Securing a Wild Future

Planning for landscape-scale conservation of Yukon's Boreal Mountains





HILARY COOKE

April 2017

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PLANNING FOR LANDSCAPE-SCALE CONSERVATION OF YUKON'S BOREAL MOUNTAINS

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Back Cover Photo:
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Photos: John Meikle

Photos: Hilary Cooke

From alpine (Big Salmon Range, top) to floodplain (Liard River, below), much of Yukon's Boreal Mountain landscape is still rich with abundant wildlife and intact ecological communities, while also remaining relatively free from industrialization. Planning now for landscape-scale conservation will secure the natural values that are important to all Yukoners.

EXECUTIVE SUMMARY

Why plan for landscape-scale conservation of Yukon's Boreal Mountains?

At the intersection of the boreal biome and the western mountain range in northwest Canada, Yukon's Boreal Mountains present a unique opportunity to proactively plan for the conservation of biodiversity, and the preservation of cultural, spiritual, and recreation values for indigenous and non-indigenous Yukoners.

The region is characterized by rugged mountains, high intermontane plateaus and broad forested valley bottoms. It supports a unique and diverse set of ecosystems with significant biodiversity, including intact populations of wide-ranging carnivores, ecologically functional predator-prey relationships, robust populations of ungulates, upwards of 200 bird species, and one of the world's longest salmon runs.

The region has been home to Yukon First Nations since time immemorial and their strong spiritual and cultural connections to the land, and subsistence hunting and gathering practices, remain in place today. Many non-indigenous Yukoners also seek opportunities for recreation, cultural and spiritual inspiration, and for gathering resources, such as by fishing and hunting, making the wildlife and wilderness of Yukon's Boreal Mountains broadly shared values.

Habitat loss, along with habitat disturbance by roads and other linear infrastructure (e.g., pipelines, rail lines), is a major cause of biodiversity loss in Canada. While much of Yukon has not yet been transformed by industrial activity, the past seven decades have been a period of rapid expansion of infrastructure and development in the territory. Continued growth in the human footprint is inevitable as global demand for resources continues and Yukoners seek the benefits of new industrial developments.

But there is strong evidence from other jurisdictions that the cumulative effects of unplanned development can result in the piecemeal erosion of ecological values, with significant impacts on wildlife populations. The capacity of Yukon's Boreal Mountains to accommodate additional growth of the development footprint before ecological values and traditional economies are significantly compromised is unknown. Just a single road through a large, continuous block of intact habitat opens an area up to further resource use, wildlife exploitation, land conversion, motorized and non-motorized recreation, and continued expansion of the road network.

To understand what it would take to avoid this fate, WCS Canada undertook a study of gaps in existing protection and opportunities and priorities for proactive landscape-scale conservation across approximately 290,000 square kilometres of Yukon, representing 60% of the landbase. The study area encompasses much of Yukon's Boreal Cordillera ecozone as well as the Selwyn Mountains ecoregion of the Taiga Cordillera ecozone.

How to plan for landscape-scale conservation of Yukon's Boreal Mountains

The principle of representation reflects the need to capture – or represent – as many of the region's species, ecosystems, and ecological communities as possible within a network of conservation areas.

Within the Yukon, decisions about land use, and managing and coordinating fish and wildlife conservation and resource development, are made by the Yukon government, First Nations, and the federal government.

Under Yukon First Nation Final Agreements, and as described in Chapter 11 of the Umbrella Final Agreement, land-use planning is mandated for seven regions covering approximately 70% of the Yukon (traditional territories of three First Nations without settled land claims cover the remaining area). Land-use planning aims to coordinate different types of land use and provides an opportunity to establish new areas managed primarily for conservation.

A primary goal of protected areas and other area-based conservation measures is to limit the exposure of ecosystems and biodiversity to human pressures, and thereby ensure their conservation. Two fundamental scientific principles for designing and systematically designating areas for conservation are securing **representation** and ensuring **persistence** of regional biodiversity. While these will not be the sole drivers for identifying new conservation areas[1] in Yukon, these principles are important for a systematic, scientific assessment of the gaps, opportunities, and priorities for conserving biodiversity across a broad region like Yukon's Boreal Mountains.

The principle of representation reflects the need to capture – or represent – as many of the region's species, ecosystems, and ecological communities as possible within a network of conservation areas.

Planning for the long-term persistence of biodiversity, meanwhile, takes conservation design beyond just capturing representative species and ecosystems in conservation areas. It requires protection of populations large enough to persist through natural fluctuations, such as swings in prey abundance, and the full range of habitats and conditions necessary for reproduction and survival, including sufficient area for seasonal movements and annual migrations. It also requires preserving the ecological processes that maintain ecosystems, such as cycling of nutrients, flow of water, and natural disturbance regimes, such as fire and wind. For many species and processes, a landscape-scale approach to conservation is required to ensure such long-term persistence.

In the boreal biome, biodiversity evolved alongside natural disturbance regimes, particularly wildfire, but also insect outbreaks. Because species are adapted to the changing landscape conditions and mosaic of habitats that result

[1] Throughout the report I use the term conservation area to include any area designated primarily for conservation, including parks (national, territorial), wildlife areas/refuges, Habitat Protection Areas, Special Management Areas, and management zones designated primarily for conservation of ecological values.

from recurrent fires, representation and persistence of boreal biodiversity is thought to be best achieved if conservation areas are large enough to accommodate the natural size and frequency of fires.

A novel approach to planning for landscape-scale conservation for Canada's boreal region was developed by the BEACONs (Boreal Ecosystem Analysis for Conservation Networks) research team at University of Alberta (Edmonton) and Université de Laval (Québec City). BEACONs developed spatial decision-support tools to identify a network of conservation areas that, individually, are large enough to accommodate natural disturbance regimes, and, collectively, capture representative ecological indicators for the study area. I selected these tools because they best address the role of fire in the ecology of Yukon's boreal, while also incorporating fundamental principles of conservation planning.

BEACONs tools identify **Benchmark Areas** and **Benchmark Networks**. Benchmark Areas are relatively intact landscapes (i.e. with little or no footprint of land disturbance resulting from human activity) that are large enough to encompass the natural fire regime and that maintain connectivity of freshwater systems by aligning with boundaries of drainages. Benchmark Areas are intended to be the core conservation areas in a region. A Benchmark Network is a system of Benchmark Areas that collectively captures the ecological variability of the study area. Because our knowledge of all levels of biodiversity is limited, coarse-filter indicators of environmental conditions, such as land cover and climate moisture, are used as proxies or shortcuts in identifying networks of representative conservation areas.

Benchmark Areas are intended to be the core conservation areas in a region. A Benchmark Network is a system of Benchmark Areas that collectively captures the ecological variability of the study area.

My approach to assessing gaps, opportunities, and priorities for conservation in Yukon's Boreal Mountains was to compare multiple scenarios for networks of landscape-scale conservation areas designed to answer the following questions:

1. **What is the minimum area necessary for a conservation area to accommodate natural fire regimes across the study area?** I used regional fire data produced by the BEACONs group to answer this question.
2. How do networks of relatively intact landscape-scale conservation areas differ in their ability to capture representative ecological conditions of the study area in the following scenarios?
    i. **Conservation areas are identified using two maps of the human footprint: a national map and a Yukon map.** The national map was developed using a Global Forest Watch dataset. It combines a national road network map with a map of human disturbance derived from interpretation of satellite imagery. I developed the Yukon footprint map using publicly available maps of current (as of October 2013) infrastructure (roads and settlements) and industrial development and resource use (mining, forestry, agriculture, and energy). Both maps include an area of influence or disturbance that extends beyond the physical footprint of roads, settlements, extraction sites, etc. in order to represent the extended impact of such land uses.

ii. **Conservation areas have different degrees of human footprint, i.e. different thresholds for intactness.** Intactness is measured as the percent land area without human footprint (towns, development sites, roads, etc.). I compared networks of conservation areas that had a minimum intactness of 80%, 90% and 100%.

iii. **The total area of a conservation area network increases.** I compared networks of conservation areas covering 15%, 25%, 35% and 50% of the study area. I selected this range in area targets to encompass the global and Canadian target of protecting 17% of terrestrial lands and inland water by 2020, and targets of 50-60% protection from intensive development that have been recommended or implemented in several northern land-use planning initiatives. I also compared the results from the area target scenarios with representation of environmental indicators in existing protected areas, which cover 4% of the study area.

iv. **Networks of landscape-scale conservation areas include or exclude existing protected areas.** The goal of these scenarios was to determine if existing protected areas enhance or constrain the ability of a conservation area network to capture regional environmental variability.

There is a need to immediately prioritize protection of valley bottoms, where human development pressure is highest.

To address these questions, I compared 24 scenarios for conservation area networks that varied in intactness, total area, and whether or not existing protected areas were included. I also compared all scenarios using each of the human footprint maps. Conservation area networks produced for each scenario were assessed and ranked for representation of four coarse-filter environmental indicators developed by the BEACONs group: gross primary productivity; climate moisture index; lake-edge density; and land-cover class. I also assessed representation of ecoregions, physiographic regions, and bedrock geology in each of the best conservation area networks that included existing protected areas and covered 15%, 25%, 35%, and 50% of the study area.

What, where, and how much of Yukon's Boreal Mountains to allocate for landscape-scale conservation?

My goal was to provide recommendations for the size of new conservation areas, the percentage of the study area that should be zoned for conservation, and the places and ecosystems that should be priorities for conservation.

My results indicate that **large (~2,000 to 7,500 km^2), highly intact (<10% human footprint by area) landscapes covering at least 50% of the total area of Yukon's Boreal Mountains should be allocated for conservation**. I also identified a need to immediately **prioritize protection of valley bottoms,** where human development pressure is highest and where we may need to include conservation areas with a slightly lower degree of intactness. Similarly, there is a need to quickly identify areas for protection in ecoregions currently lacking any area designated for conservation. Areas that are important to rare or endangered species or rare ecosystems or that address the needs of wide-ranging species may also need to be included and may include areas above and beyond the representative network.

The small existing network of protected areas does not support representation or persistence of the biodiversity and ecosystems of Yukon's Boreal Mountains. All but one of the existing protected areas, which cover just 4% of the study area, are too small to accommodate regional fire regimes and collectively they do not capture the range of conditions for the six environmental indicators across the study area.

The minimum size for conservation areas to accommodate changing landscape conditions resulting from fire – i.e. landscape-scale conservation areas – varies across the study area with a maximum of 7,500 km^2 in the southeast. However, even this size is likely too small to accommodate the seasonal movements of wide-ranging mammals, which is why a well connected conservation area network is required.

Conservation area networks covering 15% of the study area had better representation of environmental conditions than the existing protected area network. However, there was additional improvement in representation as the total area of conservation area networks increased from 15% to 50% of the study area. **The best, most representative solutions among all scenarios were those for networks comprised of less than 100% intact landscape-scale conservation areas covering 50% of the study area.**

The best, most representative solutions among all scenarios were those for networks comprised of less than 100% intact landscape-scale conservation areas covering 50% of the study area.

While it may seem counterintuitive, the ecological conditions within networks of 100% intact conservation areas were *less* representative than networks covering the same total areas, but comprised of less than 100% intact conservation areas. **This is because areas with unique environmental conditions overlapped with areas of concentrated human footprint. The consequence is these unique areas were excluded from 100% intact networks, making these networks less representative of the study area as a whole.**

In particular, valley bottom ecosystems, which cover approximately one-quarter of the study area, are disproportionately impacted by human development and infrastructure footprint. These ecosystems include dynamic river floodplains, large lakes, old spruce stands, and marsh, bog, fen, and swamp wetlands, all of which are highly productive and disproportionately important to biodiversity. Thus, intact valley-bottoms and ecosystems should immediately be prioritized for protection before their ecological values are further lost to land conversion and resource development.

The top-ranked scenarios set intactness thresholds for conservation areas at 80% and 90%. However, the actual percent intactness of conservation areas produced by these scenarios was approximately 98%, meaning the mapped human footprint covered only 2% of the total area. (The threshold for levels of anthropogenic disturbance after which ecological integrity is compromised is unknown for Yukon's ecosystems and wildlife populations.)

I concluded that the best solution for ensuring full representation and persistence of biodiversity in the Yukon Boreal Mountains region was to create **a network of large (2,000-7,500 km^2) conservation areas made up of 100% intact areas, but also including some slightly less intact areas (>90% intact), particularly in biologically richer areas such as valley bottoms, covering a minimum of 50% of the region.**

One uncertainty in this work is the actual extent of the human development footprint in Yukon and how that impacts our calculations of intactness. The Yukon footprint map indicated more land disturbance than the national footprint map (~10% and 4% footprint by area, respectively). Almost half (42%) of the footprint area across the study area is permitted mineral claims, which have varying levels of land disturbance depending on type of permit and exploration activity.

The next dominant features are roads, which collectively make up 31% of the total footprint area. However, the greatest negative impacts on terrestrial ecosystems in some parts of the study area may be associated with human activity, including motorized and non-motorized recreation. The exact extent of this activity is unknown, but is likely pervasive and has the potential to significantly negatively impact ecological values both in and outside areas zoned for conservation.

Protecting Yukon's biodiversity and ecosystems, both in and outside of areas designated for conservation, requires careful management of land outside conservation areas.

This study contributes to our knowledge of conservation values within Yukon's Boreal Mountains, but is not a complete assessment of all conservation values, nor a proposal for specific new conservation areas. Rather, **my recommendations for what, where, and how much land to allocate for landscape-scale conservation should be considered alongside other ecological values, including habitat and area requirements of rare, specialized, or wide-ranging species and areas of high and/or irreplaceable ecological value.**

This report also does not address how the type and amount of human activity outside conservation areas may affect the extent to which goals for biodiversity protection are achieved. Protecting Yukon's biodiversity and ecosystems, both in and outside of areas designated for conservation, requires careful management of land outside conservation areas. In addition to buffering species and ecosystems from future pressures of human development, a network of large, intact, representative conservation areas covering at least 50% of the region may provide numerous options for refugia from climate change and for wildlife and ecosystems to move in response to changing conditions.

Proactive planning for conservation, alongside other values, is critical to ensure Yukon's intact ecosystems and watersheds, abundant wildlife populations, wealth of ecosystem services, and cultural and social connections to the land are not eroded by the cumulative impacts of unplanned development. What, where, and how much land to dedicate to conservation, to industrial development and human infrastructure, as well as to traditional, cultural, and spiritual values, is a decision for Yukoners to make within regional land-use planning processes. This study supports a broader discussion of how much land can be allocated for economic development without compromising long-term conservation of Yukon's boreal biodiversity.

Recommendations

- Conservation areas should consist of large (~2,000-7,500 km^2 or greater) areas that can accommodate the scale of natural processes, such as fire and insect outbreaks.
- These areas should be very close to 100% intact, but allow for the inclusion of some development and infrastructure footprint (ideally <10% footprint in total) in areas that are rich in biodiversity and/or priorities for protection, such as valley bottoms.
- The network of conservation areas should cover at least 50% of the total area of Yukon's Boreal Mountains.
- Protection should be prioritized for ecoregions currently lacking any area designated for conservation and for ecologically rich valley bottoms where human development pressure is greatest.
- Regional planning should also consider what habitats and how much additional area is required to protect other ecological values, including rare, specialized or wide-ranging species and areas of high and/or irreplaceable ecological value.
- Land-use planning and management for areas outside the conservation area network must ensure that human activities and development do not compromise biodiversity or ecosystem values inside or outside the network.

Photos: Hilary Cooke

Lakes and ponds of Yukon's Boreal Mountains: near Tuchitua in southeast Yukon (top) and along the Pelly River near Ross River in central Yukon (bottom). Conserving aquatic systems means paying special attention to valleys and bottomlands.

1. INTRODUCTION

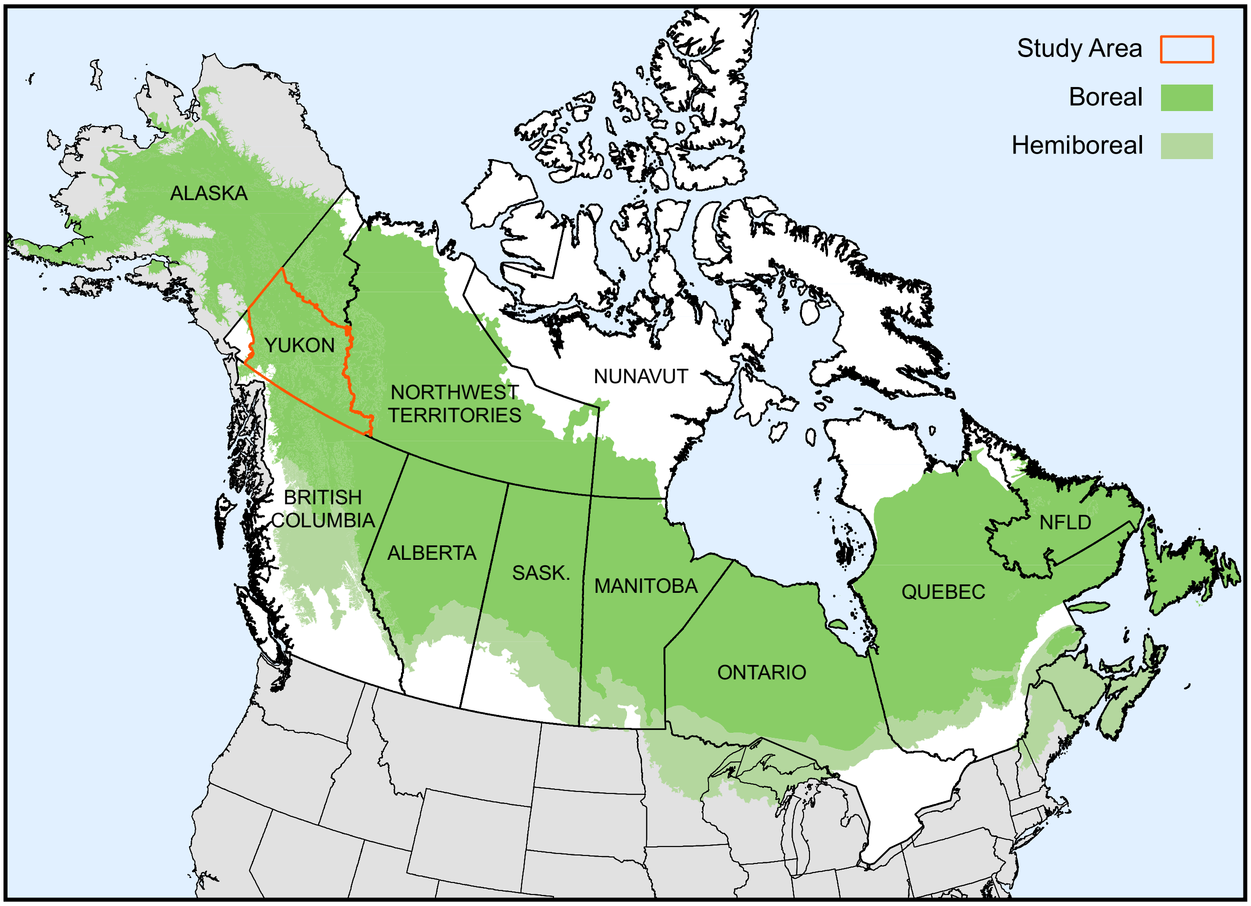
Yukon's Boreal Cordillera is characterized by rugged mountains, high intermontane plateaus, and broad forested valley bottoms, and supports a unique and diverse set of ecosystems and associated biodiversity (Smith et al. 2004). The diversity of ecosystems results from the varying combinations of topography, soil, and climate, alongside latitude and longitude.

In contrast to other northern boreal regions of Canada, which are comprised of vast areas of lakes, wetlands and peatlands, the mountainous topography of Yukon's boreal restricts most large lakes, wetlands and riparian areas to the valley bottoms.

Yukon's boreal hosts intact populations of wide-ranging carnivores, such as wolverine (*Gulo gulo*), grizzly bears (*Ursus arctos*), and wolves (*Canis lupus*); ecologically functional predator-prey relationships, such as between lynx (*Lynx canadensis*) and snowshoe hare (*Lepus americanus*); and robust populations of ungulates, including mountain caribou (*Rangifer tarandus caribou*) and thinhorn sheep (*Ovis dalli*). Upwards of 200 bird species use its diverse habitats for breeding, over-wintering and/or during migration. The Yukon River, running over 3,000 kilometres from southern Yukon through central Yukon and to the Bering Sea, supports one of the world's longest salmon runs, providing sustenance for both people and wildlife.

The region is of value to Yukon First Nations who have followed subsistence hunting and gathering lifestyles here since time immemorial. Strong spiritual, cultural, and livelihood connections continue today. And, all Yukoners value wildlife and wilderness for sustenance, recreation, inspiration, and spiritual connections.

Figure 1. Map of Canada's boreal biome and the Yukon Boreal Mountains (YBM) study area.



Map by: Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Natural Resources Canada

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Projection: Canada Lambert Conformal Conic

Photo: Lila Tauzer

Positioned at the intersection of Canada's boreal biome and the western mountain range, Yukon's Boreal Mountains region supports a diversity of ecosystems driven by varying topography, soils, and climate.

Photo: Jerry Lee

Photo: © Susan Morse

*Yukon's Boreal Mountains region remains relatively free from industrial development and infrastructure. It still supports intact populations of mammals, including northern mountain caribou and wide-ranging carnivores such as the wolverine (*Gulo gulo*) and grizzly bear (*Ursus arctos*).*

On the global stage, Canada's boreal is one of the last regions to not be significantly altered by the human footprint (i.e. human influence on land surface) (Sanderson et al. 2002a, Schmiegelow et al. 2006, Schindler and Lee 2010). From a species perspective, boreal and tundra biomes are the least compromised globally (<10% loss of species abundance and <20% loss of species richness) (Newbold et al. 2016). Covering 55% of Canada's area and accounting for 30% of the world's boreal biome (Figure 1; Brandt 2009, Brandt et al. 2013), our boreal region is critical for ecological services such as carbon sequestration, climate regulation, nutrient cycling and water and air purification.

Historically, the harsh climate, inaccessibility, and low human population of Canada's boreal resulted in *de facto* protection from industrial development (Andrew et al. 2012). However, parts of the southern boreal have already been significantly altered by the cumulative footprint of industrial development, with devastating impacts on ecosystems and species such as boreal caribou (Figure 2; Lee et al. 2010, Schindler and Lee 2010, Lee and Cheng 2014, Venier et al. 2014). There is increasing pressure to develop extractive industries in Canada's north and global demand for natural resources will continue to fuel interest in mining and oil and gas development (Jeffrey et al. 2015). As well, many northerners desire the positive impacts of industrial economies in the North, including the associated benefits of increased infrastructure and services.

In Yukon, much of the Boreal Cordillera has not yet been transformed by industrial activity (Figure 2), but the past seven decades have been a period of rapid expansion of the industrial footprint and continued growth in population and resource development is inevitable (Jeffrey et al. 2015).

Figure 2. Global Forest Watch Canada's map of human access across Canada (Lee and Cheng 2014). The Global Forest Watch Canada 'human access' dataset combines National Road Network data with manual digitization (i.e. mapping) of anthropogenic disturbances using 30m resolution Landsat imagery (Lee et al. 2010)

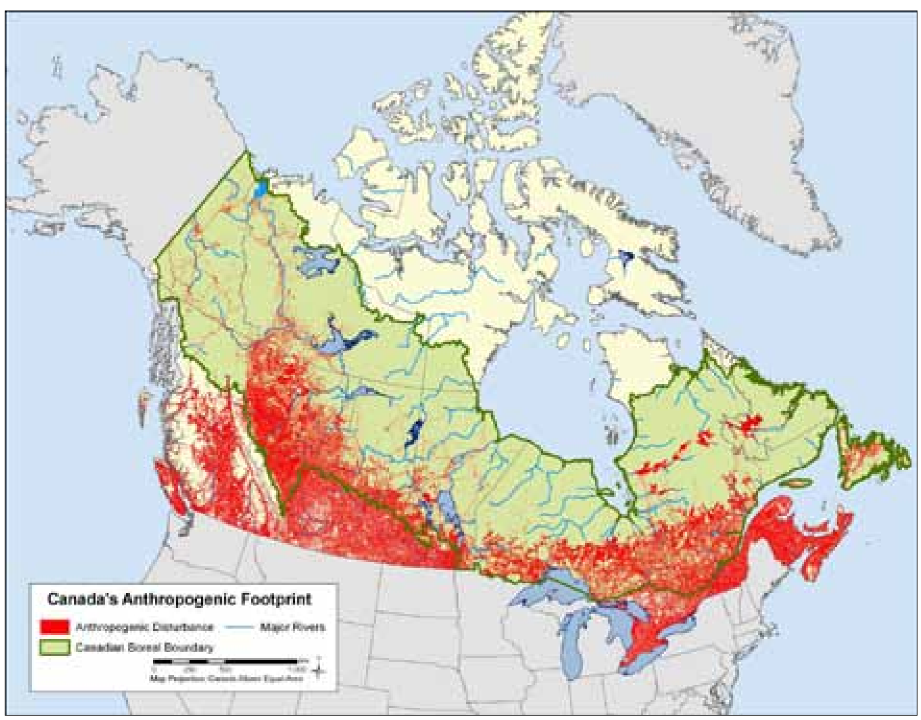
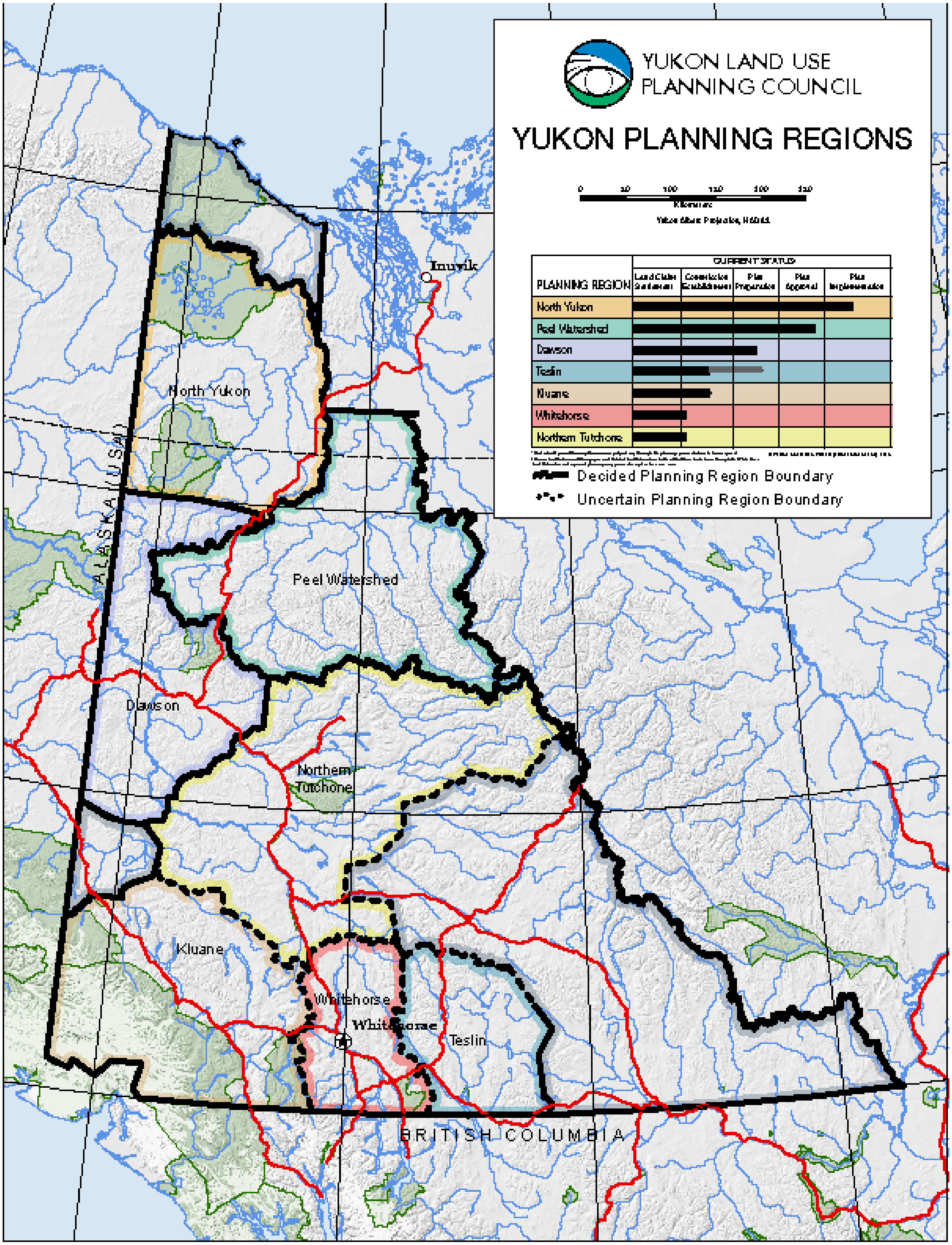


Figure 3. Yukon's Land Use Planning Regions (as of January 2013). Source: http://www.planyukon.ca/index.php/planning-regions.html



Proactive planning for conservation, alongside other values, is critical to ensure Yukon's intact ecosystems and watersheds, abundant wildlife populations, wealth of ecosystem services, and cultural and social connections to the land are not eroded by the cumulative impacts of unplanned industrial development.

