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Wells-Barkerville Community Forest Mapping Project

By
Christopher Morgan and Pamela Wright

Christopher Morgan is an MNRES Graduate Student in the Natural Resources and Environmental Studies program, University of Northern British Columbia, Prince George, B.C., Canada. Pamela Wright is a faculty member in the Ecosystem Science and Management Program and member of the Natural Resources and Environmental Studies Institute, University of Northern British Columbia, Prince George, B.C., Canada.

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For more information about NRESi contact:
Natural Resources and Environmental Studies Institute
University of Northern British Columbia
3333 University Way
Prince George, BC Canada
V2N 4Z9
Email: nresi@unbc.ca
URL: www.unbc.ca/nres-institute

Executive Summary

Introduction

The Wells-Barkerville Community Forest established in 2014 is a small, 4527 ha Forest encompassing critical viewscapes for the communities, valuable recreational opportunities, as well as timber and ecological values. Located within the interior wet-belt of BC in the Columbia Mountains and Highlands Ecoregion, the larger landscape around the Forest supports a small and threatened herd of Southern Mountain Caribou and other wide-ranging mammal species. Regionally, connectivity is critical to maintaining populations of caribou and other wide-ranging mammal and fish species, particularly in light of the rapidly changing climate.

Socio-economically, the Forest is also very valuable to the communities of Wells and Barkerville as a source of logging revenue to sustain the District of Wells. The Community Forest tenure also allows the community to express their values on the landbase by implementing approaches to forest harvesting that sustain ecological and human uses of the forest and can serve as a demonstration area to others. The Forest is located immediately adjacent to the community of Wells and serves not only as a viewscape but also as a place for recreation on the active, multi-season walking, hiking and skiing trails. In addition, the community uses the Forest as a learning environment for students and other special programs, even designating the portion of the forest nearest the community as the "Learning Forest".

Management of the Forest is facilitated by a board of directors with forest operations and cut-control along with silvicultural work conducted by a partnership with West Fraser Timber. This partnership is critical because the Forest has only two part-time staff. However, building the capacity within the community to engage in planning and management is an important objective.

In 2019, with the financial support of the Moss Rock Park Foundation and Mitacs Accelerate, faculty and students from UNBC undertook a research project to work with the Wells-Barkerville Community Forest. The purpose was to conduct analyses at two spatial scales: identifying locations of key ecological, social and recreational value within the Forest and immediate area of interest; and examining connectivity of the Forest in an ecoregional context in the light of climate change. The intent was to help build capacity within the Forest, inform planning and management as well as initiatives to improve connectivity and resiliency (including potential expansion plans for the Forest) within the region.

This research project involved spatial mapping (GIS), analysis, and planning activities for conservation (and other) values at two scales: the forest itself and of the forest in an ecoregional context. Forest scale conservation planning was focused on the landscape unit scale procedurally described in the BC Biodiversity Guidebook as Forest Ecosystem Network (FEN) planning (see Horn, 1997; BC Environment, 1995). At the ecoregional scale, analysis was guided at its broadest level by Margules and Pressey's (2000) *systematic conservation planning (SCP)* framework. However, this application involved a more limited application of the SCP framework focused more explicitly on climate-conscious connectivity planning (Mann and Wright, 2019).

On an ecoregional basis we built a data model that included current biodiversity values including landscape pattern and process, caribou suitability (by herd), grizzly, fisher and trout/salmon habitat suitability and wetlands and karst topography. We also built a future climate model that include forward and backward velocity, current flow (climate connectivity) and tree and bird refugia. Scenario models completed with Marxan-ILP demonstrated that a scenario that include targets for both current and future biodiversity features was the most efficient in meeting targets. The WBCF is situated in an area of relatively high value for all of the scenarios analyzed. Subsequently we completed a landscape resistance and connectivity analysis using Linkage Mapper to identify areas of connectivity and impediments to movement. Although there are smaller and localized movement filters located along the Wells-Barkerville highway the southern and eastern part of the landscape until the McGregor valley is generally well connected.

Connectivity in light of future climates is concentrated in the mountainous regions whereas the valley bottoms have lower levels of future connectivity.

Within the WBCF we mapped old forests (including OGMAs), riparian areas, wildlife tree retention patches, less productive higher elevation areas. We also included social/cultural/recreational mapping that incorporated key viewscapes and recreational areas identified through a community open house and one-on-one interviews with community members. The iterative design of the network identified 54% of the Forest as potential areas to consider for no, or modified, forest practices.

While small in scale, community forests play an important role in helping communities transition to more sustainable futures and in meeting a broad array of ecological and social values. Managing for the provision of ecosystem services within a community forest can provide a model for how forest practices might be re-examined elsewhere. The Wells-Barkerville Community Forest represents an initiative that is important not just to the economic livelihood of the District of Wells, but to the social and recreational livelihoods of residents and visitors to the area. At the scale of the Forest, and at larger ecoregional scales, the Community Forest also plays an important role in contributing to maintaining or restoring biodiversity values under current and future climates.

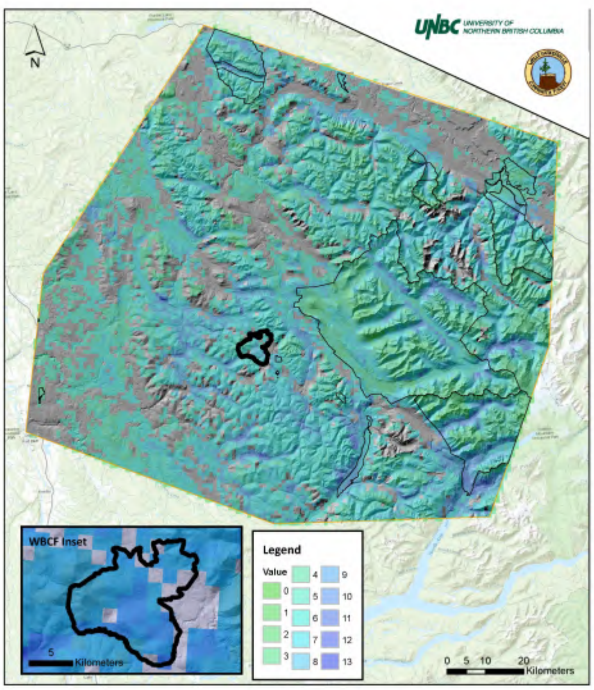

Figure i. Regionally important conservation lands around WBCF where green colours indicate lower diversity of conservation values and blue indicate higher diversity of overlapping values.

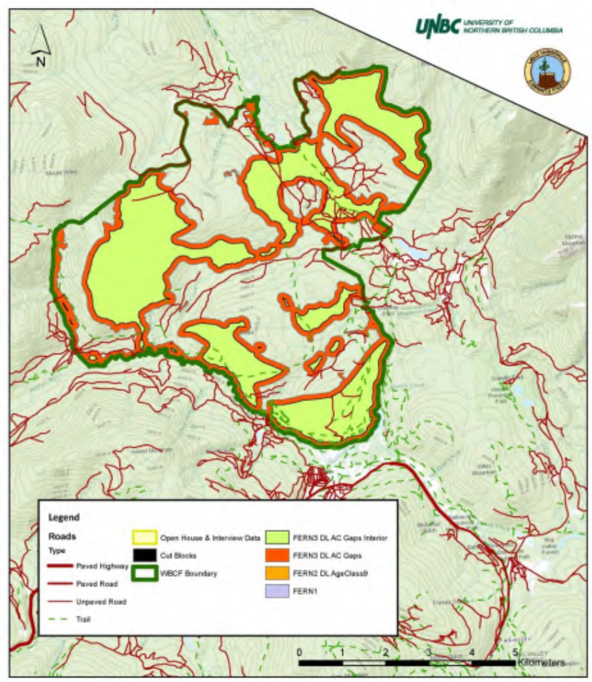

Figure ii. Forest ecosystem and recreation network within the WBCF.

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Introduction

Today, human activities dominate the earth and are having significant global, regional and local impacts on ecosystems and the critical services they provide to humanity. Extinction rates are between 100- and 10,000-times evolutionary background rates and shrinking populations and ranges are contributing to a massive anthropogenic erosion of biodiversity, which scientists have referred to as “biological annihilation”. Habitat loss and degradation is a major driver of biodiversity loss not restricted to tropical environments but equally problematic across Canada and in northern British Columbia. This is set against a backdrop of an increasingly changing climate where effects are magnified in the north.

In our own backyard, this means that without radical action, mountain caribou will likely be extinct in our lifetime. Wolverine and other critical mid-trophic carnivores will be further isolated into patchy, genetically impoverished pockets. Populations of boreal birds that rely on structurally complex forests in the north will become impoverished.

At regional and ecoregional scales, planning for connectivity within working forests and between protected areas has been implemented in Canada only in limited ways. Systematic Conservation Planning (SCP) is widely considered the most effective approach for identifying important biodiversity areas and other ecological networks. The success and effectiveness of SCP can be attributed to its efficiency in using limited resources to achieve goals, its flexibility and defensibility in the face of competing land uses, and its accountability in allowing decisions to be critically reviewed (Margules & Pressey, 2000). SCP uses detailed biogeographical information and selection algorithms to identify high value areas (Knight & Cowling, 2007; Watson et al., 2011) and strives to move the prioritization of lands beyond opportunism and toward scientific defensibility and improved efficacy (Pressey et al., 1993). Furthermore, SCP supports identification of networks that represent regional species and ecosystems diversity, be comprised of enough habitat of specific types to maintain viable species popula-tions, enable continued community and population processes – including shifts in species' ranges – and allow natural patterns of disturbance (Baldwin et al., 2014).

Systematic conservation planning continues to rapidly evolve as new information and tools become available, and increasingly sophisticated approaches are being developed every day. As the field progressively expands its scope and perspectives, it becomes more effective at incorporating previously poorly understood or connected variables. Although the SCP framework has been refined and improved over time, explicit inclusion of a climate change lens with the goal of pre-emptively planning for future climate conditions and climate change impacts is limited. With the recent widespread availability of emission scenarios and reliable climate change data (www.adaptwest.databasin.com), the SCP framework is well poised to take advantage of climate information and evolve into a climate change conscious approach to planning.

As these approaches are downscaled the identification within the working forest of both critical core areas, such as old forest stands and forest interior conditions, and connectivity corridors that allow for movement across the landscape in both current and future climates are increasingly important. In managed forests, measures to protect biodiversity are relatively limited and largely occurring at stand scales. Variable retention forest practices, for example, have been implemented on less than 3% of BC's crown forest lands (Jull and Elkin, 2018). Forest Ecosystem Networks (FENs) are landscape level (typically a 5000-50,000 ha/watershed scale type area) conservation measures designed for working forests. They were intended as a counterpoint to changes in landscape structure and composition with a focus on maintaining old and mature forest components, forest interior conditions, and connectivity. FENs may consist of reserves or zones where some modified harvesting is allowed. While landscape unit planning methods were developed and adopted in the mid 90's (BC Environment, 1995; Taylor, 1995) changes in forestry regulations mean that Forest Ecosystem Network planning or similar systems are not currently required. although possible revisions may include FEN-type landscape level measures. Old Growth Management Areas (OGMAs) fulfill some similar objectives to the core areas proposed for FENs but do not include an explicit focus on connectivity.

Wells-Barkerville Community Forest

The Wells-Barkerville Community Forest (hereafter 'Forest'), established in 2014, located just north of the two communities is a small, 4527 ha Forest encompassing critical viewscapes for the communities, valuable recreational opportunities, as well as timber and ecological values. Located within the interior wet-belt of BC in the Columbia Mountains and Highlands Ecoregion, the larger landscape around the Forest supports a small and threatened herd of Southern Mountain Caribou and other wide-ranging mammal species. Regionally, connectivity is critical to maintaining populations of caribou and other wide-ranging mammal and fish species, particularly in light of the rapidly changing climate (Figure 1).

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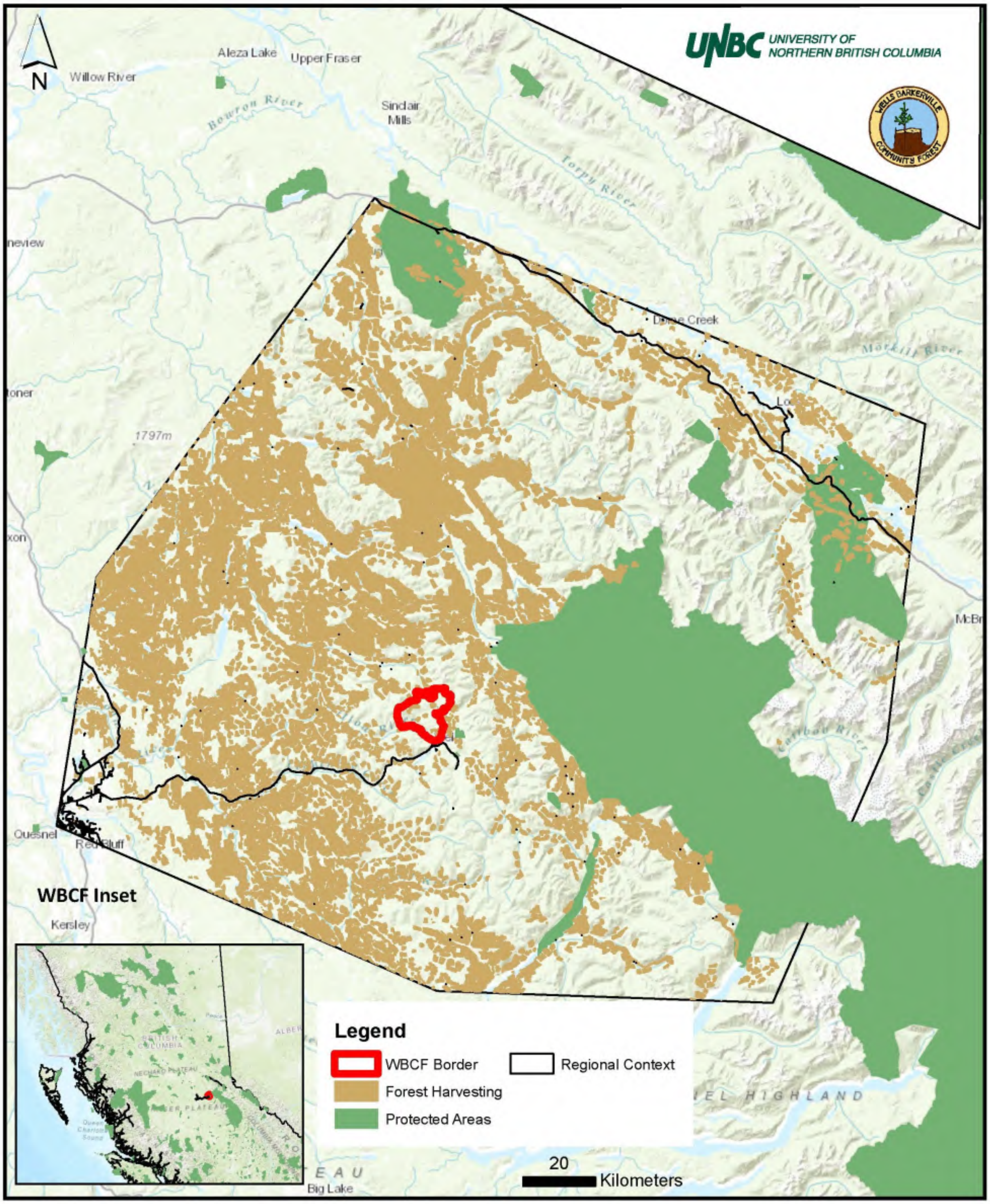


Figure 1. Wells-Barkerville Community Forest in context

Approach

This research project involved spatial mapping (GIS), analysis, and planning activities for conservation (and other) values at two scales: the forest itself and of the forest in an ecoregional context.

Forest scale conservation planning was focused on the landscape unit scale procedurally described in the BC Biodiversity Guidebook as Forest Ecosystem Network (FEN) planning (see Horn, 1997; BC Environment, 1995). At the ecoregional scale, analysis was guided at its broadest level by Margules and Pressey's (2000) systematic conservation planning (SCP) framework. However, this application involved a more limited application of the SCP framework focused more explicitly on climate-conscious connectivity planning (Mann and Wright, 2019). Broad methods are described below.

Objective 1. Identify locations of key ecological, social and recreational value within the Forest and immediate area of interest:

- Identified key biodiversity components including fine filter components such as caribou, grizzly and fisher, and coarse filter components such as old forests and new natural forests along with other biodiversity surrogates useful for FEN and SCP planning;
- Acquired and assembled spatial data in ArcGIS for the study area on key biodiversity components identified in step i) from the BC Government data warehouse, Forest data (held by West Fraser Timber, LTD.), and the Wells/ Barkerville community;
- Worked with Forest staff and directors to map key values not held within existing data sets (focus on identifying key community, economic, recreational and socio-cultural values along with local knowledge on sites of important ecological concern); and
- Worked with Forest staff, directors, and specialists to develop conservation goals and numeric targets for these key components based on previous applications in northern BC (see Curtis, 2018; Mann and Wright, 2019) and informed by the BC Biodiversity Guidebook (BC Environment, 1995).

Objective 2. Examined connectivity of the Forest (forest ecosystem network planning) and in an ecoregional context (systematic conservation planning approaches) with a climate change lens:

2a. Forest Ecosystem Network (FEN) Planning

- Using a modified FEN planning approach (BC Environment, 1995) conducted geospatial analysis using the ArcGIS-based prioritization software Marxan that operates within an integer linear programming (ILP) framework (see Curtis, 2018) to identify:
- Areas containing key values (from objective 1)
- Areas subject to harvesting constraints (e.g., Old Growth Management Areas, Ungulate Winter Range)
- Currently developed and Inoperable areas (Marxan = costs)
- Points of conflict between value layers
- Connectivity (Marxan = boundary cost modifier) targets
- Draft/working FEN network

2b. Ecoregional Connectivity/Conservation Planning

- At the ecoregional scale, constructed an SCP model using the ArcGIS-based prioritization software Marxan that operates within an integer linear programming (ILP) framework (see Curtis, 2018 for specific methods) to identify key areas for conservation under current climate conditions.
- Used AdaptWest's climate adaptation data (for example measures of forward/ backward velocity; bioclimatic

envelope; disappearing/novel climates; biotic refugia/climatic refugia) to identify conservation targets that promote climate change resiliency using the methodology developed by Mann and Wright (2019).

