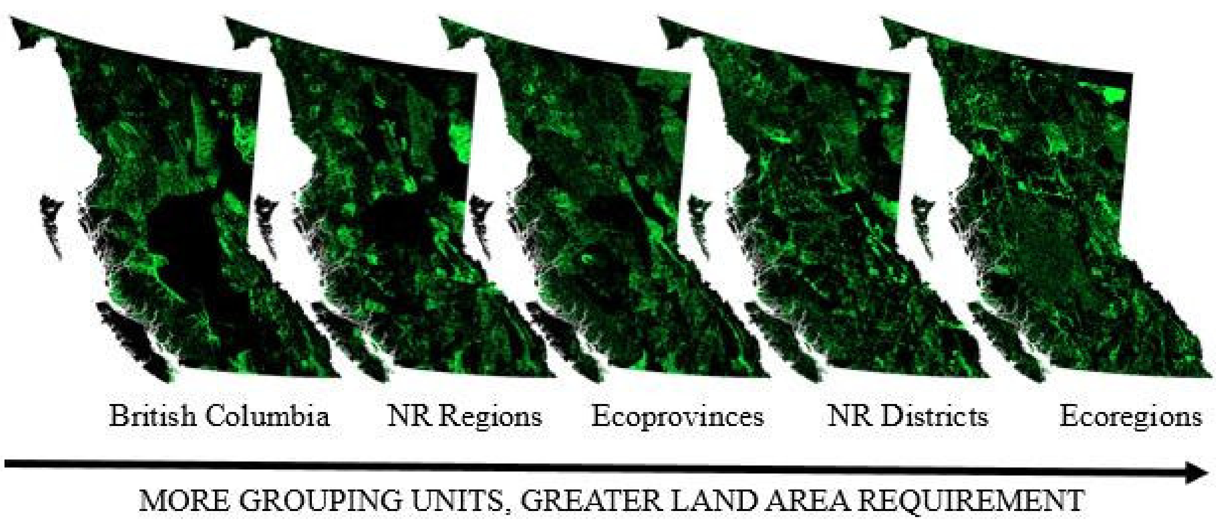


Figure 2. 7 Efficiency also scales with extent. Using larger grouping unit extents yielded more efficient solution sets.

EQUITY

The equity results demonstrate a pattern that implies equity increases as the spatial scale decreases. The finer-scale scenarios placed greater spatial constraints on the analysis, generally resulting in greater equity across Regional Districts (Figures 2.7, 2.8). There is some discernable pattern of results becoming more equitable as scale decreases, which is consistent with the hypothesis. The finer-scale Ecoregion and NR district scenarios show the most equitable results, with the majority of solutions clustering around 17% land area. The provincial scale scenario stands out as having some of most stratified land area requirements across Regional Districts, with some requiring as high as 65% of the land area. This finding is also consistent with the hypothesis, as the most efficient solution is the most disproportionate.

Table 2. 4
Sample results (n = 6) from equity analysis of each scenario by regional district (n = 61), showing the most dissimilar and most equitable solutions.

	Analysis Unit	% Land Area Required by Scenario					Index Value
	Regional District	**BC**	**NRR**	**EP**	**NRD**	**ER**	**Standard Dev**
High Dissimilarity	Highland	77	19	55	26	9	0.251
	South Saanich	62	7	0	16	2	0.230
	Cedar	10	57	21	17	62	0.217
High Equity	Peace River	17	16	17	16	19	0.011
	Helmcken	0	0	2	0	1	0.008
	Range 1 Coast	15	15	15	14	13	0.008

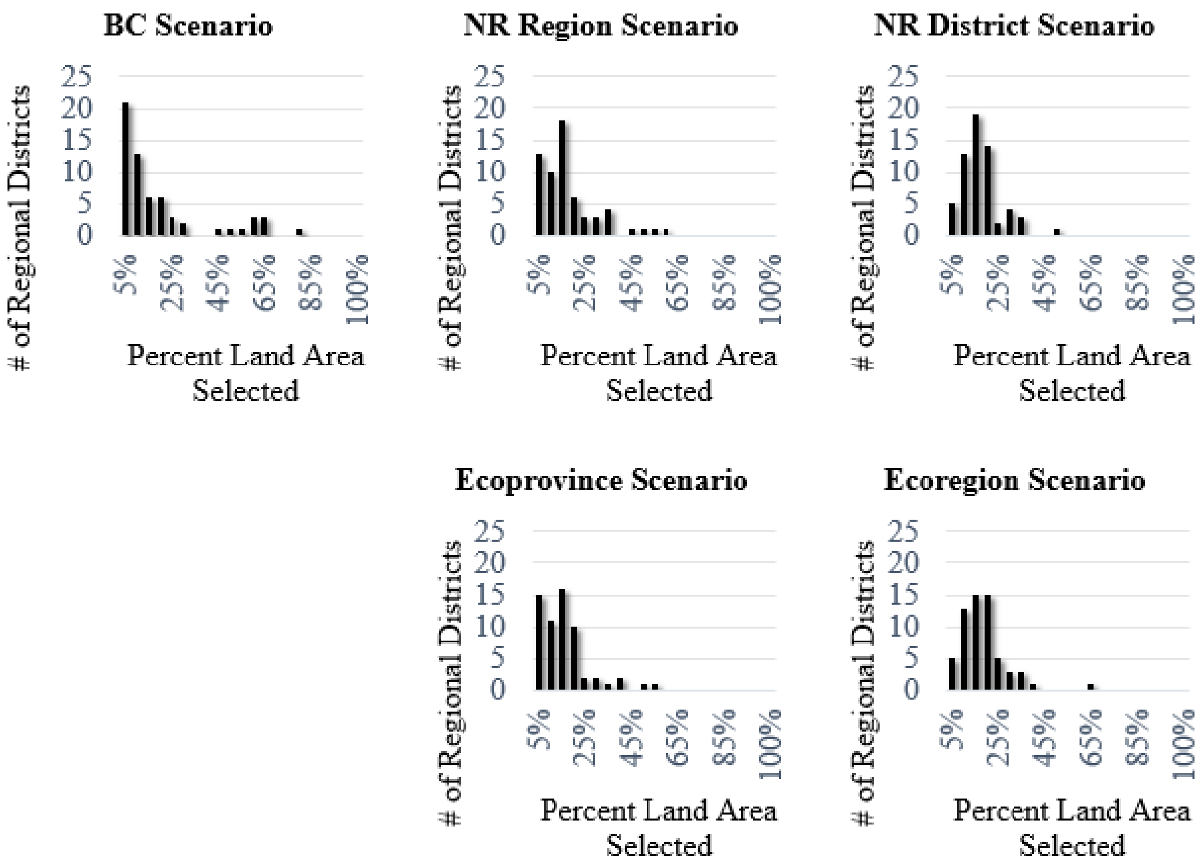
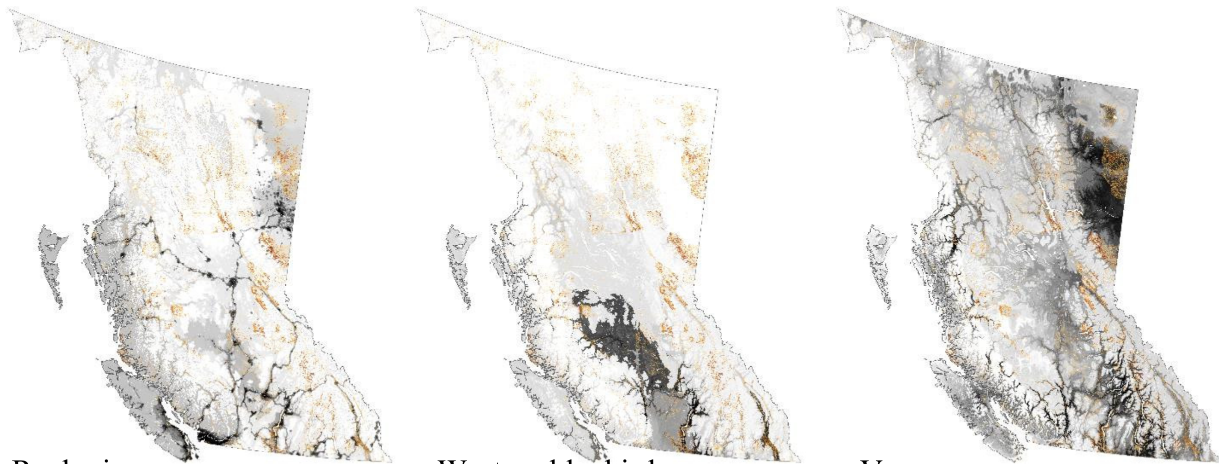


Figure 2. 8 Land use requirements between the five scenarios based on the percentage of land needed in each regional district to reach the solution.