In Yukon, decisions about land use, and managing and coordinating wildlife conservation and resource development, are made by the Governments of Yukon, First Nations, and the federal government with guidance from the Regional Land Use Planning Commissions; Yukon Fish and Wildlife Management Board (YFWMB); Yukon Environmental and Socio-Economic Assessment Board (YESAB); and, Renewable Resources Councils (RRCs).

Under Yukon First Nation Final Agreements, and as described in Chapter 11 of the Umbrella Final Agreement, land-use planning is mandated for seven regions ranging in area from ~18,000-76,000 km^2 (Figure 3; Council of Yukon First Nations and the Government of Yukon 1997). Yukon's land-use planning process is a tool to manage different types of land use, including traditional, subsistence, conservation, mining, agriculture, forestry, recreation, tourism, and transportation (Yukon EMR 2011).

Proactive planning for conservation, alongside other values, is critical to ensure Yukon's intact ecosystems and watersheds, abundant wildlife populations, wealth of ecosystem services, and cultural and social connections to the land are not eroded by the cumulative impacts of unplanned industrial development. A landscape approach to conservation planning is necessary for representation and persistence of all species and ecosystems over the long term. Intact landscapes are also important for nutrient cycling, carbon sequestration, water filtration and flood control, and the ability of ecological communities to absorb and recover from disturbances and adapt to changing conditions (Martin and Watson 2016, Potapov et al. 2017).

My goal was to conduct a systematic assessment of the gaps, opportunities and priorities for landscape-scale conservation in Yukon's Boreal Mountains. I used decision-support tools that address the scale and nature of the key processes underlying the ecology of northern boreal landscapes. Using these spatial tools and an analysis of the outcomes of multiple scenarios for conservation planning, I provide recommendations for the size of new conservation areas, the percentage of the Boreal Cordillera that should be zoned for conservation, and the places and ecosystems that should be priorities for conservation.

This study is not a comprehensive assessment of all conservation values. My recommendations for what, where, and how much land to be allocated for landscape-scale conservation should be considered alongside other identified ecological values, such as focal wildlife ranges, key habitats, and rare and endemic species within the conservation assessment process of land-use planning.

Throughout the report, I use the term conservation area to include any area designated primarily for conservation, including parks (national, territorial), wildlife areas/refuges, Habitat Protection Areas, Special Management Areas, and management zones designated primarily for conservation of ecological values. While I include protected areas as a type of conservation area, not all conservation areas are formally protected. Interpretation of these terms, and implementation of any of my recommendations, should be consistent with the processes and terms set out in Yukon First Nation Final Agreements, the Umbrella Final Agreement, and the constitutionally protected rights of Canada's Indigenous Peoples.

See Glossary for definitions of terms used in this report.

1.1 Principles and planning for landscape-scale conservation

The ultimate goal of conservation is to maintain or restore biological diversity. Biodiversity encompasses all levels of life – genes, individuals, populations, species, communities, and ecosystems – and the interactions among them – nutrient cycling, predation, competition, etc. (Margules et al. 2002). Biodiversity drives functioning of ecosystems, including producing biomass and the cycling of nutrients and other elements (Cardinale et al. 2012). Loss of biodiversity can impact ecosystem services, such as the pollination of crops or regulation of the quality and quantity of fresh water. Even the loss of a single species can have significant, cascading ecological effects. For example, the role of apex (i.e. top) predators and other keystone species on ecosystem function and biodiversity has been well described, such as for wolves, elk, beaver, and songbirds in riparian ecosystems of Yellowstone and Banff National Parks (Hebblewhite et al. 2005, Ripple and Beschta 2012); killer whales, otters, and sea urchins in marine ecosystems (Estes et al. 1998); and, woodpeckers and non-excavating cavity users in forest ecosystems (Martin et al. 2004, Blanc and Walters 2008, Cooke and Hannon 2011).

Photo: Chris Kolacz

Photo: Jukka Jantunen

*As the primary excavators of tree cavities, woodpeckers, like this Northern Flicker (*Colaptus auratus. left*), create holes in trees for breeding that are subsequently used by species such as Tree Swallows (*Tachycineta bicolor, right*) that also nest in tree cavities, but are unable to excavate their own. The loss of a species that plays a keystone role in ecosystems can have cascading effects on other species.*

Just a single road through a large, continuous block of intact habitat opens an area up to further resource use, wildlife exploitation, land conversion, motorized and non-motorized recreation, and continued expansion of the road network.

Transformation of land for human use, including agriculture, urbanization, and industrial resource extraction, is the primary driver of global biodiversity loss (Vitousek et al. 1997). Twenty-three million square kilometres of global terrestrial areas experienced an increase in the human footprint between 1993 and 2009 (Venter et al. 2014). In Canada, habitat loss is the primary cause of species endangerment, threatening 84% of 488 species assessed by the Committee on the Status of Endangered Wildlife in Canada as extinct, extirpated, endangered, threatened, or special-concern (Venter 2006).

Roads and other linear infrastructure are also a major cause of global biodiversity loss (Benítez-López et al. 2010, van der Ree et al. 2011). In addition to direct habitat loss, roads impact wildlife and ecosystems through habitat fragmentation, edge effects, barrier effects, spread of exotic and invasive species, human-caused mortality, and disturbance from human activity, including vehicle traffic and recreation (Fahrig and Rytwinski 2009, Benítez-López et al. 2010). Negative responses to roads are generally observed in species that are sensitive to traffic disturbance (e.g. some songbirds, mid- and large-sized mammals) and species at risk from hunting pressure, road mortality and disruption of movement patterns (e.g. some mid- and large-sized mammals) (Trombulak and Frissell 2000, Fahrig and Rytwinski 2009).

Road impacts on aquatic ecosystems include alteration of streamflow, groundwater levels and sedimentation patterns with significant effects on the development of channels, shorelines, floodplains and wetlands (Trombulak and Frissell 2000, Kreutzweiser et al. 2013). The cumulative effects of a road and infrastructure network at a landscape scale can have a significant, negative impact on fish and wildlife populations (Linke et al. 2013). However, just a single road through a large, continuous block of intact habitat opens an area up to further resource use, wildlife exploitation, land conversion, motorized and non-motorized recreation and continued expansion of the road network (Laurance et al. 2014).

Photo: Lila Tauzer

Industrial roads increase access into alpine areas for recreation, hunting and new mineral exploration and extraction activities.

Photo: Hilary Cooke

*Roads are a major threat to biodiversity worldwide. While roads can act as barriers to movement for some species, for others, human activity on roads causes direct mortality. Every spring in southern Yukon, Lapland Longspurs (*Calcarius lapponicus*) travel in large flocks alongside roads on their migration to their Arctic breeding grounds. These individuals, which were part of a larger flock, were killed by a transport truck on the North Klondike Highway in 2016.*

A primary goal of protected areas and other area-based conservation measures is to limit the exposure of ecosystems and biodiversity to human pressures, and thereby ensure their conservation (Geldmann et al. 2013). By the 1990s, the global conservation community had recognized that the previous *ad hoc* process of identifying areas for protection was inadequate for ensuring conservation of biodiversity. In North America, the lack of a systematic approach had resulted in protected areas disproportionately occurring at high elevation, thereby resulting in "rock and ice" protection (Joppa and Pfaff 2009).

A systematic approach to prioritizing sites for conservation to ensure representation and persistence of biodiversity was formalized in the process of systematic conservation planning (Margules and Pressey 2000). Systematic conservation planning involves multiple stages, including identifying specific, quantitative objectives for the conservation of biodiversity; conducting a gap analysis of the degree to which conservation objectives are met within the current conservation area network; and, prioritizing additional areas for conservation as necessary to achieve objectives (Kukkala and Moilanen 2013, Pressey and Bottrill 2009, Groves et al. 2002, Margules and Pressey 2000).

A fundamental principle for prioritizing sites for conservation is *representation*. The principle of representation reflects the need when planning conservation for a large region to ensure as many species, ecological communities, habitats, enduring features and other features of interest as possible are captured within a network of conservation areas (Wiersma et al. 2005).

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Since our knowledge of all levels of biodiversity is limited, coarse- and fine-filter elements are used as "proxies" for representing the biodiversity values of a region. The coarse-filter approach aims to conserve samples of higher, well-mapped, levels in the biological hierarchy, such as ecosystem classes, under the assumption that these will better represent (or sample) other levels of biodiversity than conservation areas selected randomly or for other reasons. The coarse-filter approach aims to achieve representation of the types and relative amounts of the coarse-filter elements occurring across the planning region within protected areas. Potential coarse-filter elements include land-cover types, ecosystem classes and forest types. However, coarse-filter approaches are often insufficient to adequately capture rare, endemic, and priority habitats and species, so are usually supplemented with fine-filter elements, such as critical habitat for an at-risk species or rare old-growth forest ecosystems.

The second fundamental principle of conservation planning is ensuring conservation areas support the *persistence* of biodiversity (Margules and Pressey 2000, Pressey and Bottrill 2009). This takes planning beyond just the representation of species and ecosystems in conservation areas to include the maintenance of viable populations of species and the processes that maintain ecosystems. Conservation areas must be designed to support the natural processes that generate and maintain ecosystems and the conditions necessary for wildlife populations to survive. A landscape-scale approach is critical because many of the ecological and evolutionary processes that support the persistence of biodiversity operate across ecosystems, e.g. animal migrations and river connectivity (Rouget et al. 2006, Bixler et al. 2016).

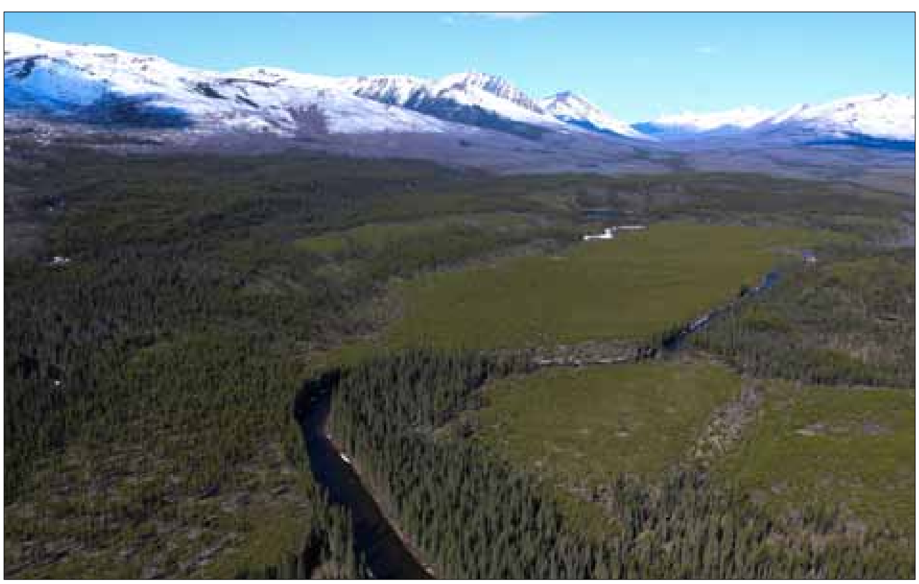
Boreal biodiversity evolved alongside natural disturbance regimes, principally fire, flooding and insect infestations, and thus species are adapted to changing conditions resulting from recurrent disturbances to a landscape.

The goal of landscape-scale conservation, then, is to conserve both pattern and processes. Whereas pattern refers to the what and where of elements of biodiversity at a single point in time (i.e. a static snapshot of species and habitats), process includes those ecological, genetic, behavioural, evolutionary, and physical processes that together, and over time and space, resulted in that present-day snapshot of biodiversity (Pressey et al. 2007).

While not rich in numbers of species, the intact landscapes of Canada's northern boreal continue to support their natural full array of flora and fauna. Boreal biodiversity evolved alongside natural disturbance regimes, principally fire, flooding and insect infestations, and thus species are adapted to changing conditions resulting from recurrent disturbances to a landscape. Following a natural disturbance event, forest succession changes stand composition (tree species that make up the forest stand) and structure (size, height, abundance, spacing, and condition of live and dead trees - Brassard and Chen 2006). Stands of different ages and composition support different assemblages of species, including birds (Schieck and Song 2006), mammals (Fisher and Wilkinson 2005), and arthropods (Buddle et al. 2006).

At a landscape scale, boreal fauna have adapted to move as patches of suitable habitat are created and lost through natural forest dynamics. For example, some species move to take advantage of recent burns, such as woodpeckers that benefit from the influx of beetles drawn to newly killed trees, while others benefit from the new growth of regenerating stands, such as moose and hare, which browse on young stems of willows and aspen. Representation and persistence of boreal biodiversity is thought to be best achieved if conservation areas are designed to accommodate the size, frequency, and intensity of fire disturbances.

The term "minimum dynamic reserve" is used to describe a conservation area large enough to accommodate – and to allow for the persistence of – the spatial and temporal patterns of ecosystems that occur under a natural fire regime (Schmiegelow et al. 2006, Leroux et al. 2007, Krawchuk et al. 2012).



Photos: Hilary Cooke

Fire is a natural and fundamental part of boreal ecosystems. Boreal biodiversity has adapted to recurring fire disturbance and the resulting changing ecosystems and landscape patterns. Just a month after a fire consumed much of a stand of spruce and pine in central Yukon, fireweed reclaimed the charred land (top). After the immediate disturbance, willow, rose, aspen saplings, and other woody plants are some of the early successional plants that dominate (middle). In the boreal biome, wildlife have evolved alongside the natural fire regime and the resultant size and pattern of disturbance to a landscape. In the boreal, most of the area burned is in large fires, but patterns of burned areas and forest regeneration can be highly variable (bottom).

In boreal Yukon, it is estimated that a minimum dynamic reserve needs to be at least three times the maximum regional fire size in order to be large enough to accommodate persistence of biodiversity over the long term (Leroux et al. 2007, Anderson 2009b). In simplest terms, a conservation area that is too small could lose characteristic ecosystems and biodiversity elements, such as old forest stands and associated biodiversity, in a single fire event. Or, conversely, a small conservation area may have limited supply of early-successional habitats in the period between fires.

1.2 Yukon context: economy and resource development

A conservation area that is too small could lose characteristic ecosystems and biodiversity elements, such as old forest stands, in a single fire event.

Much of Yukon's population of ~37,000 is concentrated in its southern capital, Whitehorse. A national map estimates 4% of Yukon is covered by the human-access footprint, i.e. roads and infrastructure (Figure 2; Lee and Cheng 2014). The current footprint of transportation and other human land disturbance grew from two major events in the past century. The Klondike Gold Rush in the late 1890s linked Skagway and Whitehorse via the White Pass and Yukon railway, thereby transforming Yukon's Southern Lakes region into a transportation centre (Coates and Morrison 2005, SLWCC 2012). Following the Gold Rush, transportation throughout the Territory was primarily via river, trail and the railway. In 1942, the United States Army built the Alaska Highway, connecting Alaska, Yukon and northern British Columbia to the south. From the initial 800 km of Alaska Highway constructed in 1942, Yukon's system of paved and gravel highways has tripled to reach over 2,700 km from east to west, and south to north. Today, the total length of all mapped roads is ~6,300 km.

Mining has continued to be the primary industry in Yukon since the Klondike Gold Rush. Between 2009 and 2014, the mining, quarrying, and oil and gas industries contributed 15-21% of total Gross Domestic Product (GDP) (Yukon Bureau of Statistics 2016). In 2015, mining industry GDP fell to 12%, lower than the contribution of the real estate industry (14%) for the first time since 2007. Currently only one major mine is producing, but there are ~215,000 active and pending mineral claims, leases, and permits across Yukon (Yukon Energy, Mines, and Resources Mining Claims Database: http://apps.gov.yk.ca/ymcs/f?p=116:1:4316516437771492; accessed on February 12th, 2017).

Anthropogenic land disturbance will continue to expand with mineral exploration activities and new mine sites will require new transportation and energy infrastructure. The Yukon government has explored alternative energy sources to meet projected future energy needs, including new water power development (Yukon Development Corporation 2014) and biomass (Yukon Government 2016). The latter would promote wood biofuel over oil, gas, and electric heating. Both are likely to increase the industrial footprint in relatively intact parts of the territory. There is also interest in increasing Yukon's local food production (Agriculture Branch 2015), which will put additional pressure on the most productive habitats of Yukon's valley bottoms.

1.3 Yukon context: existing conservation areas

Approximately 14% (~70,000 km^2) of Yukon is currently protected in 26 conservation areas, ranging from 4-22,155 km^2 (11 are less than 100 km^2 - Table 1). Yukon's protected areas are split among the two dominant ecozones: 47% of the total area in protection is in the Taiga Cordillera; and 43% is in the Boreal Cordillera (Table 2). However, protection is unevenly distributed among the 23 ecoregions, particularly in the Boreal Cordillera where five ecoregions have almost no protection and one (St. Elias Mountains) has almost one-third of the total area in protection in the Yukon. Three ecoregions (Klondike Plateau, Pelly Mountains, Yukon Plateau North) cover 25% of the Boreal Cordillera ecozone, but have no or little protection. For example, the Yukon Plateau-North ecoregion covers 12% of the Territory but has only 3% of its area protected. East of Johnson's Crossing and the South Canol Road in south-central Yukon, the only areas formally protected are the Nisutlin River Delta National Wildlife Area (55 km^2) and Coal River Springs Ecological Reserve (16 km^2). Much of the Pelly River and Stewart watersheds, and essentially the entire Upper Liard watershed, are without formal protection, as is much of the lower part of the Yukon and White River drainages.

In Yukon, the capacity of the land outside protected areas to accommodate additional growth of the human footprint before ecological values and traditional economies are significantly compromised is unknown. The exception is the Southern Lakes region, where a rapidly expanding human population and footprint have already substantially transformed natural habitats and impacted wildlife populations, particularly caribou, sheep, moose, and grizzly bears (SLWCC 2012).

A partial recovery of the Carcross caribou herd in the Southern Lakes region has been facilitated by a no-harvest agreement among First Nations and the Government of Yukon, but the population is still threatened by human-caused cumulative effects of habitat loss and fragmentation, vehicle collisions and disturbance from motorized and non-motorized off-road recreation (Florkiewicz 2008, Reid et al. 2013, Francis and Nishi 2015). The grizzly bear population in this region has also declined over the past two to three decades, potentially as a result of increased human development and bear mortality resulting from human-bear conflict (COSEWIC 2012, SLWCC 2012).

Declines of the Carcross caribou and grizzly bear populations in the Southern Lakes region are a strong signal that Yukon's wild places and wildlife will be negatively impacted by unplanned growth of the human footprint.

Declines of the Carcross caribou and grizzly bear populations in the Southern Lakes region are a strong signal that Yukon's wild places and wildlife will be negatively impacted by unplanned growth of the human footprint. Increasing disturbance and conversion of land for human uses, and increasing access into previously intact regions via new roads and off-road vehicles, threaten the ability of Yukon's boreal landscapes to support ecological values and traditional livelihoods, such as hunting, fishing, and trapping. Regional planning is critical to manage the cumulative effects of multiple activities on the land and to de-escalate conflict over incompatible land uses (Kennett 2010). In the absence of regional land use planning, concurrent project-based environmental assessments tend to result in piecemeal erosion of ecological values (Chetkiewicz and Lintner 2014).

Table 1. Yukon's current protected area network covers ~13% of the Yukon landbase (note, Vuntut National Park overlaps Old Crow Flats Special Management Area). Seventeen protected areas are included within the Yukon Boreal Mountains (YBM) study area (indicated by *); 3 of the 17 have less than 100% of their total area within the study region: Kluane Wildlife Sanctuary (49%), Kluane National Park (18%), and Tombstone Territorial Park (4%).

Name	Area (km^2)
Agay Mene Natural Environment Park*	725
Asi Keyi Natural Environment Park	2,984
Big Island Habitat Protection Area*	8
Coal River Springs Ecological Reserve*	16
Ddhaw Ghro Habitat Protection Area*	1,609
Devil's Elbow Habitat Protection Area*	75
Fishing Branch Ecological Reserve	169
Fishing Branch Habitat Protection Area	978
Fishing Branch Wilderness Preserve	5,355
Herschel Island Territorial Park	113
Horseshoe Slough Habitat Protection Area*	77
Ivvavik National Park	9,704
Kluane National Park and Reserve*	22,155
Kluane Wildlife Sanctuary*	3,423
Kusawa Natural Environment Park*	3,082
Lewes Marsh Habitat Protection Area*	20
Lhutsaw Wetland Habitat Protection Area*	32
Nisutlin River Delta National Wildlife Area*	55
Nordenskiold Habitat Protection Area*	78
Old Crow Flats Special Management Area	12,099
Pickhandle Lake Habitat Protection Area*	51
Tagish Narrows Habitat Protection Area*	4
Ta'Tla Mun Special Management Area*	33
Tombstone Territorial Park*	2,050
Vuntut National Park	4,350
Total Area of PA in Yukon[1]	**64,898**
Total Area of PA in YBM Study Area	**11,720**

Table 2. Ecozone and ecoregion area within Canada, Yukon Territory, and Yukon's protected areas network. Ecozones are large, generalized units within a hierarchical ecological framework; ecoregions, nested within ecozones, have distinctive physiographic and ecological responses to climate.

Ecozone	Ecoregion	Total ecoregion area (km^2) in Canada	% Total ecoregion area within Yukon	% Yukon by ecoregion	Protected areas (km^2)	% Yukon ecoregion area within protected areas	% Total protected areas
Southern Arctic	Yukon Coastal Plain	12,761	37.4	1	2,541	53.2	3.9
Pacific Maritime	Mount Logan	4,205	99.4	0.9	4,185	100.1	6.5
Taiga Plain	Fort MacPherson Plain	30,405	9	0.6	-	0	0
	Muskwa Plateau	24,106	2.9	0.1	-	0	0
	Peel River Plateau	60,678	24.6	3.1	-	0	0
	All	***115,189***	***16***	***3.8***	***0***	***0***	***0***
Taiga Cordillera	British-Richardson Mountains	26,826	86	4.8	8,034	34.8	12.4
	Eagle Plains	20,540	100	4.3	694	3.4	1.1
	Mackenzie Mountains	87,067	49.5	8.9	1,592	3.7	2.5
	North Ogilvie Mountains	39,452	100	8.2	6,179	15.7	9.5
	Old Crow Basin	14,651	100	3	6,665	45.5	10.3
	Old Crow Flats	6,009	100	1.2	4,651	77.4	7.2
	Selwyn Mountains	72,426	49.3	7.4	-	0	0
	All	***266,972***	***68.4***	***37.8***	***27,816***	***15.2***	***42.9***
Boreal Cordillera	Boreal Mountains & Plateaus	105,582	0.8	0.2	30	3.4	0
	Hyland Highland	26,076	56.4	3	-	0	0
	Klondike Plateau	38,746	100	8	1	0	0
	Liard Basin	34,466	61.1	4.4	16	0.1	0
	Pelly Mountains	35,526	96.3	7.1	-	0	0
	Ruby Ranges	22,867	100	4.7	3,724	16.3	5.7
	St.Elias Mountains	24,533	78.7	4	18,588	96.3	28.7
	Yukon Plateau-Central	26,986	100	5.6	144	0.5	0.2
	Yukon Plateau-North	57,428	100	11.9	1,856	3.2	2.9
	Yukon Southern Lakes	35,868	83.8	6.2	1,765	5.9	2.7
	Yukon-Stikine Highlands	24,849	28	1.4	4,192	60.2	6.5
	All	***432,928***	***63.1***	***56.6***	***30,317***	***11.1***	***46.7***

[1] excluding Vuntut National Park

Photo: Lila Tauzer

*In winter, woodland caribou (*Rangifer tarandus*) in Yukon's Boreal Mountains make seasonal movements to lower elevations to forage on ground lichens. Loss of this critical winter habitat due to land-use change and human disturbance are factors affecting the viability of the Carcross Caribou Herd in southern Yukon.*

In Yukon, there have been several efforts to identify priority areas for conservation over the past four decades (e.g., (Theberge et al. 1980, Revel 1981, Inukshuk Planning & Development 1994, Pojar 2007). The nature of each assessment reflects the popular approach to identification and design of conservation areas at the time. The early assessments identified sites with unique ecological features without much consideration of the scale of ecological processes, whereas the later assessments incorporated more recent approaches to systematic conservation planning, such as representation of coarse- and fine-filter indicators and minimum areas to encompass large-scale processes.

The Yukon Protected Areas Strategy of the late 1990s had the goals of protecting representative core areas within each of Yukon's 23 ecoregion; protecting special places and, applying principles of ecosystem management and sustainable development to land outside protected areas (Yukon Department of Renewable Resources, 1998). Core protected areas within each ecoregion were to be identified and designated on the basis of being representative of the full range of terrestrial and aquatic ecosystems in the ecoregion; largely in a natural state (i.e. with few human-caused disturbances); large enough to sustain the natural functioning and evolution of ecosystems on a long-term scale; and providing opportunities for research and education (Yukon Department of Renewable Resources, 1998).

Following the general principles of landscape-scale conservation planning at the time, it was recognized that large core protected areas should be linked through protected wildlife migration routes and that management of the land outside protected areas should aim to conserve natural habitat (Yukon Department of Renewable Resources, 1998). It was also recognized that a consistent approach to identification and management of protected areas across the territory and integration of a protected areas strategy with regional land-use planning was needed. Work on Yukon's Protected Areas Strategy was discontinued in 2003.

1.4 Making decisions about land use in Yukon Territory

Today, the framework and tools for making decisions about land use and wildlife management in Yukon include federal legislation (e.g. Fisheries Act, Migratory Bird Convention Act), territorial legislation (e.g. Yukon Environment Act; Yukon Lands Act), and processes, councils, and Boards established through Final Settlement (i.e. land claim) Agreements between Yukon First Nations and the Governments of Yukon and Canada.

Eleven of Yukon's 14 First Nations have signed modern treaties with the Governments of Yukon and Canada. An Umbrella Final Agreement acts as a global guide for the legally-binding Final Agreements for land claims of individual First Nations (see https://www.aadnc-aandc.gc.ca/eng/1297278586814/1297278924701). First Nation Final Agreements have designated 9% of Yukon Territory as Settlement Lands, where the First Nation maintains ownership of surface rights on all settlement blocks and additional subsurface rights on some. First Nation Final Agreements also set out provisions for regional land-use planning and establishment of new conservation areas.

Regional planning is intended to balance varying, and potentially conflicting, types of land use and thus provide certainty for Yukon First Nations, as well as non-First Nations Yukoners, on future decisions regarding land use and land management.

Regional planning is intended to balance varying, and potentially conflicting, types of land use and thus provide certainty for Yukon First Nations, as well as non-First Nations Yukoners, on future decisions regarding land use and land management (YLUPC 2012). There are currently seven land-use planning regions (Figure 3). To date, only one Land Use Plan has been finalized – the Regional Land Use Plan for the North Yukon, an area covering 55,548 km^2 of northern Yukon. Not included in regional land-use planning are the traditional territories of the three First Nations without settled land claims, which together cover 30% of Yukon.

Several of Yukon's existing conservation areas were designated during settlement of First Nation Final Agreements. Broadly called "Special Management Areas," these sites can be designated as: national wildlife areas (e.g., National Parks, territorial parks, or national park reserves); special fish or wildlife management areas (e.g. Habitat Protection Areas; migratory bird or wildlife sanctuaries); Designated Heritage Sites; watershed protection areas; or other areas within a Traditional Territory as agreed to by the First Nation and Yukon Government (Council of Yukon First Nations and the Government of Yukon 1997).

Under the Umbrella Final Agreement, Special Management Areas are to be established for the purpose of recognizing and maintaining important features of Yukon's natural and cultural environment for the benefit of Yukon residents while respecting the rights of Yukon First Nations (Council of Yukon First Nations and the Government of Yukon 1997, Yukon EMR 2011). Today, new Special Management Areas may be established as long as they are consistent with any existing land-use plan and do not adversely affect the rights of Yukon

First Nations with a Settlement Agreement, including rights for harvesting of fish and wildlife.