- Used Linkage Mapper software [which calls upon Circuitscape (McRae et al. 2016)] to quantify landscape permeability and potential for species' movement (measured as current flow) under current and future climate scenarios.
- Drafted SCP network

The mapping work was supplemented by a community workshop hosted by the Forest and UNBC undergraduate students and by a series of one-on-one interviews conducted by graduate student Chris Morgan with select community members.

Identifying Current and Future Biodiversity Areas within an Ecoregional Context

At the ecoregional scale, analysis was guided at its broadest level by Margules and Pressey's (2000) systematic conservation planning (SCP) framework. However, this application involved a more limited application of the SCP framework focused explicitly on climate-conscious connectivity planning (Mann, 2020) (Figure 2).

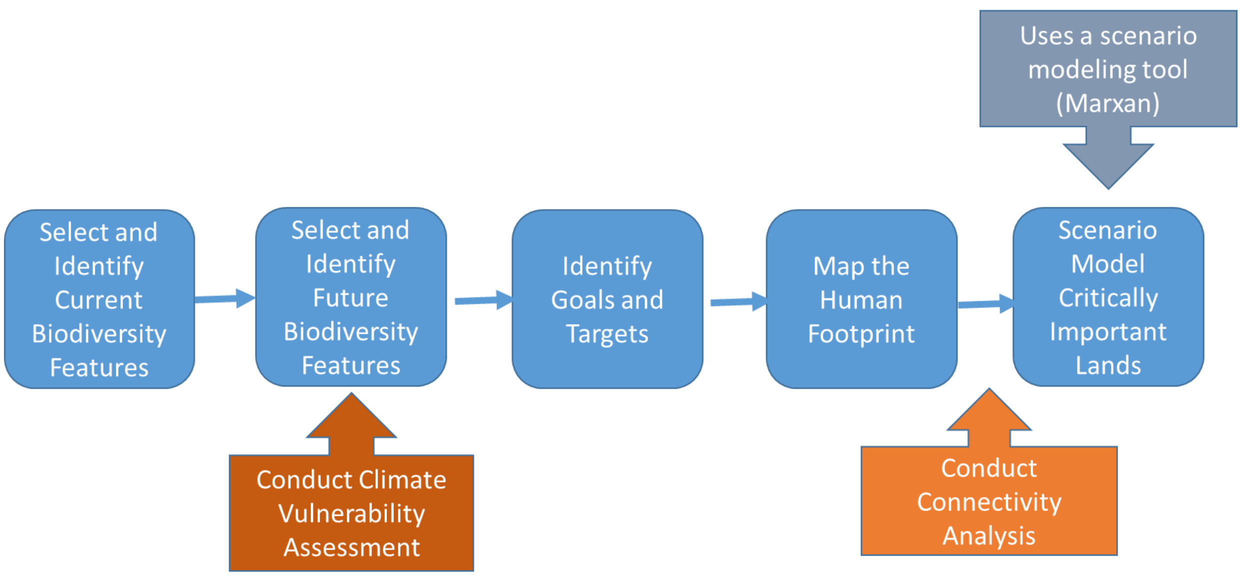


Figure 2. Broad steps involved in ecoregional mapping and planning process.

We constructed an SCP model using the ArcGIS-based prioritization software Marxan that operates within an integer linear programming (ILP) framework to identify key areas for prioritization under current climate conditions (Figure 3). We then used AdaptWest's climate adaptation data (for example measures of forward/backward velocity; bioclimatic envelope; disappearing/ novel climates; biotic refugia/climatic refugia) to identify targets that promote climate change resiliency. To examine connectivity, we used Linkage Mapper software [which calls upon Circuitscape (McRae et al. 2016)] to quantify landscape permeability and potential for species' movement (measured as current flow) under current and future climate scenarios. Detailed methods can be found in Mann and Wright (2020).

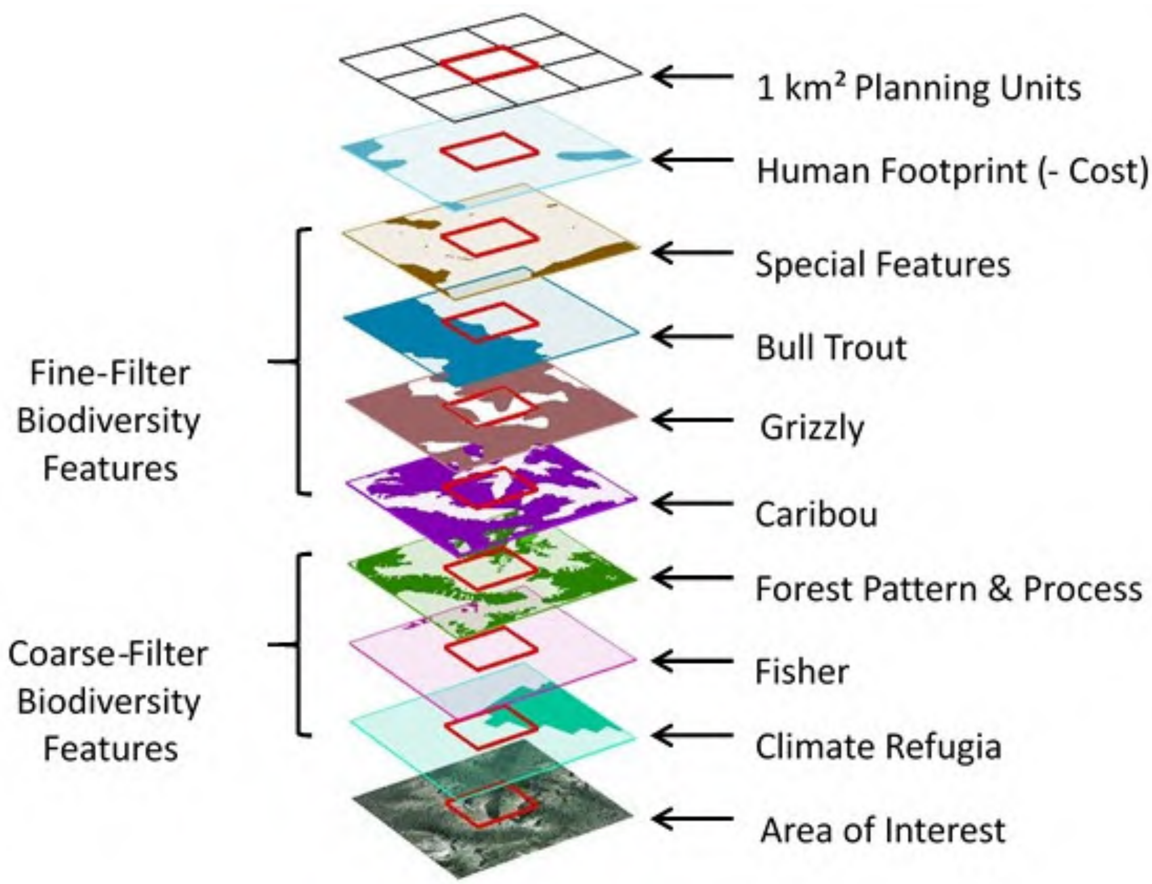


Figure 3. Graphical overview of the analytical process involved in Marxan-ILP modeling that involves examining areas of high value for select biodiversity features while minimizing overlap with the human footprint.

Understanding the landscape context for the WBCF allows the Forest to address questions such as:

- What areas contain high ecological value for the current distribution of select coarse and fine filter biodiversity values?
- What areas contain more theoretical diversity and thus might be higher priority for special management?
- What areas retain these values despite the presence of the human footprint?
- Where might the human footprint be compromising important high value areas or connectivity between values and present opportunities for ecological restoration?
- What does a climate change vulnerability assessment tell us about this landscape and the WBCF within it?
- Where might current biodiversity values shift in the future?
- How will future climate conditions likely affect forest values?
- What does this ecoregional analysis tell us about the role and potential importance of the forest regionally and about the influence of these larger dynamics on the forest itself?

Current Biodiversity Values

Biodiversity value feature layers were constructed from provincial government data sets and overlaid across the entire ecoregional area and made available for selection by Marxan-ILP. Feature values were transformed to raster data to allow for continuous pixel values in the preferential selection of areas with the highest biodiversity value. All biodiversity values were given an equal value of 1 if they were present in the landscape.

Coarse-filter Biodiversity Values – Forest Pattern and Process

Forest pattern and process represented an intersection of BEC zone, natural-disturbance regime (NDT), and age/condition with specific selection for Mature/Old forest types (as defined by the Biodiversity Guidebook) and early seral/natural burned forests in 10 individual layers (Figure 4). The intent was to provide sufficient late-seral stage forest to withstand average fire sizes without collapses in biodiversity and to accommodate the habitat requirements of fire-obligate species.

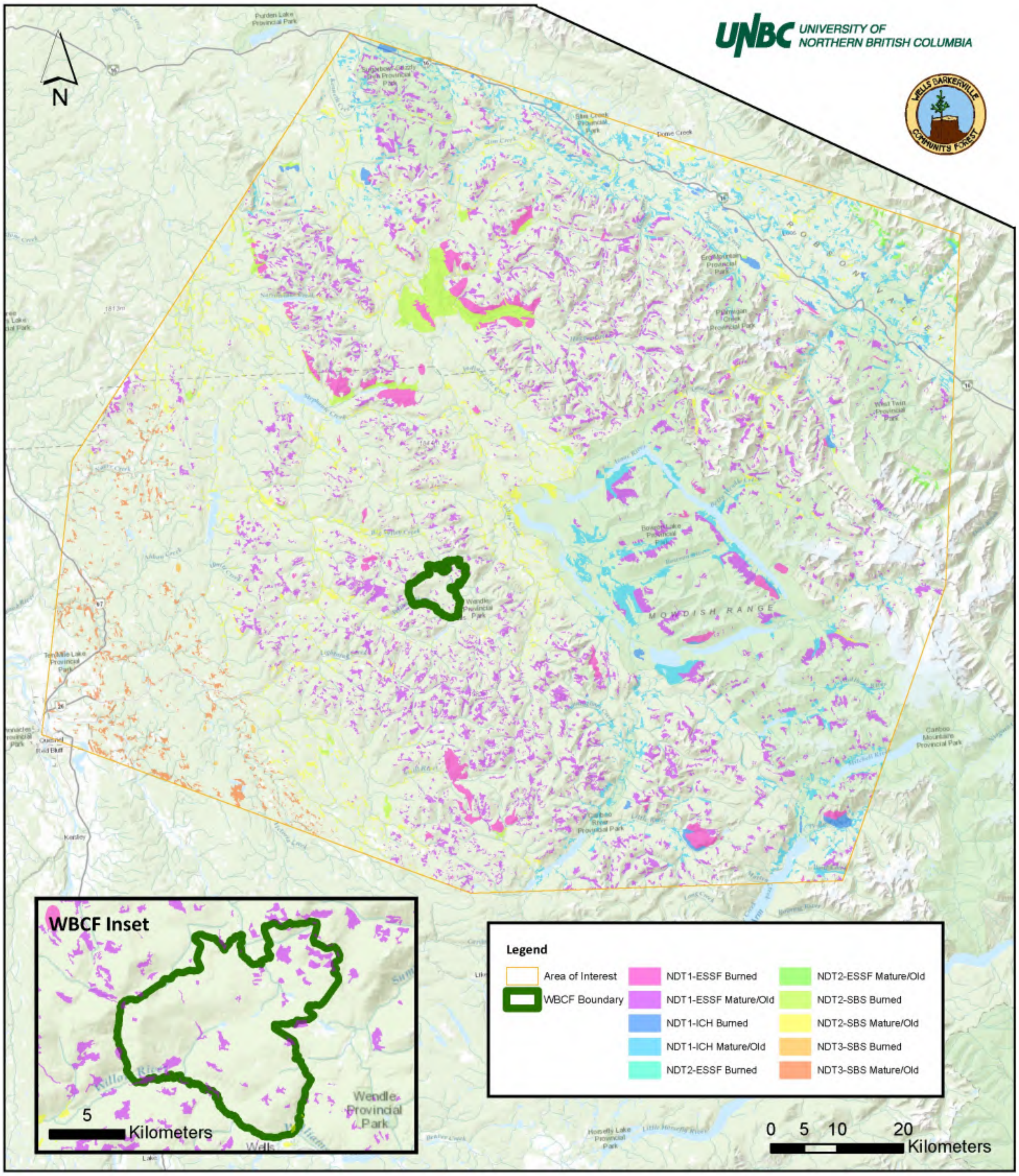


Figure 4. Spatial extent of all forest pattern and process layers used by Marxan-ILP to prioritize lands for selection in the WBCF ecoregion; inset provides detail for the Forest specifically.

Fine-Filter Biodiversity Values

Five fine-filter biodiversity values were mapped including woodland caribou (by herd), grizzly bear, fisher, salmonids/bull trout and wetlands (special features).

Woodland Caribou

We used best available data to map suitable habitat for caribou. Habitat Suitability Models (HSI) for caribou in this region are not as detailed as in other regions, particularly in the northern half of the study area. Our estimate is that the HSI data available within the ecoregion more generously maps good habitat and that in reality it is somewhat more restricted. Five herds currently occupy some portion of the regional range with the Barkerville Herd more likely to occur in the western and northern parts of the Forest (Figure 5). Better Caribou HSI mapping in the future as part of herd recovery planning will allow for refinement of these maps.

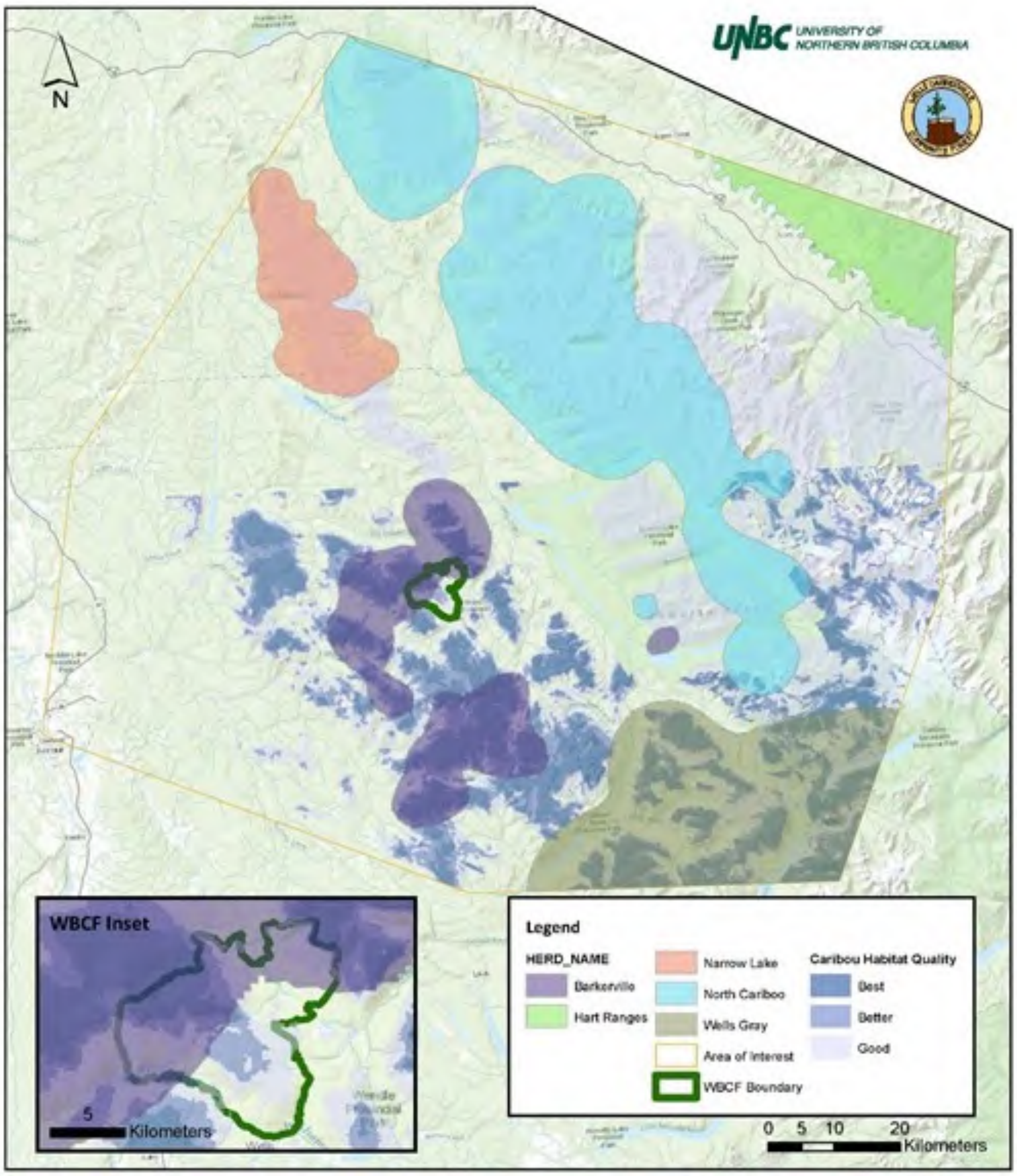


Figure 5. Potential caribou habitat and caribou herd distribution

Grizzly Bear

Grizzly bear were selected as an umbrella species that represent intact landscapes, open canopy forests and avalanche chutes. As disturbance sensitive species, grizzly bears have low tolerance for human encounters. Grizzly habitat is predominantly associated with the upland areas of the region, with habitat differentiated as high or very high quality habitat only available for the southern part of the region developed as part of the Cariboo Land Use Plan (Figure 6).