Effect of Long-Ranging Features

Using the bird and tree feature data layers, I analyzed whether some areas may have been over-emphasized in the solution due to a proportionally small piece of their range crossing into the study area, as compared to their range across North America. These features did not seem to drive the solution. The results did not display bias towards bird species with only a small amount of their range in BC. This is particularly evident for bird species such as Rock Pigeon, Veery, Western Bluebird, and Western Kingbird (Figure 2.9).



Rock pigeon Western bluebird Veery

Figure 2. 9 Instances where a small portion of a bird's range occurs in BC (black) did not seem to bias the cumulative results (red tones).

2.4. DISCUSSION

RESULTS AND IMPLICATIONS

(1) DO THE BOUNDARIES EMPLOYED IN SYSTEMATIC CONSERVATION PLANNING AFFECT THE AREAS SELECTED FOR CONSERVATION?

The scale and extent of planning units have a demonstrable effect on the outcomes of conservation planning optimizations. Congruence and efficiency both scale with the number of grouping units employed. The units most similar in extent (ecoprovinces and natural resource regions) showed the most similar results (3.8% difference) in terms of land area requirement.

Based on the features and targets used in this analysis , it appears the smaller administrative grouping units (NRDs) are most effective at achieving both efficiency and equity. When the number of grouping units increases (ex. ERs), efficiency is sacrificed without gaining much more equity. At the larger scales (BC, EPs, NRRs) there is high inequity without a significant improvement in efficiency. This suggests that there may be an optimal number of planning units for conservation planning in the province. As the 23 grouping units from NRDs falls just below the efficiency curve, the optimal number may be closer to 25-30 units, bringing the balance closer to the more equitable ER scenario.

When the scenario results are overlaid, the clustering of highly-selected cells suggests there are important areas despite the overall dissimilarity between results. This analysis is only meant to illustrate the concepts behind SCP, and not act as a conservation plan for BC. Still, further analysis into the relationships of these clusters might give conservation planners commonalities to use as a framework for navigating the challenges outlined by this study.

(2) How could these difference affect the efficiency of conservation planning?

The most efficient grouping unit is that which allows ILP the freedom to select those cells that achieve the highest level of complementarity. This points to the value of coarse-scale planning, which provides an overview of conservation priorities at the provincial scale. It also serves as a reminder that planning at even the provincial scale employs an artificial, administrative boundary, and that there is value in looking both within and beyond it. While achieving high complementarity is cost efficient, conservation priorities must be kept in context, as areas which are a high priority in BC might not make the cut if the analysis were national, continental, or global.

Achieving efficiency at the provincial scale is nonetheless meritable. Highly efficient scenarios outline actionable priorities for the strongest protection mechanisms (ex. *Park Act* designations). They indicate where effort and resources can best be spent to add the most ecologically valuable and relevant land to the provincial network. The results also indicate diminishing returns when planning for efficiency at fine-scales, illustrating that prioritizing efficiency is more appropriate for coarse-scale planning needs. Despite the evident tradeoffs in efficiency with the use of finer scales, it is noteworthy that all of the solution sets came in under the Aichi Target 11 minimum threshold of 17% land area. This implies that there is room within the scope of provincial conservation planning to increase the focus on biodiversity conservation. Further, with an expected new target of at least 30% land area (Convention on Biological Diversity, 2021), there is significant latitude for future conservation in the province to increase and expand feature targets.

(3) How might these differences affect the equity in resource-dependent communities across the province?

These results also illustrate that it is critical to keep social context in mind when conducting SCP analyses. As discussed, conservation efforts demonstrably fail when human equity is left out of the discussion until after the fact (Halpern et al., 2013; Wilhere, 2008). The results here demonstrate that similar conservation outcomes can be achieved even with moderate equity considerations. The inclusion of equity as an explicit planning objective can help minimize the tradeoffs and shortfalls in conservation. Planning conducted at too fine of a scale could results in lower-value lands being slated into conservation, unnecessarily impeding needed development opportunities. For small communities, this could be the difference between having local employment or needing to relocate to find those opportunities. Interestingly, this is similar to the problem that can arise from overly coarse-scale planning, where an unequal distribution of the conservation burden can unduly fall on few communities. These effects highlight a need for planners to be mindful of blindly prioritizing equity without taking on-the-ground context into account.

It would be insensitive to assume that protected area priorities, as identified through Western scientific methods, are the only way of knowing the value of the land. Indigenous knowledge systems have historically been left out of conservation conversations. By incorporating these ways of knowing into conservation planning, planners could gain a more robust understanding of the landscape and the communities who rely on and often steward it. Here ecological boundaries often make sense, as administratively-derived boundaries may unknowingly divide places that are integrally connected.

It is also worth acknowledging that the equity results are influenced by the number of features present within each Regional District and the size of the Regional Districts themselves. This part of the analysis is reliant upon the assumption that all RDs are created equal. Since British Columbia has such a large land area with few major cities, it is not possible that the RDs are perfectly comparable. There are likely RDs that might be appropriately allocated a higher conservation burden to offset their larger footprint, such as the Cariboo RD, home of Prince George, the largest city in the northern part of the province. This would produce a solution that is truly more equitable, rather than simply equal.

(4) What insights can be gleaned from these analyses for CAP-BC users and other conservation planners?

For conservation planners, the questions of when to apply what planning scale has been unclear, despite carrying potentially large consequences. The results provide guidance around the appropriate applications for different scales. Coarse-scale analyses are especially appropriate for climate change-related conservation planning, especially for connectivity corridor identification and migration-related applications. The coarse-scale results prioritize complementarity between cost efficiency and biodiversity target-meeting. Broad ecological patterns are easily recognized here, providing a big-picture view of biodiversity conservation opportunities. Fine-scale analyses are appropriate for seeing how the priorities shift when humans are factored in. They give a clearer picture of necessary adjustments and compromises that a biodiversity-centered solution doesn't account for. Rather than being at odds, these findings are complementary, and can help guide SCP practitioners going forward. The speed of the CAP-BC tool allows planners to compare the results of multiple scenarios, including at differing scales, as I have done here. CAP-BC users are able to run several iterations of a SCP problem and see the results based on multiple considerations. These results showcase the novel flexibility and utility of the CAP-BC tool, and can act as a guideline for planners to balance landscape- and regional-scale considerations within a single SCP application.