In addition to designating new Special Management Areas, a land-use plan can also use management area zoning to protect ecological and cultural values from industrial development. For example, the Regional Land Use Plan for the North Yukon applied a Land Use Designation System of Protected Areas, Integrated Management Areas, and Community Areas to 13 Landscape Management Units (North Yukon Planning Commission 2009). Integrated Management Areas have four levels of development: lowest, low, moderate, and high corresponding to areas with very high, high, moderate, and low ecological and heritage/cultural values. This approach depends on sufficient knowledge of ecological thresholds and adequate consideration within the environmental and socio-economic impact assessment process. The adequacy of this approach for conserving ecological and cultural values has not yet been fully tested.

Regardless of the process used to designate land for conservation in Yukon, the associated management plan must aim to prevent human activity from eroding ecological values while ensuring the Rights and Interests of Yukon First Nations, and the terms and provisions in Yukon First Nation Final Agreements, are upheld, including (but not limited to) the rights for harvesting of fish and wildlife within any area identified for protection.

In large intact regions such as Yukon's Boreal Mountains, conservation areas can be proactively designed to maintain large-scale ecological processes and wide-ranging species, which often serves to conserve species with smaller-scale habitat needs at the same time.

1.5 A framework for planning for landscape-scale conservation across Yukon's Boreal Mountains

Most efforts to achieve conservation goals are reactive, i.e. a response to loss and degradation of habitat and declines in species populations. When a landscape is already impacted by the footprint of human activity and development, achieving landscape-scale conservation goals, such as protecting wide-ranging mammals, requires a mosaic of approaches including conservation areas and conservation-based measures in the developed landscape, or matrix, surrounding conservation areas (Groves et al. 2002, Lindenmayer and Franklin 2002, Sanderson et al. 2002b, Sarkar 2003, Margules and Sarkar 2007). In large intact regions such as Yukon's Boreal Mountains, however, conservation areas can be proactively designed to maintain large-scale ecological processes and wide-ranging species, which often serves to conserve species with smaller-scale habitat needs and ecosystems at the same time (Poiani et al. 2000, Groves et al. 2002, Sanderson et al. 2002b).

Thus, state-of-the-art conservation design for intact regions of Canada's boreal includes proactive planning (Schmiegelow et al. 2006, Leroux and Kerr 2013); conservation areas of sufficient size to maintain large-scale ecological processes, including natural disturbance regimes (Schmiegelow et al. 2006, Leroux et al. 2007, Leroux and Rayfield 2014); prohibitions or restrictions on road development and other degrading land uses within the conservation area (Leroux and Kerr 2013); limits to – and/or effective management of – land use and development in the surrounding landscape (Leroux and Kerr 2013); and functional connectivity with other conservation areas.

A novel approach to planning for landscape-scale conservation for Canada's boreal region was developed by the Canadian BEACONs (Boreal Ecosystem Analysis for Conservation Networks) Project, which is composed of researchers at University of Alberta (Edmonton) and Université de Laval (Québec City) (Schmiegelow et al. 2014). They introduced the concept of a Conservation Matrix Model, which has four landscape elements: (1) Networks of Ecological Benchmark Areas; (2) Site-specific Protected Areas; (3) Active Management Areas; (4) Conservation Matrix (Figure 4).

Ecological Benchmark Areas are the core conservation areas of the region. The fundamental criteria for an area to function as a Benchmark Area (BA) are: sufficiently large to support the ecological dynamics of the region, i.e. a minimum dynamic reserve; supportive of terrestrial and hydrologic connectivity; and relatively intact (i.e. little or no human development footprint).

The fundamental criteria for an area to function as a Benchmark Area are: sufficiently large to support the ecological dynamics of the region; supportive of terrestrial and hydrologic connectivity; and relatively intact.

A BA network, or Benchmark Network (BN), is a system of BAs that captures the environmental variability of a landscape or planning area. Systematically planning for a network of BAs ensures the full range of environmental conditions occurring across the planning area are represented in a conservation network. Environmental conditions can be described using various coarse-filter indicators, such as land cover.

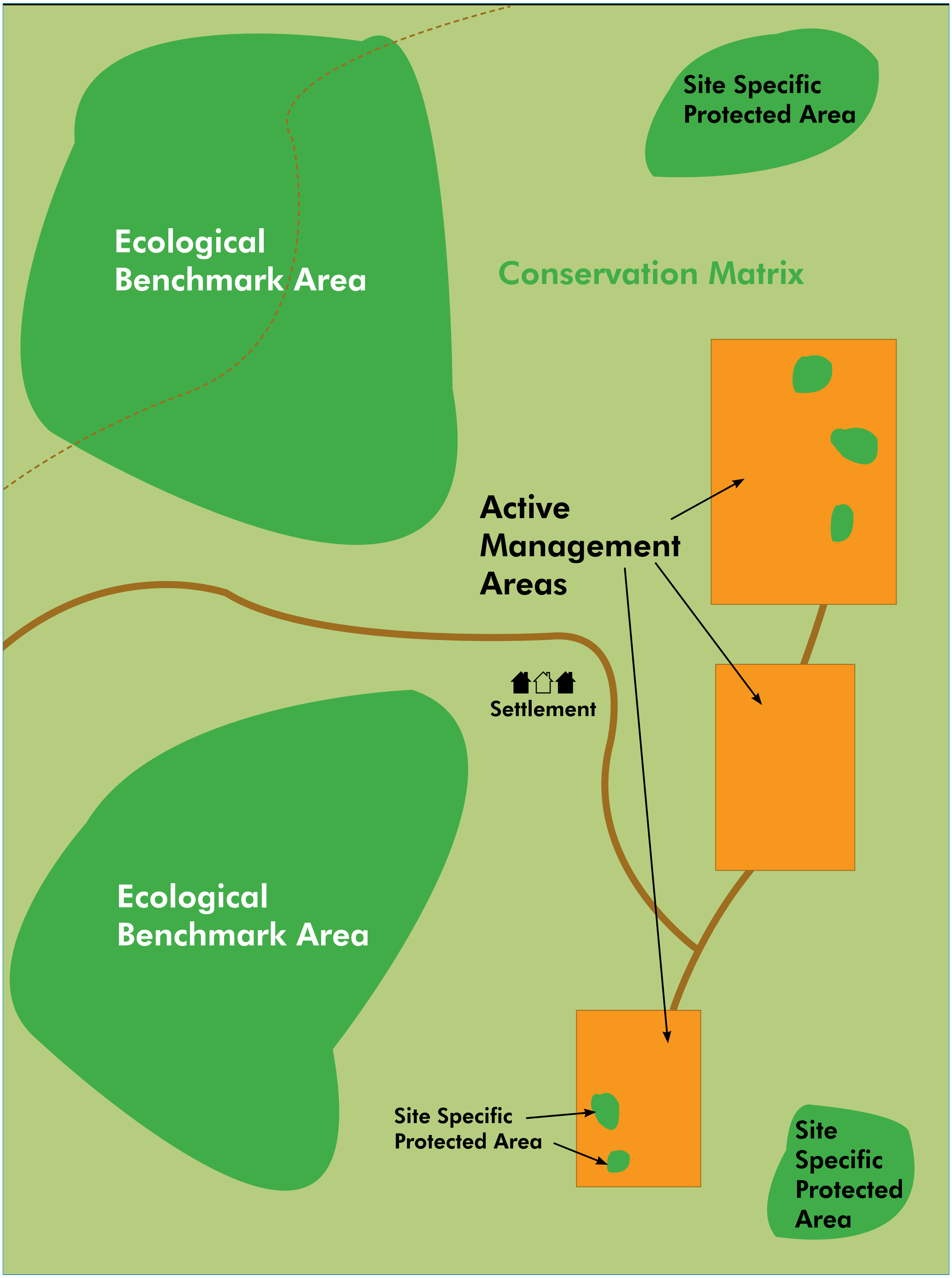
The second set of landscape elements are Site-specific Protected Areas (Figure 4). These areas capture values that may not be well represented within a BN, but require protection. Possible values that may be protected by Site-Specific Protected Areas include areas of cultural or heritage significance, key habitats of focal wildlife species, and occurrences of rare, unique, or sensitive species or habitats.

The third set of elements in the landscape are Active Management Areas. These are discrete areas of relatively intense human development, e.g. human settlements, forestry, mining, agriculture and associated infrastructure.

Finally, all three elements (BAs, Site-Specific Protected Areas, Active Management Areas) are embedded in what the researchers describe as a "conservation matrix." The matrix comprises the majority of land outside conservation areas. Management of the matrix is critical to landscape-scale conservation. For example, less-intense human activities, such as recreation, must be carefully managed to ensure that ecological values both within conservation areas and within the matrix are not eroded. Therefore, in contrast to regions that have been heavily developed, such as industrialized landscapes, the goal is for the matrix to remain in a relatively natural condition with ecological values protected, including buffering key habitats and conservation areas, supporting movements of fish and wildlife, and, maintaining the integrity of aquatic ecosystems (Schmiegelow et al. 2006).

Many spatial conservation prioritization tools use site-selection algorithms that maximize efficiency in identifying sites that will achieve biodiversity conservation goals, i.e. maximizing the ratio of conservation benefits to cost where benefits are measured with respect to objectives for representation and persistence of biodiversity in the planning area and costs are measured in terms of land area and lost economic opportunities. This is necessary in landscapes

Figure 4. The Conservation Matrix Model incorporates four landscape elements: (1) Networks of Ecological Benchmark Areas; (2) Site-specific Protected Areas; (3) Active Management Areas; and (4) the Conservation Matrix. Figure adapted from the Canadian BEACONs Project (http://www.beaconsproject.ca/).



already significant transformed by human activity where conservation is competing for the last patches of natural space with multiple other forms of land use. The BEACONs Project has developed several tools for identifying and ranking BAs and BN (Benchmark Builder and Ranker). However, BEACON's tools also find the best solutions for potential BAs and a BN *without* consideration of the cost in terms of land or lost economic opportunity.

The BEACONs tools are spatial decision-support tools for landscape-scale conservation that incorporate planning for pattern – specifically representation of ecological indicators – and process – specifically natural disturbance regimes and hydrological connectivity. I selected these tools because they are uniquely designed to address the scale of processes that drive the ecology of Yukon's northern boreal landscapes while incorporating the fundamentals of systematic conservation planning. The tools therefore provide an effective way to identify a comprehensive network of conservation areas that achieve all conservation goals.

1.6 The project goals

My goal was to evaluate and map gaps, opportunities, and priorities for landscape-scale conservation across Yukon's Boreal Mountains (YBM). To support this goal, I compared multiple scenarios for networks of landscape-scale conservation areas designed to answer the following questions.

The goal was to evaluate and map gaps, opportunities, and priorities for landscape-scale conservation across Yukon's Boreal Mountains.

First, what is the minimum area necessary for a conservation area to accommodate natural fire regimes across the study area? As noted, to ensure conservation areas support ecological integrity and biodiversity, several studies have recommended conservation areas be large enough to accommodate the scale of natural disturbance regimes and the associated range of natural variability in ecosystems both spatially and temporally. I used the work of Leroux et al. (2007) and Anderson (2009b) on estimated maximum fire size and minimum dynamic reserve for northwest boreal systems to estimate minimum size of conservation areas across my study area.

Second, how do networks of relatively intact, landscape-scale conservation areas differ in their ability to capture representative ecological conditions of the study area when conservation areas are identified using two maps of the human footprint: a national map and a Yukon map? At the time of analysis, the only comprehensive map of the human footprint for the Boreal Cordillera in Yukon was produced at a national scale by Global Forest Watch Canada (Lee et al. 2010). The Global Forest Watch Canada "human access" dataset combines National Road Network data with manual digitization (i.e. mapping) of anthropogenic disturbances using 30m resolution Landsat imagery (Lee et al. 2010). As with other efforts to map the human footprint at national or global scales, the Global Forest Watch map (hereafter, the national footprint map) is not necessarily appropriate for regional planning because the scale of mapping does not fully capture the human footprint in the region. Thus, to ensure the most accurate representation of land disturbance from human activity, I constructed a more detailed human footprint map using current (as of October, 2013) publicly available spatial data on human and industrial activity across Yukon (hereafter, the Yukon footprint map).

This study examined multiple scenarios for networks of landscape-scale conservation areas designed to explore what, where, and how much land must be allocated to conservation to ensure the diverse ecosystems and abundant wildlife of Yukon's Boreal Mountains persist long into the future.

Third, how do networks of relatively intact, landscape-scale conservation areas differ in their ability to capture representative ecological conditions of the study area when conservation areas have different amounts of human footprint – i.e. different thresholds for intactness – and the total area of a conservation area network increases? And, does inclusion of existing protected areas in a network of landscape-scale conservation areas enhance or constrain the ability of a conservation area network to capture regional environmental variability? In addition to identifying potential networks of BAs that featured 100% intactness (based on the national and Yukon footprint maps), I also explored scenarios that accommodated low levels of physical disturbance of the land. With some disturbance features, such as small clearings and trails, it is the human activity, such as hunting or motorized recreation, that most negatively effects wildlife (Trombulak and Frissell 2000, Fahrig and Rytwinski 2009). The cumulative effects of roads and other physical disturbance can significantly negatively impact wildlife and terrestrial and aquatic ecosystems, but very low levels of physical disturbance may not impair ecological integrity if human access and activity is effectively managed. Therefore, I also examined scenarios for BN less than 100% intact; in other words, with small amounts of human footprint.

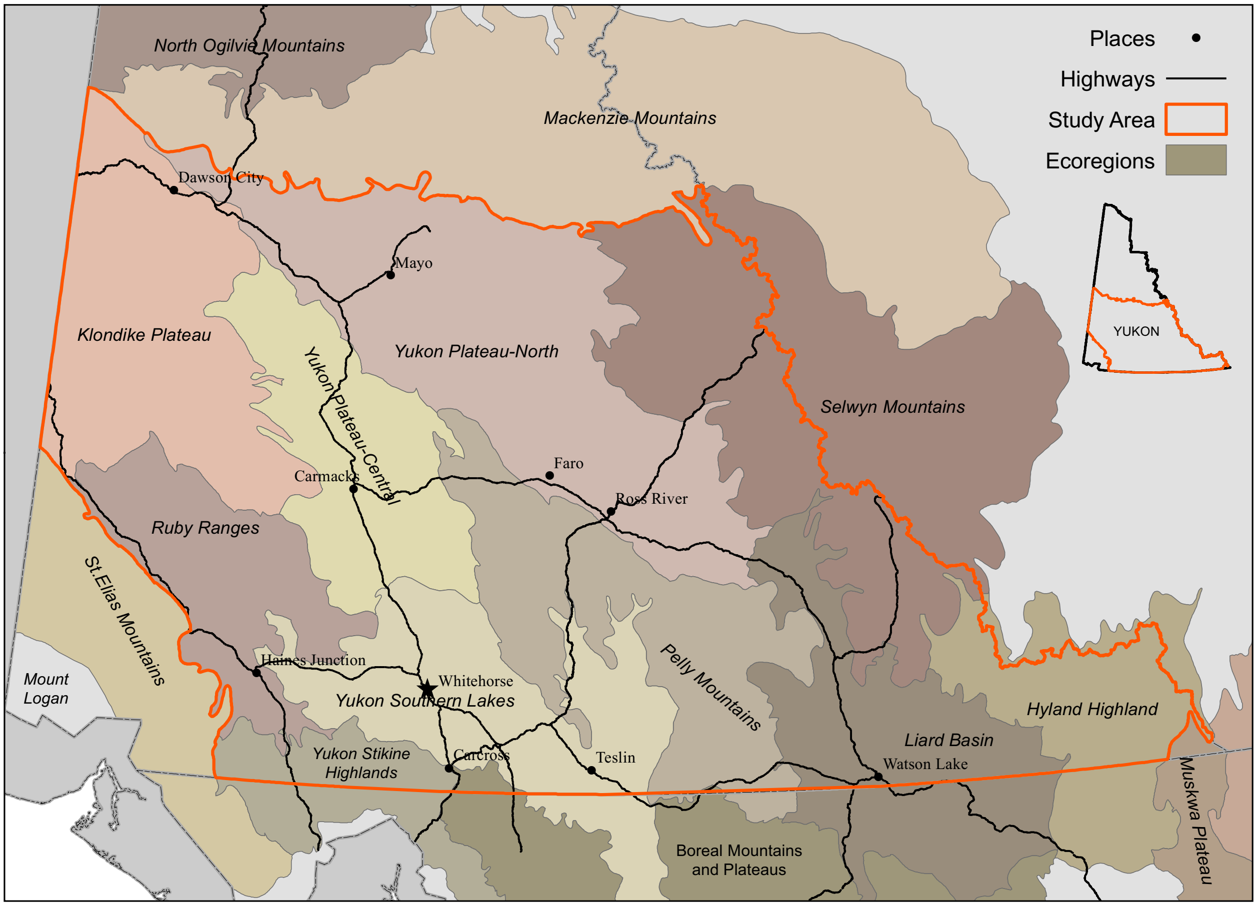
2. METHODS

2.1 The study area: Yukon's Boreal Mountains

The area included in this study, described hereafter as Yukon's Boreal Mountains (YBM), encompasses much of the Boreal Cordillera in Yukon (Figure 5). In addition, I included the Selwyn Mountains ecoregion in the Taiga Cordillera in order to maintain hydrologic connectivity within the Stewart, Pelly, and Upper Liard watersheds. This aligns with a recent proposal to revise the Yukon portion of the National Ecological Framework by shifting the boundary between Taiga and Boreal Cordillera ecozones to include the Selwyn Mountains ecoregion in the Boreal Cordillera (Environment Yukon 2016). I excluded the St. Elias Mountains ecoregion of the Boreal Cordillera because it is well represented in the existing protected areas network. The total study area is 289,611 km^2 or ~60% of Yukon, with 4% currently in parks or protected areas. Two parks (Kluane and Tombstone) are bisected by the study area boundary. The study area encompasses all or part of five of Yukon's land-use planning regions, plus the Traditional Territories of three First Nations without settled land claims.

The distribution of forested and naturally unforested areas in the YBM study area are determined primarily by altitude, but also by aspect, slope, cold air drainage, precipitation, and soil (Brandt 2009). Ecosystems are classified by bioclimate zone – areas of similar vegetation as influenced by climate condition, which is driven primarily by elevation and/or latitude (Environment Yukon 2016). Four bioclimate zones are described for the study area: boreal low; boreal high; subalpine; and, alpine. The boreal low bioclimate zone occurs at the lowest elevation. It includes the continuously forested valley bottoms, with mixed forests of white spruce (*Picea glauca*), black spruce (*P. mariana*), lodgepole pine (*Pinus contorta*), trembling aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), and paper birch (*Betula neoalaskana*). Valley bottoms also support the major rivers, large lakes, and wetlands of the region. The study area is drained by three major river systems: the Yukon, Liard, and Alsek.

Figure 5. Ecoregions of the Yukon Boreal Mountains study area.



Occurring above the boreal low zone, the boreal high bioclimate zone is the middle to upper elevation forested area. It is characterized by steep slopes in the southern ecoregions and gently sloping plateaus in the central and eastern ecoregions. The subalpine zone is a transition from the forested boreal zones to the alpine tundra. Vegetation cover in the subalpine includes tall shrubs and stunted open forests of white spruce and subalpine fir.

The alpine bioclimate zone occurs at the highest elevations with a cover of dwarf shrubs, mosses, herbs, lichen-covered rock fields and ice or snow. Seventy percent of the study area is within the boreal low and boreal high bioclimate zones.

2.2 The tools

The Canadian BEACONs Project (www.beaconsproject.ca) has developed a set of tools and datasets for identifying potential Benchmark Areas (BAs) and Benchmark Networks (BNs), as well as for evaluating representation of environmental conditions within a BN. These tools are called Benchmark Builder and Ranker.

Photo: John Meikle

The diverse ecosystems of Yukon's Boreal Mountains are distributed among four bioclimate zones, which are delineated as areas of similar vegetation influenced by elevation, latitude, and climate. From lowest to highest elevation the four zones are: boreal low; boreal high; sub-alpine; and alpine.

2.2.1 Benchmark Builder

The Benchmark Builder software constructs a BA using small (<500 km2) drainages or catchments (Canadian BEACONs Project 2011). A catchment is an area of land within which all surface water drains to a common point. The catchment data layer used in this study was derived by BEACONs using drainage network data and a digital elevation model (www.beaconsproject.ca/datasets). The study area is comprised of 5065 catchments ranging in area from 1 to 487 km2 (mean 52.9 km2; median 32.1 km2; Figure 6). Catchment intactness is calculated as the percentage area of an individual catchment that is free from human footprint. Intactness parameters are defined by the user at the scale of individual catchments and at the scale of an individual BA (area-weighted mean intactness). BEACONs derived intactness values for individual catchments using Global Forest Watch Canada's human access dataset.

BAs are constructed through aggregation of neighbouring catchments, starting with a catchment seed. Catchments added to a growing BA must meet or exceed the catchment-level intactness threshold set by the user and must not result in benchmark-level intactness lower than the user-defined threshold. Hydrologic connectivity and watershed integrity are maintained during the process of combining adjacent catchments into a potential BA. The BA is grown until the user-defined size is reached, as determined by the estimated size of a minimum dynamic reserve. The Benchmark Builder tool identifies all potential BAs within a study area based on the parameters for intactness and BA size set by the user.

2.2.2 Ranker

Ranker is an R-based script that constructs BNs out of potential BAs, and then ranks BNs based on representation of ecological indicators (Canadian BEACONs Project 2012). The Ranker script can also be used to assess and rank ecological representation of existing protected areas. BNs are assembled under all scenarios until either the user-defined total area of the BN is achieved or the user-defined number of BAs within a BN is achieved. Multiple options for assembling a BN are provided.

Environmental representation of a BN is assessed by comparing the distribution, i.e. the range and relative frequencies of classes or conditions, of an environmental indicator within the BN to its distribution across the entire study area (Canadian BEACONs Project 2012). The more similar the two distributions, the more representative the BN is of the study area. For each environmental indicator, statistical dissimilarity metrics are derived from two-sample univariate goodness-of-fit statistics: Kolmogorov-Smirnoff for continuous variables; Bray-Curtis for categorical variables. Representation values are rescaled between 0 and 1, with 0 indicating complete agreement, i.e. minimum distance or difference, between the distribution of an environmental indicator in the BN and the study area, and 1 indicating complete disagreement, i.e. maximum distance or difference, between indicator distribution in the BN and study area. The overall representation value for a BN is calculated by Ranker as the Euclidean distance for all environmental indicators scaled between 0 and 1. Thus, a BN with an overall representation value close to 0 is more representative of the collective variability in environmental indicators across the study area than a BN with a representation value close to 1.

To identify the most representative solution for the study area, I constructed and ranked a large number of candidate BNs. BEACONs recommends constructing 500,000 networks to ensure results are repeatable (Canadian BEACONs Project 2012). Ranker can also be used to identify areas that occur most frequently within the most representative networks – these areas are considered irreplaceable and thus most essential for achieving representation and conservation goals.

2.3 The planning scenarios and data inputs

I used Benchmark Builder (version 3.1.2.8, 2012) and Ranker (version 1.7.7, 2012) to identify and compare potential BAs and BNs across 24 scenarios that varied in intactness of catchments and BAs (3 thresholds), BN composition (networks of BAs with and without existing protected areas), and BN area target (4 levels) (Table 3). I evaluated all 24 scenarios using two catchment intactness maps derived from different maps of the human footprint.

2.3.1 Maps of human footprint and intactness

I first used the national map of catchment intactness produced by the BEACONs research group from the Global Forest Watch human access dataset (hereafter, the national catchment intactness map). I also constructed a detailed human footprint map for Yukon using current (as of October 2013) publicly-available spatial data on human and industrial activity (Table 4). I downloaded spatial data from the websites of Yukon Geomatics and Natural Resources Canada and included all land use activities requiring a permit or license in Yukon.

In Yukon, placer and quartz mineral claims are the parcels of land granted for mining under a free-entry system. Exploration activities on a claim fall into four classes, depending on the types and levels of activities, with Class 1 activities having the least and Class 4 having the greatest potential to have negative environmental impacts. Activities falling within Classes 2-4 require a permit, i.e. approval from the Government of Yukon. Class 4 activities also require a water license. Prospecting, staking, and Class 1 activities can be performed without a permit. I considered the spatial extent of a claim covered by a permit or license, plus associated buffer, as physical disturbance or "human footprint" for the purpose of this analysis.

All human footprint features were buffered using widths derived from Global Forest Watch Canada Intact Forest Landscape methods (Lee et al. 2010). Any features not specifically addressed in the Global Forest Watch data were assigned the same buffer width as similar features: industrial features were buffered by 1000 m; non-industrial features were buffered by 500 m. The final map of the human footprint for Yukon (hereafter, the Yukon human footprint map) included all buffered features of human disturbance. I used this map to produce a map of catchment intactness for the study area (hereafter, the Yukon catchment intactness map) by calculating the percentage area of each catchment not covered by features in the Yukon human footprint map. All planning scenarios were run using the national catchment intactness map and the Yukon catchment intactness map (Figure 6).

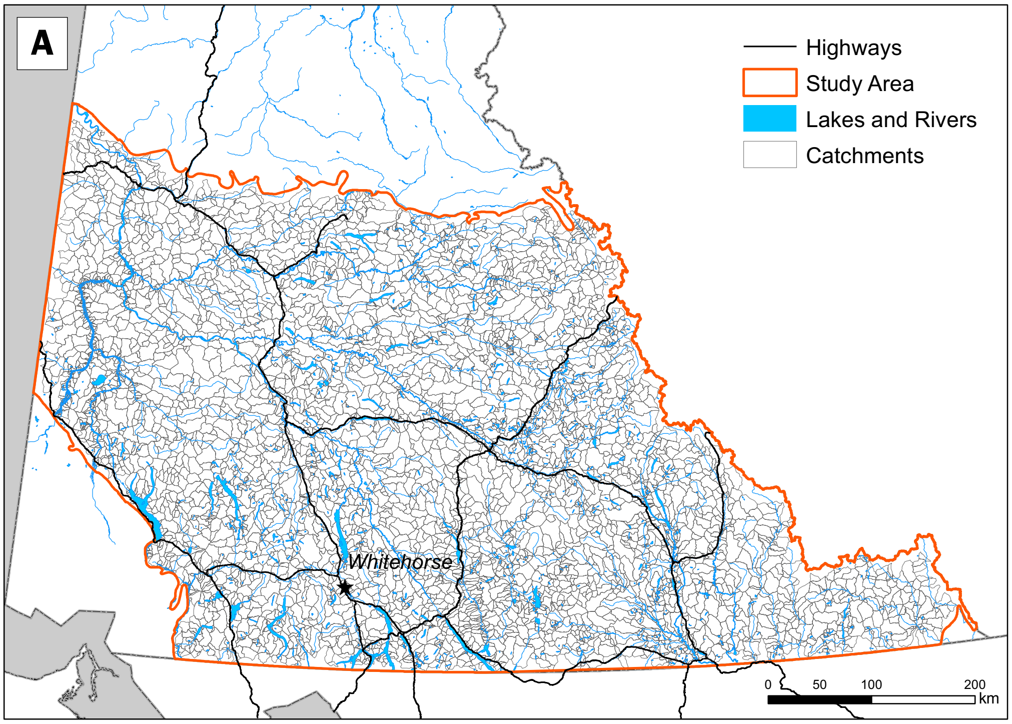
Table 3. Twenty-four scenarios for networks of landscape-scale conservation areas across Yukon's Boreal Mountains were assessed for their ability to represent – or capture – the ecological variability of the study area. The BEACONs Project tools were used to identify and compare Benchmark Areas and Benchmark Networks that varied by intactness threshold (i.e. minimum% intactness) at the scale of catchments and individual Benchmark Areas; inclusion or exclusion of existing protected areas in Benchmark Networks; and percent coverage by Benchmark Network of the entire study area.