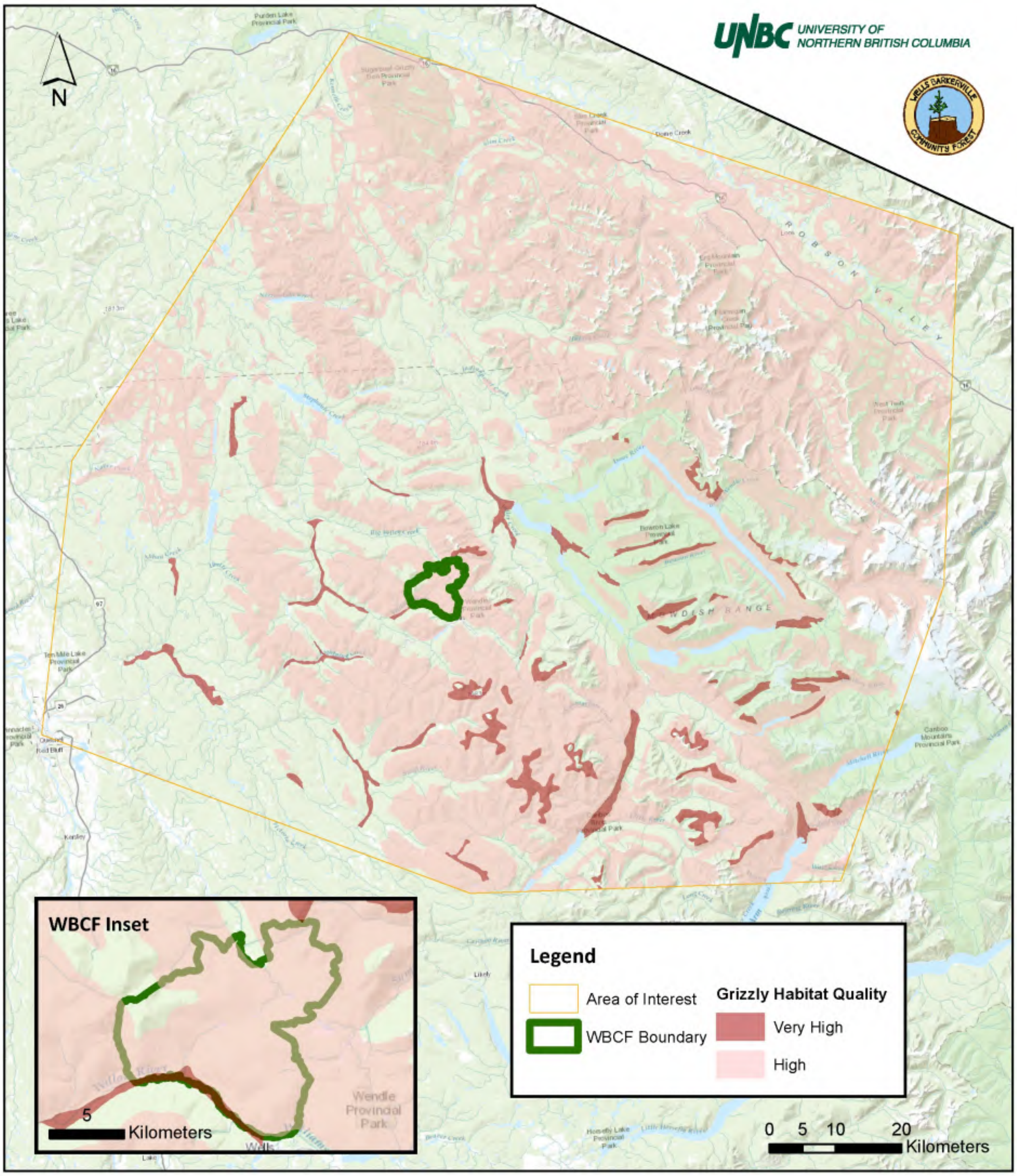


Figure 6. Grizzly Bear Habitat. More detailed habitat mapping differentiating between high/very high quality is only available for the southern half of the region.

Fisher

Fishers are a mid-trophic, carnivorous furbearer found only in North America with most of their range located in Canada. These forest-dependent species require very specific habitats for several life requisites at a variety of spatial scales. The need for a conservation strategy for fishers in British Columbia has become increasingly apparent in recent years due to anthropogenic disturbances resulting in changes in the composition and distribution of adequate fisher habitat. The effectiveness of past management strategies remains largely unknown and relatively little is known about fisher ecology in British Columbia. Consequentially, fishers have been classified as “Blue-listed” (of special concern) in the province. Although fishers are widespread over close to half of the province, the number of individuals is relatively low and they are vulnerable to trapping and habitat loss through logging, hydro-electric development or other land use changes. The recent mountain pine beetle outbreak in British Columbia has exacerbated the loss and degradation of fisher habitat.

Within BC, fishers occur in 4 different habitat zones: boreal, sub-boreal (moist subzones), sub-boreal (dry subzones), and dry forest zones. Fisher habitat data (April 2017 release) was obtained from the BC Fisher Habitat Working Group (www.bcfisherhabitat.ca). This Fisher Habitat Spatial Data was generated to provide quantitative guidance to help forest planners incorporate habitat needs of fishers into their forest planning decisions. This spatial data was developed to help planners make informed decisions of where and what to harvest (or avoid), while providing options to help maintain the habitats that fishers need within harvested stands and across landscapes. Including fisher habitat in this SCP promoted the selection of mid-elevation forested ecosystems required by fisher that are not well represented by the other biodiversity features used in the study (Figure 7).

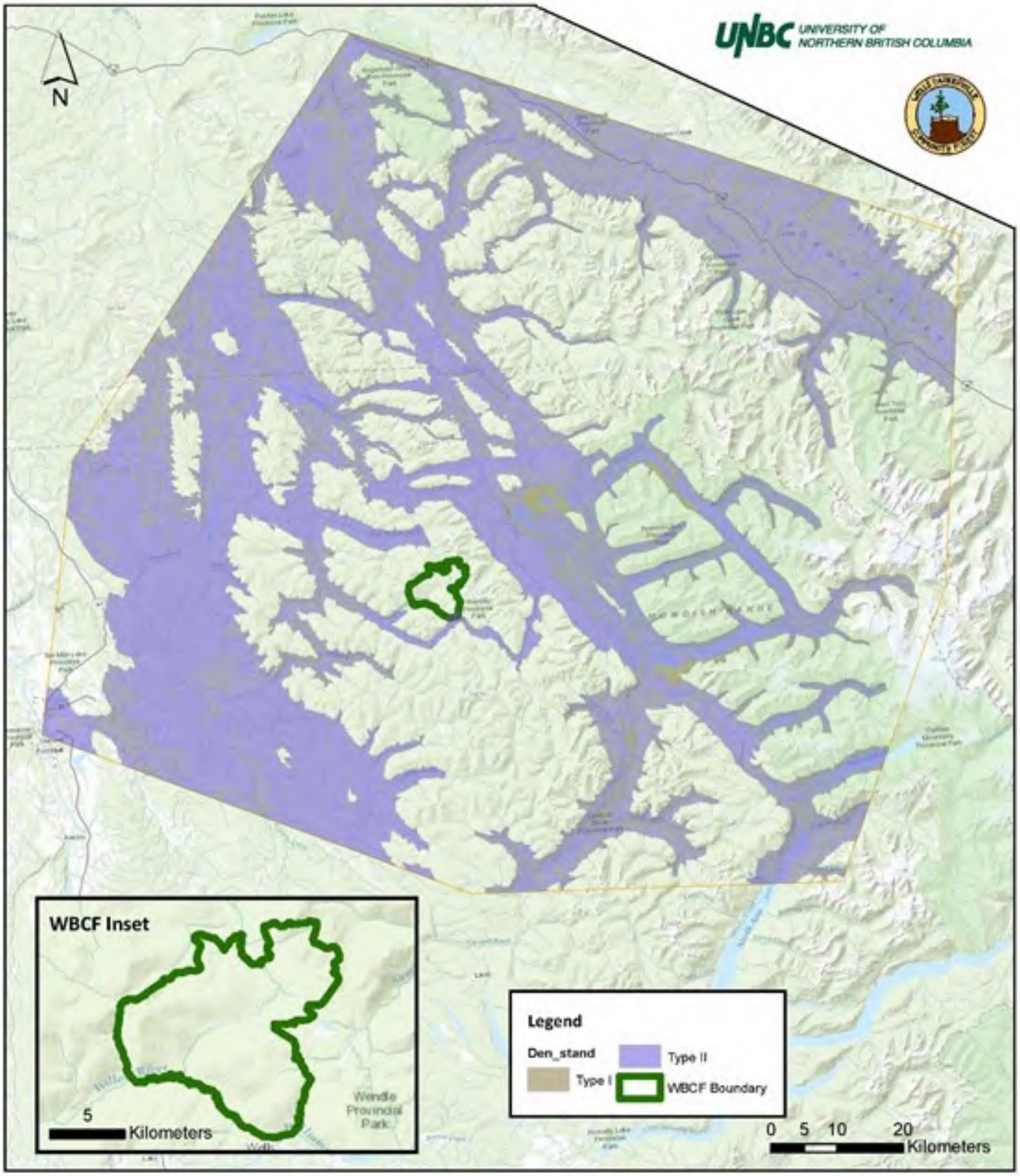


Figure 7. Fisher habitat by type where Type 1 is used 75% of the time and Type 2 is used 25% of the time

<u>Bull Trout / Salmon</u>

Bull trout and other members of the salmon family were selected as a fine-filter conservation feature as their habitats represent a broad diversity of aquatic values. Bull trout are associated with cold, high-elevation streams characterized by clean gravel beds and undisturbed riparian vegetation. Within British Columbia, suitable bull trout habitat has been reduced by anthropogenic disturbances including large-scale hydroelectric projects and forestry-related riparian degradation. Key areas were identified from the provincial critical fish habitat layer (Figure 8).

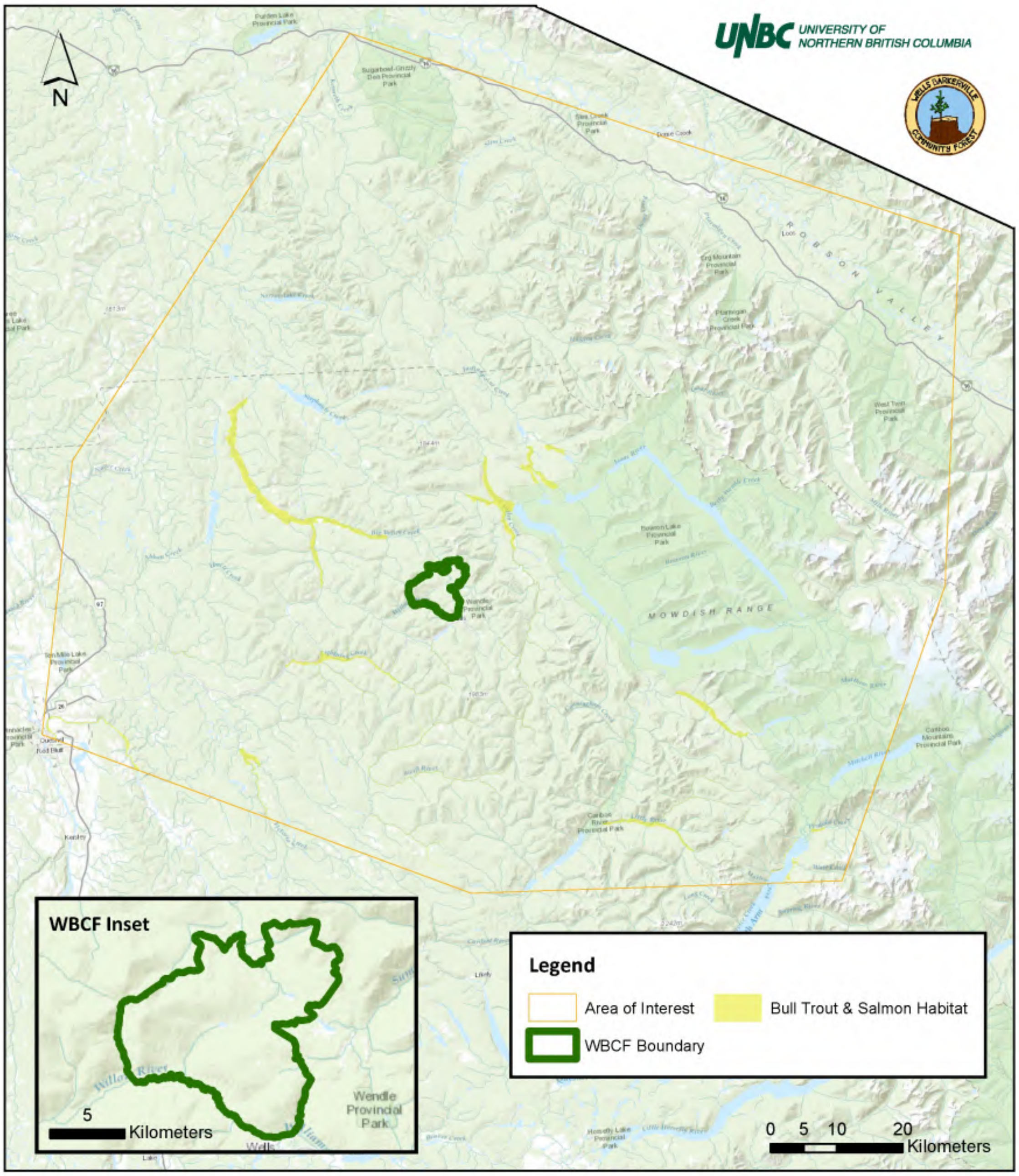


Figure 8. Critical bull trout and salmon habitat

Special Features – Wetlands & Karst Deposits

Special features are described as fine-filter ecosystem components that are of high biodiversity value, and sensitive and/or spatially-limited (Heinemeyer et al, 2004). Wetlands perform valuable ecosystem functions such as water filtration and provide important habitat for species such as migratory waterfowl. We incorporated wetlands for their aquatic value since their full distribution may not be adequately represented by the bull trout data. Karst formations were also included as special features as they provide habitat for flora and fauna that utilize caves for some or all of their life cycle (Curtis, 2018). In the WBCF region, karst formations are predominantly located in the north/McGregor whereas wetlands are scattered broadly across the landscape in the low elevation areas (Figure 9).

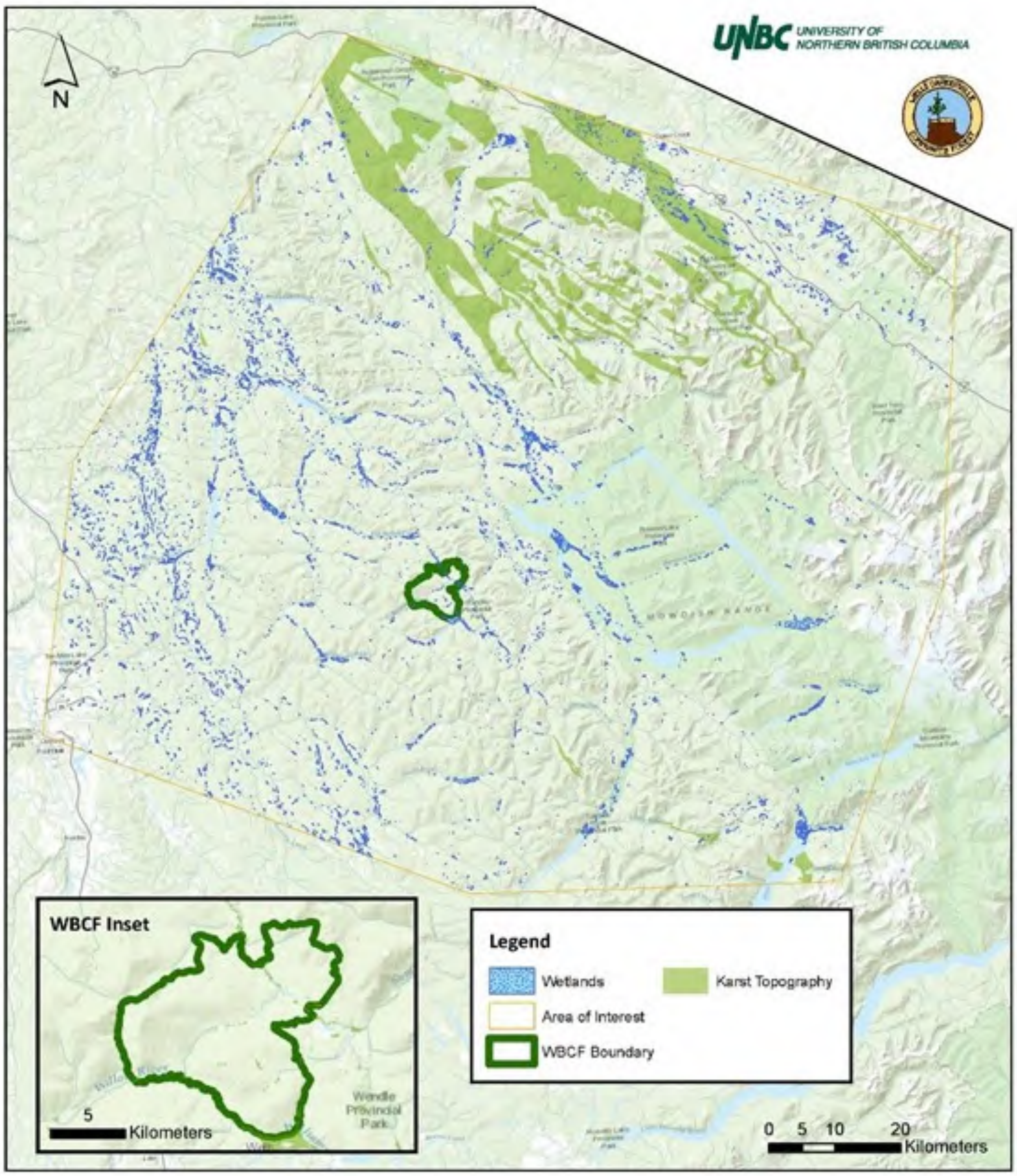


Figure 9. Special features: wetlands and karst topography

Climate Vulnerability & Climate Features

As climates continue to warm, there will be dramatic changes to the BC landscape. Climate projection data developed to examine climate change impacts on conservation identifies that the Wells-Barkerville Community Forest region will be significantly negatively affected by the changing climate, but will also provide some regional resilience to this change. This section summarizes climate features used in the Marxan analysis but also interprets their relevance to the WBCF area.

Climate vulnerability assessment involves examination of a number of different measures. Different measures are important at different scales and help to tell different parts of the story. Vulnerability is a product of examining the exposure of a biodiversity component to climate change compared to the inherent sensitivity of that component to change. Ideally, the resulting potential impact is then examined in light of the inherent adaptive capacity in the system to respond to that impact, or the ways in which management can enhance the adaptive capacity of the system to mitigate the potential impact (Figure 10).

We used a broad vulnerability assessment to identify climate features (for which data was available) that could be used in mapping where current biodiversity values may change because of future climate implications.

Changing Temperature and Precipitation

Climate projections predict that it will be warmer and wetter in the Wells area over the next 100 years. While Mean Annual Temperatures (MAT) will rise typically by 5 degrees from historic averages to 2085, in particular, summers will be significantly warmer in the last half of this century (Figure 11). Precipitation will also increase approximately 113 mm (from historic averages to 2085) however, summers are predicted to be dryer (Figure 12).