Further Research Opportunities

Alternative analysis structures, such as maximum coverage or utility maximization, could be more successful in finding solutions that are balanced in terms of conservation effectiveness, efficiency, and equity (Di Minin and Moilanen, 2012; Moilanen and Arponen, 2011). Further analysis might take the structure used here to evaluate the effect of grouping units on these SCP approaches. Target-based conservation, such as that utilized here, is a prescriptive process that has been criticized. Target amounts may be set arbitrarily, features that are critical to ecosystem function may be excluded, and the approach does not account for socioeconomic factors (Carwardine et al., 2009). Over-emphasized features may also drive solution results, as may be the case in this research with regards to caribou in the northeastern corner of the province. Attempts to counteract these shortfalls can lead to over-complicating the SCP analysis, potentially leading to inefficient solutions (Di Minin and Moilanen, 2012). Target-related uncertainty is exacerbated by climate change, and incorporating climate-projected data is complicated (Hannah et al., 2007; Robillard et al., 2015). In this research, I attempt to mitigate most of these issues by carefully selecting target features for their life-history characteristics, role in ecosystem function, and relative threat level. Additionally, the use of ILP solvers such as *prioritizr* helps mitigate the limits of minimum-set problems by solving for complementarity (a "best" solution), rather than simply for efficiency (a "cheapest" solution).

To further contextualize this analysis, it would be beneficial to review the scenario results while using road density as a cost overlay. This cost imposition would increase the efficiency of the solutions as it would force the selections to be made from a smaller land base. The effect on efficiency would likely be greatest at the broadest scales, as transportation corridors are not evenly distributed across BC. Similarly, imposing this cost would further stratify the equity results; resource-dependent communities that are located nearer to transportation would be more heavily impacted by land-use restrictions. This consequence may be alleviated by using the Canadian Human Footprint as a cost layer instead. This would prioritize conservation further from communities as well as transportation infrastructure, reducing land-use conflict.

Conservation planning is designed to create solutions that are complementary to existing protected areas, by evaluating the existing protection of features and the improving the system until all features are adequately protected (Hannah et al., 2007; Margules and Pressey, 2000) However, this approach assumes that existing protected areas are maintaining species representation (Venter et al., 2018). As this analysis was not designed to yield and actionable conservation plan for BC, I opted not to lock existing protected areas into or out of the solutions. The results of the 5 scenarios did not overlap substantially with existing PAs (14-16% of solution area). However, locking in existing PAs would substantially reduce the land area required in each solution, and might affect the equity:efficiency tradeoffs. Locking PAs out would also change the results; assuming that existing PAs are representing the target features well, eliminating PAs might yield solutions that all require more land area to achieve the same targets.

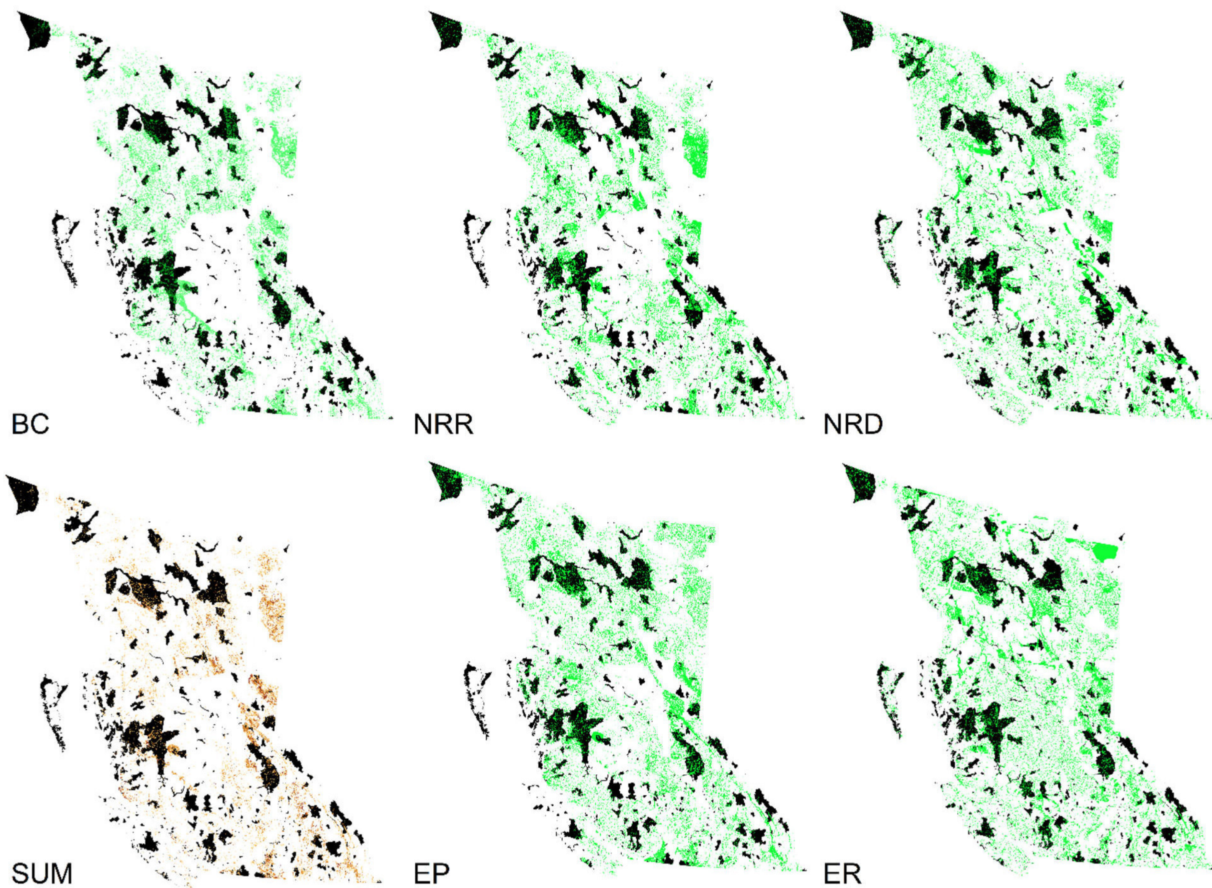


Figure 3. 1 Existing protected areas (black) overlaid with the results of the 5 scenarios (green). The summed scenario overlay (red tones) shows the cells that were selected in 3, 4, and 5 of the scenarios.

Further analysis could explore the comparative effectiveness of the datasets used in this research as different surrogate groups. Historically, there has been a limited set of data available to represent biodiversity. Conservation planners are then restricted to using those datasets, which tend to consist of environmental surrogates alongside a few charismatic species (Grantham et al., 2010). Due to data advances in recent years, SCP has seen the development of robust, fine-scale datasets for entire taxa which span the continent, such as the bird and tree distribution layers used here

(McKenney et al., 2011; Stralberg et al., 2018; Wilsey et al., 2019). These datasets present an opportunity to reevaluate the effectiveness of surrogate data and perhaps improve upon the criticisms of the practice (Grantham et al., 2010). It would be possible to demonstrate how effective biological surrogates are at standing in for larger distribution datasets by comparing SCP solutions generated using the tree and bird distribution data against the other individual, more generalized data layers. Such an analysis would further inform how best to use these datasets in the context of the province.

SUMMARY

The study results are intended to identify how initial extent and scaling decisions influence the relative priority assigned to conservation areas, carve pathways to overcoming the limitations in SCP, and provide rationale for keeping landscape-scale planning embedded within regional-scale analyses. The results of this analysis should inform planners and practitioners about the strengths and weaknesses of spatial optimizations to achieve biodiversity conservation targets. As some significant difference is demonstrable between the scenarios, future conservation plans will need to carefully consider the boundary and scale selected for their potential impact on the prioritization outcomes. Additionally, places with polarized results across the scenarios might necessitate a review of conservation plans where the scale and boundary design may have biased the results and subsequent protection and management actions.

3. Conclusion: Contributions of this Project

This research project is intended to evaluate some of the underlying assumptions in SCP, and anticipate how they might affect the results of conservation planning in practice. Rather than act as a critique, the results of these analyses are intended to illustrate potential limitations of SCP and highlight opportunities for proactive mitigation of such issues. Though these studies are focused on British Columbia, many of the principles explored are applicable for conservation practitioners anywhere.