Scenario	Intactness Thresholds	Network Composition	Network Area (% of Study Area)
1	Catchment=100% Benchmark Area=100%	Random Benchmark Areas	15
2			25
3			35
4			50
5		Existing Protected Areas + Random Benchmark Areas	15
6			25
7			35
8			50
9	Catchment=80% Benchmark Area=90%	Random Benchmark Areas	15
10			25
11			35
12			50
13		Existing Protected Areas + Random Benchmark Areas	15
14			25
15			35
16			50
17	Catchment=70% Benchmark Area=80%	Random Benchmark Areas	15
18			25
19			35
20			50
21		Existing Protected Areas + Random Benchmark Areas	15
22			25
23			35
24			50

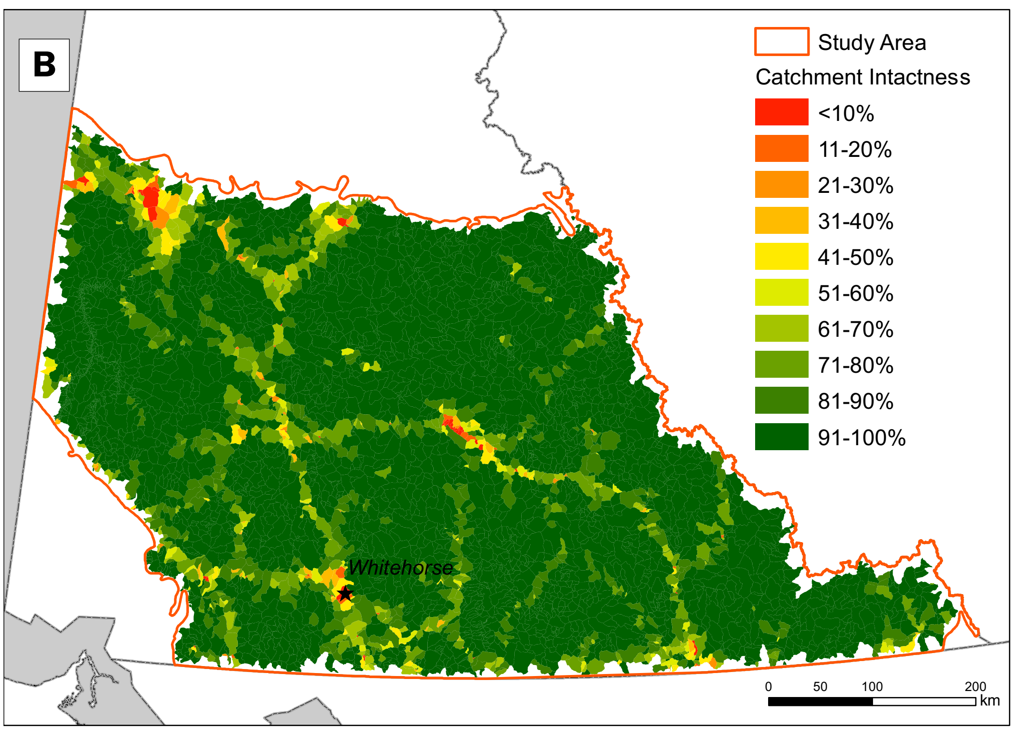
Table 4. Spatial data features and buffer widths used to map Yukon's human footprint. Spatial data features were acquired in October 2013 from Yukon Geomatics and Natural Resources Canada websites. Buffer widths were derived from methods used by Global Forest Watch Canada to identify Intact Forest Landscape (Lee et al. 2010).

Category	Type	Buffer Width (m) (m)
Agriculture	Agricultural Disposition	500
	Agricultural License	500
Energy	Hydro	1000
	Utility Disposition	500
	Utility License	500
	Wind	500
Forestry	Cutblocks	500
General Commercial	Commercial Disposition	1000
	Commercial License	1000
	Commercial Wilderness Disposition	500
	Commercial Wilderness License	500
	Institutional	500
General Industrial	Garbage Dump	1000
	Industrial Disposition	1000
	Industrial License	1000
Marine	Marine Disposition	500
	Marine License	500
Mining	Coal Lease	1000
	Gravel Pit	1000
	Placer Land Use Permit	500
	Placer Operation	1000
	Quarry Disposition	1000
	Quarry License	1000
	Quartz Land Use Permit	500
	Seismic Lines	500
	Well Location	500
Recreation	Campgrounds	500
Residential	Country Residential	500
	Municipal Boundaries	1000
	Places	1000
	Residential Disposition	500
	Residential License	500
Transportation	Airport Disposition	1000
	Airport License	1000
	All Other Roads	500
	Bridgehead	500
	Highways	1000
	Resource Road	500
	Rail	500
	Roadway Disposition	500
	Roadway License	500

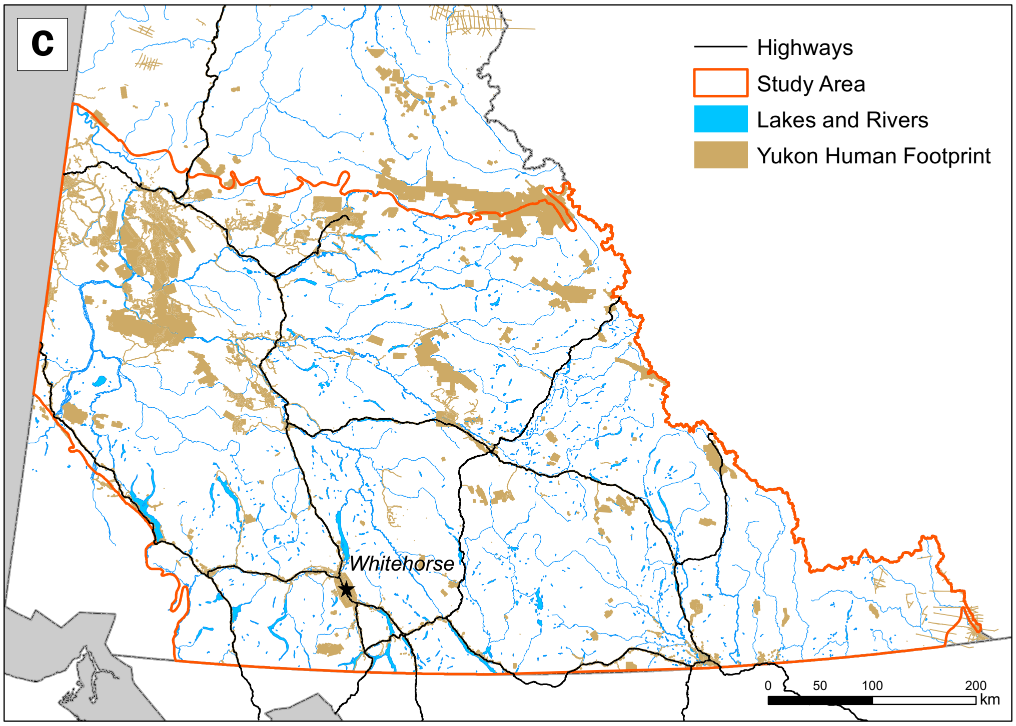
Figure 6. The human footprint (i.e. physical land disturbance) and associated catchment intactness (i.e. percent catchment area without human footprint): (A) catchments; (B) national catchment intactness map (derived from Global Forest Watch Canada human footprint map); (C) updated map of the Yukon human footprint (compiled by author based on publicly available regional data on anthropogenic disturbance, current as of October 2013); (D) Yukon catchment intactness map (derived from the Yukon human footprint map). See text for descriptions of Global Forest Watch data and methods and data sources of the Yukon footprint map.



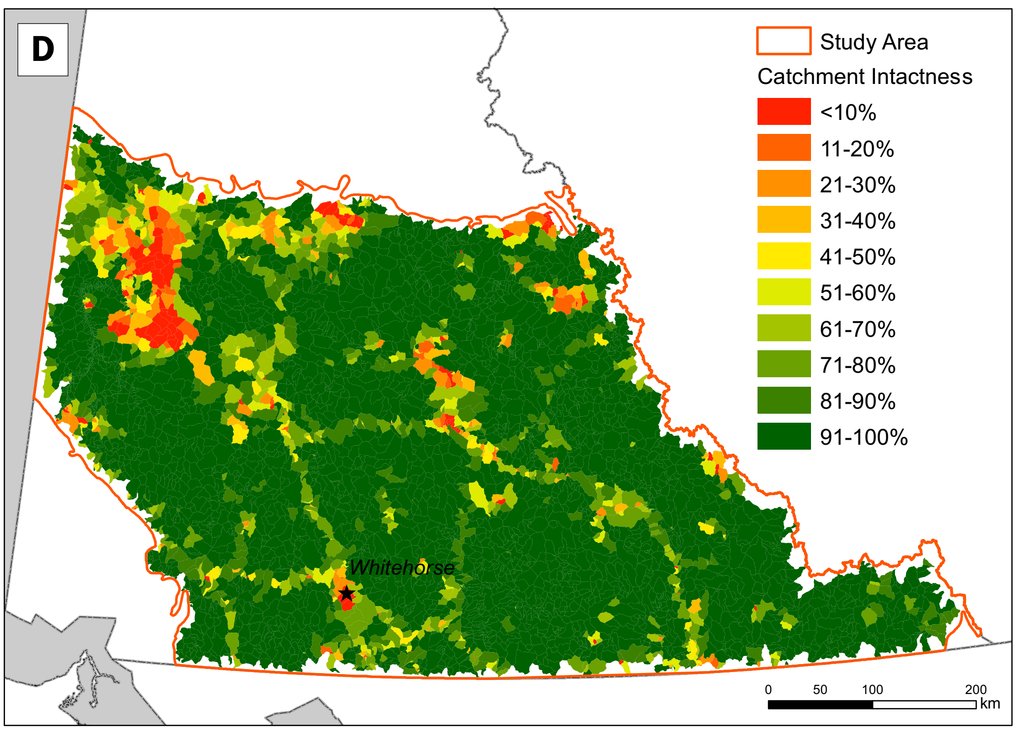
Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017 *Projection: Yukon Albers*
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017 *Projection: Yukon Albers*
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project; Global Forest Watch Canada



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada
Projection: Yukon Albers



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

I evaluated the accuracy of my Yukon catchment intactness map using a catchment intactness map derived from a highly detailed map of the human footprint for southern Yukon. Reid et al. (2013) used high-resolution remote sensing data and ground mapping of recreation trails in winter to compile a detailed map of surface disturbance for 12,000 km^2 of the Carcross caribou herd winter range in southern Yukon and northern B.C. I buffered all mapped features in the Reid et al. map using the same widths as in the Yukon human footprint map (Table 4). I then calculated total footprint area and percent intactness for catchments within the area covered by the Reid et al. map (includes 127 catchments) and compared them to estimates of catchment intactness for the same area in my Yukon catchment intactness map.

2.3.2 Catchment and Benchmark Area intactness

I set different intactness thresholds (i.e. minimum percent intactness) for catchments included in a BA, and for the BA as a whole (Table 3). Intactness thresholds for individual catchments included in a BA were 100% for scenarios 1-8, 80% for scenarios 9-16, and 70% for scenarios 17-24. For the BA as a whole, intactness thresholds were 100% for scenarios 1-8, 90% for scenarios 9-16, and 80% for scenarios 17-24. Thus, the 24 scenarios are organized in 3 groups based on intactness thresholds. In all planning scenarios, catchment seeds were at least 80% intact.

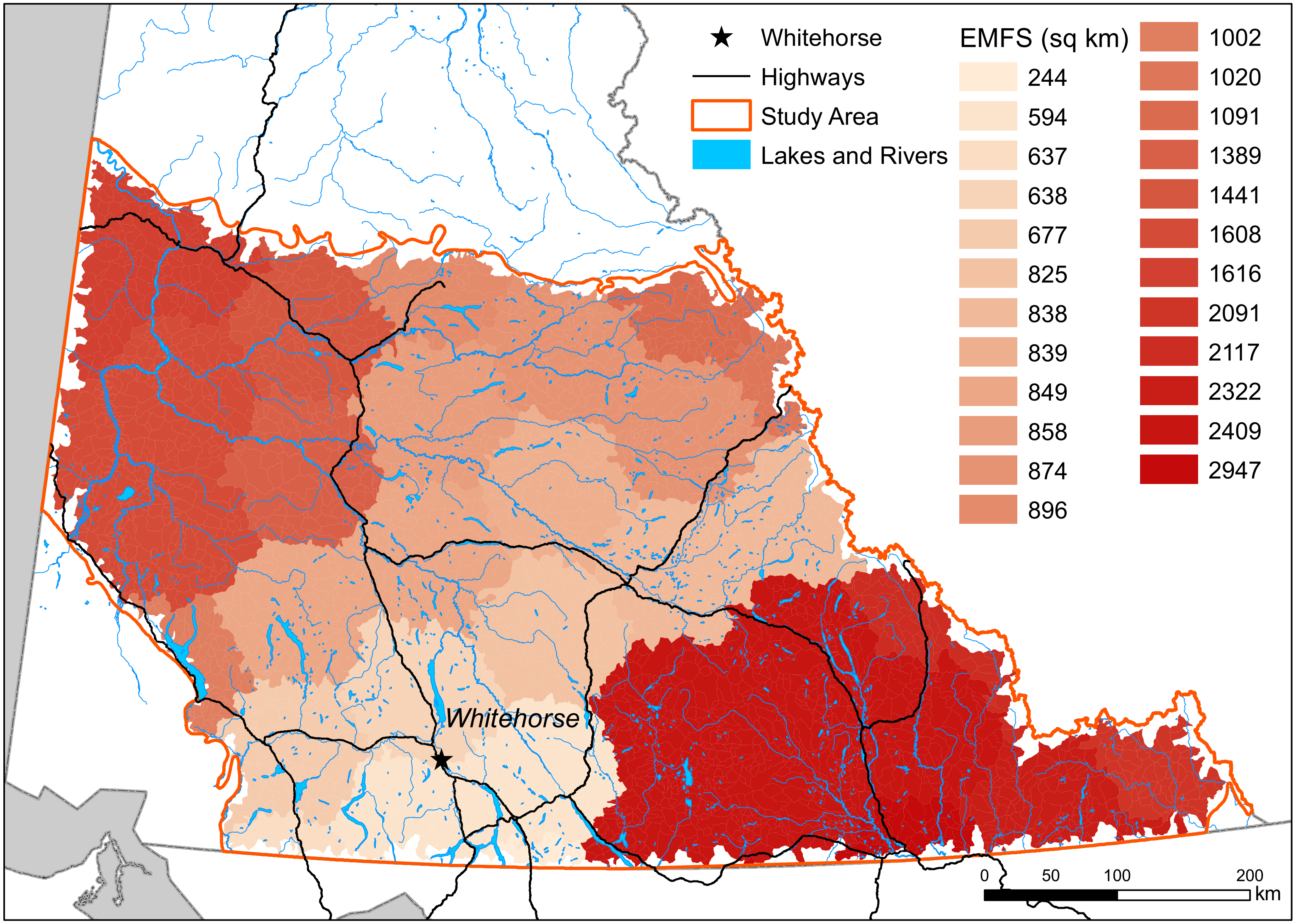
2.3.3 Benchmark Area size

Based on minimum dynamic reserve estimates for northwest boreal by Anderson (2009b) and Leroux (2007b), I set BA size to be three times the local Estimated Maximum Fire Size (Figure 7). Estimated Maximum Fire Size was modelled across a grid of 10,000 km^2 hexagons by the BEACONs group using regional fire characteristics (size, frequency) derived from large (>200 hectares) fires between 1959 and 1999 (www.beaconsproject.ca/datasets). Across the study area, Estimated Maximum Fire Size for each 10,000 km^2 hexagon ranged from 244 to 2,947 km^2 (median=1,091 km^2).

2.3.4 Benchmark Network size and composition

Within each intactness scenario group, I constructed BNs that varied in total area: 15%, 25%, 35%, and 50% of the study area. In systematic conservation planning, new protected areas are identified that complement the existing protected areas network to achieve conservation goals. Thus, for each combination of intactness threshold and area target, I also evaluated two types of BN composition: networks assembled from a random sample of all potential BAs; networks assembled by adding potential BAs to the existing protected areas network. For each planning scenario, I constructed 500,000 possible BNs from all potential BAs.

Figure 7. Estimated Maximum Fire Size (km2) by catchment for Yukon's Boreal Mountains. Estimated maximum fire size was modelled by the Canadian BEACONs Project at the scale of 10,000 km2 hexagons using Canada's large (>200 ha) fire database.

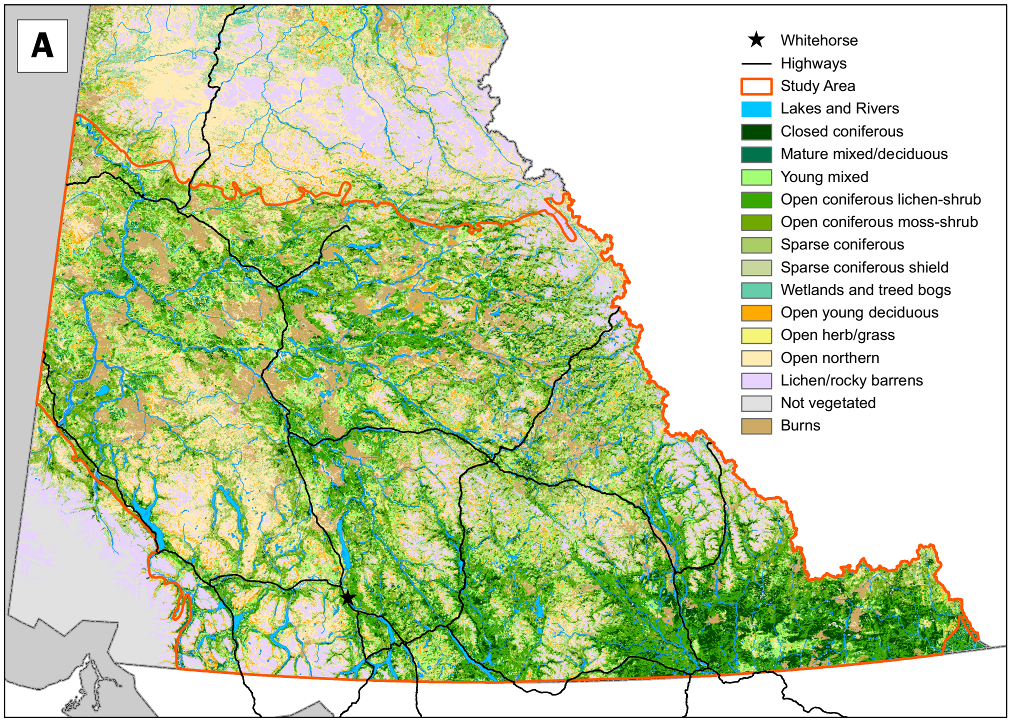


Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017

Projection: Yukon Albers

Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project

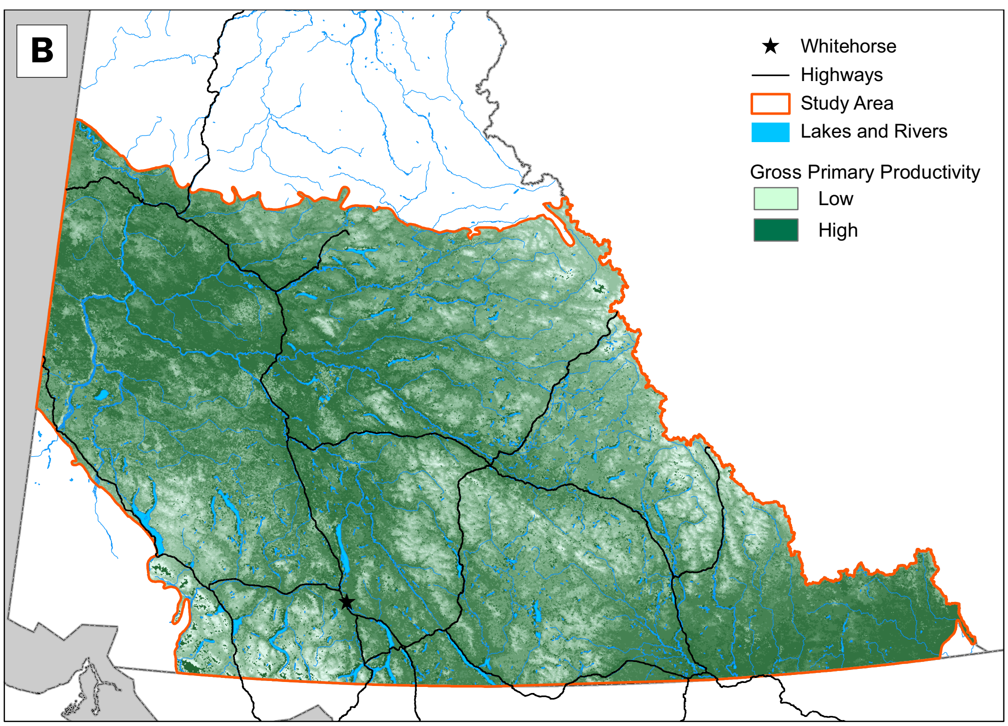
Figure 8. Four environmental indicators were used to construct and rank Benchmark Networks for all planning scenarios: (A) land cover class was reclassified to relevant classes for the study area; (B) gross primary productivity; (C) climate moisture index; (D) lake-edge density. See text for descriptions.



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project

0 50 100 200 Km

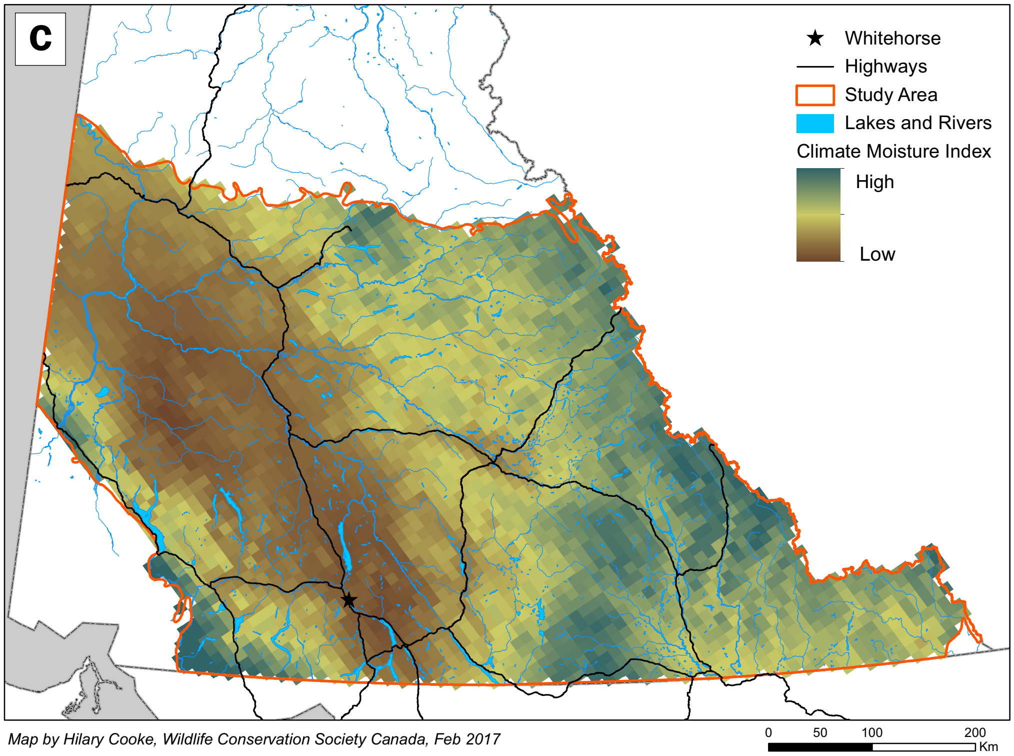
Projection: Yukon Albers



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project

0 50 100 200 Km

Projection: Yukon Albers



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
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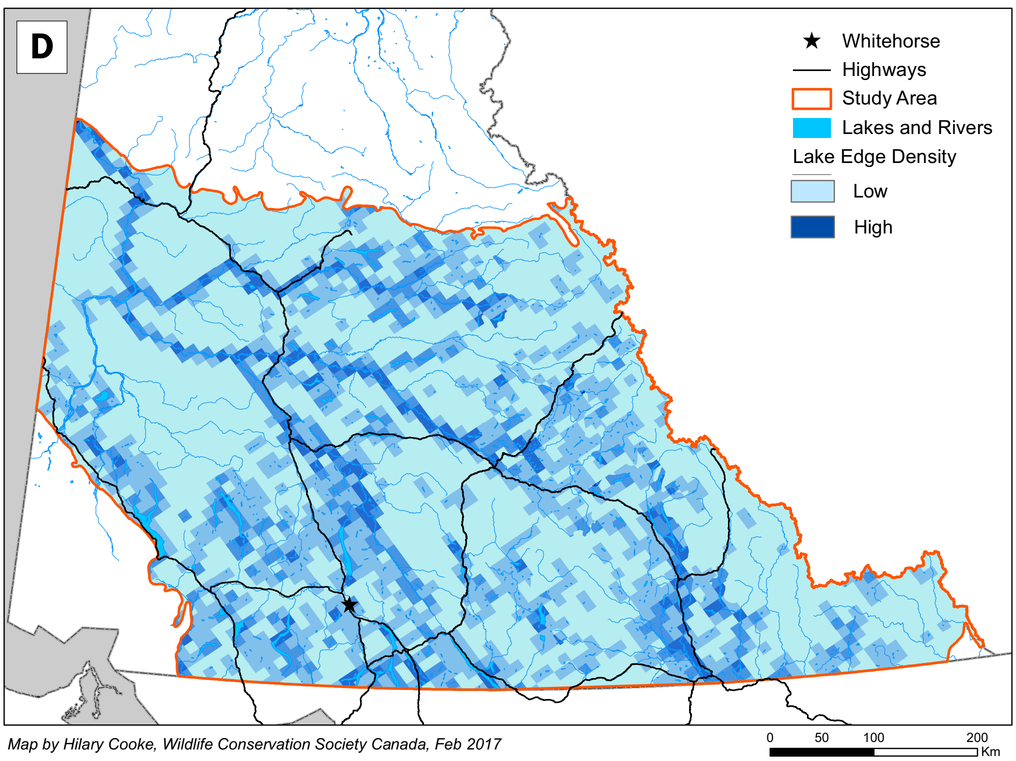
Projection: Yukon Albers



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

2.3.5 Representation of environmental indicators within Benchmark Networks

The BEACONs project identified four environmental indicators that collectively are intended to represent ecological variation of a region and thus capture biodiversity patterns: gross primary productivity, climate moisture index, lake-edge density, and land cover class (Figure 8). I modified the land cover indicator by grouping the 39 types into 14 to eliminate those with little or no occurrence in the study area (Appendix 1). I used the Kolomogorov-Smirnov statistic for continuous variables (gross primary productivity, climate moisture index, lake-edge density) and the Bray-Curtis statistic for discrete (categorical) variables (land cover). I assessed representation of each ecological indicator and all four combined within BNs relative to the study area as a whole. For a given scenario, the best BN, i.e. most representative of all 500,000, was the one with the lowest overall representation value.

2.3.6 Evaluating the effect of area and intactness on representation within Benchmark Networks

To determine the effect of BN area and intactness thresholds on representation of environmental indicators, I compared scenarios based on average representation value across all 500,000 BNs for each scenario. While the BN with the lowest representation value represents the best solution for a scenario, each of the 500,000 BNs satisfies the scenario parameters, including BA size (i.e. 3xEMFS) and intactness (i.e. 80%, 90%, or 100%), and total area of the BN (i.e. 15%, 25%, 35%, or 50%).

In land-use planning, decisions regarding allocation of land to conservation must consider additional ecological values, such as key wildlife areas, as well as social, cultural, and economic values and constraints. Thus, the top BN for a given scenario may not be incorporated directly as a network of conservation areas in a land-use plan, given the inclusion of other conservation and societal values. Other BNs would need to be considered to accommodate other values. Therefore, to determine how total BN area may affect the effectiveness of a conservation network in achieving environmental representation, I compared average representation among area targets. I limited this analysis to scenarios for BNs comprised of existing protected areas plus random BAs, and among these 12 scenarios to the best scenario for each area target. I calculated mean representation overall, and for individual indicators, across all BNs for each scenario and tested for differences using one-way Analysis of Variance (ANOVA). I also examined effect size, which is the relative degree to which the variance found in the ANOVA is associated with the main effect, i.e. what percentage of the variation in representation values among all BNs is attributable to differences in total BN area. The statistical software NCSS was used for this analysis (Hintze 2012).