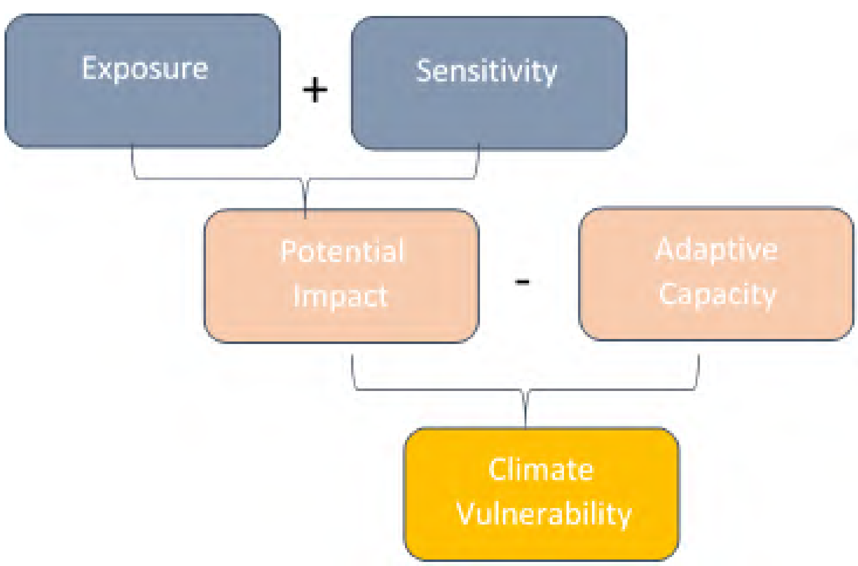


Figure 10. Climate vulnerability assessment

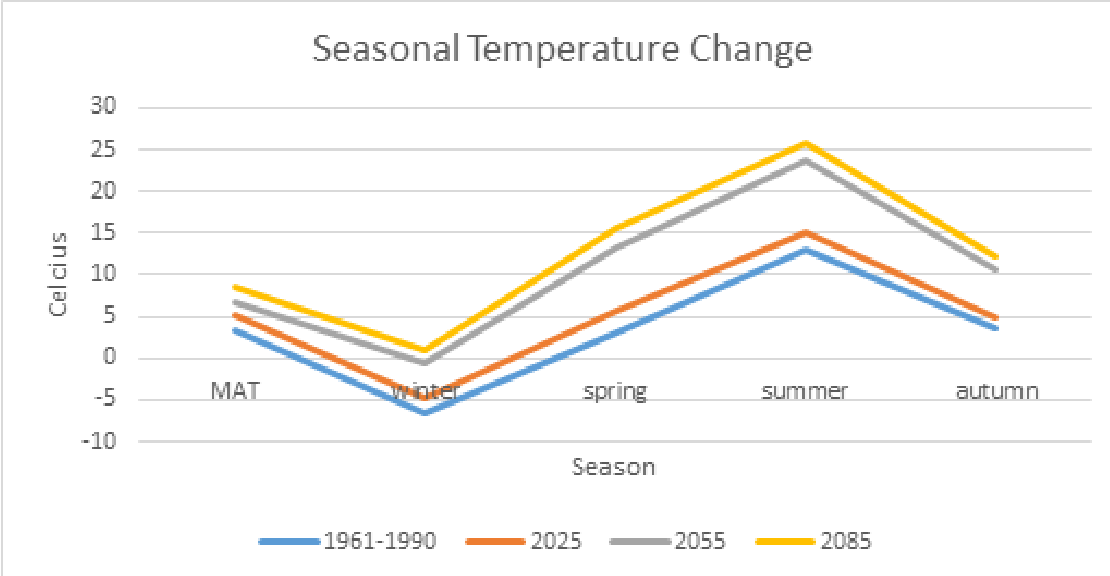


Figure 11. Mean annual temperature and seasonal temperature from historic normal to 2085.

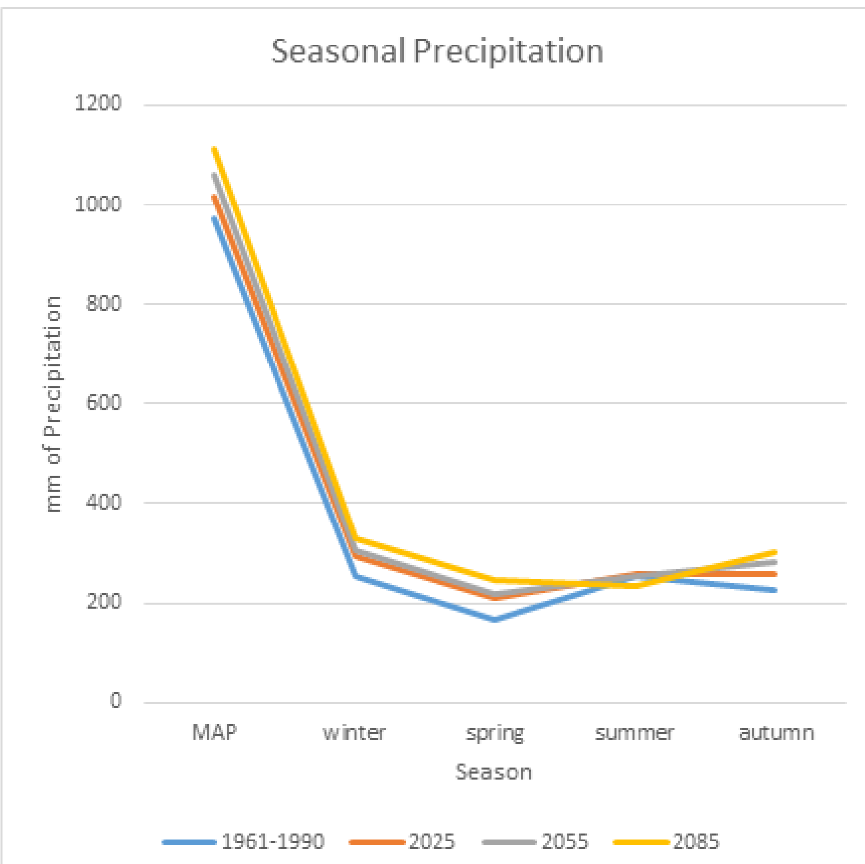


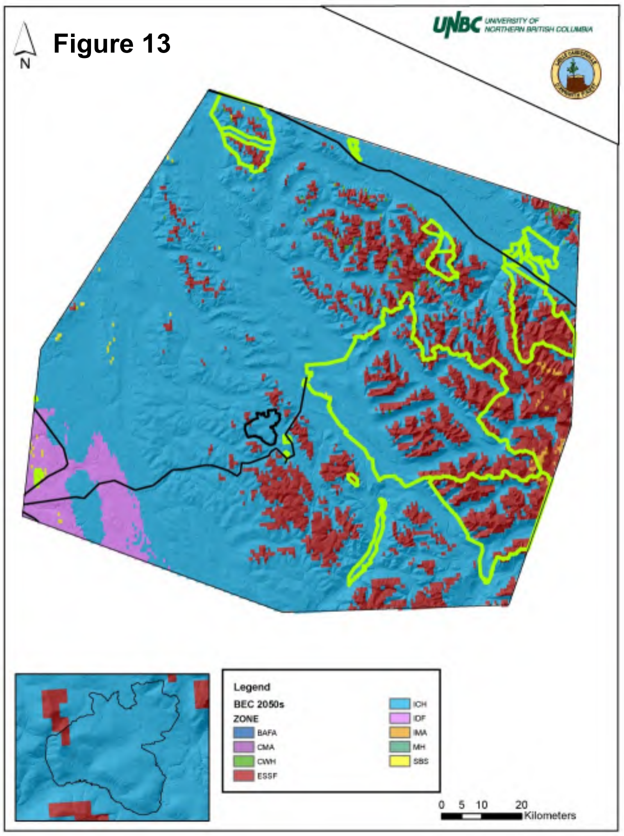
Figure 12. Mean annual precipitation and seasonal precipitation from historic normal to 2085.

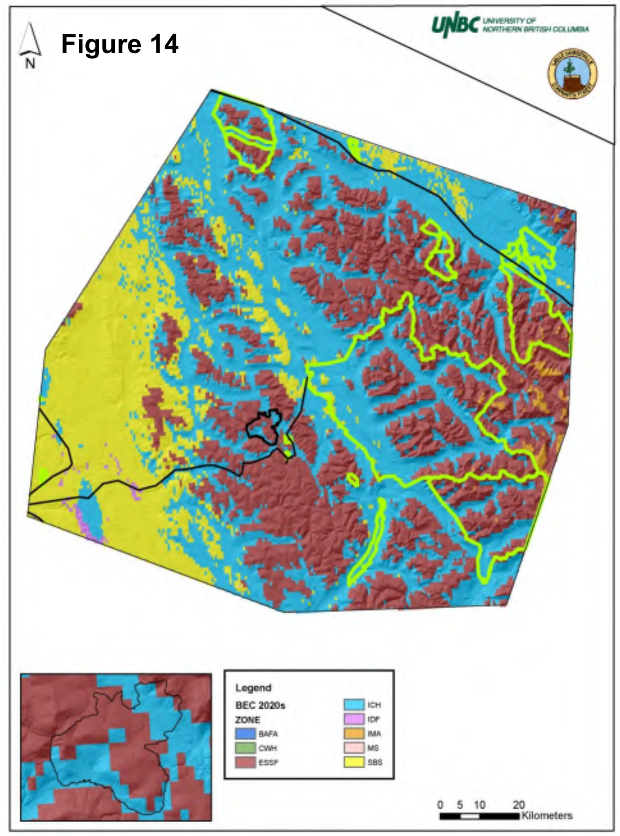
Climatic Dissimilarity and Sensitivity

Fundamentally, examining the sensitivity of a feature to a changing climate is about examining how dissimilar the change is from the current situation to the future situation. The more dissimilar the climate environment the biodiversity value will face the more likely it will be to be vulnerable to that change. However, not all change is equal. Measures of absolute climatic dissimilarity track change without analyzing the local context. Such an analysis at the North American scale shows us that areas with higher latitudes and elevations will be most climatically dissimilar in the future. However, relative climatic dissimilarity where context is part of the analysis will show that the climate exposure in mountainous areas (elevational change) will likely be less impactful than an absolute climate dissimilarity measure would show. This is because mountainous environments are areas that already are exposed to high interannual variation in temperatures and precipitation amounts and thus are inherently less sensitive to change.

Shifting Vegetative Communities

At a broad level, changes in temperature and precipitation will drive shifts in vegetative communities either northward or up slopes. For mountainous environments, alpine environments are shrinking as trees colonize further up mountains (Figure 13-15). However, where there is insufficient soil development (as is the case on what is now, or what has recently been glaciated landscapes) these areas will not be able to support vegetative shifts upward. BGC envelope mapping predicts that ESSF and SBS BEC Zones are expected to decline significantly with significant increases in ICH (Figure 16).





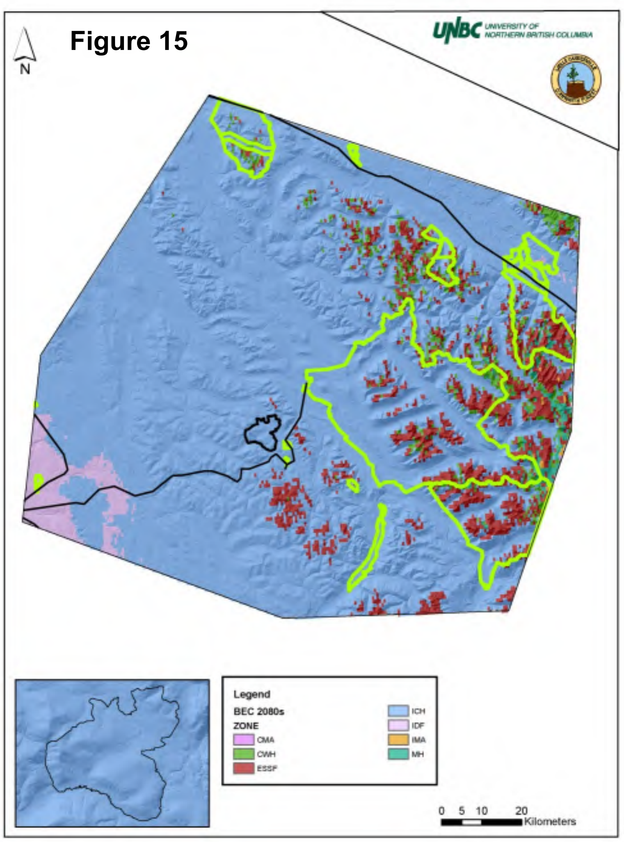


Figure 13-15. Current and projected biogeoclimatic (BGC) zone distributions in 2050 and 2080 under RCP 8.5.

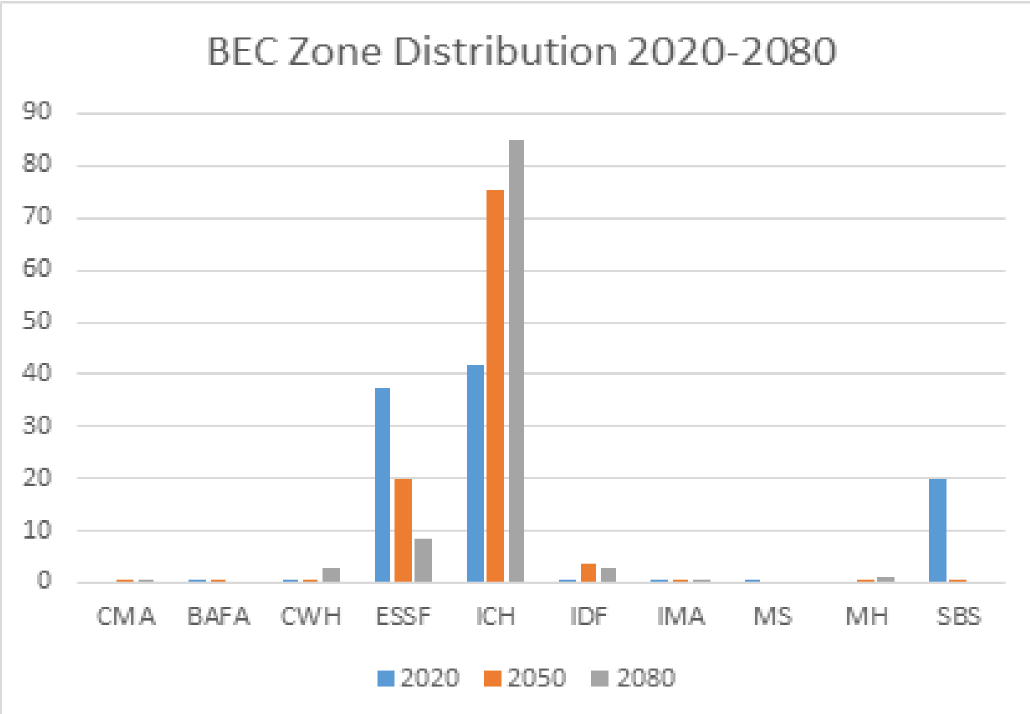


Figure 16. Biogeoclimatic (BGC) zone distributions

Disappearing Climates and Novel Ecosystems

Not only will current vegetative communities shift, but there will be ecosystems that disappear as new, or novel, ecosystems will emerge (Figure 16). High elevation and latitude areas often are characterized by exceptionally high or infinite forward climate change velocities that represent disappearing climates. Disappearing climates increase the probability of declining populations, species extirpations, extinctions, and community disruption for species endemic to particular climatic regimes. Identification of these areas may lead to responses associated with combating species extinctions and losses to biodiversity. These dead-end climates may need managed relocations, or *ex situ* measures such as captive breeding or gene banking.

In some cases, high or infinite backward velocities can mean there is no climate analog and a new or novel climate that we have not yet seen before (Carroll et al., 2015; Mahony et al., 2017, 2018) (Figure 17). Mahony, MacKenzie, and Aitken (2018) found that within British Columbia, novel climates with no historical analog are expected to emerge by the mid-21st century, predominantly in low elevation areas in the coastal, southern interior, and northeastern regions of the province. Although the emergence of novel climates tends to occur in areas of the lowest elevations, they can also occur in high elevations of mountainous regions. Novel climates may promote the development of novel species associations, biomes, and other ecological surprises (Williams et al., 2007). They also are likely to contain a depauperate assortment of species adapted to future climate conditions, presenting the potential opportunity for establishing non-native species through managed relocation (Carroll et al., 2015).