These analyses demonstrate how varying spatial constraints produce potential incongruences in SCP solutions. This is an early-stage decision for conservation planners, and understanding its impacts is important for creating robust conservation plans going forward. In addition, these results highlight where existing protected areas may prove inadequate, which is illustrative for ongoing management and stewardship of these areas. This study adds to a small existing body of literature that explicitly explores the effects of spatial constraints on SCP. Additionally, I explore the relationship between the congruence of these solutions, their efficiency in terms of land use, and the consequential inequity that can result from disproportional land-use restrictions. I examine these tradeoffs and open a door towards finding an optimal balance.

3.1 Provincial Relevance

This analysis is timely and relevant for conservation planners within the resource management and governance branches of BC. Because of the province's significant regional biodiversity, it is an exceptional place. Humans derive incalculable benefits from its vast natural resources, but the ever-increasing rate of extraction threatens ecosystem health, and the system could collapse if it is not managed. The impacts of climate change only amplify the urgency of the biodiversity crisis in BC, as it compounds the existing impacts of land conversion, habitat degradation and fragmentation, and invasive species while also introducing new environmental stressors. For all that is known about the biodiversity of BC, there is much that is still unknown about its present state, and even more uncertainty about exactly how climate change will affect the system. These shortfalls limit our ability to understand and react to the situation.

This research is part of an effort to inform the ongoing conservation and management processes in the province, and to fill the existing information gap around conservation planning efforts. Because of the diversity and spatial enormity of BC, it would be impossible to create a singular plan to effectively protect all of its resources. Still, it is critical that smaller assessments are done in an integrative manner. The results of this research provide context for selecting appropriate management boundaries where possible, and developing more useful ones when needed. Moreover, these results illustrate the need for collaborative and intentional conservation planning that keeps the big picture in mind; they show how siloed conservation efforts contribute to both inefficiency and inequity overall.

3.2 Climate-Adaptive Conservation Planning in British Columbia

As the datasets collected for this research are being made available to conservation planners in BC through the CAP-BC tool, it is important to contextualize their utility to end-users. The project partners specifically requested information about the apparent strengths and weaknesses of the data and process behind the tool, and the results of this study should provide a comprehensive look. These results provide context and guidance for selecting appropriate spatial parameters for provincial SCP, and showcase the quality and flexibility of the included datasets.

The direct input of project partners at The Nature Trust of BC, Canadian Parks and Wilderness Society, and the BC Parks Foundation has steered this research and helped ensure that it has further practical applications. These NGOs are committed to the conservation of high biodiversity land, and deal directly with the process of identifying and protecting land that is as resilient to the twin crises of climate change and biodiversity loss as possible. Through this collaboration, project partners have provided valuable insight for developing meaningful, necessary, and practical information to support conservation planning practitioners in BC. This is a critical component of the project, as cooperative partnerships are more likely to result in equitable and lasting conservation solutions.

The CAP-BC project is an opportunity project supported and funded by the Pacific Institute for Climate Solutions (PICS). PICS opportunity projects support innovative approaches for climate change mitigation and adaptation. As conservation planners seek climate-adaptive SCP strategies that are both comprehensive and manageable, there is a need for technology that can keep the pace. By developing a climate-informed SCP tool that is accessible, fast, and flexible to users with less intensive training, the CAP-BC project is helping to bring SCP up to speed, making it a more viable tool in a rapidly changing world.

3.3 Other Effective Conservation Measures

Here we have also underscored the need for balanced solutions to both biodiversity protection and accommodation of human resource needs. Multiple objectives can only be successfully achieved when they are accounted for at the outset of conservation efforts. If we only begin to consider the full context of a conservation plan at steps 5 and 6 of the SCP process, those efforts are destined to fall short. Using the results of this research, we can better the practice of holistic conservation planning and work towards refine, effective, and actionable conservation solutions.

Protected area designation is only one tool for effectively managing land, biodiversity, and resources. Aichi Target 11 states, "By 2020, at least 17% of terrestrial and inland water, and 10% of coastal and marine areas, especially areas of particular importance for biodiversity…. are conserved through…. protected areas *and other effective area-based conservation measures* (Convention on Biological Diversity, 2010)" (emphasis added). The CBD later added a definition of other effective conservation measures (OECMs), "a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socioeconomic, and other locally relevant values (Donald et al., 2019)". Other effective conservation measures include Indigenous Protected and Conserved Areas (IPCAs), community forests, elective private land conservation, and marine protected areas, among others.

Many of these OECMs allow for more direct management of resources by those who use and coexist with them, facilitating the achievement of multiple, more equitable objectives, including the safeguarding of biodiversity. By better leveraging OECMs, we can advance a triple bottom line of equity, efficiency, and effectiveness for conservation.

3.4 Conclusion

In conclusion, this research project contributes to the advancement and improvement of systematic conservation planning, which should in turn create protected areas that robustly safeguard biodiversity. It provides information and resources for a tangible conservation tool, which will be used by conservation planners in BC to identify on-the-ground conservation opportunities for the province, contributing to Canada's CBD commitment. Finally, this research imparts context for my intended career in large-landscape land conservation, and highlights the considerations that will be critical for conservation planning in the near future.

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1

Appendix A: Spatial Data Used for Analysis

Dataset	Source	Year
BC Natural Resource Districts	Ministry of Forests, Lands, Natural Resource Operations and Rural Development - Forest Tenures	2019
BC Natural Resource Regions	Ministry of Forests, Lands, Natural Resource Operations and Rural Development - Forest Tenures	2019
BC Ecoprovinces	Ministry of Environment and Climate Change Strategy - Knowledge Management	2019
BC Ecoregions	Ministry of Environment and Climate Change Strategy - Knowledge Management	2019
BC Regional Districts	Ministry of Municipal Affairs and Housing - Governance and Structure	2019
Biogeoclimatic Ecosystem Classification Zones	Ministry of Forests, Lands, Natural Resource Operations and Rural Development - Forest Analysis and Inventory	2018
Caribou Herd Locations for BC	Ministry of Environment and Climate Change Strategy - Ecosystems	2019
Elk Range	Shackelford et al. 2018	2018
Fish Ranges (sockeye, bull trout)	Ministry of Env and CC Strategy	2019
Fisher Range	Shackelford et al. 2018	2018
Freshwater Atlas (rivers, lakes)	Ministry of Forests, Lands, Natural Resource Operations and Rural Development - GeoBC	2011
BC Grizzly Bear Habitat Classification and Rating (BEU)	Ministry of Environment and Climate Change Strategy - Ecosystems	2019
Mountain Goat Range	Shackelford et al. 2018	2018
Climate-based bird distribution models (present)	Audubon Survival by Degrees	2019
Tree Species distribution model projections (present)	McKenney et al. 2011b	2011
Wild Mountain Sheep Range (bighorn sheep)	FLNRORD	2019