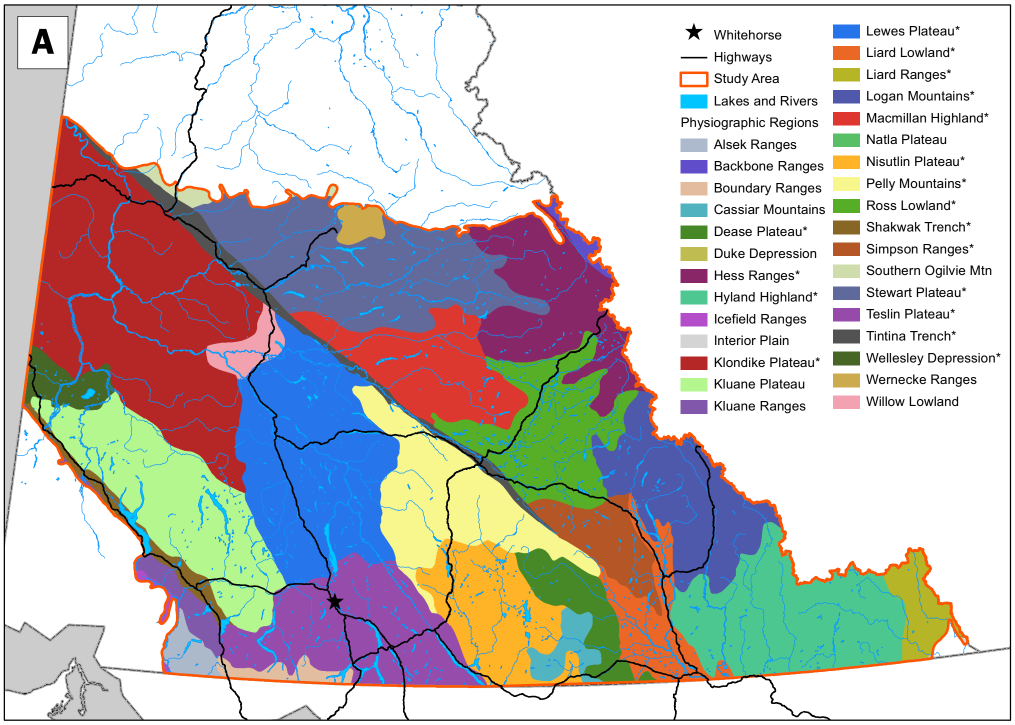
Photo: John Meikle

Land cover classes describe general ecosystem types, such as the deciduous forest, coniferous forest, and mixed deciduous-coniferous forest seen in this picture of the Pelly River floodplain near Ross River. Land cover classes are used as coarse-filter indicators of ecological conditions when assessing the adequacy of conservation areas for capturing a region's representative ecosystems.

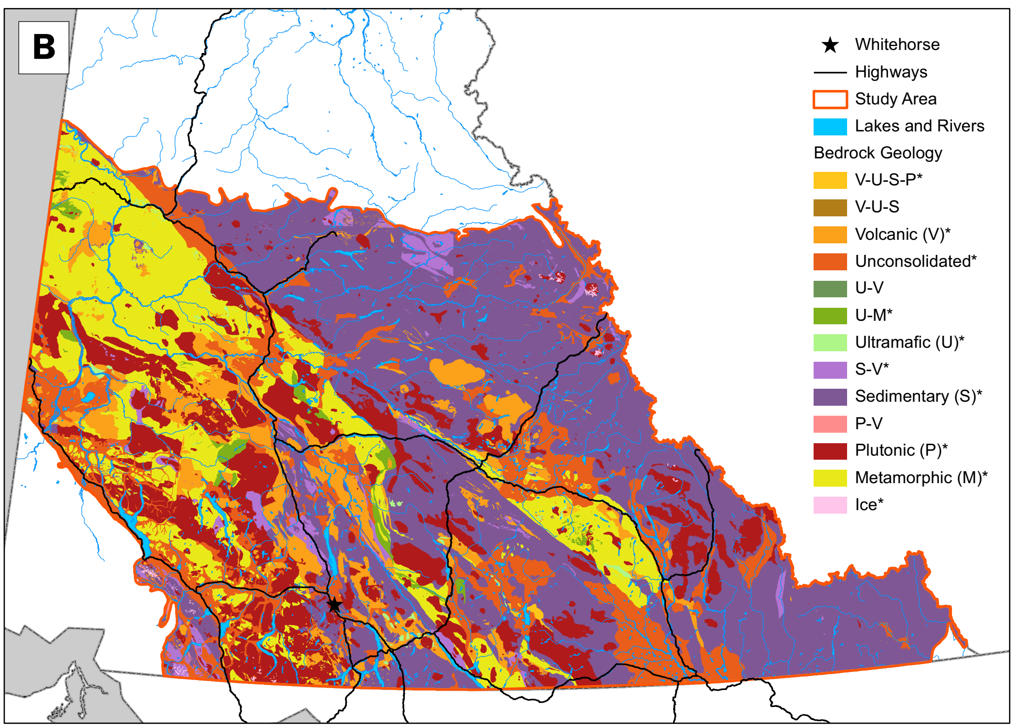
2.3.7 Testing representation of other environmental indicators

The final analysis I conducted was to test representation for a subset of BNs using environmental indicators other than those developed by BEACONs. The goal of this assessment was to validate the results of the scenario analysis, specifically the results of varying the total area of BN, using coarse-filter indicators not used to construct BNs. I assessed representation of ecoregions, physiographic regions, and bedrock geology (Figure 9) in the best BN constructed using existing protected areas and potential BAs from within each area target group (i.e. 15%, 25%, 35%, and 50%). I used Fisher's Exact Test in R (version 3.1.1) to compare proportions of each of these indicators within a BN to the study area as a whole.

Figure 9. Two environmental indicators used to assess representation of the best Benchmark Networks in the top planning scenarios: (A) physiographic regions and (B) geological classes.



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada

3. RESULTS

3.1 Catchment intactness

The percentage area of anthropogenic disturbance was lower, and the associated degree of intactness was higher, in the national maps compared with the maps I produced for Yukon. Based on the national (Global Forest Watch) human footprint map, 4% of Yukon is impacted by anthropogenic disturbance (Lee and Cheng 2014). Percent intactness of catchments in the study area averaged 92.5% in the national intactness map, with 68% of catchments 100% intact (Figure 6).

Based on my Yukon human footprint map, the total area of anthropogenic disturbance is 9.7% (46,787 km^2) of Yukon and 11% (32,525 km^2) of the study area (Table 5). Average catchment intactness in my Yukon intactness map is 89%, with 64% of catchments 100% intact.

The differences between the two maps are likely due to my inclusion of features not easily detected by the Global Forest Watch Canada method of mapping footprint (i.e. National Road Network data plus manual digitization of anthropogenic disturbances using 30 m resolution Landsat imagery), such as mineral claims with permits for low levels of exploration. Differences may also be the result of increases in anthropogenic disturbance between 2010 (year of national footprint map) and 2013 (year of Yukon footprint map).

Table 5. Summary of buffered human footprint features across Yukon and study area. See Table 4 for buffer widths applied to individual features.

Type	Feature	Yukon		Study area	
		Footprint area (km^2)	% Total footprint area	Footprint area (km^2)	% Total footprint area
Point	Campgrounds	44	0.07	41	0.09
	Communities	153	0.26	142	0.33
	Hydro Energy	13	0.02	13	0.03
	Oil and Gas Wells	57	0.10	5	0.01
	Placer Operations	566	0.96	559	1.28
	Wind Energy	1	0.00	1	0.00
Linear	All Other Roads	3,373	5.73	3,311	7.59
	Resource Roads (Forestry, Mining)	6,645	11.29	5,876	13.47
	Major Highways	5,449	9.26	4,512	10.34
	Rail	100	0.17	100	0.23
	Seismic Lines	7,830	13.30	402	0.92
Area	Agriculture Disposition	351	0.60	351	0.80
	Coal Lease	51	0.09	51	0.12
	Forestry Cutblocks	734	1.25	651	1.49
	Land Disposition (Select Industrial)	3,199	5.43	2,855	6.54
	Land Disposition (Select Non-industrial)	1,336	2.27	1,292	2.96
	Land License (Select Industrial)	110	0.19	106	0.24
	Land License (Select Non-industrial)	1,077	1.83	814	1.86
	Municipal Boundary	1,198	2.03	1,197	2.74
	Placer Mining Land Use Permit	3,065	5.21	3,007	6.89
	Quartz Land Use Permit	23,526	39.96	18,341	42.04

While the Yukon footprint map captured anthropogenic disturbance not mapped by the national footprint map, other activities also result in land disturbance. To evaluate this potential gap in footprint mapping for the study area, I compared my map with a higher-resolution map of the human footprint produced by Reid et al. (2013) for the Carcross Caribou Herd range in south-central Yukon (covers <5% of my study area). The estimate of total footprint area is 17% greater using the Reid et al. (2013) map compared to my Yukon human footprint map (footprint area=1,474 km^2 and 1,263 km^2, respectively).

This difference was associated with a lower median catchment intactness: 84% for the Yukon intactness map; 79% for the Reid et al. (2013) map. My map of human footprint estimated greater percent intactness compared with the Reid et al. (2013) map for 68% of catchments and lower for 29% of catchments. Overall, 87 and 84 catchments were classified as ≥70% intact based on the maps produced for this study and by Reid et al. (2013), respectively. Thirteen catchments switched from ≥70% to ≤70% intact between my map and Reid et al.'s map, and 10 switched in the other direction.

The Reid et al. footprint map included backcountry recreational trails used by off-road vehicles and hikers, which are a potential disturbance to caribou. Thus, differences in footprint and intactness maps reflect different scales of mapping and highlight the importance of selecting a scale and resolution that is appropriate to the size of the planning region and/or ecological process or species of interest. A detailed map of backcountry activity, as produced by Reid et al. (2013), is not feasible for the size of my study area.

3.2 Size of potential Benchmark Areas

Across the study area, the target area for potential Benchmark Areas (BAs) under the 24 planning scenarios ranged from 732 to 8,841 km^2 based on minimum dynamic reserve three times the estimated maximum fire size.

Using the national catchment intactness map, the number of potential BAs identified for the study area was 238, 511, and 574 for the 100%, 90%, and 80% intactness scenario groups respectively. Mean BA area was 3,947 km^2 for the 100% intactness scenario group, 3,890 km^2 for the 90% intactness group, and 3,997 km^2 for the 80% intactness group.

Fewer potential BAs were identified using the Yukon intactness map: 215, 449, and 489 BAs were identified for the 100%, 90%, and 80% intact scenario groups, respectively. Mean BA area was 4,246 km^2 for the 100% intactness scenario group, 3,689 km^2 for the 90% intactness group, and 3,776 km^2 for the 80% intactness group.

3.3 Planning scenario results

3.3.1 National versus Yukon intactness maps

Despite differences in estimates of catchment intactness and the size and number of potential BAs produced by the Yukon and national intactness maps, overall representation values and rankings of the 24 planning scenarios based on representation of their best BN were similar for both (Table 6, Appendix 2). The top two (#16 and #24) and bottom two (#4 and #8) ranked scenarios based on overall representation values were the same for the scenario analyses using the national and Yukon intactness maps. The top-ranked scenario in each intactness scenario group was also the same for both analyses. Thus, the remaining results and discussion will focus on analyses using the Yukon intactness map.

3.3.2 Planning scenario trends: intactness

Networks of 100% intact BAs were less representative of the four environmental indicators than networks of 80% and 90% intact BAs (Figure 10, Table 6). When ranked by overall representation, <100% intact BN filled the top 13 positions and 100% intact BN filled the bottom 5 positions. The two lowest-ranked scenarios (#4 and #8) had no BN solution, i.e. the parameters of the planning scenario could not be met. Both were for 100% intact BNs covering 50% of the study area – they differed in having BN composed of random BAs (#4) and existing protected areas plus random BAs (#8). The top scenario within each area target group (i.e. 15%, 25%, 35%, and 50%) were also for networks of <100% intact catchments and BAs.

3.3.3 Planning scenario trends: area targets

All planning scenarios performed better at representing both individual and combined environmental indicators than existing protected areas within the study area (Table 6). Existing protected areas cover 4% (11, 720 km^2) of the study area. The overall representation value for existing protected areas is 0.340 (GPP=0.200; CMI=0.222; LED=0.147; LCC=0.159). The overall representation value of the four environmental indicators across the existing protected areas network was greater (i.e. poorer representation) than both the representation value of the top Benchmark Network (BN) for each planning scenario and the mean representation value for all random BNs produced in each planning scenario.

For scenarios within the 80% and 90% intactness groups, overall representation of environmental indicators for the best BN tended to increase with increasing BN area, particularly as area increased from 15 to 35% (Figure 10). Among individual indicators, the trend toward better representation with increasing area is strongest for land cover (Figure 11). In contrast, networks of 100% intact BAs had decreasing representation when BN area increased from 35% to 50% of the study area (Figure 10). This trend is driven by two indicators: gross primary productivity and climate moisture index (Figure 11). Across all 24 planning scenarios, networks covering 15% and 25%, regardless of intactness, ranked 9th and lower, indicating overall representation was lower for BNs covering ≤25% of the study area (Table 6). Thus, based on the best

Table 6. Representation values and ranking based on representation values for networks of Benchmark Areas (BA) identified for 24 scenarios using the Yukon intactness map (see Appendix 3 for results using the national intactness map). Of the 500,000 Benchmark Networks produced for each scenario, the best was the Benchmark Network most representative of four environmental indicators, i.e. greatest similarity between the environmental indicators within the Benchmark Network and the study area as a whole. Representation index values close to 0 indicate the Benchmark Network is similar to the study area; values close to 1 indicate dissimilarity in environmental indicators between the Benchmark Network and area. All scenarios were ranked based on overall representation of their best Benchmark Network (top 8 are in bold). Subsets of scenarios were also ranked within groups of similar intactness threshold (8 scenarios in 3 groups); network composition (12 scenarios in 2 groups); and area target (6 scenarios in 4 groups).

Scenario #	Intactness Thresholds	Network Composition	% Area Target	Ranking by overall representation index				Environmental indicator representation index of best Benchmark Network				
				All Scenarios	By Intactness Threshold Group	By Network Composition Group	By Area Target Group	Overall (combined)	GPP[1]	CMI[2]	LED[3]	LCC[4]
1	Catchment=100%, Benchmark Area=100%	Random BA	15	22	6	11	6	0.076	0.053	0.041	0.034	0.091
2			25	20	4	9	6	0.074	0.052	0.036	0.037	0.046
3			35	21	5	10	6	0.075	0.047	0.047	0.034	0.033
4			50	24	8	12	6	0.136	0.069	0.111	0.034	0.033
5		Existing protected areas + random BA	15	17	3	9	3	0.054	0.023	0.040	0.027	0.061
6			25	14	1	7	5	0.053	0.034	0.027	0.028	0.046
7			35	15	2	8	5	0.053	0.030	0.030	0.030	0.041
8			50	23	7	12	5	0.125	0.059	0.105	0.030	0.029
9	Catchment=80%, Benchmark Area=90%	Random	15	16	7	8	2	0.053	0.033	0.035	0.022	0.070
10			25	12	6	6	4	0.041	0.020	0.027	0.022	0.049
11			35	7	4	3	3	0.029	0.013	0.023	0.011	0.045
12			50	6	3	2	4	0.028	0.021	0.017	0.009	0.037
13		Existing protected areas + random BA	15	18	8	10	4	0.055	0.017	0.046	0.024	0.062
14			25	10	5	6	2	0.038	0.013	0.029	0.019	0.062
15			35	3	2	3	1	0.024	0.010	0.019	0.010	0.039
16			50	1	1	1	1	0.019	0.009	0.013	0.011	0.030
17	Catchment=70%, Benchmark Area=80%	Random	15	13	7	7	1	0.052	0.033	0.028	0.026	0.078
18			25	11	6	5	3	0.04	0.028	0.024	0.015	0.043
19			35	8	4	4	4	0.034	0.019	0.019	0.020	0.028
20			50	4	2	1	3	0.024	0.017	0.013	0.010	0.016
21		Existing protected areas + random BA	15	19	8	11	5	0.057	0.019	0.047	0.025	0.069
22			25	9	5	5	1	0.037	0.015	0.028	0.019	0.073
23			35	5	3	4	2	0.027	0.013	0.020	0.013	0.033
24			50	2	1	2	2	0.021	0.008	0.011	0.016	0.025

[1]GPP=Gross Primary Productivity [2]CMI=Climate Moisture Index [3]LED=Lake Edge Density [4]LCC=Land Cover Class

BNs, scenarios of less than 100% intact BN covering at least 35% of the study area performed better than all scenarios covering 15 and 25% of the total area.

The top-ranked scenarios within the 15%, 25%, 35%, and 50% area target groups (limited to scenarios for BN comprised of existing PA plus random BAs) were #5, #22, #15, and #16, respectively (Table 6). For these four scenarios, mean overall representation indices (i.e. mean for all 500,000 BN produced for each of the scenarios) decreased with increasing BN area (Figure 12; 15% area, mean=0.153; 25% area, mean=0.114; 35% area, mean=0.091; 50% area, mean=0.074) and were significantly different from each other (ANOVA, $P<0.0001$; Figure 12). I used multiple comparison tests to evaluate trends in the differences in mean representation by area target. A significant linear trend was evident ($P<0.001$), indicating increasing mean representation with area. Because of very large sample size ($n=500,000$ for each), the standard errors of mean are very small (<0.0001) for each of the four network representation value datasets; thus, the estimate of the mean representation value is highly accurate. In other words, we can be confident that it is an accurate estimate of the average representation for all possible solutions for a given scenario. Note, however, this does not mean that any given BN will have that level of representation of environmental indicators or that a comparison of two random BNs covering, for example, 25% and 50% of the study area will have lower and higher representation respectively. But the significant difference in mean environmental representation by area target, and the significant, positive linear trend between area and representation, indicates that a network covering 50% of the study area is likely to achieve greater representation than a 35% BN, which is likely to achieve greater representation than a 25% BN, etc.

Figure 10. Overall representation of four environmental indicators within the best Benchmark Network for 24 planning scenarios compared to the study area as a whole. The combined relative amounts of different land cover classes and levels of gross primary productivity, climate moisture index, and lake-edge density are completely similar between the Benchmark Network and entire study area when representation index = 0, and completely dissimilar when representation index = 1. Intactness percentages in legend refer to Benchmark Area intactness thresholds for each scenario (see Table 4). Overall representation index for existing protected areas within the study area = 0.34; protected areas currently cover 4% of the study area.

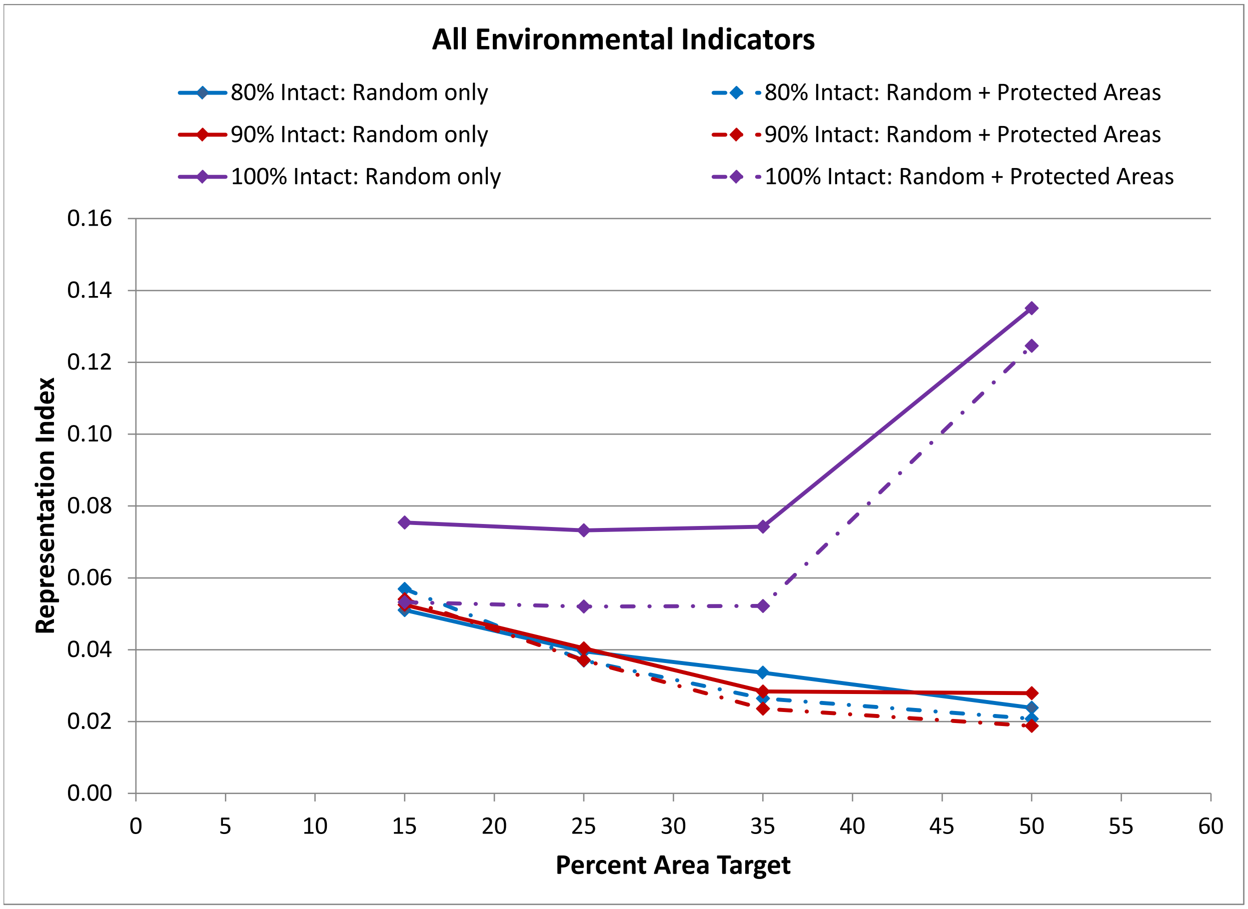
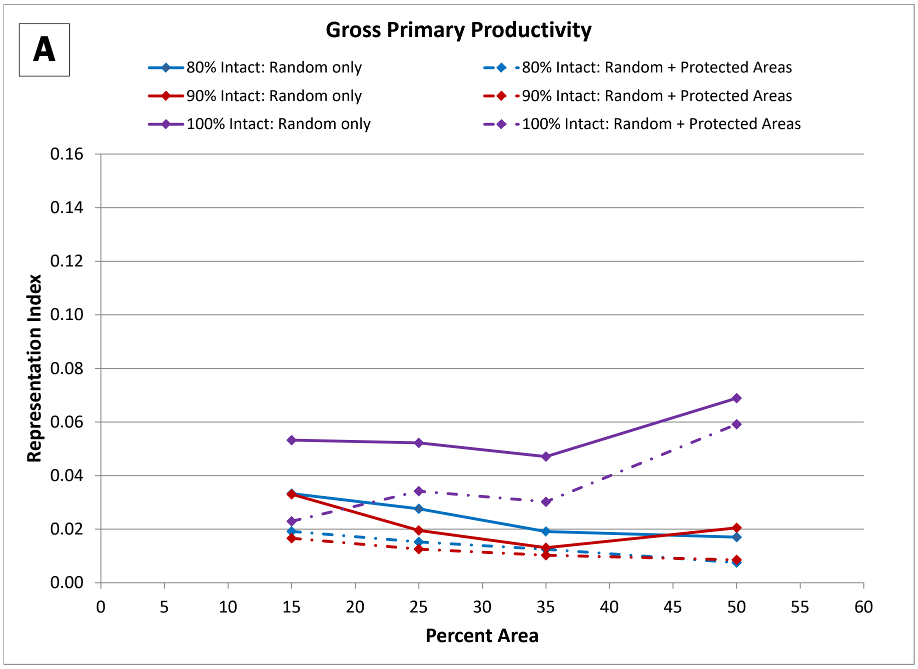
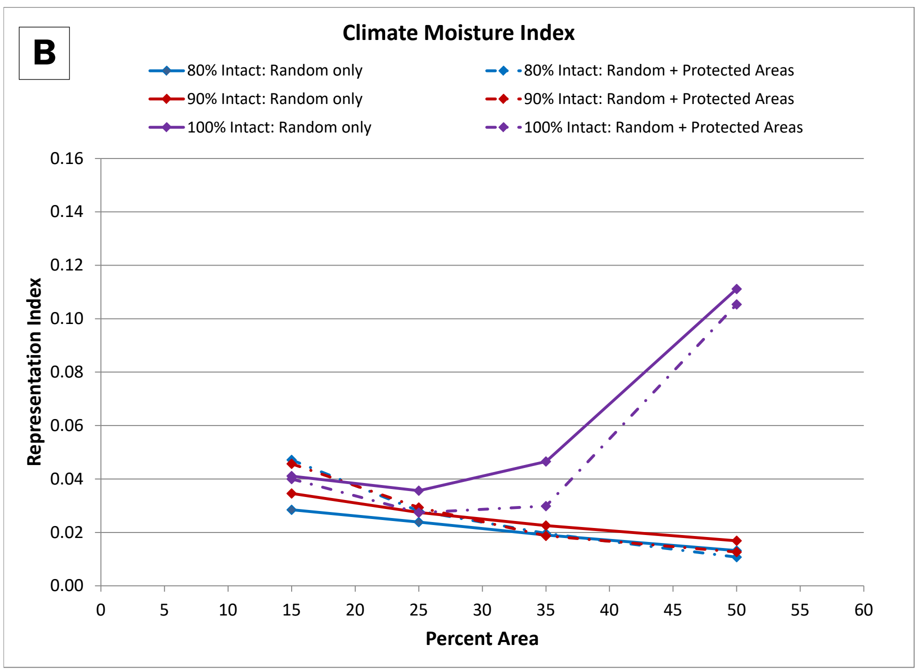
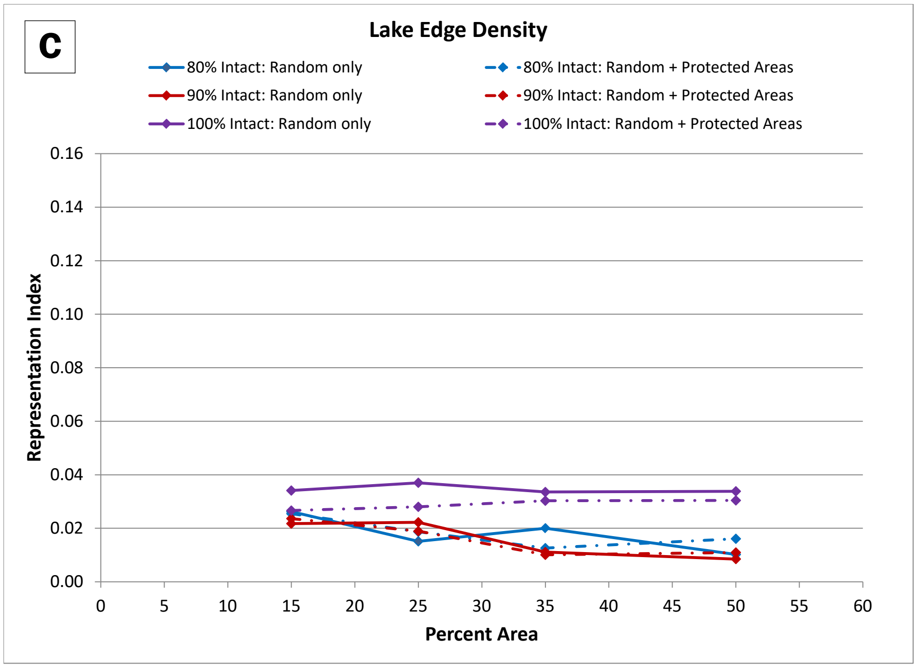


Figure 11. Representation of four environmental indicators within the best Benchmark Network for 24 planning scenarios compared to the study area as a whole. The distribution (i.e. relative amounts) of the different values for (A) gross primary productivity (GPP), (B) lake-edge density (LED), and (C) climate moisture index (CMI), and (D) of different land cover classes (LCC), are completely similar between the Benchmark Network and entire study area when representation index = 0, and completely dissimilar when representation index = 1. Intactness percentages in legend refer to Benchmark Area intactness thresholds for each scenario (see Table 4). Existing protected areas cover 4% of the study area; representation values for existing protected areas compared to study area are: GPP=0.20; CMI=0.22; LED=0.15; LCC=0.16.