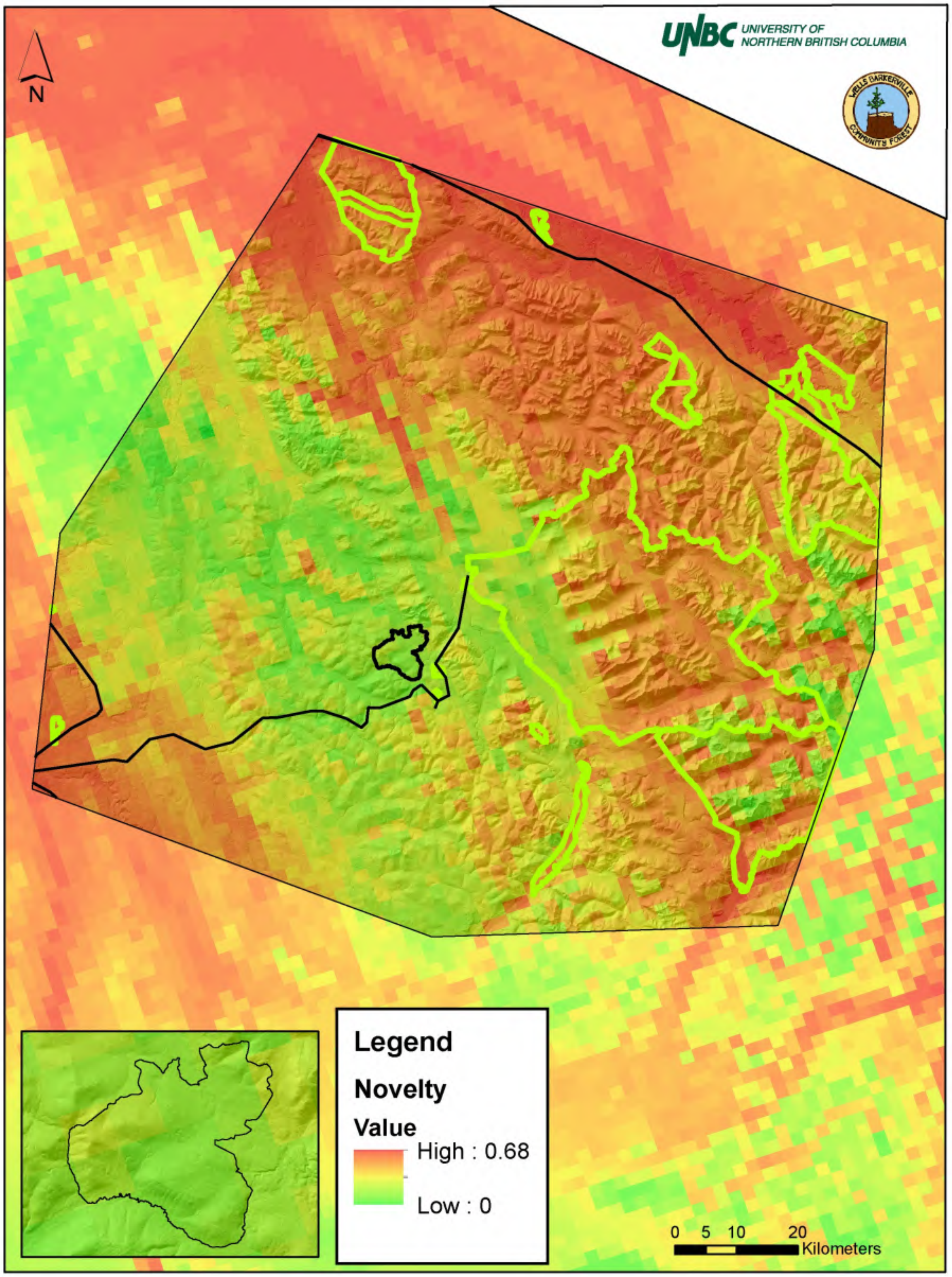


Figure 17. Potential for novel ecosystems to emerge

Climate Velocity

Species that are adapted to these ecosystems will either need to move to keep up or will be out-of-sync with the habitats that they need to survive. A species can track climate if climate velocity is less than its potential dispersal rate. However, the rate of climate change is likely to be significantly faster than many plants and animals can move. This means that most species will need to make dramatic changes in their distribution over only a few generations in order to keep up with their biophysical niche.

Forward climate velocity describes how fast (e.g. km/year) climates are shifting across a landscape (i.e. geographic shifts of climate analogs over time). Forward climate change velocity can be used as a tool for forecasting climate change-induced migration as it represents the rate at which species must migrate over the surface of the earth to maintain constant climate conditions. For example, trees on average have a medium velocity of just a few km/decade whereas nearest climate analogs for RCP8.5 suggest a global average of 20 km/decade. Split hoofed mammals in contrast have an average velocity of 90 km/decade and thus are more likely to be able to move across the landscape. The rate of projected climate change is unprecedented and, overall, is expected to be 10- to 100-times faster than the ability of trees to migrate in Canada. This discrepancy may result in species becoming maladapted, less productive and more vulnerable to insects and diseases.

Species can keep up with these changes either through mobility, assisted mobility, or because they have enough adaptive capacity to tolerate a wider spectrum of climatic conditions than they are currently experiencing. Species at the edge of current distribution can be particularly important and/or vulnerable under these conditions.

Low velocity values indicate that future climate analogs (i.e., suitable climate/ habitat) can be found nearby, whereas high velocity values indicate the converse. Forward velocity is often higher in alpine areas as the nearest future climate analog may require migration to distant higher elevation mountaintops (Figure 18-19). If the forward climate velocity rate exceeds the rate of biological response (i.e. the rate of migration or adaptive evolutionary change) the resulting impacts to species distributions, community structure and ecosystem function could be profound. Hence, climate-sensitive species inhabiting a site with high forward velocity are potentially threatened with extinction.

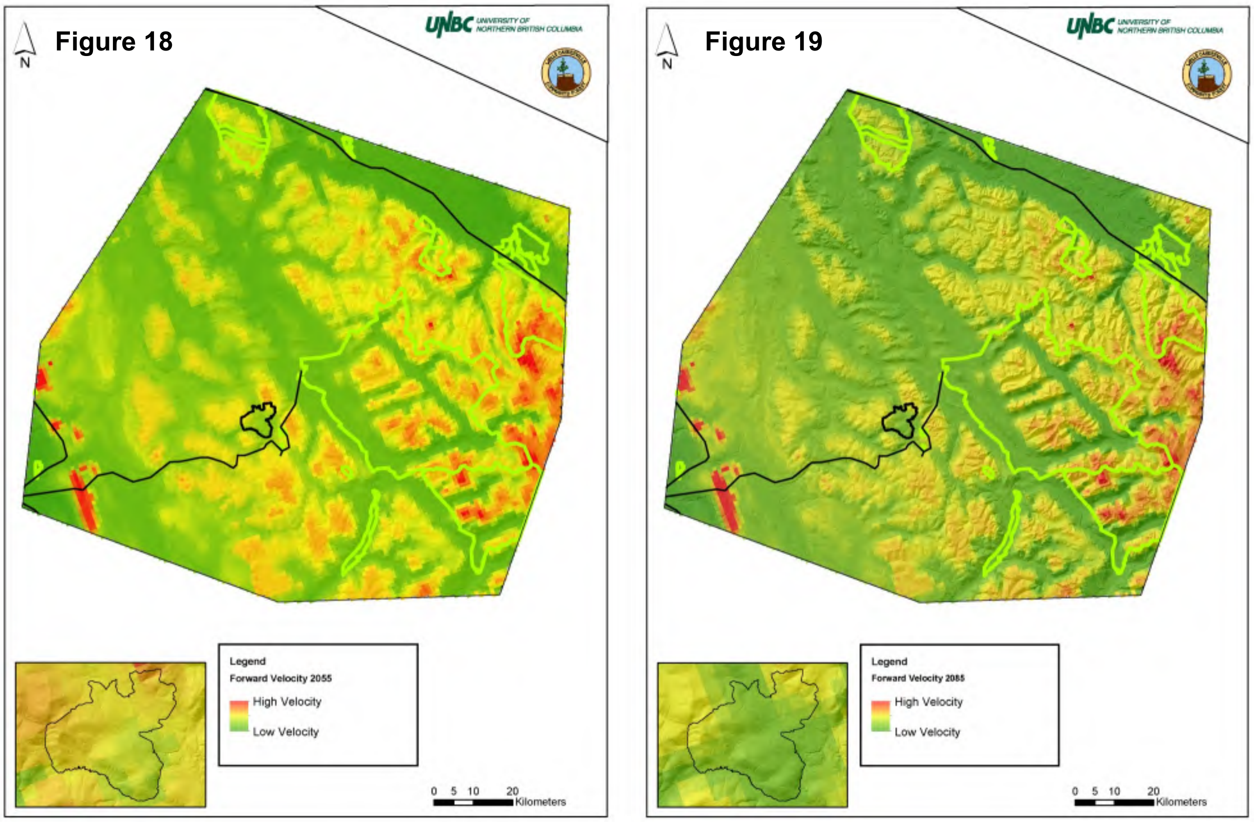


Figure 18-19. Forward velocity for 2055 and 2085

Climate Refugia

Locations that are resistant to climate change are known as refugia and can facilitate species persistence under changing conditions (Roberts and Hamann, 2012). Refugia can be described as macrorefugia or microrefugia, as well as *in situ* or *ex situ* refugia (whether climate refugia are located within or outside of a species' current distribution). Microrefugia have potential to withstand greater amounts of warming than macrorefugia and may persist even when regional climate conditions are unsuitable (Ashcroft, 2010). Consequently, conserving microrefugia may be one of the only means of conserving rare or threatened species that occur in small, fragmented populations (Maschinski, Baggs, Quintana-Ascencio, & Menges, 2006). These microrefugia may also serve as steppingstones as climate shifts over time.

Microrefugia are best identified where there is very fine scale climate mapping, however it is topography that creates complex variations of exposure to precipitation, wind and radiation, and sheltered locations that may be buffered from regional climate change (Figure 20) (Morelli et al., 2016). Thus, coarse-scale methods like areas of high land facet diversity may actually prove more successful at microrefugia identification than fine-scale models (Trivedi et al., 2008; VanDerWal et al., 2009b).

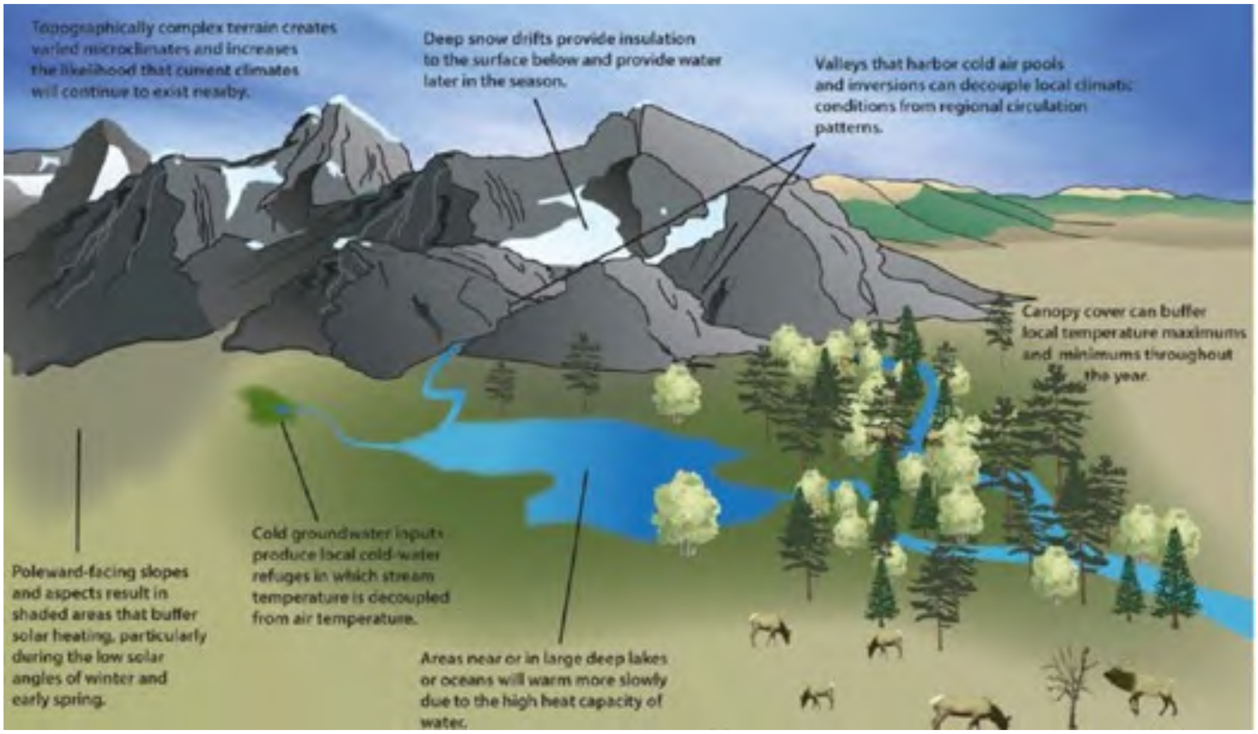


Figure 20. Illustration of potential microrefugia resulting from topographic diversity (Morelli et al., 2016)

Land facet diversity maps (Figure 21) can be used to predict areas of potential microrefugia and suggest areas of potential examination for microrefugia where resource use should be minimized to protect the adaptive capacity of the system. At smaller scales the LiDAR data available for the Forest can also be used to identify some potential microrefugia.

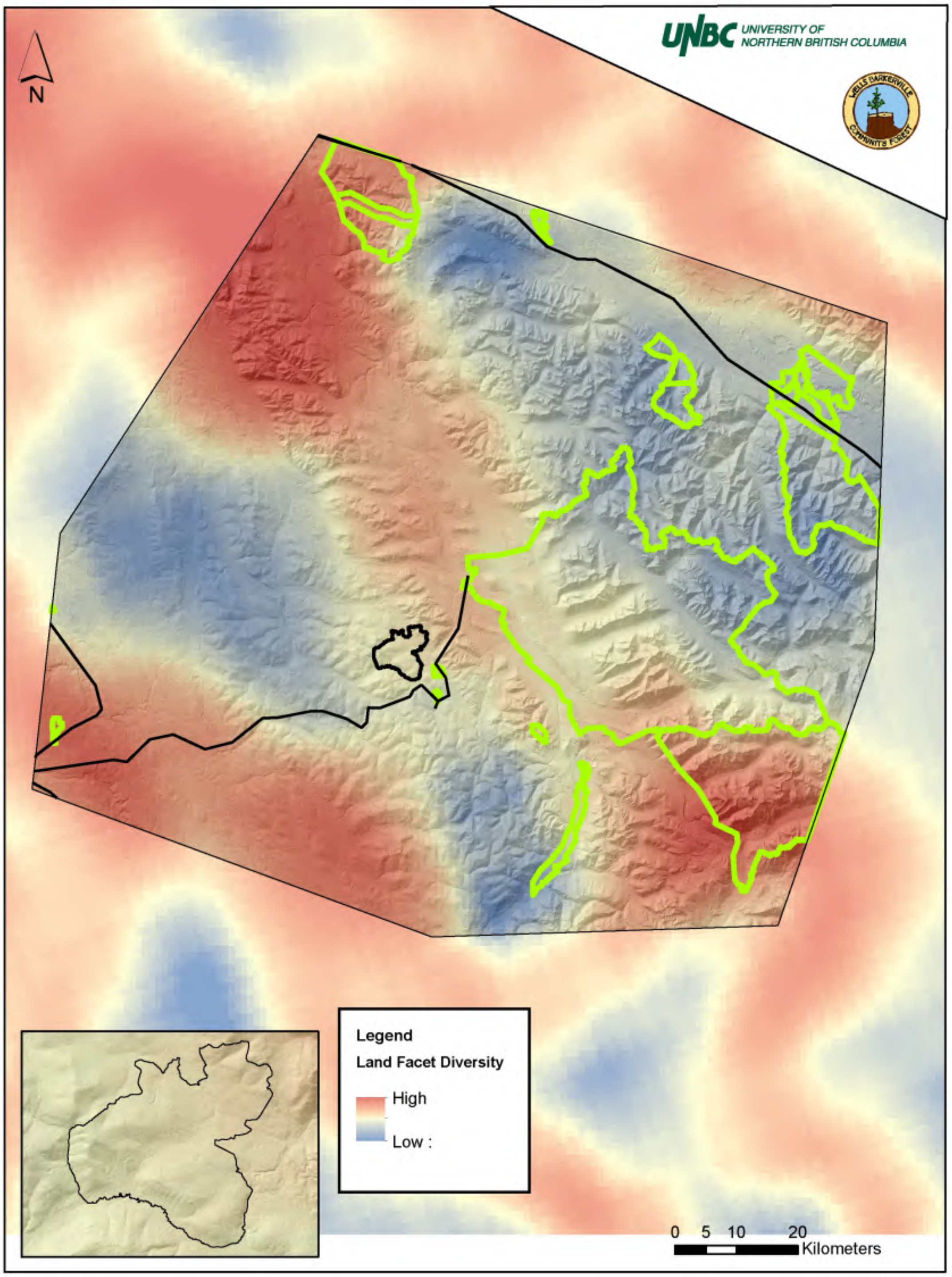
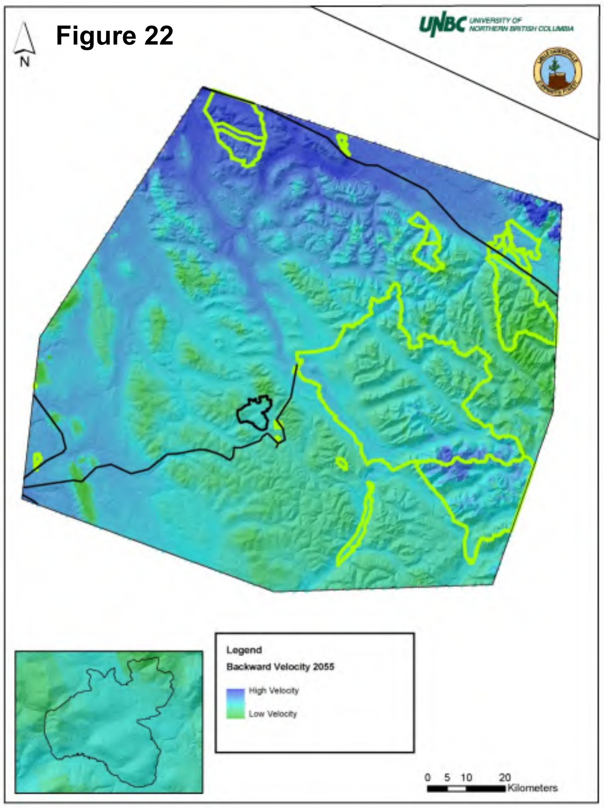


Figure 21. Land facet diversity analysis can help identify potential micro-refugia sites

Macrorefugia can provide a more robust buffer against extinction especially for large-bodied mammals or those with larger home ranges (Stewart, Lister, Barnes and Dalen, 2010). These refugia can be identified using backward velocity analysis (Figure 22-23). Analysis of the WBCF region suggests that the potential macrorefugia are located to the north and east of the Forest. The Forest may serve moderately as a mid-term macrorefugium but has relatively limited long-term potential in this regard. However, its mid-term value as a macrorefugium combined with potential microrefugia may serve as steppingstones to help species move north, east, and up slope.