Appendix B: Table of Grouping Units by Scenario

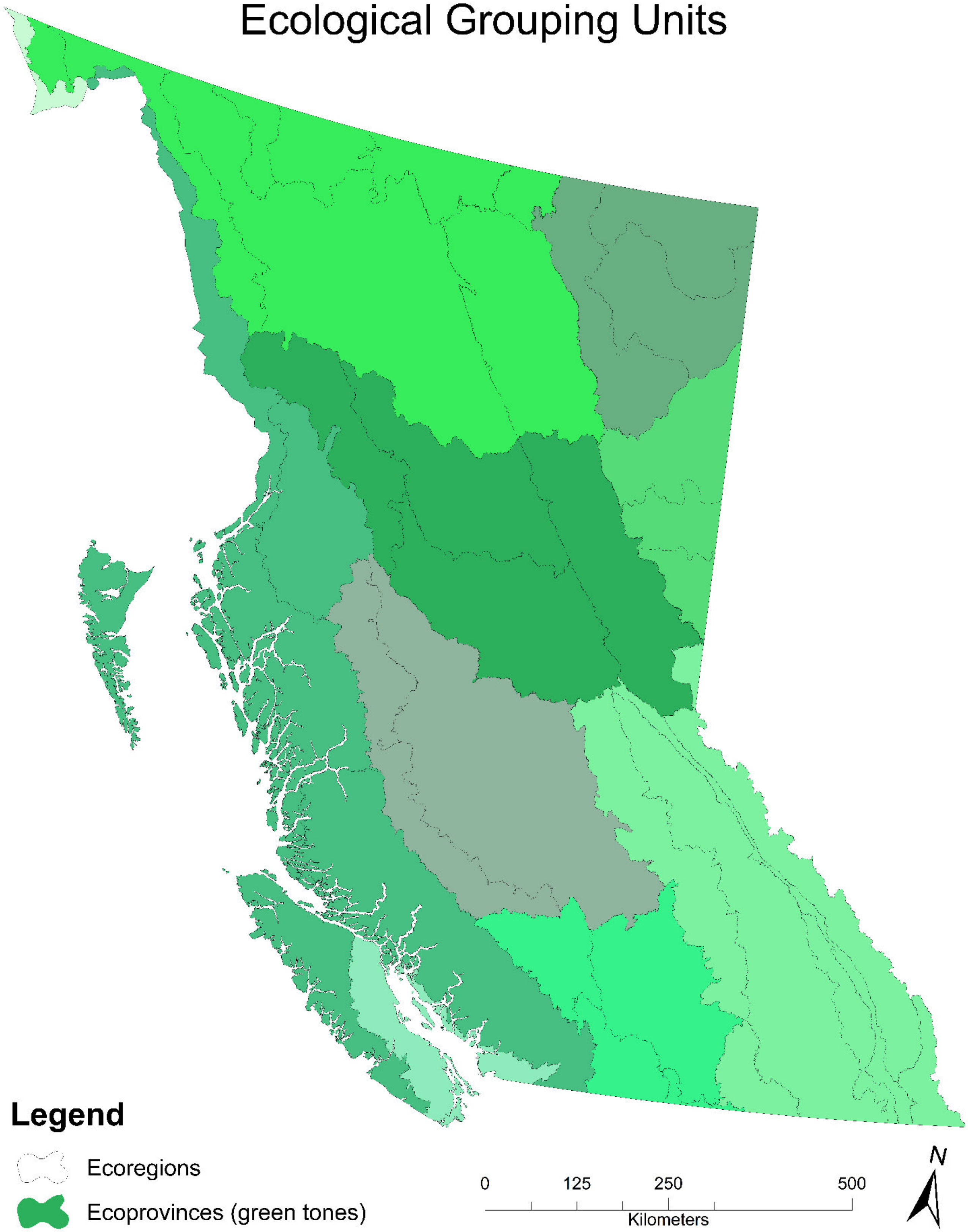
BC	NRR	EP	NRD	ER
British Columbia	Cariboo Natural Resource Region	Boreal Plains	100 Mile House Natural Resource District	Boreal Mountains And Plateaus
	Kootenay Boundary Natural Resource Region	Central Interior	Campbell River Natural Resource District	Boundary Ranges
	Northeast Natural Resource Region	Coast And Mountains	Cariboo Chilcotin Natural Resource District	Central Alberta Upland
	Omineca Natural Resource Region	Georgia Depression	Cascades Natural Resource District	Central Canadian Rocky Mountains
	Skeena Natural Resource Region	Northern Boreal Mountains	Chilliwack Natural Resource District	Chilcotin Ranges
	South Coast Natural Resource Region	Southern Alaska Mountains	Coast Mountains Natural Resource District	Chugach Mountains And Icefields
	Thompson Okanagan Natural Resource Region	Southern Interior	Fort Nelson Natural Resource District	Coastal Gap
	West Coast Natural Resource Region	Southern Interior Mountains	Haida Gwaii Natural Resource District	Columbia Highlands
		Sub Boreal Interior	Mackenzie Natural Resource District	Eastern Continental Ranges
		Taiga Plains	Nadina Natural Resource District	Eastern Hazelton Mountains
			North Island Central Coast Natural Resource District	Eastern Vancouver Island
			Okanagan Shuswap Natural Resource District	Fraser Basin
			Peace Natural Resource District	Fraser Plateau

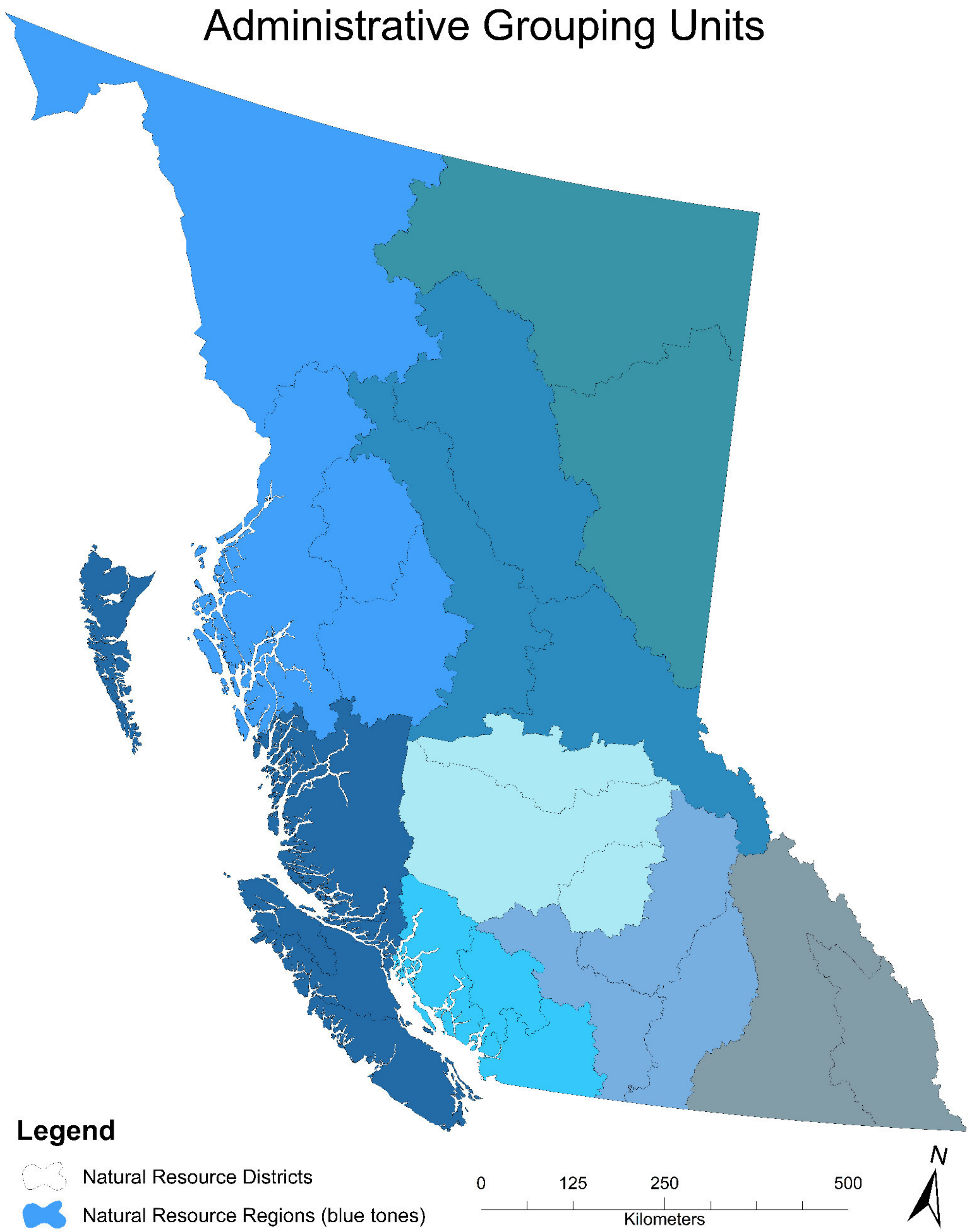
	Prince George Natural Resource District	Georgia Puget Basin
	Quesnel Natural Resource District	Gwaii Haanas
	Rocky Mountain Natural Resource District	Hay Slave Lowland
	Sea to Sky Natural Resource District	Hecate Continental Shelf
	Selkirk Natural Resource District	Hyland Highland
	Skeena Stikine Natural Resource District	Inner Pacific Shelf
	South Island Natural Resource District	Interior Transition Ranges
	Stuart Nechako Natural Resource District	Liard Basin
	Sunshine Coast Natural Resource District	Lower Mainland
	Thompson Rivers Natural Resource District	Muskwa Plateau
		Nass Ranges
		Northern Alberta Upland
		Northern Canadian Rocky Mountains
		Northern Cascade Ranges
		Northern Columbia Mountains