C
Lake Edge Density
80% Intact: Random only
90% Intact: Random only
100% Intact: Random only
80% Intact: Random + Protected Areas
90% Intact: Random + Protected Areas
100% Intact: Random + Protected Areas
Representation Index
0.16
0.14
0.12
0.10
0.08
0.06
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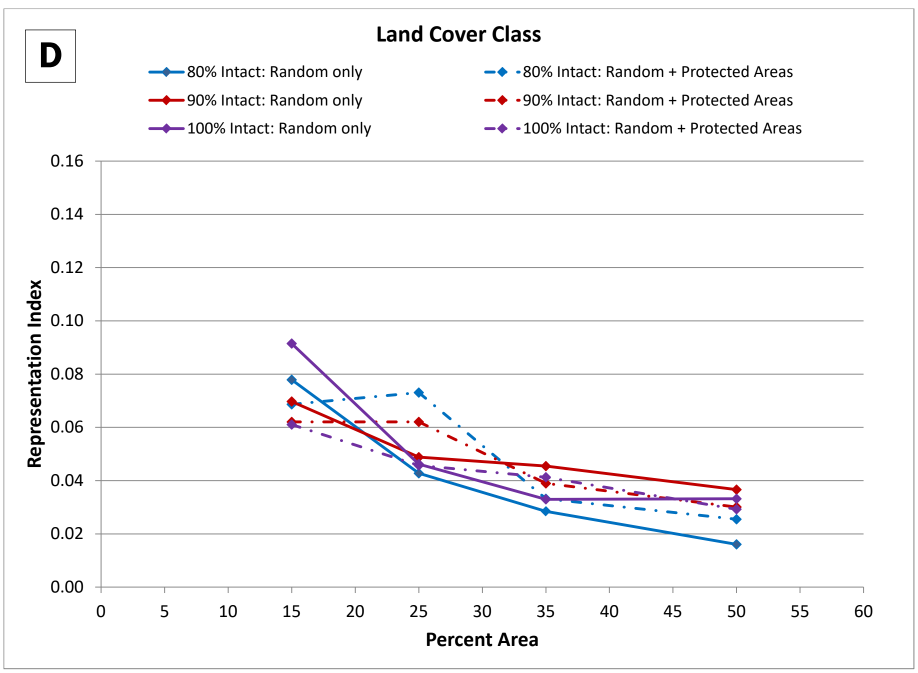
Percent Area


D
Land Cover Class
80% Intact: Random only
90% Intact: Random only
100% Intact: Random only
80% Intact: Random + Protected Areas
90% Intact: Random + Protected Areas
100% Intact: Random + Protected Areas
Representation Index
0.16
0.14
0.12
0.10
0.08
0.06
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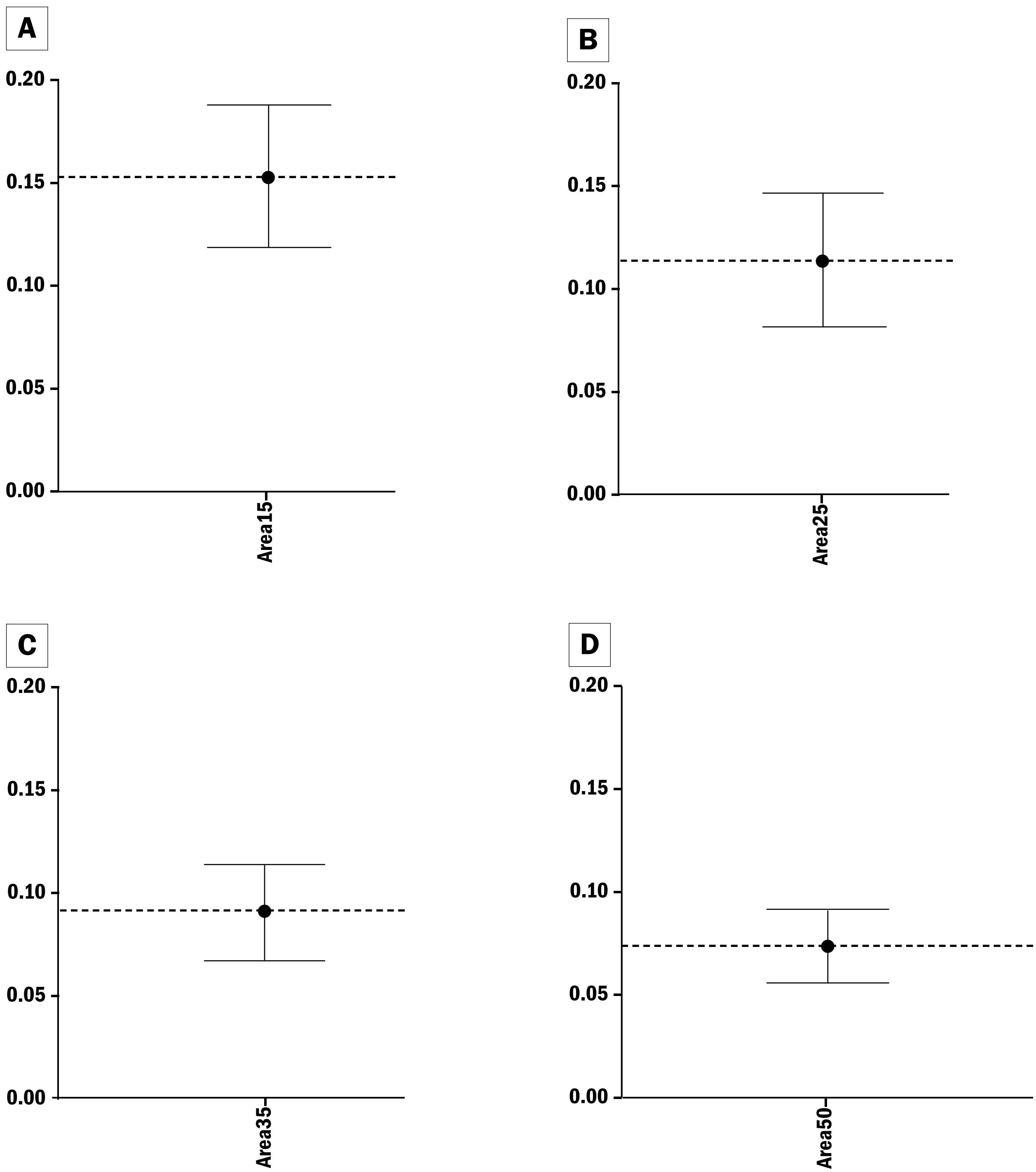
60
Percent Area

Figure 12. Plots of the mean (+ standard deviation) overall representation value for all random Benchmark Networks (n=500,000) produced for the top scenario in the group of scenarios with a BN area target of (A) 15%, (B) 25%, (C) 35%, and (D) 50% of the study area. Lower overall representation values indicates better representation, i.e. less difference between the environmental indicators within the BN and the study area as a whole. Mean overall representation was significantly different among area targets and improved (i.e. representation value decreased) with increasing network area. Effect size analysis indicates 53% of the total variation in overall representation values among the 500,000 Benchmark Networks can be accounted for by differences in percent area, leaving 47% of the variance due to error or unaccounted for by area effect.



3.3.4 Test of subset of planning scenarios using other environmental indicators

I assessed representation of ecoregions, bedrock geology classes, and physiographic regions within each of the best BNs for scenarios #5, #22, #15, and #16 (top-ranked scenarios for BNs composed of PA and random BAs for 15%, 25%, 35%, and 50% area respectively). Compared to the study area as a whole, percent composition of ecoregions within the 15% and 25% area BNs were both significantly different from percent composition of ecoregions across the study area (Fisher's exact test: P=0.03 and P=0.04, respectively; Table 7).

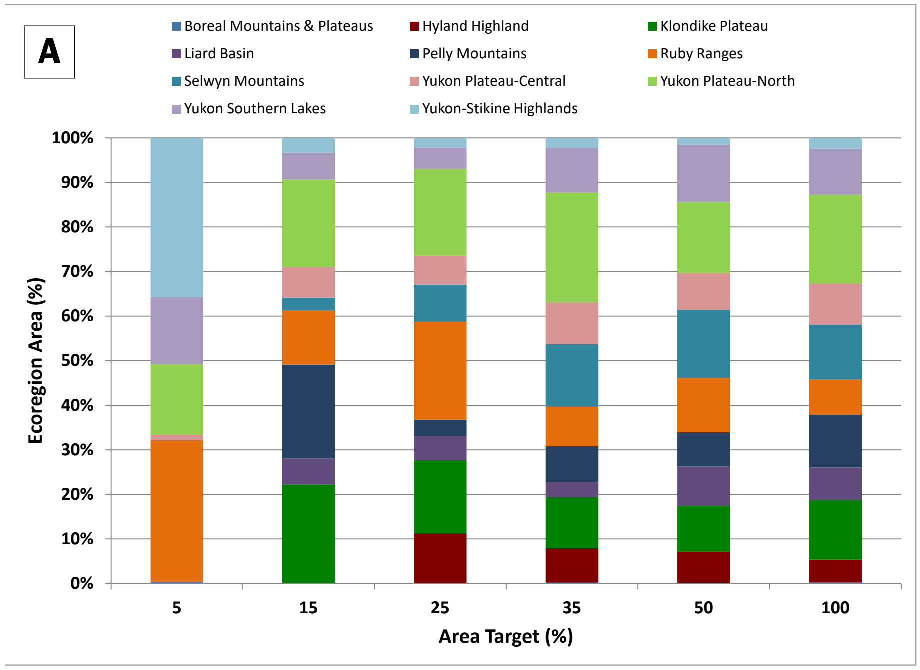
In other words, the coverage (percent area) of ecoregions within the BNs covering 15% and 25% of the study area were disproportionate to their coverage across the entire study area. In contrast, the 35% and 50% area BNs had similar percent composition of ecoregions as the study area (Fisher's exact test: P=0.92 and P=0.93, respectively) suggesting proportional representation of ecoregions is achieved for BNs covering at least 35% of the study area.

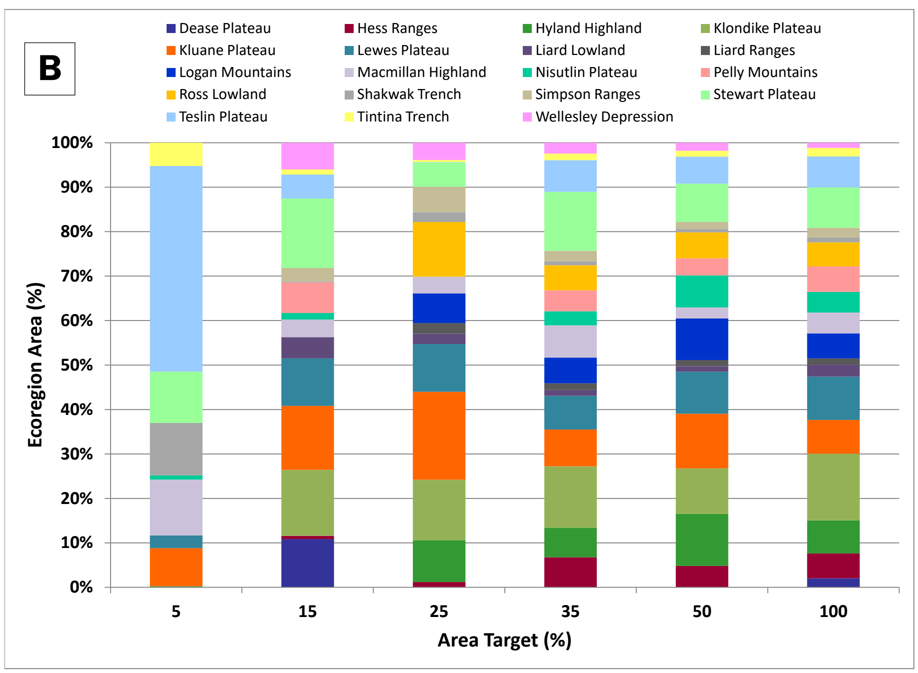
The 19 physiographic regions were also proportionally represented in the 35% and 50% BN (Fisher's exact test: P=0.99 and P=0.96, respectively), but not in the 15% and 25% BN (Fisher's exact test: P=0.001 and P=0.002, respectively; Figure 13). In contrast, bedrock geology had relatively stable representation of most classes in each of the BN tested. For the six bedrock geology classes that cover >1% of the study area, representation was not significantly different in any BN compared to the study area (Fisher's exact test: 15% area BN, P=0.95; 25% area BN, P=0.88; 35% area BN, P=0.92; 50% area BN, P=0.99). Thus, results for ecoregions and physiographic classes were similar to the planning scenario analysis – representation was achieved in BNs that covered at least 35-50% of the study area, but not for bedrock geologic classes.

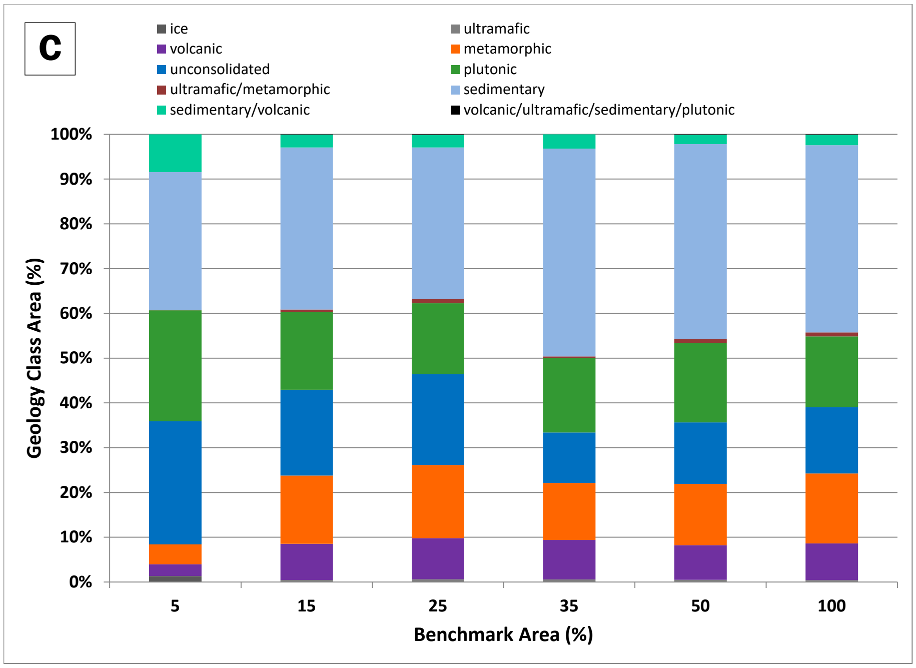
Table 7. Percent area of ecoregions captured by the best Benchmark Network for each of the top-ranked scenarios in the 15%, 25%, 35%, and 50% area target scenario groups (limited to scenarios comprised of existing protected areas plus random Benchmark Areas).

Ecoregion	Ecoregion area (km^2) within YBM	15% area target (scenario 5)	25% area target (scenario 22)	35% area target (scenario 15)	50% area target (scenario 16)
Hyland Highland	14,704	0.0	42.9	47.4	61.4
Klondike Plateau	38,746	17.6	23.7	26.6	33.7
Liard Basin	21,071	8.5	14.4	14.5	53.4
Pelly Mountains	34,212	18.9	6.0	21.0	28.9
Ruby Ranges	22,867	16.4	53.7	34.8	68.1
Selwyn Mountains	35,672	2.4	13.1	35.5	54.7
Yukon Plateau-Central	26,986	7.9	13.5	31.2	39.3
Yukon Plateau-North	57,428	10.5	19.0	38.5	35.4
Yukon Southern Lakes	30,060	6.1	8.8	30.0	54.6
Yukon-Stikine Highlands	6,960	14.6	17.8	28.7	28.1

Figure 13. Percent of total area of (A) ecoregions, (B) physiographic regions, and (C) bedrock geology classes within the top Benchmark Network by area target (i.e. covering 15%, 25%, 35%, and 50% of the study area). The 5% area target represents the existing parks and protected areas within the study area; the 100% area target represents the total study area. The percent area of all ecoregions and physiographic regions within Benchmark Networks was similar to percent area across the study area when the networks covered 35% and 50% of the total study area. Percent area of ecoregions and physiographic regions in networks covering 15% and 25% of the study area were significantly different from the study area as a whole. The percent area of bedrock geology classes was similar to the study area for all area targets.







3.3.5 Identification of priority areas for conservation

The final step of this project was to map priority areas for conservation. I used the results from the eight top-ranked scenarios to identify these areas. Each of these scenarios had intactness thresholds less than 100% and area targets greater than 35% (Table 6). The representation value of the best BN for these scenarios each fell within the top 1% of representation values for all 500,000 BNs for the top-ranked scenario (#16). Thus, the best BN for each of eight top-ranked planning scenarios performed similarly in representation of environmental conditions and thus are alternate solutions for a BN for the study area (Figure 14).

It is important to note that while the best BN solution for the scenarios including both 35% and 50% area targets were similar in terms of environmental representation, on average 50% area BNs performed better than 35% BNs (as described in section 3.3.2). The latter result gives us an indication of how different the scenarios are on average and thus what is more likely to be achieved when these scenario parameters are applied to designation of conservation areas in a regional planning process. It is also important to note that the priority areas I've identified are based on the best BN solutions given the parameters and data used for the scenario analysis; other parameters for intactness and area and different environmental indicators would produce different solutions.

Figure 14. Alternate networks of landscape-scale conservation areas for the Yukon Boreal Mountains study area. The best network for each of the top eight of 24 planning scenarios assessed using the Yukon intactness map had similar representation of four primary environmental indicators and thus each may be considered an alternate conservation area network. The top eight planning scenarios are #16 (Fig 12A), #24 (Fig 12B), #15 (Fig 12C), #20 (Fig 12D), #23 (Fig 12E), #12 (Fig 12F), #11 (Fig 12G), and #19 (Fig 12H) (see Table 3 for planning scenario parameters).

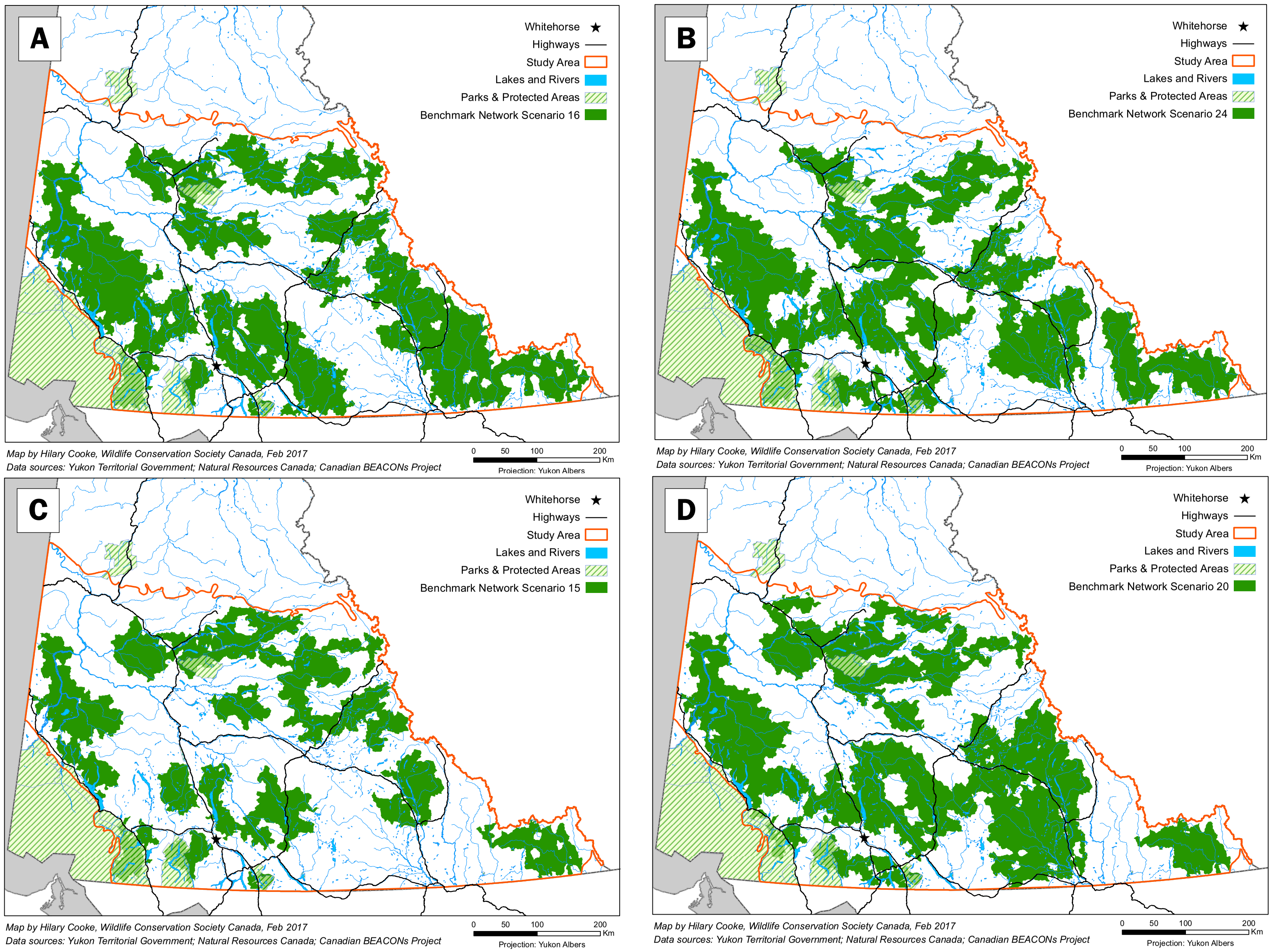
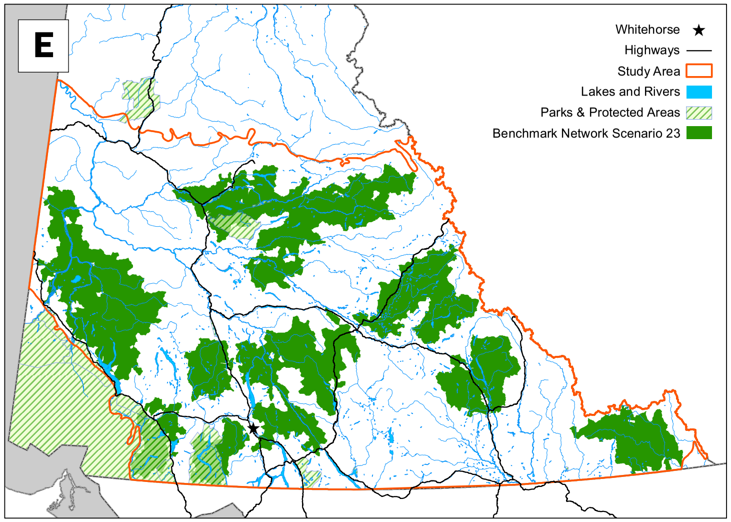
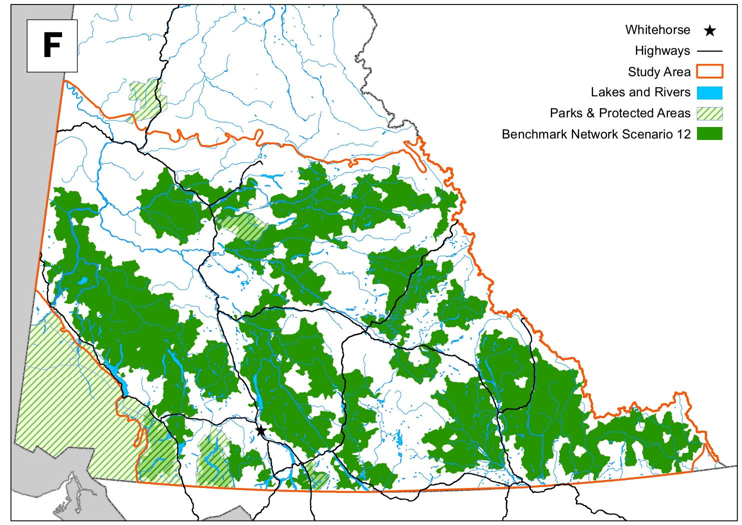


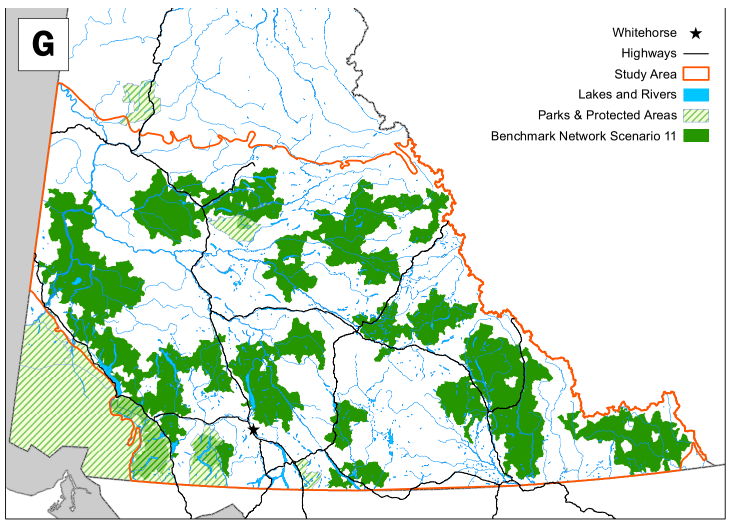
Figure 14 continued



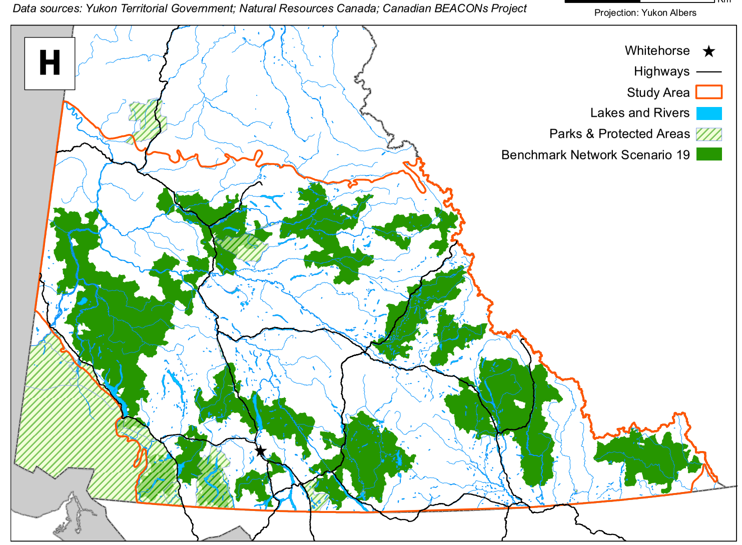
Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project

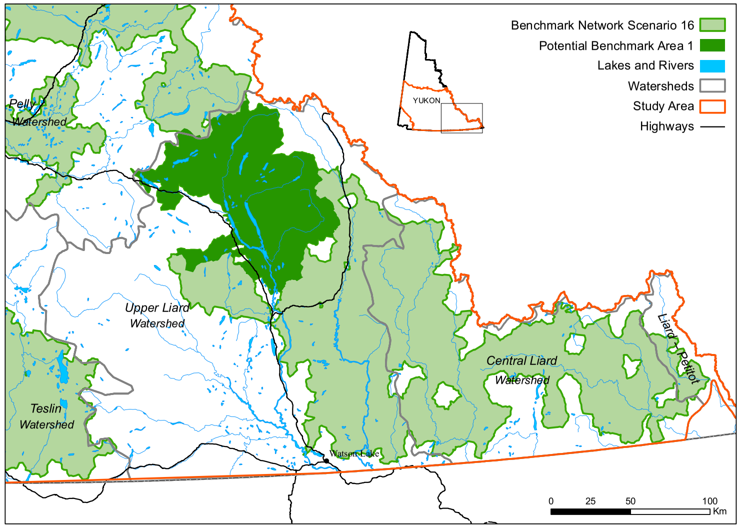


Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project

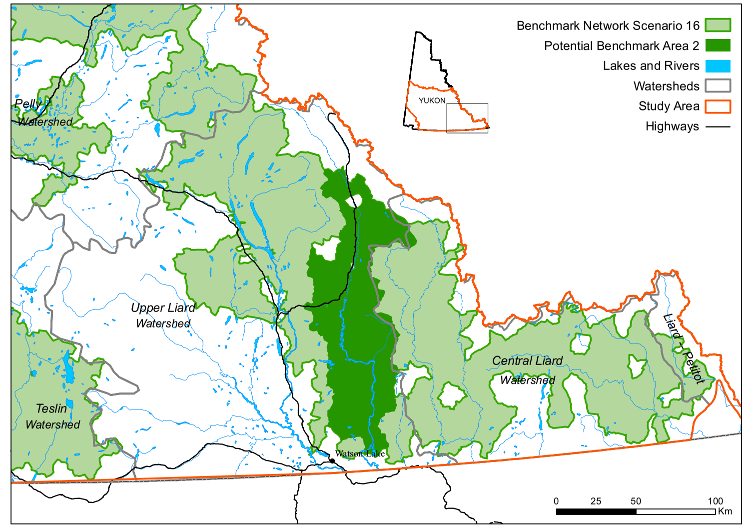
In addition to multiple best solutions for a BN, multiple, overlapping potential BAs were identified within the boundaries of each of the best BNs for the top eight scenarios. For example, within the Upper Liard watershed, I identified 11 unique potential BAs within the boundaries of the best BN for scenario #16 (Figure 15).