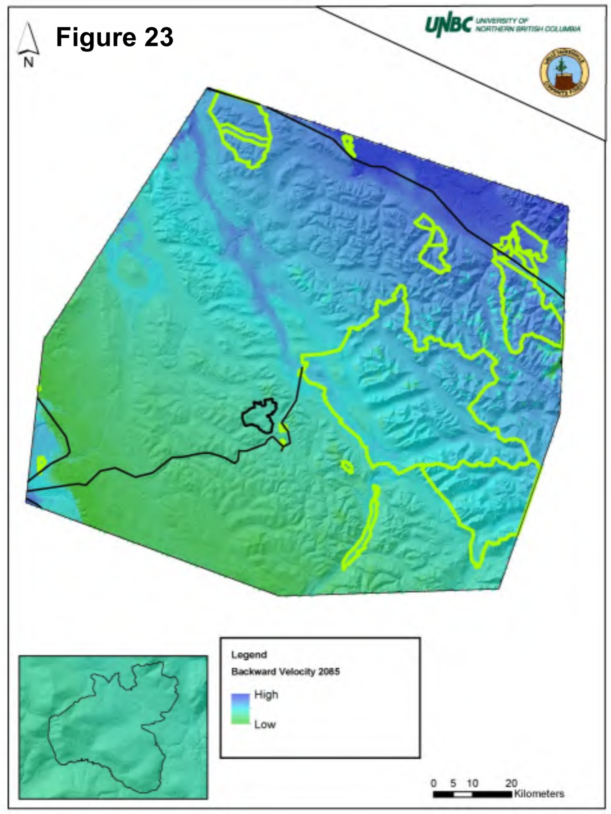
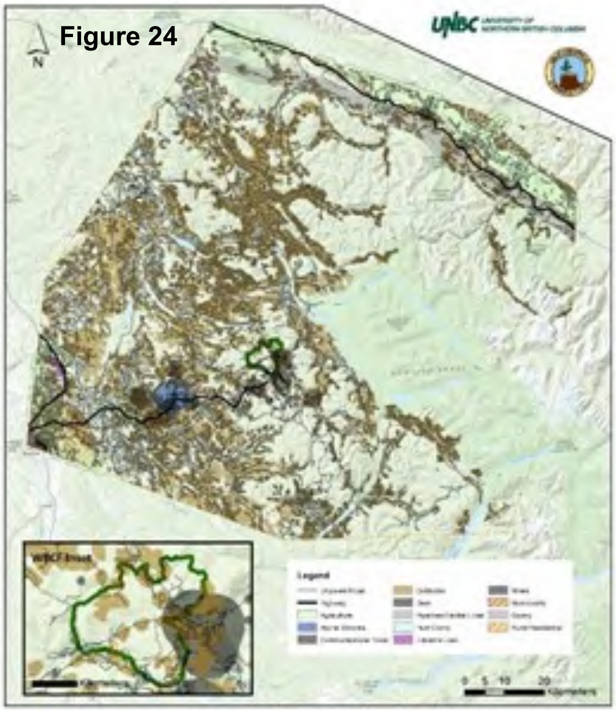


Figure 22-23. Potential for macrorefugia identified through backward velocity analysis for 2055 and 2085

Cost Layer: Human Footprint

Marxan-ILP allows for the preferential selection of high biodiversity value areas while simultaneously avoiding the selection of certain areas through the use of a cost surface. A cost surface is a spatial representation of elements in a planning region that have been identified as having a negative impact on the conservation features being selected for. A human footprint layer was constructed consisting of features such as mining, forestry, roads, pipelines/hydro-lines, urban/rural residential areas, dams etc (Figure 24).

These layers were buffered according to standardized approaches adjusted from Mann and Wright (2018). We separated the human footprint into hard/permanent human footprint (e.g., roads, mines, urban areas) and soft (semi-permanent human footprints) (e.g., forestry clear cuts) and weighted the hard footprints. The datasets were combined and summed to obtain a disturbance rating from 0 (no disturbance) to 13 (all disturbance layers overlapped) (Figure 25).



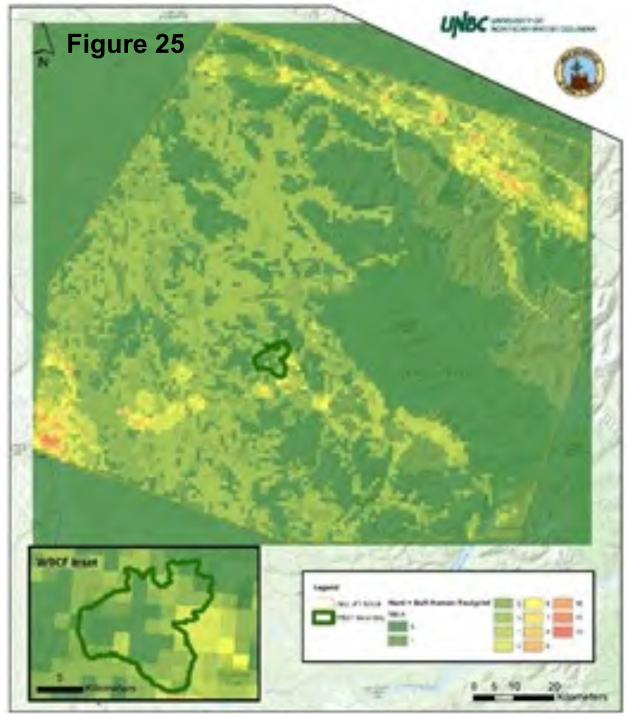


Figure 24-25. Buffered human footprint and cost surface constructed from overlapping hard and soft human footprint

Scenario Targets and Results

One of the primary goals of this project was to prioritize lands within the broader region based on their biodiversity value to help identify the place of the WBCF in the region and to identify the biodiversity and ecological context, connectivity and promote climate change resiliency. We ran three scenarios to model the results to include current, future, and current plus future biodiversity feature targets (Table 1).

Scenario targets were selected based on previous research. As there were no specific targets available for these biodiversity features within the local region we selected adjacent targets from: the *Implementation Plan for the Ongoing Management of South Peace Northern Caribou in British Columbia* (Ministry of Environment, 2013), the *Muskwa-Kechika Management Area Biodiversity Conservation and Climate Change Assessment* (Yellowstone to Yukon Conservation Initiative, 2012), the *Biodiversity Guidebook* (Province of British Columbia, 1995), and the *Conservation Area Design for the MKMA* (Heinemeyer et al, 2004). In Scenario A targets were set only for biodiversity features and not for climate features with the converse for Scenario B. In Scenario C, targets were set for both biodiversity and climate features.

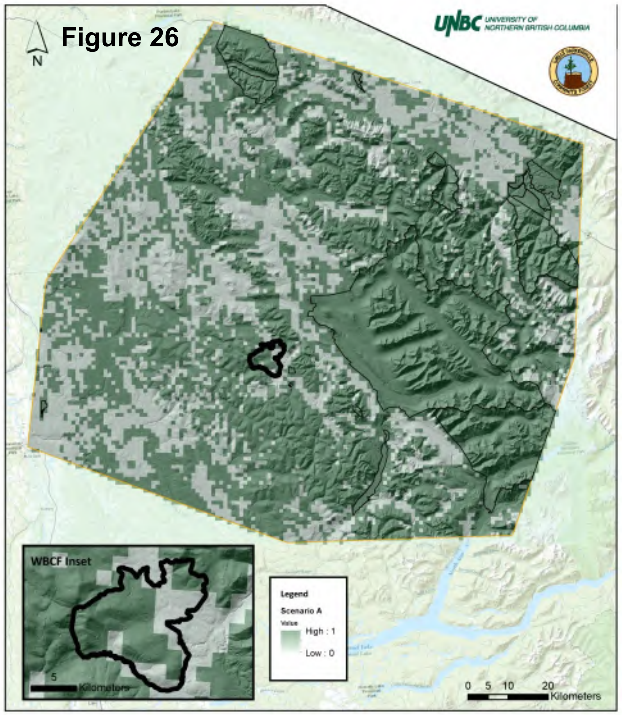
Table 1. Scenarios

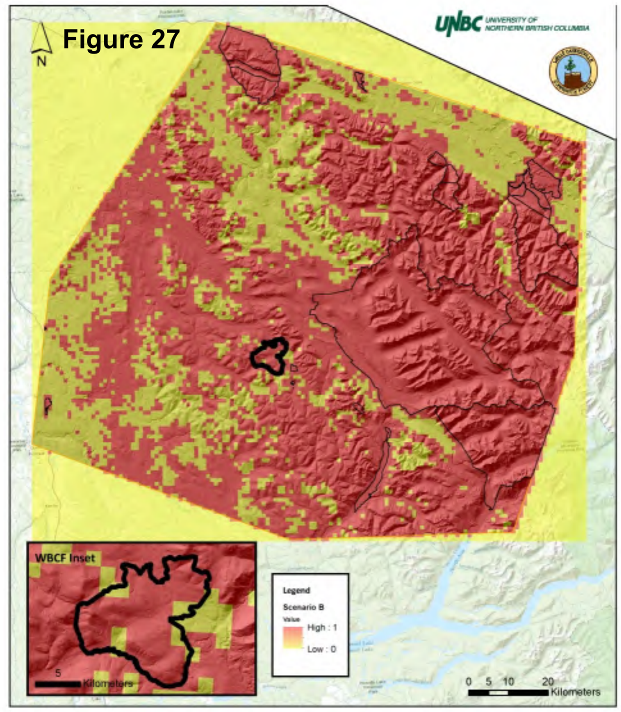
Scenario	Biodiversity Value Inputs
A (Current)	caribou (5 herds); fisher; grizzly bear; trout/salmon; special features; forest patterns & processes
B (Future)	backward velocity (2055 & 2085); forward velocity (2055 & 2085); current flow; tree/bird refugia
C (Current + Future)	All of the above

For each of the three scenarios, Marxan-ILP produced a solution by selecting those planning units that met conservation targets, had the highest individual and cumulative conservation value, and had the lowest cost. Analysis was done in a 1 km^2 planning unit grid contributing to the coarsely pixelated solution. Table 2 presents the tabular results of all three scenarios. While in other applications of the approach setting only current climate/biodiversity feature targets has performed reasonably well at also achieving future climate targets (see Mann, 2020), in the WBCF region, scenario C (Current and Future Climates) was clearly superior in achieving or exceeding all targets (Figures 26-28).

Table 2. Scenario targets and results

	Scenario A - Current Climate		Scenario B - Future Climate		Scenario C - Current & Future Climate	
Biodiversity Feature	**Target**	**Result**	**Target**	**Result**	**Target**	**Result**
Caribou - Barkerville Herd	90	90.04	0	77.31	90	90.04
Caribou - Hart Ranges Herd	90	90.45	0	65.17	90	90.45
Caribou - Narrow Lake Herd	90	90.13	0	77.15	90	90.13
Caribou - North Cariboo Herd	90	90	0	87.86	90	90
Caribou - Wells Gray Herd	90	90.08	0	91.67	90	90.36
Fisher Habitat	60	60.01	0	61.05	60	64.85
Grizzly Habitat	60	76.72	0	75.96	60	81.22
Trout/Salmon Habitat	60	64.2	0	73.92	60	77.01
Special Features	60	62.91	0	62.89	60	67.79
NDT1-ESSF Burned	100	100	0	63.23	100	100
NDT1-ESSF Mature/Old	74	79.14	0	79.39	74	84.55
NDT1-ICH Burned	100	100	0	61.72	100	100
NDT1-ICH Mature/Old	75	75	0	68.06	75	75
NDT2-ESSF Burned	100	100	0	66.67	100	100
NDT2-ESSF Mature/Old	75	75.57	0	71.87	75	87.92
NDT2-SBS Burned	100	100	0	35.74	100	100
NDT2-SBS Mature/Old	66	66	0	65.53	66	66.01
NDT3-SBS Burned	100	100	0	73.72	100	100
NDT3-SBS Mature/Old	76	76.02	0	39.66	76	76.07
Backward Velocity 8.5 2055	0	74.51	75	80.94	75	81.56
Backward Velocity 8.5 2085	0	64.51	75	75.01	75	75.01
Forward Velocity 8.5 2055	0	65.32	75	75	75	75.01
Forward Velocity 8.5 2085	0	59.17	75	75	75	75
Current Flow	0	83.57	20	86.34	20	88.39
Tree/Bird Refugia	0	80.11	90	90.01	90	90.01





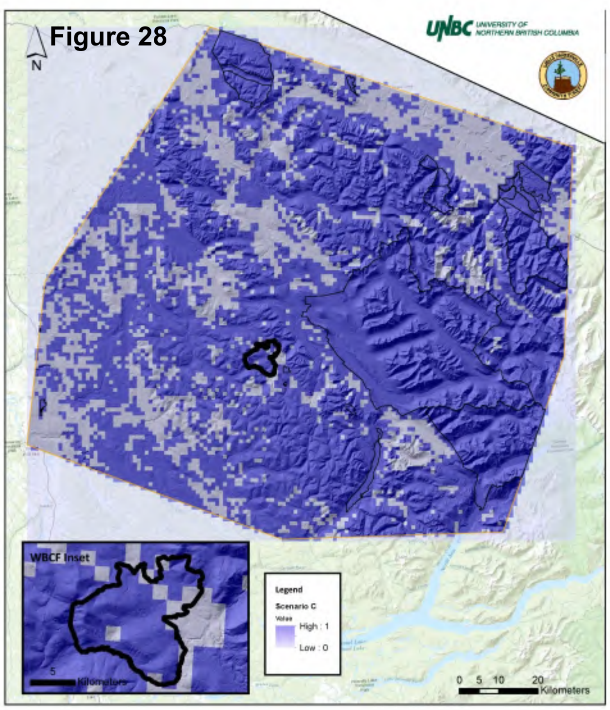


Figure 26-28. Marxan Scenario Solutions A-C where lands in Scenario A: Current Biodiversity Values (green), Scenario B: Future Climate (yellow), or Scenario C: Current and Future (blue) are selected as important conservation lands.

Scenario A (current biodiversity values) preferentially selected areas within protected areas and on high elevation lands whereas Scenario B (future climate values) identified a more dispersed solution across the landscape (Figure 27). Scenario C, with targets for both current and future climates/biodiversity features, covers approximately 76% of the WBCF region (Figure 28). The WBCF is situated in an area of relatively high value for all 3 scenarios with existing human footprint strongly influencing what areas are selected.

Using Scenario C as the primary model we introduced value back into the Marxan solution. Figure 29 displays the number of conservation features captured per planning unit. The maximum number of overlapping conservation features that Scenario C was able to capture was 13, with the highest numbers predominantly in the lower elevation areas that were selected. The WBCF captures some moderately high diversity areas and while small, makes a critical contribution from a north/south and east/west perspective for current and future climates.

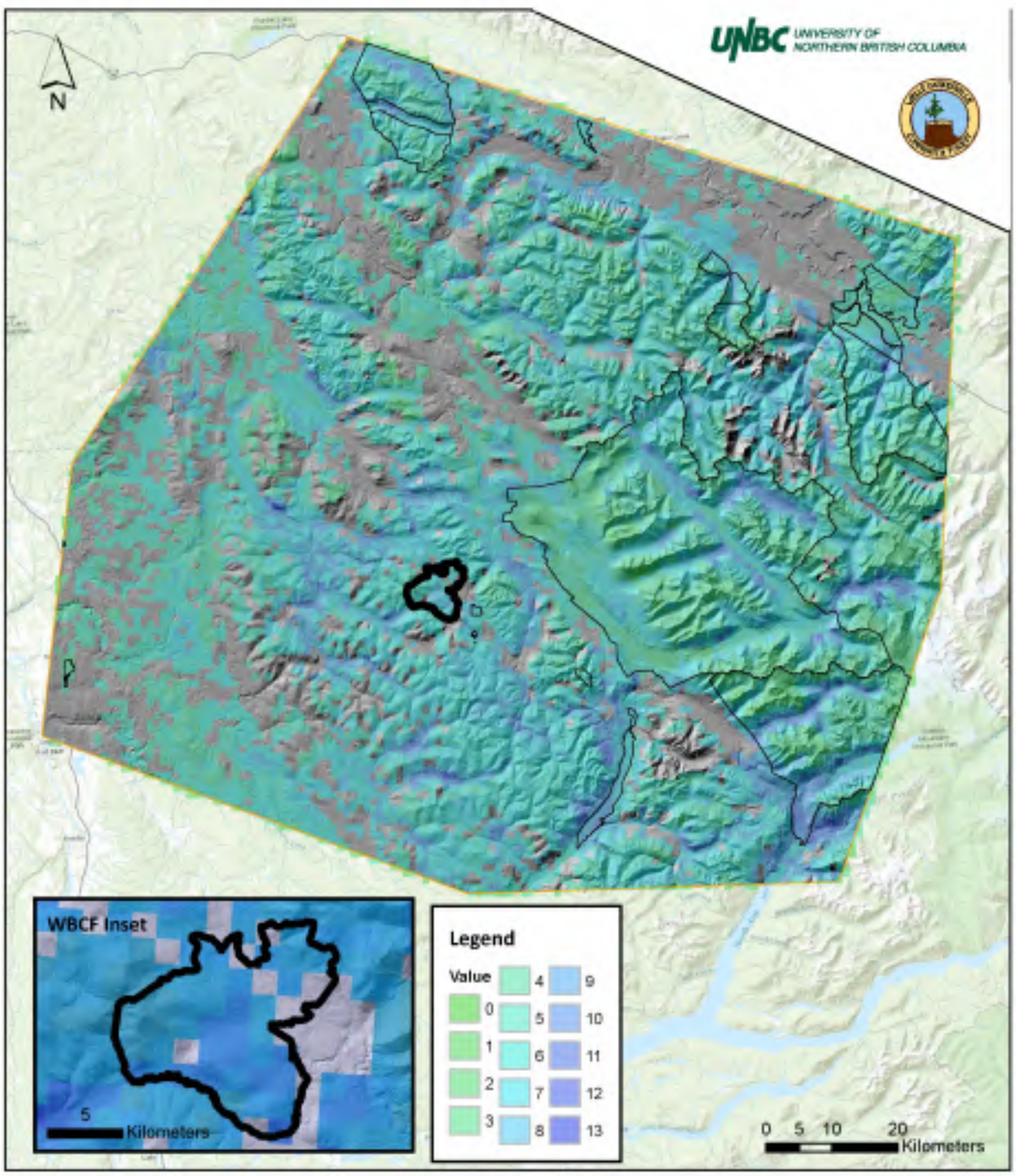


Figure 29. Regionally important biodiversity features displaying density of overlapping features

Landscape Resistance and Connectivity

Connectivity across the landscape promotes ecological persistence by facilitating dispersal, allowing for critical ecological exchanges at the genetic and population levels (Wright, 2016). By enhancing the structural connectivity (landscape permeability) across landscapes, functional connectivity (actual movement of organisms and their genetic material) can be significantly improved, thus promoting ecological persistence (Doerr et al., 2011). Connectivity is also particularly important when we consider climate change, as plants and animals need the opportunity to be able to move through the landscape to keep up with changing environments.