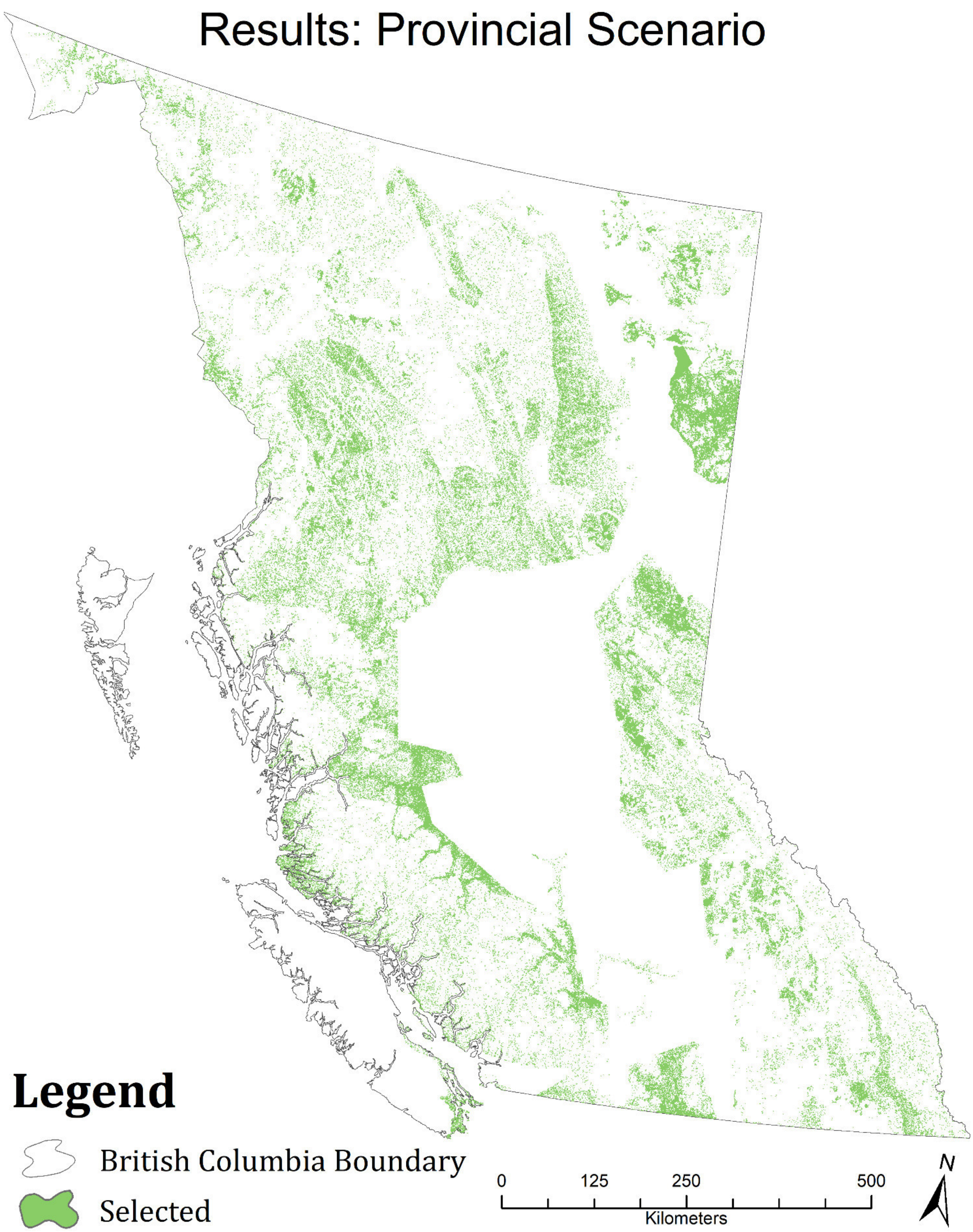
				Northern Continental Divide
				Okanogan Highland
				Omineca Mountains
				Outer Pacific Shelf
				Pacific Ranges
				Peace River Basin
				Pelly Mountains
				Purcell Transitional Ranges
				Selkirk Bitterroot Foothills
				Skeena Mountains
				Southern Alberta Upland
				Southern Rocky Mountain Trench
				St Elias Mountains
				Thompson Okanagan Plateau
				Western Continental Ranges
				Western Vancouver Island
				Yukon Southern Lakes
				Yukon Stikine Highlands
1	**8**	**10**	**23**	**46**