To account for the multiple solutions for both BAs and BNs, I identified priority areas for conservation using a measure of catchment importance. Catchment importance is a measure of the number of times an individual catchment occurs in the top 100 out of 500,000 random BNs for a given scenario (Canadian BEACONs Project 2012). This provides a measure of irreplaceability with respect to achieving the conservation goals in that scenario. Catchments that occur more frequently in the top 100 BNs for a given scenario could be considered irreplaceable and thus a priority for conservation. Overall catchment importance was calculated for each catchment by summing importance across the top eight scenarios and rescaling between 0 and 10 (Figure 16). Catchments ranking ≥4 in overall importance covered 52% of the study region; catchments with overall importance ≥6 covered 34% of the study region (Table 8).

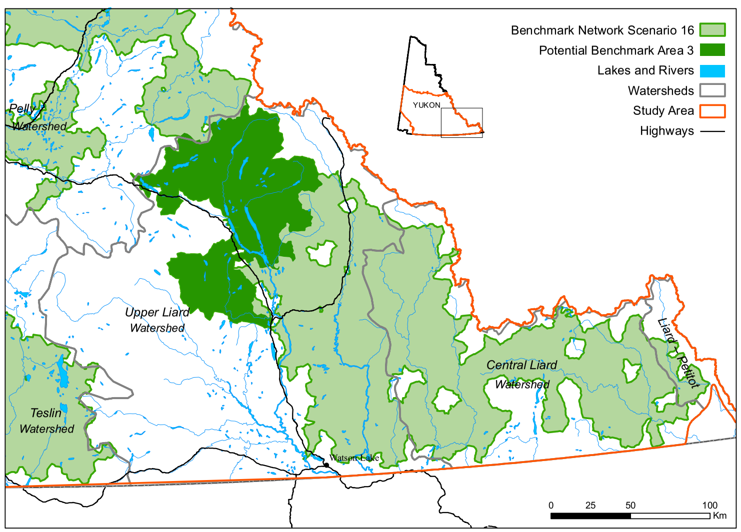
Figure 15. Example of multiple, overlapping potential Benchmark Areas within the boundary of a single Benchmark Network: 11 potential Benchmark Areas were identified within the Upper Liard Watershed for the best Benchmark Network for the top planning scenario (#16).



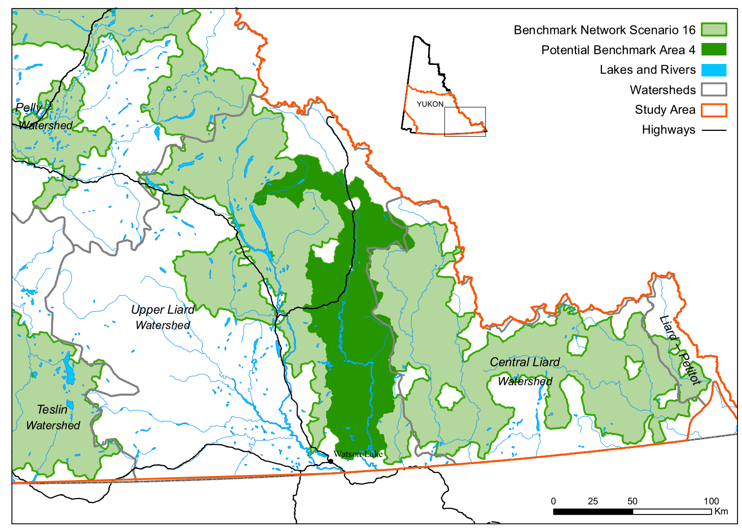
Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

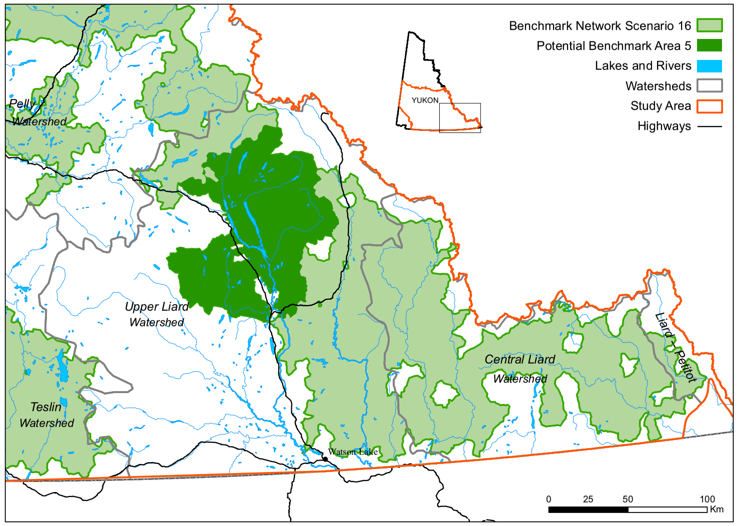


Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

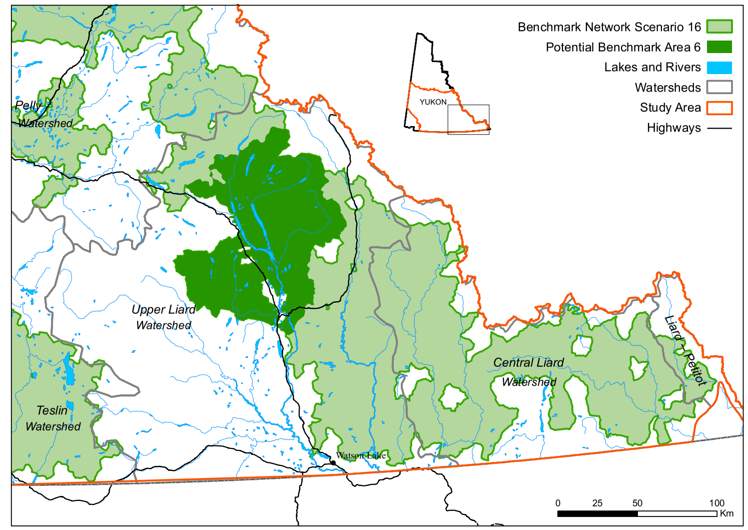


Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

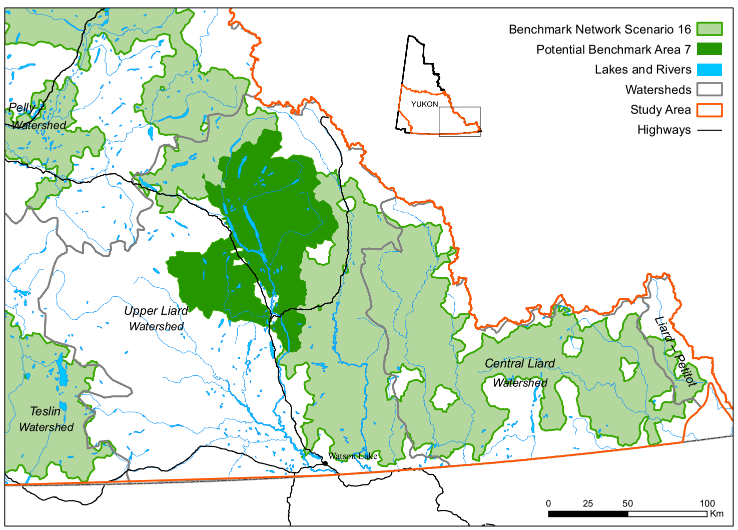
Figure 15 continued



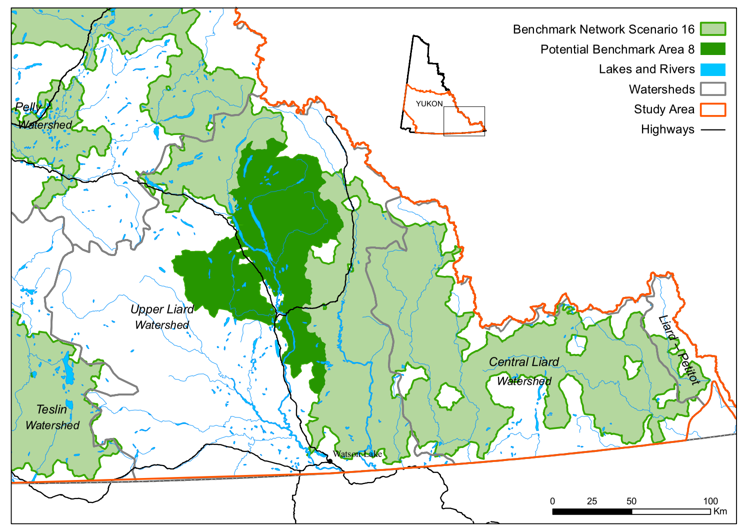
Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

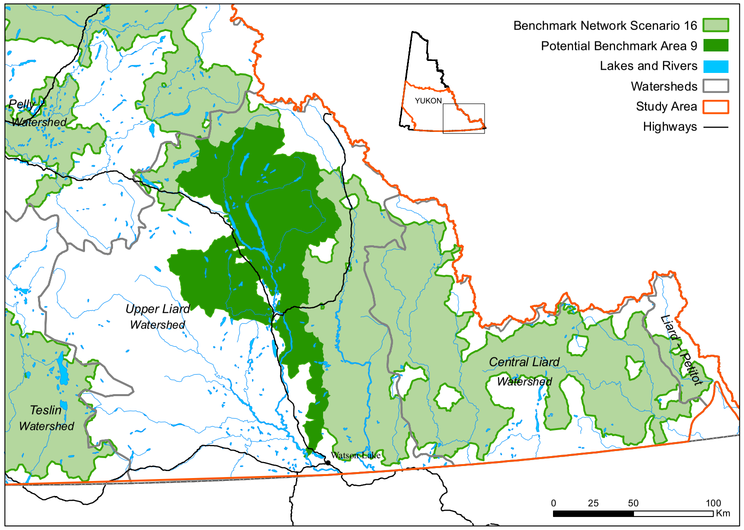


Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

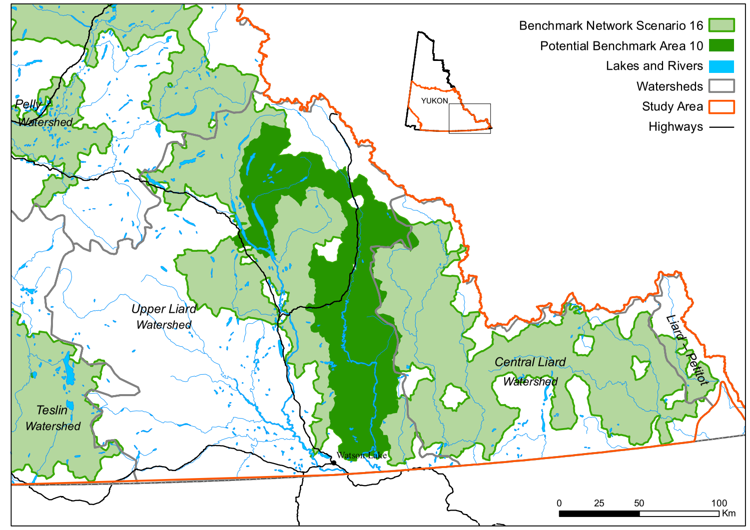


Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

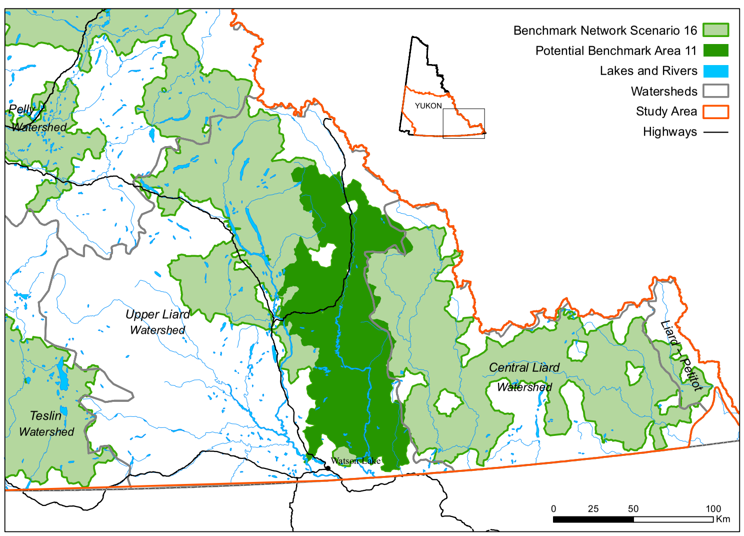
Figure 15 continued



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

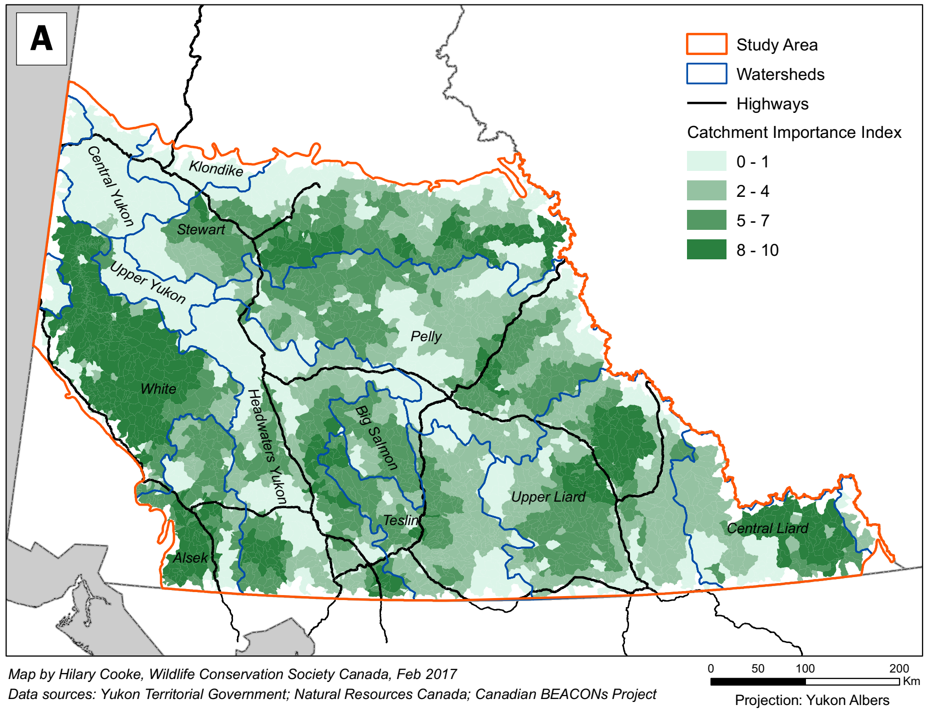


Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

Figure 16. Overall catchment importance for the top Benchmark Networks in the top eight planning scenarios highlighting A) watershed and B) ecoregion boundaries. Catchments that occur in the top 100 Benchmark Networks for each of the top eight scenarios have the highest catchment importance (10). Catchments that do not occur in any of the top 100 Benchmark Networks for any of the top eight scenarios have the lowest catchment importance (0).



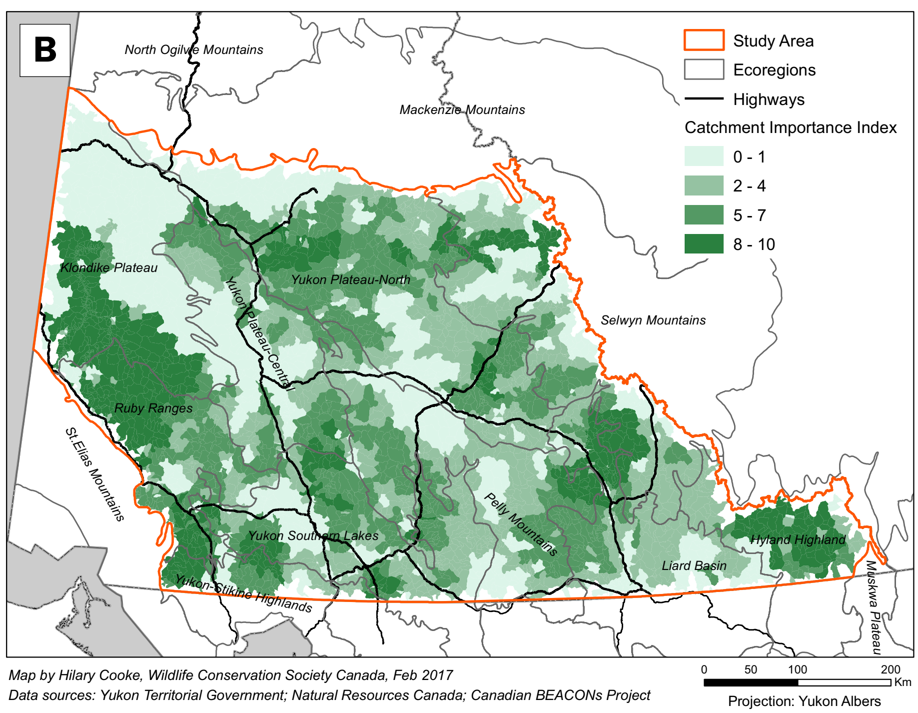


Table 8. Summary for all study area catchments by overall catchment importance index. Catchment importance was calculated as the sum of the number of times an individual catchment occurred in the top 100 Benchmark Networks for the top eight planning scenarios, scaled between 0 and 10. Catchments that occur in the top 100 Benchmark Network for each of the top eight scenarios have the highest catchment importance (10). Catchments that do not occur in any of the top 100 Benchmark Network for any of the top 8 scenarios have the lowest catchment importance (0).

Catchment Importance Index	Area (km^2)	Study area	
		% Total Area	Cumulative % Total Area
10	1,158.6	0.4	0.4
9	22,962.0	8.6	9.0
8	21,546.6	8.0	17.0
7	21,394.3	8.0	25.0
6	23,841.2	8.9	33.9
5	21,861.4	8.2	42.1
4	27,392.7	10.2	52.3
3	21,213.7	7.9	60.2
2	26,789.4	10.0	70.2
1	23,556.0	8.8	79.0
0	56,295.9	21.0	100.0

Photo: Hilary Cooke

Large trees and dead trees in old spruce stands provide important habitat for many of Yukon's boreal birds and mammals.

4. DISCUSSION

Proactive planning for conservation, alongside other values, is critical to ensure Yukon's intact ecosystems and watersheds, abundant wildlife populations, wealth of ecosystem services, and cultural and social connections to the land are not eroded by the cumulative impacts of unplanned industrial development. The goal of my study was to conduct a systematic assessment of conservation gaps, opportunities, and priorities for Yukon's Boreal Mountains using a decision-support tool that addresses the scale and nature of the key processes underlying the ecology of northern boreal landscapes and achieving representation of the ecological diversity of the study area. I analyzed multiple scenarios for networks of landscape-scale conservation areas to provide recommendations for the size of new conservation areas, the percentage of the study area that should be zoned for conservation, and the places and ecosystems that should be priorities for conservation.

All but one existing protected area, which collectively cover 4% of the study area, are too small to accommodate regional fire regimes. Collectively, they do not capture the full range of environmental conditions of Yukon's Boreal Mountains. Rather, my scenario analysis demonstrates that, at a minimum, large (~2,000 to 7,500 km^2), relatively intact (<10% human footprint by area) landscapes covering 50% of the total area of Yukon's Boreal Mountains should be allocated for conservation. Further, ecoregions currently lacking any area designated for conservation and intact valley bottoms and associated ecosystems should both be immediately prioritized for protection.

At a minimum, large (~2,000 to 7,500 km^2), relatively intact (<10% human footprint by area) landscapes covering 50% of the total area of Yukon's Boreal Mountains should be allocated for conservation.

4.1 Minimum size of conservation areas

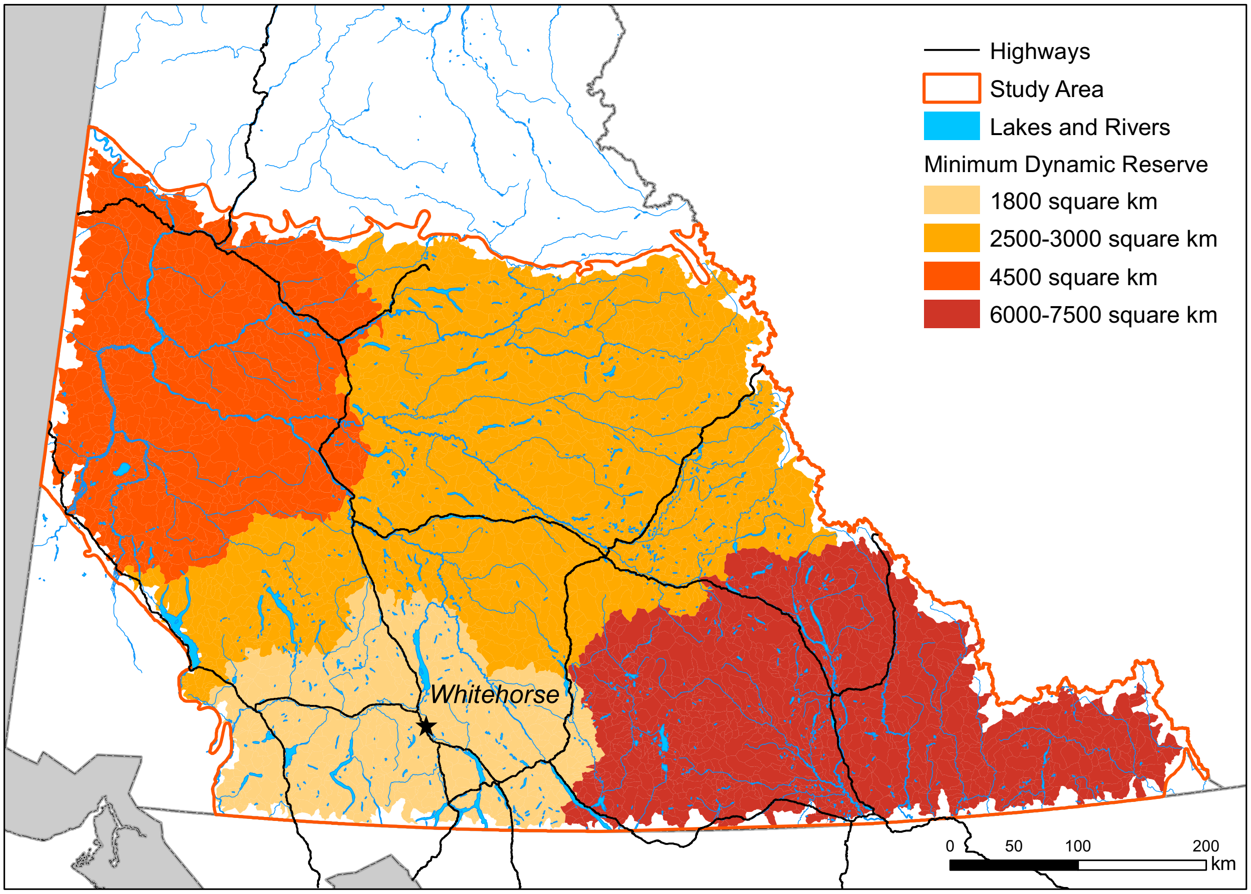
The biodiversity of the study area will best be protected if conservation areas are large enough to accommodate the spatial scale of ecological processes, principally the natural fire disturbance regime (i.e. minimum dynamic reserve or MDR). The diverse topography, physiography, climate and ecological systems of Yukon's Boreal Mountains are associated with a variable fire regime. Consequently, estimated MDR also varies widely from ~800 to 8,000 km^2, with an average of ~4,000 km^2. Among ecoregions (excluding Boreal Mountains and Plateaus, which has limited distribution within the study area), median size of a MDR ranges from 1,782 km^2 for the Yukon Stikine Highlands to 7,227 km^2

for the Pelly Mountains. Eight of 10 ecoregions had a median MDR greater than 2,500 km^2 (Table 9). The study area can generally be delineated into four zones based on MDR range (Figure 17). First, in south-central Yukon including the Southern Lakes ecoregion, MDR is ~1,800 km^2. Second, a zone of ~2,500-3,000 km^2 MDRs covers a broad area of the central and northeastern parts of the study area, including the Ruby Ranges, Yukon Plateau ecoregions, and parts of the Pelly and Selwyn Mountains. The third zone includes MDRs of ~4,500 km^2 and encompasses the Klondike Plateau. And, the fourth zone occupies southeast Yukon across the Liard Basin and Hyland Highlands and has the largest estimates for MDR at 6,000-7,500 km^2.

Table 9. Median, mean, and range (minimum - maximum) Minimum Dynamic Reserve (MDR) estimated for within ecoregions of the Yukon Boreal Mountains study area based on the BEACONs Estimated Maximum Fire Size dataset. An MDR is an area large enough to accommodate, and to allow for the persistence of, the spatial and temporal variability of ecosystems and associated biodiversity that occurs under the natural fire regimes. MDR has been estimated for this region to be approximately three times the estimated maximum fire size.

Ecoregion	Median (km^2)	Mean (km^2)	Range (km^2)
Boreal Mountains and Plateaus	732	996	732-1,782
Hyland Highland	6,312	6,573	6,273-7,227
Klondike Plateau	4,824	4,794	2,547-4,848
Liard Basin	7,227	7,527	6,966-8,841
Pelly Mountains	7,227	5,586	1,782-7,227
Ruby Ranges	3,006	3,141	1,914-4,824
Selwyn Mountains	3,060	3,582	2,514-7,227
Yukon Plateau-Central	2,547	3,048	1,914-4,824
Yukon Plateau-North	2,574	2,826	2,514-7,227
Yukon Southern Lakes	1,914	3,495	732-7,227
Yukon-Stikine Highlands	1,782	1,860	1,782-2,031

Figure 17. Zones of similar minimum dynamic reserve size across Yukon's Boreal Mountains. A minimum dynamic reserve is the minimum size necessary for a conservation area to accommodate the size and frequency of wildfire and resultant spatial and temporal patterns of ecosystems occurring under a natural disturbance regime. Estimates for boreal Yukon and Northwest Territories suggest minimum dynamic reserve should be at least three times the regional estimated maximum fire size (Leroux et al. 2007a, Anderson 2009).



Map by Hilary Cooke, Wildlife Conservation Society Canada, Feb 2017
Data sources: Yukon Territorial Government; Natural Resources Canada; Canadian BEACONs Project
Projection: Yukon Albers

Within my study area, only one protected area (Kusawa Natural Environment Park) is large enough to function as an MDR. The dominant fire regime for Kusawa Natural Environment Park (area=3,082 km^2; ~40% freshwater) is associated with an estimated maximum fire size of ~600 km^2 suggesting an MDR of at least 1,800 km^2. Two protected areas – Agay Mene (725 km^2) and Ddhaw Ghro (1,609 km^2) – would each need to approximately double in area to function as a BA (MDR= ~1,200 km^2 and ~2,500 km^2, respectively). The remaining 11 protected areas within my study area are all less than 100 km^2 and one or two orders of magnitude smaller than their associated estimated maximum fire size. Thus, none are large enough to accommodate the scale of the natural disturbance regime.

Photo: Lila Tauzer

At ~3,000 square kilometres, Kusawa Natural Environment Park in southern Yukon is the only protected area in the study area that is large enough to accommodate the natural fire regime, i.e. large enough to experience a large fire disturbance and not lose the representative ecosystems it protects.

Previous regional conservation assessments have identified priority areas for protection, but few have identified areas large enough to function as a minimum dynamic reserve. Most efforts were not systematic. In other words, they did not employ analytical techniques to identify conservation areas based on principles of representation; disturbance regimes (i.e. minimum dynamic reserve); unique, rare, or otherwise important ecosystems; or minimum area required to sustain populations of focal species, particularly large mammals. Approaches that considered the scale of disturbance regimes and/or the requirements of wide-ranging mammals proposed conservation reserves comparable in area to potential BAs identified in my study. In contrast, those that identified site-specific protected areas on the basis of unique or rare features (e.g. Carcross Dunes) or local habitats for focal species (e.g. spring staging for waterbirds) tended to be several magnitudes smaller than necessary to accommodate the natural disturbance regime.