Permeability, or its converse resistance, demonstrates the potential for species and ecological processes to move across the landscape. Highly resistant landscapes are those that have permanent human footprints, land covers like glaciers that are not suitable for most species, or very steep slopes that are difficult to move across. The landscape resistance/permeability analysis for the WBCF region displays landscape resistance as determined by land cover, slope, and anthropogenic disturbance. Figure 30 shows landscape resistance in the WBCF region where yellows are the most resistant and darker blues are the least resistant.

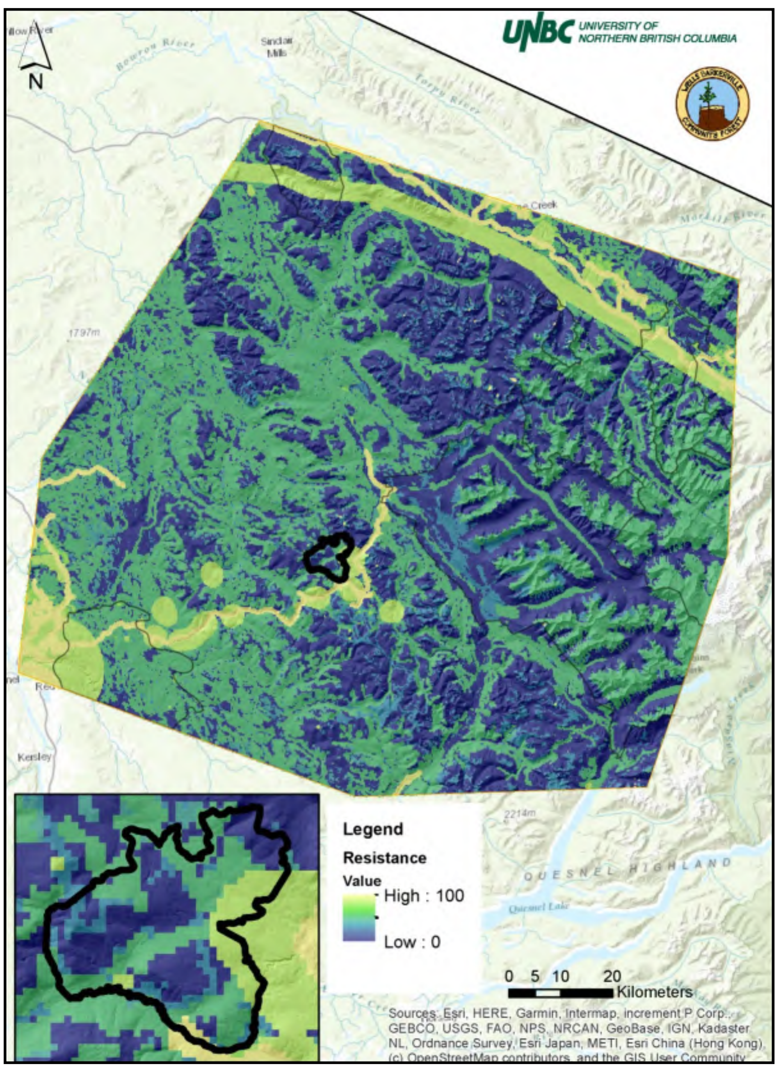


Figure 30. Landscape resistance where yellows are the most resistance to movement and dark blues are the least resistant to movement.

Based on the permeability of the landscape, potential connectivity was modelled to examine potential pathways between protected areas within the region (Figure 31). The potential connectivity shows how species and ecological processes may be able to move across the landscape (dark greens represent the areas of strongest connectivity and deep reds lower connectivity). This connectivity map shows that the region to the east of the Forest, as well as from the Forest south, is relatively well connected, aided in large part by the large block of protected areas to the east. However, to the north, west and east of the region there are significant impediments to movement caused primarily by human disturbance.

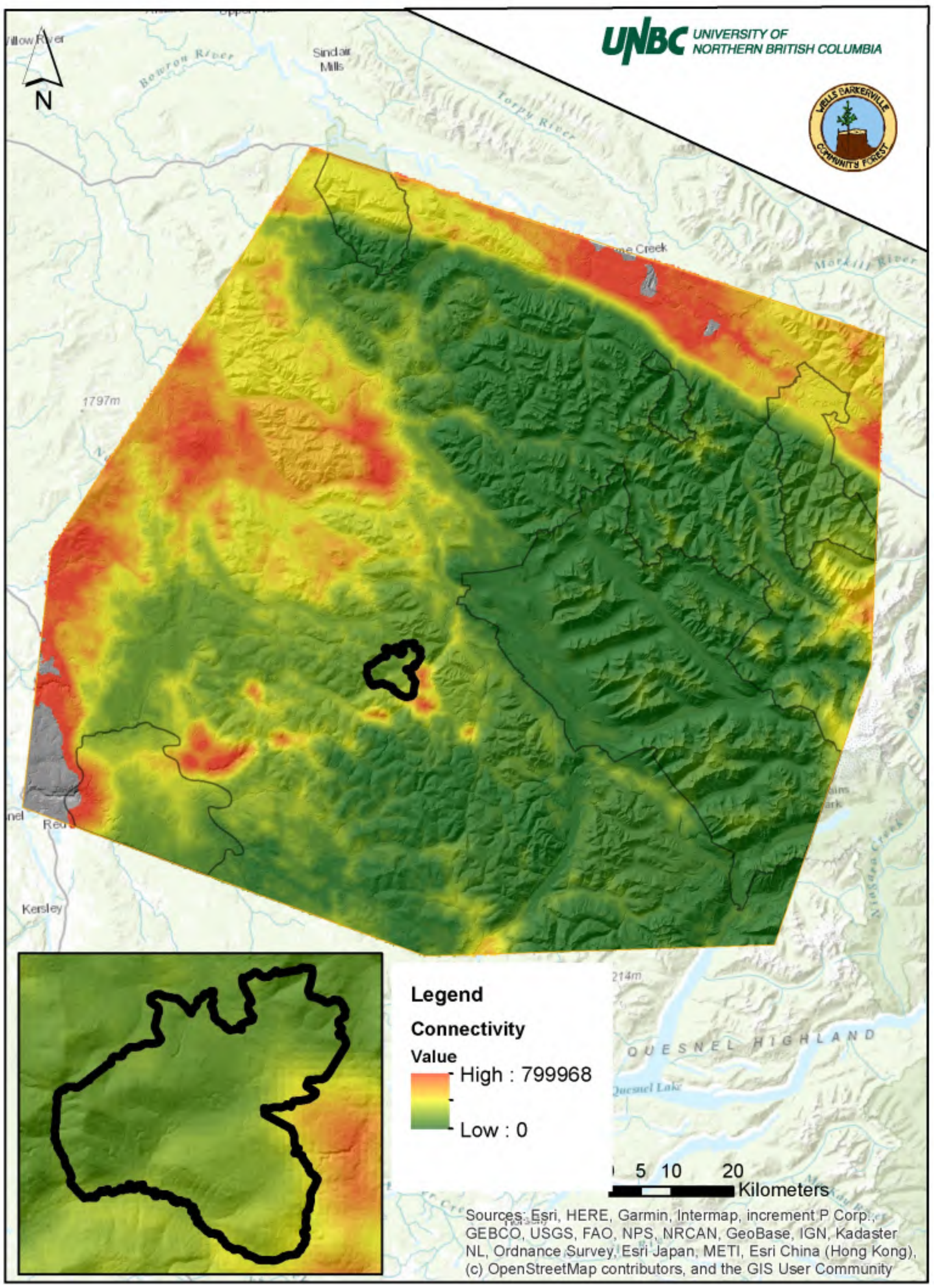


Figure 31. Connectivity in the region based on current climate

When we re-ran the model to look for more likely connectivity corridors (concentrated pathways) the general trend persisted but the areas in yellow to red represent the areas where the corridors are more precarious and least likely to be used (Figure 32). Areas without red-green colours represent potential barriers to movement.

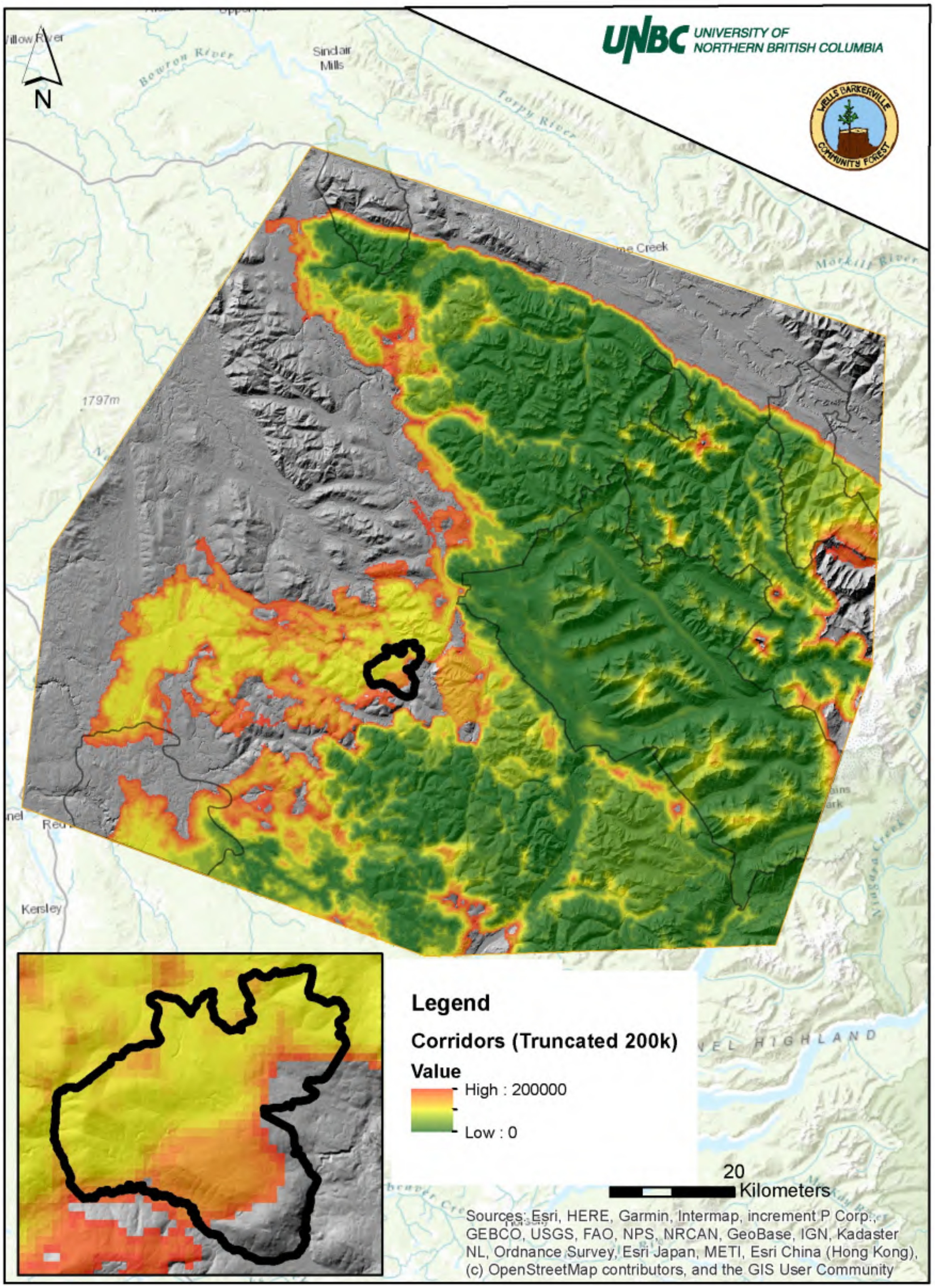


Figure 32. Concentrated connectivity corridors in the region based on current climate where dark green are the areas of most-likely movement and red less-likely movement.

Climate Connectivity

Moving beyond current climate connectivity, climate flow models look at the potential pathways for one climate type to move stepwise to the next area and then beyond. At a broad scale, dispersal paths are often funneled by topography into north-south trending passes and valley systems. These climate pathways tend to avoid areas of novel and disappearing climates but do not currently include the human footprint and movement barriers that may result from that. The study area is generally characterized by low climate connectivity, although the mountain range to the east has relatively high climate corridor values (deep blues) consistent with a pattern of high flow in north/south areas (Figure 33).

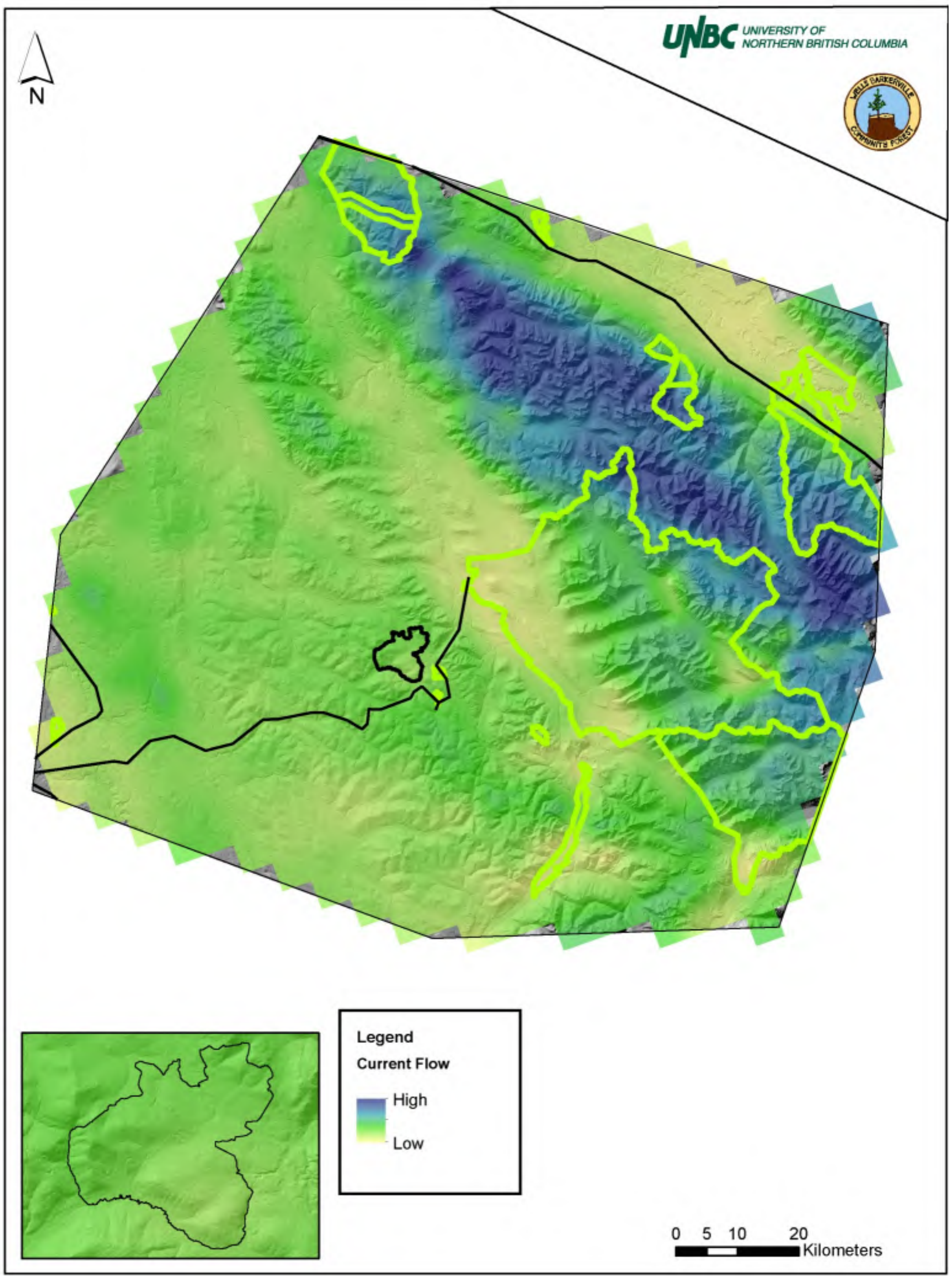


Figure 33. Current flow between current and future climate analogs

Forest Ecosystem and Recreation Networks

Forest-scale mapping was focused on the landscape unit scale based broadly on procedures described in the BC Biodiversity Guidebook as Forest Ecosystem Network (FEN) planning (BC Environment, 1995) and in more detail by Taylor (1995). We also took guidance from the Aleza Lake Research Forest identification of a network for ecosystem values accomplished through explicit OGMA and special management area zones presented in the management plan (Figure 34) (ALRF, 2019). We adapted FEN mapping to the Forest by explicitly incorporating recreational/social values as part of the process, describing the result as a Forest Ecosystem and Recreation Network (FERN).

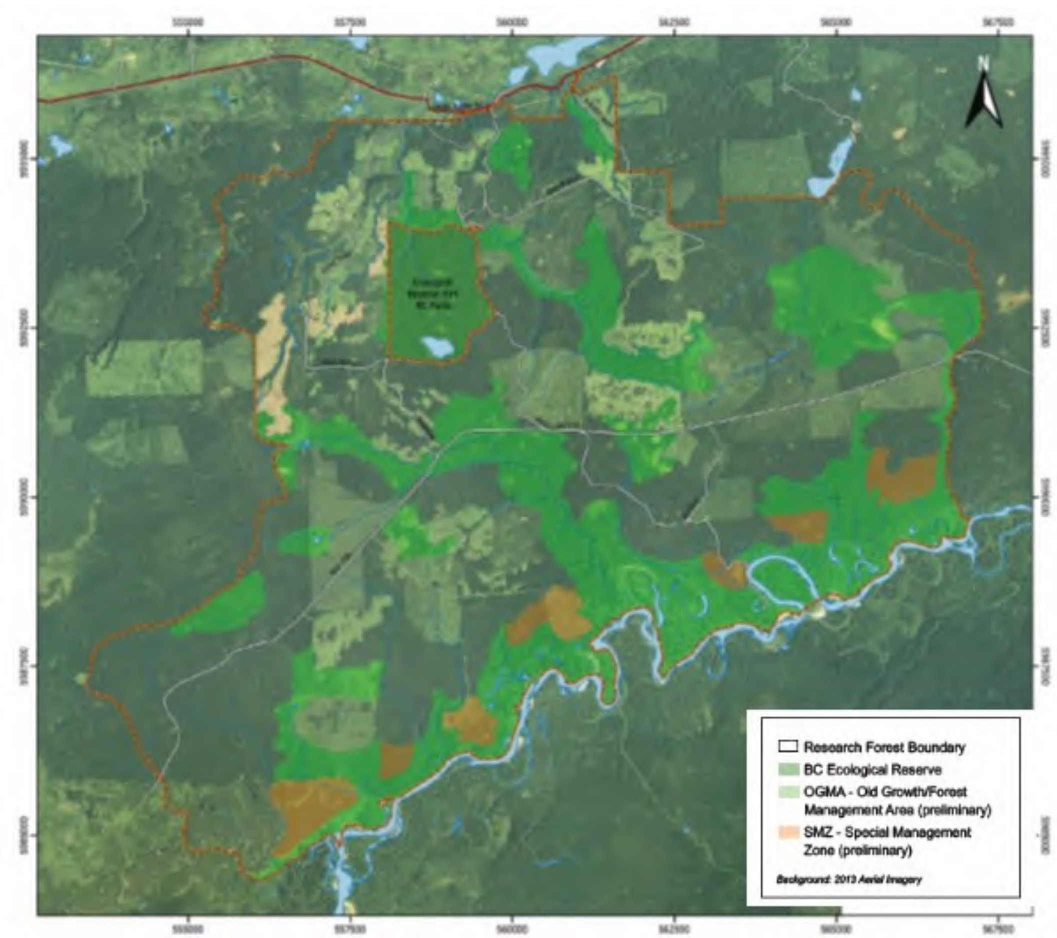


Figure 34. FEN equivalents in a similar type of tenure (research forest) designated using an Ecological Reserve, Old Growth/Forest Management Areas and Special Management Zones.