Appendix C: Additional Maps

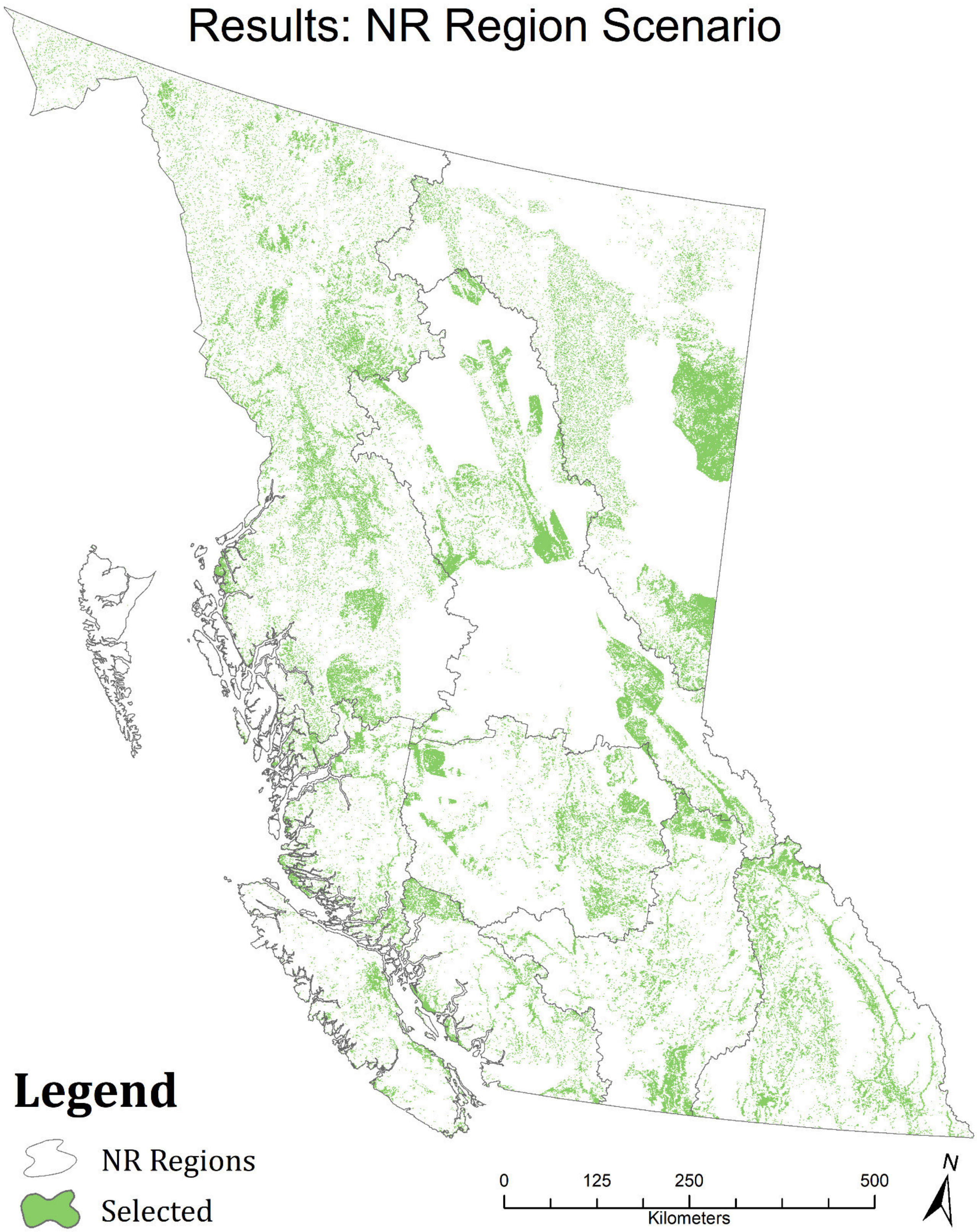
Ecological Grouping Units



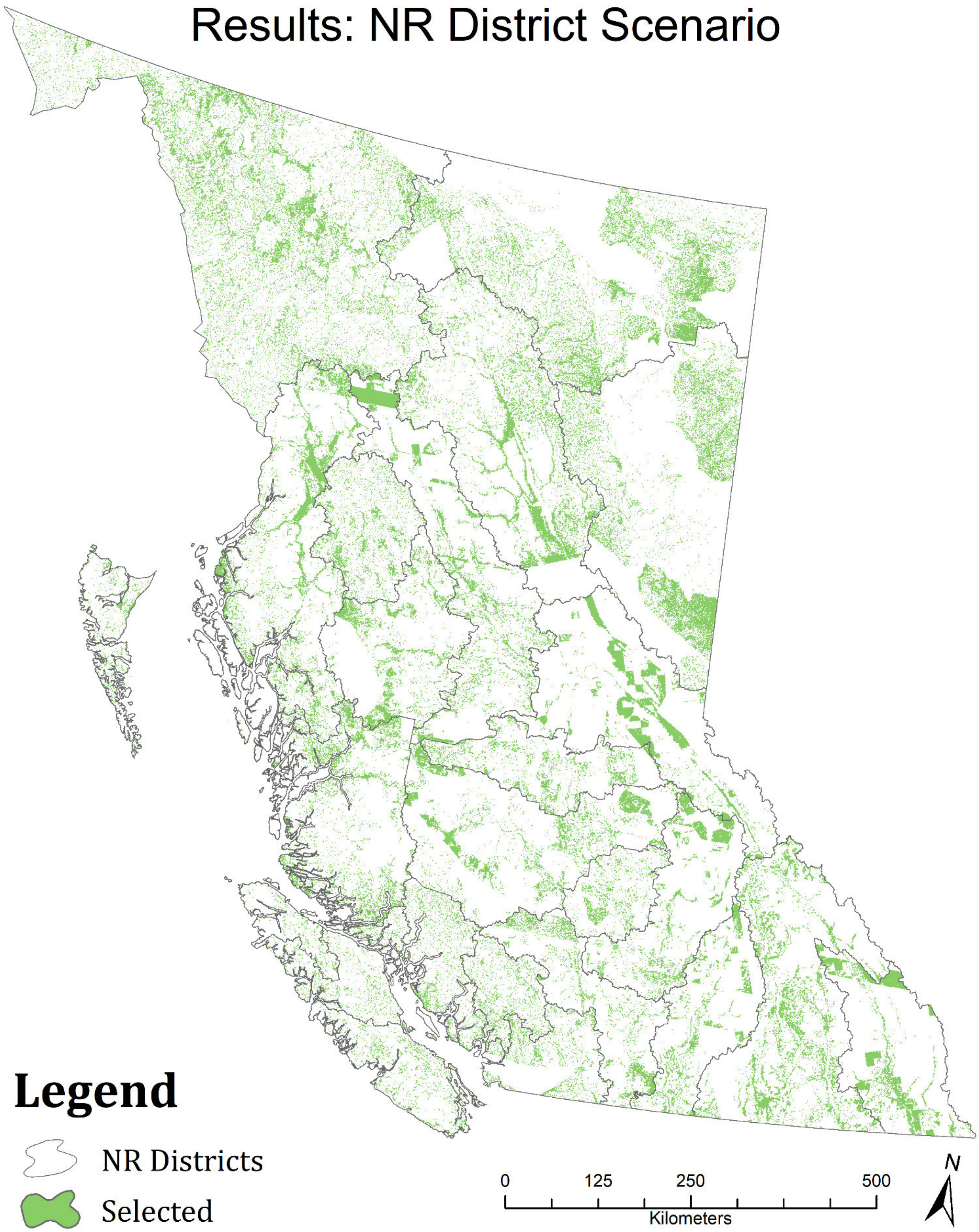

Administrative Grouping Units
Legend
Natural Resource Districts
Natural Resource Regions (blue tones)
0
125
250
500
Kilometers
N


Results: Provincial Scenario
Legend
British Columbia Boundary
Selected
0
125
250
500
Kilometers
N