Data for FERN planning came from three primary sources: 1) the BC Government Data Warehouse; 2) WBCF Management Plan data layers provided by West Fraser Timber; and 3) public input from a community open house and one-on-one interviews conducted by UNBC students in fall of 2019 (see appendix A). There are some important caveats to note in our application and adaptation of FEN-FERN mapping. Where feasible, we used areas that were already constrained from harvest (e.g., OGMAs, riparian areas and Wildlife Tree Reserves). We designed the FERNs in three iterative steps in which we successively built the FERNs by adding additional values (Table 3 and Figures 35 - 37).

Table 3. Iterative steps of FERN development

FERN 1				
Old Growth Management Areas	+	Visual Quality Objectives: Retain & Preserve	+	Water Buffers (Lakes, Wetlands, Fish-bearing Streams)
FERN 2				
FERN 1	+	Wildlife Tree Retention	+	Forest Age (VRI Age Class 9; >251 Years)
FERN 3				
FERN 2	+	Gap Fills (with VRI Age Class 8; >141 Years)	+	Community Input Considerations
FERN 3 helped reach goal of 54% coverage for high biodiversity emphasis				
Forest Interior Goal met (>= 100 ha block)				

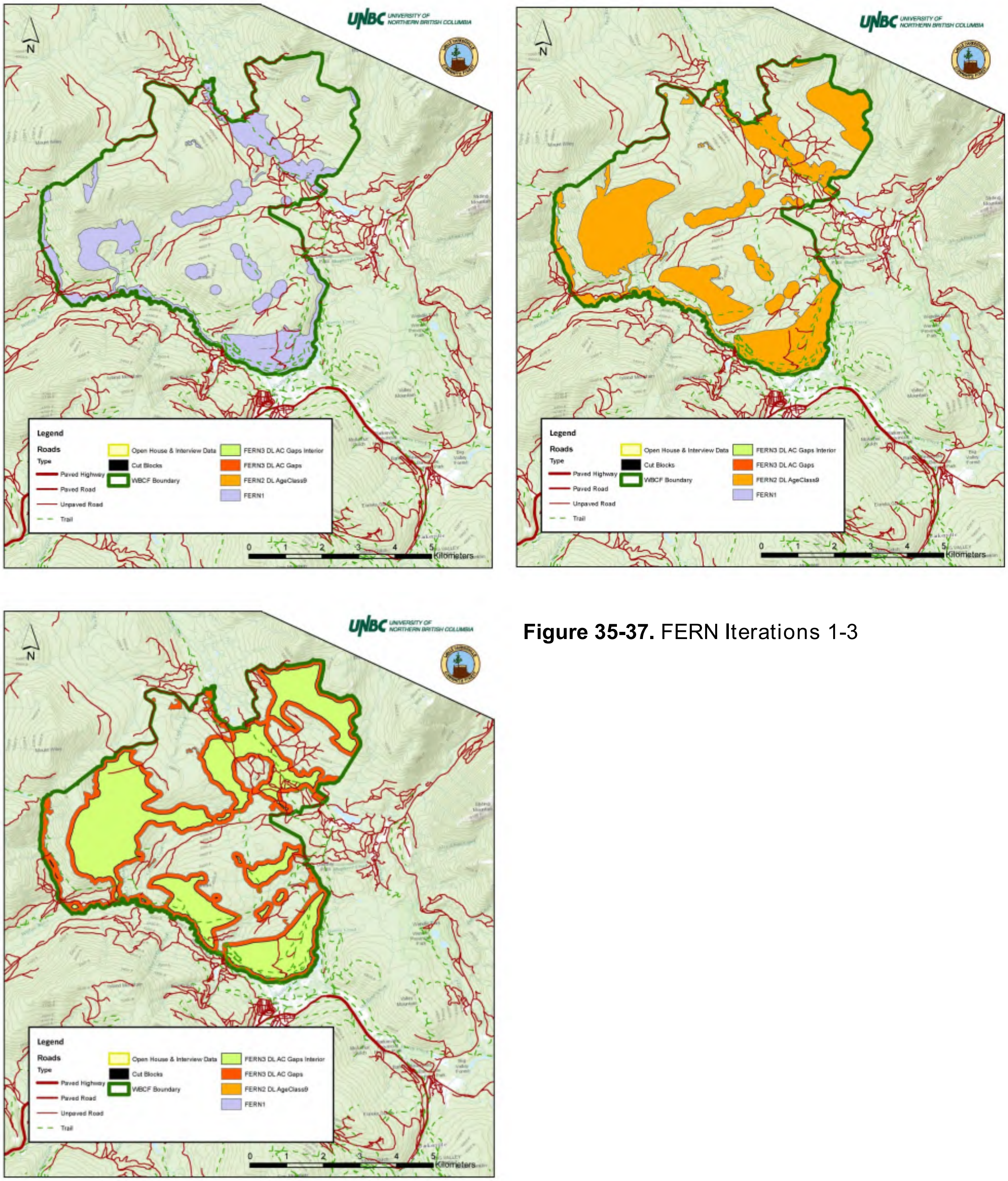


Figure 35-37. FERN Iterations 1-3

We did not set absolute hard targets for percentages of the Forest or of specific values to be included in FERNs but were guided by Biodiversity Guidebook high biodiversity emphasis guidelines for the associated biogeoclimatic zones and suggestions from Taylor (1995). The FERN areas we identified are not fixed but rather a working map that the community can incorporate into future initiatives and adjust when new information becomes available or values are ground-truthed. Like Aleza, WBCF may wish to use a combination of OGMA (already included) designation tools and other formal and informal designation tools to more formally designate some, or all, of a suite of FERNs.

We are not suggesting that all areas within the FERNs should be completely off-limits to harvesting: indeed, some portions of the FERNs have had a harvest history (Figure 38). Rather, areas within the FERN suggest that site planning should consider the effect that forest harvesting might have on the values identified (see, for example, the use of Special Management Zones in Aleza Lake Research Forest).

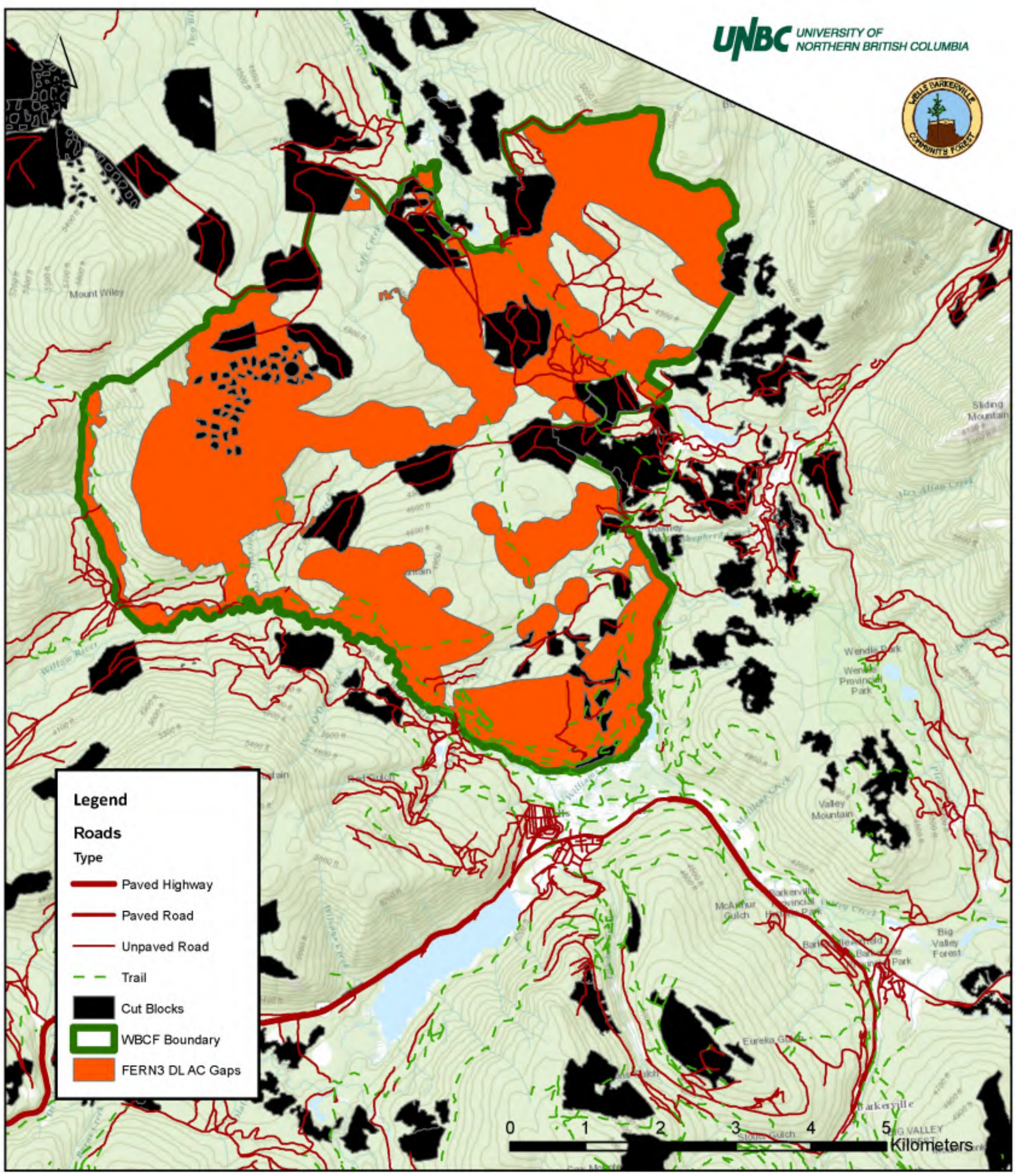


Figure 38. Forest harvesting relative to FERN 3

The working FERN 3 design represents about 54% of the Forest, of which 65% is made up of Old Growth Management Areas, Wildlife Tree Reserves and Buffered Riparian Corridors. High visual quality areas, important community recreation/value areas and connectivity elements make up the rest (Figure 39).

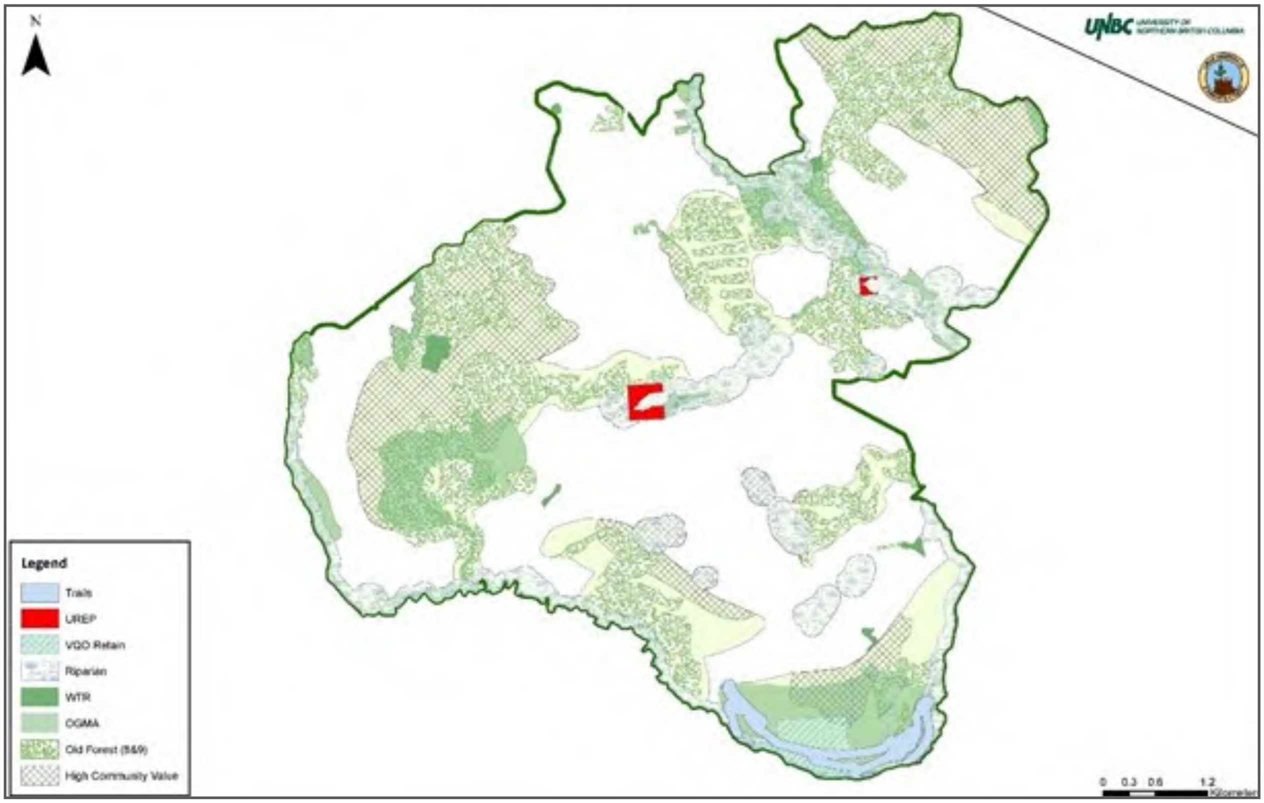


Figure 39. FERN3 map delineating specific values that comprise FERNs

Recommendations and Conclusions

Analysis and mapping of biodiversity values and connectivity under current and future climates at the ecoregional scale provides a picture of the role that the Forest places in the larger environment. The Forest is situated in such a place that it contains moderate to high biodiversity values under current climates and continues to play an important role as climate shifts. While the broader vegetative community shifts rapidly with the potential for significant transition, the Forest may play an important role in providing microrefugia and as a steppingstone for species moving from lower elevations in the west to the higher elevations in the east and along climate corridors running south to north.

Mapping microrefugia at the site level and reviewing forest practices in light of the potential for these sites to act as microrefugia is one next concrete step to take. FERNs could also be adjusted to incorporate microrefugia. The Forest could make significant contributions in monitoring the impacts of climate by installation of a climate station, establishing permanent biodiversity and growth and yield monitoring plots, along with other climate protocols. Additionally, the Forest could support regional initiatives that provide better quality data acquisition for caribou habitat and other critical species.

Forest Ecosystem and Recreation Network (FERN) mapping represents a first-draft attempt to incorporate biodiversity values, recreation values and connectivity into the working forest. These FERN maps should be ground-truthed and adjusted based on local knowledge and compared to the Total Harvesting Landbase (THLB) existing spatial data if this becomes available. Revised FERN mapping could then be identified as discrete polygons with appropriate harvest prescriptions added and designated as Special Management Zones.

While small in scale, community forests play an important role in helping communities transition to more sustainable futures and in meeting a broad array of ecological and social values. Managing for the provision of ecosystem services within a community forest can provide a model for how forest practices might be re-examined elsewhere. The Wells-Barkerville Community Forest represents an initiative that is important not just to the economic livelihood of the District of Wells, but to the social and recreational livelihoods of residents and visitors to the area. At the scale of the Forest, and at larger ecoregional scales, the Community Forest also plays an important role in contributing to maintaining or restoring biodiversity values under current and future climates.

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Appendix A—Community Input

Open House – Oct. 6, 2019

(Compilation of general comments received)

- There's good backcountry skiing just east of the Forest; Never see any other skiers even though it's so close to town
- Good mushroom harvesting opportunities in the Forest
- Would like to see a boardwalk from the school to the Learning Forest and potential shelter that is accessible for those with mobility issues (e.g. wheelchair-bound)
- The Forest has many herbal medicine opportunities:
  - Non-cut areas have pipsissewa (or prince's pine) – once trees are harvested it won't grow
  - Yarrow is plentiful
  - Wild sarsaparilla
  - Aspen bark for tea as a painkiller
- It would be cool to have a trail connecting the fire tower atop Twin Sister towards the southwest into the Community Forest; The existing trail up to the tower is very steep and difficult to get down
- Focus should be put on salvage harvesting in the northeast portion of the Forest where pine beetle kill has taken place

(Compilation of geographic comments received)

- Old historic town of Centreville was located just west of present-day Wells
- There are old bottle dumps east of the proposed Learning Forest site
- There is possible old brothel on Moose Island in the marsh east of town
- There is good cross country skiing in the marsh east of town
- There is quality backcountry skiing in the hills east of the marsh

One-on-one meetings with select community members – various dates

- It would be nice to have a shelter or some picnic tables at Cornish Lake
- Options for supplying high value tone wood for musical instruments should be explored
- A trail that bisects the Forest and connects to Cornish Lake would be wonderful; this would be motorized to allow a loop for quads and also include a non-motorized spur to the north end of the lake to offer a more peaceful experience
- Increase emphasis on wildlife viewing tourism
- High elevation areas in the Forest (1400+ m) should be considered for conservation as they are more likely to be fragile ecosystems
- Areas that offer high quality berry picking should be conserved

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