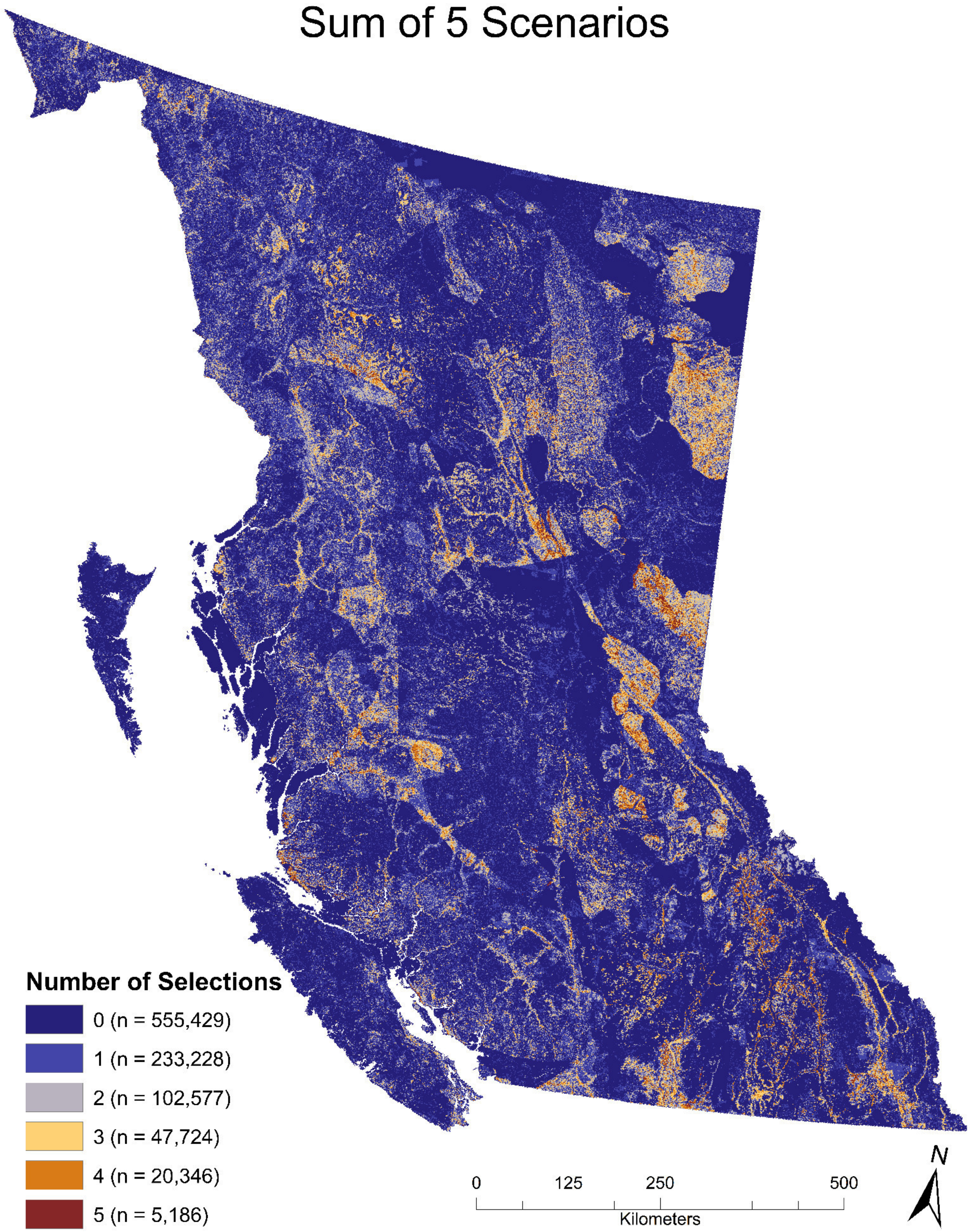
Results: NR Region Scenario



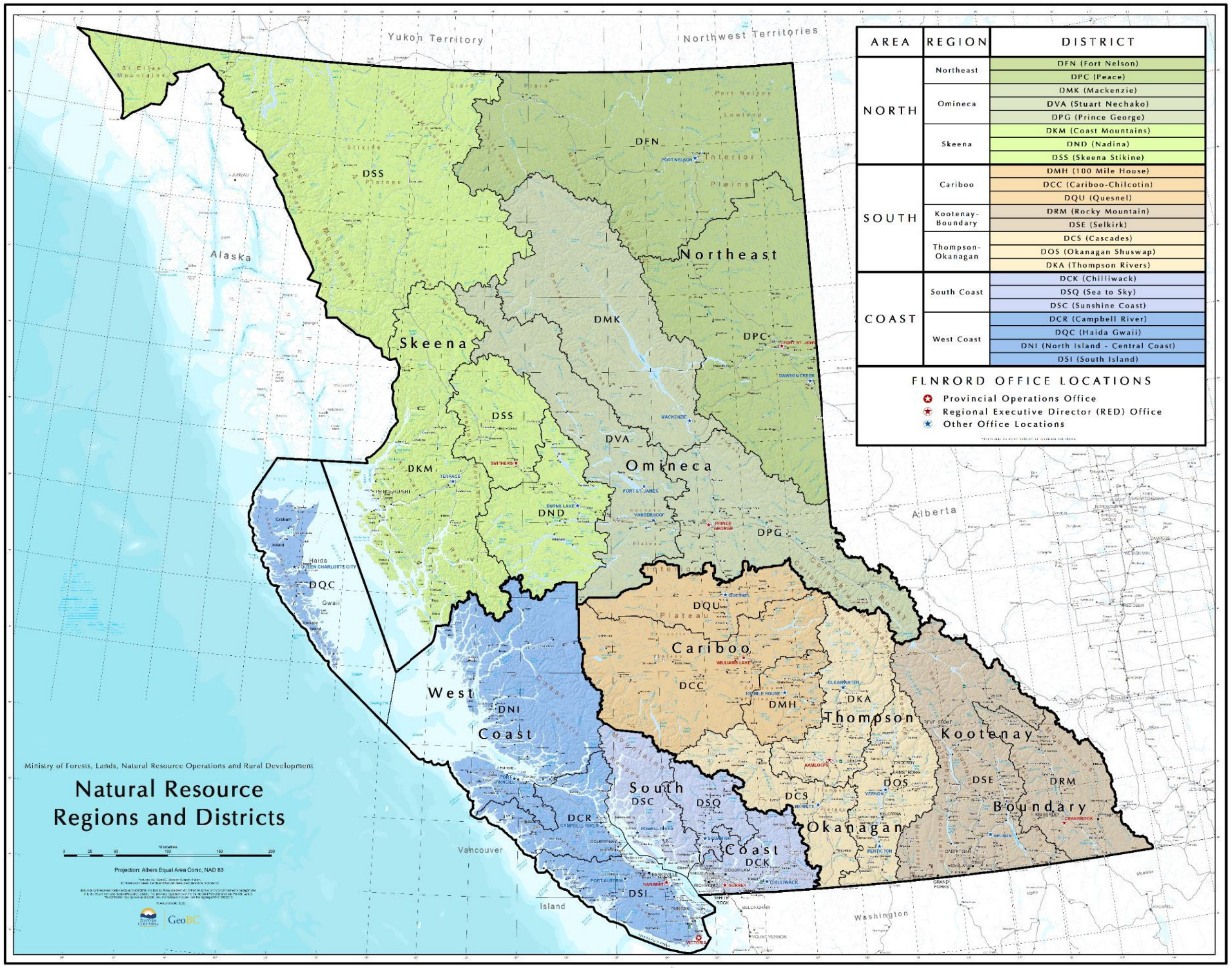

Results: Ecoprovince Scenario
Legend
Ecoprovinces
Selected
0
125
250
500
Kilometers
N


Results: NR District Scenario
Legend
NR Districts
Selected
0
125
250
500
Kilometers
N


Results: Ecoregion Scenario
Legend
Ecoregions
Selected
0
125
250
500
Kilometers
N


Sum of 5 Scenarios
Number of Selections
0 (n = 555,429)
1 (n = 233,228)
2 (n = 102,577)
3 (n = 47,724)
4 (n = 20,346)
5 (n = 5,186)
0
125
250
500
Kilometers
N

1


Ministry of Forests, Lands, Natural Resource Operations and Rural Development
Natural Resource Regions and Districts
Projection: Albers Equal Area Conic, NAD 83
AREA
REGION
DISTRICT
NORTH
Northeast
DFN (Fort Nelson)
DPC (Peace)
Omineca
DMK (Mackenzie)
DVA (Stuart Nechako)
DPG (Prince George)
Skeena
DKM (Coast Mountains)
DND (Nadina)
DSS (Skeena Stikine)
SOUTH
Cariboo
DMH (100 Mile House)
DCC (Cariboo-Chilcotin)
DQU (Quesnel)
Kootenay-Boundary
DRM (Rocky Mountain)
DSE (Selkirk)
Thompson-Okanagan
DCS (Cascades)
DOS (Okanagan Shuswap)
DKA (Thompson Rivers)
COAST
South Coast
DCK (Chilliwack)
DSQ (Sea to Sky)
DSC (Sunshine Coast)
West Coast
DCR (Campbell River)
DQC (Haida Gwaii)
DNI (North Island - Central Coast)
DSI (South Island)
FLNRORD OFFICE LOCATIONS
Provincial Operations Office
Regional Executive Director (RED) Office
Other Office Locations
Yukon Territory
Northwest Territories
Alaska
Alberta
Washington
Vancouver
Island
Northeast
Skeena
Omineca
Cariboo
Thompson
Okanagan
Kootenay
Boundary
West
Coast
South
Coast
DFN
DSS
DMK
DPC
DVA
DKM
DND
DPG
DQC
DQU
DCC
DMH
DKA
DNI
DOS
DSE
DRM
DCS
DSC
DSQ
DCR
DCK
DSI
GeoBC