Within my study area, only one protected area (Kusawa Natural Environment Park) is large enough to function as a Minimum Dynamic Reserve.

In 1965, a Canadian Committee for the International Biological Programme (IBP) was formed to assess sites in arctic and subarctic Canada for their conservation value (Table 10) (Revel 1981). Eight of the 81 sites identified across the sub-arctic region of Yukon and NWT are within the YBM study area. Excluding two small site-specific conservation areas (areas proposed for protection based on unique or rare features, namely Carcross Dunes and Coal River Spring), the IBP sites occurring within my study area ranged from 205 to 5,120 km^2. Building on the identification of sites under the IBP, Theberge et al. (1980) identified environmentally significant areas (ESA) of Yukon. The 15 in my study area ranged from 34 to 8,554 km^2, with five greater than 2,500 and two greater than 6,500 km^2. The largest (Wolf Lake) is in the zone with the largest estimated MDR zone (6,000-7,500) and would be of sufficient size for the regional fire regime.

Table 10. Spatial overlap (Full (F), Partial (P), none (N)) of candidate conservation areas identified in previous assessments, and priority areas for conservation identified in this study. Spatial overlap was assessed visually for reports that had printed maps or based on the text description of the candidate site for reports without maps.

Conservation Assessment	Candidate Conservation Area	Area (km^2)	Overlap with priority areas for benchmarking?
International Biological Programme (Revel 1981)	Aishihik Lake	1,024	F
	Carcross Dunes	NA	N
	Coal River Spring	8	F
	Mayo Swampland	256	N
	McArthur Range	1,600	F
	Pelly Mountains	230	N
	Semenof Hills	205	F
	Wolf Lake	5,120	P
Environmentally Significant Areas of the Yukon (Theberge et al. 1980)	Aishihik Lake	1,944	F
	Bennett Lake/Carcross Dunes/Tagish Lake	1,814	P
	Big Salmon River	39	F
	Coal River Springs	804	F
	Frances Lake	2,877	F
	Kusawa Lake	156	F
	Macmillan Pass	3,603	N
	Mayo Swamplands	259	N
	McArthur Game Sanctuary	6,739	F
	Nisling River	648	F
	Pelly Mountains	285	N
	Primrose River	34	F
	Semenof Hills	213	F
	Streak Mountain	3,784	P
	Wolf Lake	8,554	P
Pelly Ranges & Southwest Interior Landscapes Gap Analysis (Inukshuk Planning & Development 1994)	Aishihik Uplands	2,700	F
	Carcross Dunes	<2	N
	Kloo-Sulphur Lake	100	N
	Kluane River	3,000	F
	Kusawa North	~1800	F
	Laberge North	1,000	F
	Nisling River	2,000	F
	Pickhandle Lakes	80	N
	Quiet Lake/Big Salmong River Corridor	2,000	F
	Shallow Bay/Swan Lake	75	F
	Tarfu-Snafu Michie Creek Extension	2,000	P
	Twin-Fox Mountains/Lapie River	2,800	N
	Wellesley Basin	~2,500	F
	Wolf Lake East (Cassiar Mountains)	2,300	P
	Wolf Lake West	3,600	N
Candidate National Parks in Parks Canada Region 7 (Pojar 2007)	Beaver River	7,900	F
	Coal-Rock Rivers	9,470	N
	Frances Lake	1,475	P
	Keele-Itsi	14,075	P
	Klondike-Ruby	35,000	P
	Wolf Lake	20,580	P

Blood and Anweiler (1984) proposed 15 sites in Yukon to be federal National Wildlife Areas (NWA) based on importance to waterfowl. Eleven of 15 proposed NWAs were within the Boreal Cordillera and ranged from five to greater than 3,500 km^2. Most were small, at less than 100 km^2, and primarily identified on the basis of open water in early spring, which is of importance to migrating waterbirds. The three largest proposed NWAs (~300, 600, and 3,700 km^2) are all located in southeast Yukon but are too small for the regional MDR range. Only one area (Nisutlin River Delta NWA, area=4,483 km^2) was eventually established as a NWA, but seven of the 11 found in the Boreal Cordillera are partly or fully protected through other designations.

The first assessment to use a systematic approach to identifying potential conservation areas was in 1994. A protected areas gap analysis was completed for the Pelly Ranges and Southwest Interior Landscapes in support of the Yukon Protected Areas Strategy (Inukshuk Planning & Development 1994). Fifteen potential protected areas were assessed: three in Pelly Mountains ecoregion, six in Southern Lakes ecoregion, four in Ruby Ranges, and two in the Wellesley Basin. Four sites were small (<100 km^2) site-specific areas for protection. The others ranged from 1,000 to 3,600 km^2; four were smaller than their associated MDR but the remainder were of sufficient size (assuming that the two adjacent Wolf Lake areas are combined).

Recognition of the need to identify areas large enough to accommodate disturbance regimes and wide-ranging mammals expanded across North America in the 1990s and early 2000s such that landscape-scale conservation is now widely embraced. Drawing from the scientific literature of relevance to Canada's northern species and ecosystems, Wiersma et al. (2005) summarized estimates of the minimum area necessary for a single conservation area based on principles of MDR, as well as minimum area necessary to protect the full number of species and viable populations of species that make landscape-scale movements, such as grizzly bears. All but one estimated a minimum area of at least 1,000 km^2; several estimates greater than 10,000 km^2 were based on the area necessary to conserve wide-ranging mammals. The only Yukon study referenced was an analysis of fire regimes by Frid (2001 in Wiersma et al. 2005): ~2,000 km^2 was suggested to be large enough to contain the largest fire on record for Yukon. However, based on the work of Leroux et al. (2007a) and Anderson (Anderson 2009), this is too small to function as an MDR for much of my study area.

In a report commissioned by the Canadian Parks and Wilderness Society – British Columbia Chapter (CPAWS-BC), Pojar (2007) used a systematic reserve-selection approach to identify 14 areas in Yukon and B.C. as candidates for a Region 7 National Park. Parks Canada's Region 7, the Northern Interior Plateaux and Mountains, encompasses northern British Columbia and central and southern Yukon. Pojar (2007) ranked candidate areas on six criteria: naturalness or intactness; coarse-filter representation; fine-filter special features, including rare, threatened, endangered or otherwise special species, ecosystems or physical features; long-term viability, including minimum critical area for large wide-ranging species and minimum dynamic area; and connectivity (lateral, longitudinal, elevational, hydrologic) and transregional linkages.

The candidate protected areas identified by Pojar (2007) were the largest of all those proposed in historical assessments. Proposed conservation area range from 1,475 to 20,580 km^2. All but one (Frances Lake) are well over estimated MDR size and may also be large enough to accommodate the area required by wide-ranging mammals (as estimated by Wiersma et al. 2005).

Most recently, Anderson (2009) developed and applied the BEACONs Benchmark Builder and Ranker tools to identify BNs in boreal Yukon and northern British Columbia. His study area was the intersection of the Pacific Ocean Drainage in the Boreal Cordillera ecozone. It differed from my study area by not including the Selwyn Mountains ecoregion in the Taiga Cordillera or the Upper Liard and Central Liard watersheds in southeast Yukon. In his study area, targets for candidate BAs (based on EMFS) ranged from 441 to 4,479 km^2.

4.2 Benchmark Networks and conservation area targets

There is growing evidence that area targets for conservation set by policymakers are insufficient for achieving biodiversity conservation goals.

The results of my study clearly indicate that the current network of parks and protected areas is not representative of the environmental variability of the study area, and that representation improves with increasing area allocated for conservation. Overall representation of gross primary productivity, climate moisture index, land cover classes, and lake-edge density tended to be better with increasing area of the best BNs, particularly when the area target increased from 15% to 35%. Also, overall representation was significantly greater for BNs covering 50% of the study area than for those covering 15%, 25% and 35% of the total area. In addition, two of three validation indicators (ecoregions and physiographic regions) were better represented in BNs covering at least 35% of the study area. These results are based on BN <100% intact because there were no solutions within the study area for 100% intact BNs that covered 50% of the study area (scenarios #4 and #8).

There is growing evidence that targets for conservation set by policymakers are insufficient for achieving biodiversity conservation goals. An area target of 35-50% is at least two times greater than Canada's 2020 target of 17% terrestrial areas in protection (biodivcanada.ca/default.asp?lang=En&n=9B5793F6-1). The Canada 2020 target is a policy-driven target adhering to the international Aichi target 11, part of the 2011-2020 Strategic Plan of the Convention on Biological Diversity, which Canada has ratified (www.cbd.int/doc/strategic-plan/2011-2020/Aichi-Targets-EN.pdf).

A review by Svancara et al. (2005) found that policy-driven area targets averaged 10-12%, whereas those derived from evidence-based research on area required to conserve species and/or ecosystems averaged between 30% and 60%. Noss et al. (2012) argue that a 50% area target is scientifically defensible as a global conservation target based on recent evidence-based estimates. In a review of quantitative conservation assessments, Schmiegelow et al. (2006) found percent area targets ranging from <10% to >90% depending on the ambitiousness of conservation goals, with a majority of studies reporting targets between 40% and 80% and a median value of >50%. In a global assessment, Venter et al. (2014) concluded that meeting the Aichi target of 17% of terrestrial land in protection using a business-as-usual approach (i.e. achieving

Photo: John Meikle

Many northern jurisdictions have embraced the need for ambitious conservation targets to conserve large mammals.

targets at a national level and minimizing opportunity cost) will be insufficient to achieve the Aichi target of preventing extinction of all known threatened species. Finally, conservation assessments for large landscapes that incorporate area and connectivity needs of large mammals with ecosystem representation targets and habitat requirements of other focal species also result in high area targets, e.g. 60-70% of the Greater Yellowstone Ecosystem (**Noss et al. 2002**).

Conservation assessments for large landscapes that incorporate area and connectivity needs of large mammals with ecosystem representation targets and habitat requirements of other focal species also result in high area targets.

High conservation targets for large landscapes have been proposed or implemented in many northern boreal regions of Canada. For example, the draft Decho Land Use Plan proposes allocating approximately 50% of the 214,000 km^2 Dehcho territory in NWT for conservation zoning, which would permit tourism, but not oil and gas, mining, agriculture or forestry (Dehcho Land Use Planning Committee 2006). The Tlicho Land Use Plan in NWT also restricts most resource development (exceptions are hydro-power generation, and utility and transportation corridors) from 60% of their ~39,000 km^2 traditional lands (Tlicho Government 2013). Ontario and Quebec governments have both made proactive protection commitments in advance of introducing development into the north of each province, which has experienced very low levels of development thus far. Quebec's Plan Nord dedicates 50% of ~1.2 million km^2 of the northern part of the province to non-industrial uses and protection of environmental values and biodiversity (Gouvernement du Québec. 2015). Ontario's Far North Act legislates a conservation target of 50% of 452,000 km^2 for protection of ecological and cultural values. However, the province's current land-use planning and environmental assessment processes will not ensure large, intact watersheds and landscape-scale ecological integrity are conserved (Chetkiewicz and Lintner 2014). In Yukon, the Final Land Use Plan for the North Yukon Planning Region (55,548 km^2) and the Final Recommended Land Use Plan for the Peel Watershed Planning Region (67,400 km^2) call for 36% and 55% in

Photo: Jukka Jantunen

*Planning will also need to include finer-scale elements, such as rare or endangered species or sensitive habitats. The collared pika (*Ochotona collaris*), shown here, is considered at risk due to the impacts of climate change on this cold-adapted species.*

permanent protection respectively (North Yukon Planning Commission 2009, Peel Watershed Planning Commission 2011). And, the Ross River Dena Council identified 29 priority areas for protection covering ~60% of 63,000 km^2 of their Traditional Lands in east-central Yukon (Ross River Dena Council 2014).

No empirical studies have identified conservation area targets for my study area. However, two studies have included part or all of Yukon in systematic conservation assessments that identified percent area required to achieve specific conservation goals. Pearce et al. (2008) prioritized avian biodiversity "hotspots" across the Yellowstone-to-Yukon (Y2Y) region (a proposed network of protected wildlife habitat and corridors stretching ~3,200 km from Yellowstone National Park to Yukon Territory). They found the best solution for the region as a whole comprised 19% of the area, with targets between 15% and 23% when assessed by eco-province. Wiersma and Urban (2005) found the minimum area required to conserve the diversity of disturbance-sensitive mammals averaged 23% (range 1-61%) by ecoregion (across all Yukon ecoregions), and averaged 21% (range 9-39%) for those ecoregions in my study area. Neither study considered system dynamics (i.e. natural disturbance regimes and ecosystem successional pathways), connectivity or wildlife population viability.

My scenario analysis identified best outcomes for landscape-scale conservation given the scenario parameters examined and the data used. Additional data could support or refute my conclusion of the need to set targets of conserving at least 50% of the region in large, intact landscapes. For example, it is unknown if over- or under-representation of attributes of environmental indicators (e.g. GPP level or a specific land cover class) are ecologically significant. Small differences may not be important. However, underrepresentation of GPP and CMI values associated with valley bottoms, for example, may well be ecologically significant if these are associated with highly productive wildlife habitats.

For example, previous reports have described the Frances Lake and River drainage as providing some of the most productive and diverse habitats of Yukon and providing critical habitat for a diverse number of species, including moose, caribou, freshwater fish, and waterfowl (Bastedo 1979, CPAWS-Yukon 2000, Theberge et al. 1980). The productive habitats in the lowlands surrounding Frances Lake are reflected in the unique GPP and CMI values for this area. Catchments in this area also had high importance (>8) based on inclusion in the top 100 BNs for each of the top eight scenarios (see Section 4.4., Figure 16).

The next step to determine the total area that should be in a network of conservation area would be to test the area targets with other values using the same scenario analysis approach as in this study (e.g. using maps of important areas and/or habitats for caribou, grizzly bear, moose, wolves, breeding birds, rare plants, endemic species, etc.). One potential shortcoming of basing design of a conservation area network on proportional representation of ecological conditions is the risk that ecological attributes or conditions that have relatively low coverage across the entire study area will have only small areas in conservation, but may be disproportionately important to wildlife, e.g. riparian, wetland, and other lowland habitats of valley bottoms. Within individual land use planning regions, consideration of both additional ecological values and the relative importance of different ecosystems will likely result in compromises in representation of some ecological conditions and/or increased total area required for conservation.

For example, my analysis identified 53% of the Liard Basin, which covers ~61,500 square kilometres in southeast Yukon, as having high importance for landscape-scale conservation. Several ecological values have been mapped for this area, including caribou ranges, raptor breeding sites, some important wetlands for staging waterbirds, and key habitats for beaver, moose, mountain goat and thinhorn sheep (www.env.gov.yk.ca/animals-habitat/wildlife_key_areas.php). As mapped, these focal species habitats cover 66% of the Liard basin. A composite map of focal species habitats and priority areas identified in this study covers 85% of the basin, with 51% of the basin in non-overlapping areas (i.e. areas exclusively identified as focal species habitats or priorities in this study).

A comprehensive conservation strategy for the region should also address key habitats for many focal species by employing a combination of conservation areas and conservation measures in areas managed for development.

A comprehensive conservation strategy for the region should therefore also address key habitats for many focal species by employing a combination of conservation areas and conservation measures in areas managed for development. Conservation measures would include management practices such as spatial buffers and timing windows on critical habitats and at critical periods (Hayes and Reid 2014). For example, timing windows could prescribe limits to human disturbance on open water during spring migration when waterbirds depend on these sites as stopovers for resting and refueling (SLWCC 2012). Similarly, spatial buffers would be employed around raptor nest sites and ungulate mineral licks (www.emr.gov.yk.ca/forestry/operational_standards.html).

4.3 Benchmark Area intactness and the human footprint

Examination of the spatial overlap of the human footprint and environmental conditions reveals the lowland boreal ecosystems of the valley bottoms have been disproportionately impacted by development and infrastructure footprint, and this trend limited the options for a representative BN that is 100% intact and covers at least 50% of the study area.

Photos: Hilary Cooke

As in other mountainous regions, transportation corridors and human settlements disproportionately occur in valley bottoms, particularly in the south of Yukon where much of the population lives.

Photo: Hilary Cooke

The most productive agricultural land is found in floodplains, which also support productive and diverse ecological communities. Careful allocation of land for agriculture is required to minimize impacts on aquatic and terrestrial ecosystems and fish and wildlife.

The trend of decreasing representation with increasing area for 100% intact BNs was driven by gross primary productivity and climate moisture index. Climate moisture index provides a measure of the availability of moisture for plant growth, with low climate moisture index associated with higher available moisture. Thus, areas with low climate moisture index and high gross primary productivity are associated with higher plant growth and more productive and diverse habitats for wildlife.

Catchments with high gross primary productivity and low climate moisture index are concentrated along valley bottoms, primarily along the major rivers. Most human land disturbance and infrastructure, particularly roads and settlements, are also concentrated in valley bottoms (the exception is quartz exploration and development, which is not restricted to lower elevations). As the area of a network of 100% intact BAs increases, the availability of 100% BAs that include valley bottoms declines, and thus the final BN must be composed of more area at higher elevations. The ecological values of catchments at higher elevations are then disproportionately represented in large, 100% intact BNs and overall representation of environmental conditions within the network compared to the study region declines. When the intactness thresholds were relaxed (i.e. when BN were constructed using <100% intact Bas) small amounts of footprint in valley bottoms were allowed and the unique values of gross primary productivity and climate moisture index were captured. Thus, if we only select 100% intact watersheds for conservation, and exclude those with small amounts of human footprint, it will be at the cost of representation.

Valley bottom habitats support diverse, abundant, and productive ecological communities. Hauer et al. (2016) argue that this is particularly true for gravel-bed river floodplains in mountainous regions of western North America, citing estimates that they support 60% of plant species and 70% of bird species. In particular, a mosaic of patches of aquatic and terrestrial ecosystems in various successional stages provide resources for a high diversity and abundance of birds during breeding and migration.

Photos: Hilary Cooke

Photo: Lila Tauzer

Valley bottoms comprise approximately one-quarter of Yukon's Boreal Mountains and provide productive ecosystems with high biodiversity. However, these areas are also disproportionately impacted by human infrastructure and development. Undeveloped valley bottoms (bottom) should be prioritized for protection, as should important wildlife habitats such as old spruce forest (top left) and marsh wetlands (top right).

Human alteration of river floodplains can have significant impacts on both aquatic and terrestrial ecosystems and wildlife. For aquatic species, fragmentation occurs with just a single barrier on a river (Cote et al. 2009). For large, wide-ranging species like grizzly bears and mountain caribou, development in floodplains of mountainous regions displaces individuals through avoidance behaviour; removes and isolates critical habitats; reduces connectivity within and between populations; increases human-caused mortality (both direct, through hunting, and indirectly through human-wildlife conflict and vehicle collision), among others (Hauer et al. 2016). When large predators are lost from valley floodplains, their ungulate prey are 'released', resulting in increased herbivory, with cascading effects on species, such as birds and beaver, that rely on floodplain plant communities (Beschta and Ripple 2016).

The valley bottom ecosystems of Yukon's Boreal Mountains include large lakes, dynamic river floodplains, old spruce stands, and marsh, bog, fen, and swamp wetlands. Seventy-five percent of the study area is comprised of catchments associated with small streams on mountain slopes and headwaters, leaving only a quarter of the land area adjacent to large rivers, lakes, and tributaries in the valley bottoms. Human development, including transportation networks, urban and suburban areas, and agriculture, among others, are concentrated along large rivers. It has been previously noted that this pattern, and its impacts, are amplified in mountainous regions (Tockner et al. 2002), and this study supports that conclusion for Yukon's Boreal Mountains. Thus, intact valley bottom ecosystems should be prioritized for protection from new development.

Human alteration of river floodplains can have significant impacts on both aquatic and terrestrial ecosystems and wildlife.

Including scenarios with intactness thresholds of <100% allowed for better representation of valley bottom ecosystems in networks of BAs. However, this assumes that the benchmarking function is not impaired with <100% intactness, i.e. that large-scale ecological processes, particularly wildfire and movements of large mammals, as well as small-scale ecological functions, such as suitability of habitat for different wildlife species, are not impaired by low levels of human footprint. In addition, my assessment assumed that all features included in the human footprint map have similar impact on wildlife and ecosystems.

When assessing the impact of small amounts of human footprint in areas designated for conservation, the nature of that footprint should be considered. Across the study area, almost half (42%) of the buffered footprint area was permitted mineral (quartz and placer) claims (Table 5), which have varying levels of physical disturbance depending on type of permit and exploration activity. Physical disturbance within the area of a quartz or placer claim may include trails and roads; lines, corridors, and trenching; and, clearings, including for helicopter pads and camps. The total area disturbed by these activities varies by permit level; all permit classes have limits on allowable disturbance level. I treated all claims with permits or licenses equally when buffering and calculating human footprint area. However, given the permit limits on the allowable area disturbed, the physical footprint may be less than the total claim area. In addition, some footprint "expires," i.e. is not permanent.

There has been extensive study of the impacts of forestry and oil-and-gas development on terrestrial and aquatic ecosystems in Canada's southern boreal. In contrast, there has been relatively little study of the direct impacts of mineral exploration and mining (Kreutzweiser et al. 2013, Venier et al. 2014). However, many mining disturbance impacts can be inferred from study of similar anthropogenic disturbances, including impacts of habitat loss and fragmentation and new roads. Human activity associated with mining can also result in air and ground disturbance to wildlife. Disturbance can prompt range or habitat shifts, decreased foraging efficiency, increased vigilance and fleeing in mammals, and decreased pairing success and body condition in songbirds, with potential impacts to individual reproduction and eventually population size (Habib et al. 2007, Bayne et al. 2008, Hayes and Reid 2014, Ware et al. 2015). The primary impact of mining on aquatic ecosystems is through potentially toxic compounds and sediments leaching from tailings and/or being discharged in the mining process. In addition, mining impacts groundwater and surface water flow and conditions through water extraction and use and construction of the mine site and associated infrastructure (Kreutzweiser et al. 2014). Metal contamination associated with mining effluent can have significant and long-lasting adverse effects on zooplankton, phytoplankton, macroinvertebrates and fish.

Photos: Hilary Cooke

Across Yukon's Boreal Mountains, the largest development footprint is related to mining and ranges from minor disturbance for marking a claim or clearing for early exploration to major disruption as mineral extraction operations get underway, such as at the now-closed Faro mine, which was at one time the world's largest open-pit zinc mine.

The next most important human land disturbance is roads. Just a single road, such as the Robert Campbell Highway (bottom), opens up an area to recreation and local resource use, such as wood cutting, mushroom gathering, hunting and fishing. New roads are also gateways for new infrastructure, putting wildlife at risk from human disturbance and further habitat loss and fragmentation.

The second- through fourth-dominant anthropogenic features in my study area are resource (i.e. forestry and mining) roads, major highways, and secondary roads respectively. Collectively, roads comprise 31% of the total footprint area. There has been little study of the impacts of roads and the physical footprint of mining on wildlife and ecosystems in Yukon's Boreal Mountains. However, there has been extensive study elsewhere demonstrating the negative impacts of roads, infrastructure, and industrial development on wildlife habitat and biodiversity and thus the potential impact on ecological intactness of BAs (summarized in Introduction).

The greatest negative impacts on terrestrial ecosystems in the study area may be associated with human activity rather than cumulative habitat loss and fragmentation. In remote regions where vehicle traffic is minimal, an individual road may not result in significant habitat loss or disruption of connectivity or pose a significant risk from vehicle mortality. However, a single road can significantly increase recreation disturbance, local resource use (e.g. wood cutting), and hunting and fishing pressure. And new roads pose a threat by providing access to previously undeveloped areas and thus providing gateways for additional infrastructure, resource development and human activity (Laurance and Balmford 2013).

In remote regions where vehicle traffic is minimal, an individual road may not result in significant habitat loss or disruption of connectivity or pose a significant risk from vehicle mortality. However, a single road can significantly increase recreation disturbance, local resource use (e.g. wood cutting), and hunting and fishing pressure.

The actual footprint of human influence in the study area likely differs from that estimated using either the national map or the Yukon map I produced: the area-of-influence of different footprint features may have been over- or underestimated and several human activities lack mapped data. In a meta-analysis of road effects on bird and mammal populations, Benítez-López et al. (2010) found decreased abundance of bird and mammal populations at distances from infrastructure up to 1 km and at 5 km, although effects varied with species group and habitat type. If the effects identified in their review are applicable to Yukon's Boreal Mountains, the footprint associated with infrastructure has been significantly underestimated in this study.

Some human activity in Yukon is associated with an "on-the-ground" footprint, but is not mapped by any existing data and may not be captured by the area-of-influence buffer on roads and trails. Mineral exploration activities that do not require a permit, i.e. Class 1 activities, are not monitored or mapped. Motorized (e.g. all-terrain vehicle, snow machine) and non-motorized (e.g. hiking, camping, skiing, etc.) recreation is extensive throughout the Territory, is unmapped, and, particularly for motorized activity, is generally not restricted to within a few kilometres of the road network or populated areas.

The footprint map produced by Reid et al. (2013) for the Carcross Caribou Herd range included ground-mapping of motorized and non-motorized winter recreation trails because of the potential disturbance to caribou. This method mapped more footprint in this area than my Yukon footprint map, resulting in lower average catchment intactness compared to my Yukon intactness map. Both motorized and non-motorized recreation pose potentially significant disturbances to wildlife and sensitive ecosystems (Stankowich 2008, Naylor et al. 2009, Steven et al. 2011, Arp and Simmons 2012, Sato et al. 2013, Hayes and Reid 2014). There is increasing concern by Yukon First Nations and various user groups that the unregulated proliferation of off-road vehicle trails is significantly compromising the ecological integrity of roadless areas, with impacts

Photo: Lila Tauzer

Photo: Hilary Cooke

Yukon's flora and fauna can be negatively impacted by the physical footprint and human disturbance of motorized and non-motorized recreation. Sensitive habitats, such as wetlands (top left) and the Carcross Dunes in southern Yukon (bottom right) are particularly vulnerable.

Table 11. Summary of national and Yukon human footprint area within the top Benchmark Network (BN) for each scenario. See Table 3 for parameters of planning scenarios. Scenario ranking based on combined representation index for four environmental indicators (see Table 6).

Scenario #	Scenario ranking	Total area of top BN (km^2)	Area (km^2) of footprint within top BN	Percent area (%) of footprint within top BN
1	22	42,923	0	0
2	20	68,181	0	0
3	21	94,628	0	0
4	24	115,570	0	0
5	17	30,682	0	0
6	14	55,779	0	0
7	15	85,609	0	0
8	23	115,570	0	0
9	16	41,295	1,227	3
10	12	73,744	1,687	2
11	7	97,682	2,465	3
12	6	137,134	2,842	2
13	18	29,613	736	2
14	10	52,854	1,230	2
15	3	89,814	1,970	2
16	1	127,786	2,825	2
17	13	43,202	1,247	3
18	11	68,016	2,661	4
19	8	93,867	3,605	4
20	4	134,258	4,990	4
21	19	25,840	780	3
22	9	55,994	1,998	4
23	5	93,167	3,172	3
24	2	127,674	4,619	4

on sensitive habitats (alpine, wetland) and wildlife. Given the extent of unpermitted mineral exploration activities and the popularity of motorized and non-motorized recreation, I expect that, although it is an improvement on the national map, my map of the human footprint in Yukon underestimates the extent of anthropogenic disturbance.

The true area of disturbance from human activity was likely underestimated by the Yukon human footprint map.

While the true area of disturbance from human activity was likely underestimated by the Yukon human footprint map, the best BN for each planning scenario actually had lower levels of physical disturbance than the intactness threshold parameter. For the 90% intact scenario group, the best BNs had a median footprint area of 2% of the BN area (Table 11). The best BNs in the 80% intact scenario group had a median footprint area of 4% of BN area. Thus, while the top eight scenarios had relaxed intactness threshold parameters (i.e. 80% and 90% intact Bas), the best BNs for these scenarios were >95% intact by area. Across Canada's boreal, protected areas classed as IUCN Category 1a (strict nature reserve) and Category 1b (wilderness area) have average intactness of 95% based on the national intactness map (Anderson 2009). This suggests that, as a whole**, the best BN for the top eight planning scenarios all meet the standard for the highest level of protection under the IUCN classification**.

4.4. Priority areas for landscape-scale conservation within Yukon's Boreal Mountains

I identified priority areas for conservation across Yukon's Boreal Mountains using overall catchment importance estimated by this study. In the west, the entire White River watershed was identified as a priority area, providing representation of both the Klondike Plateau and Ruby Range ecoregions (Figure 16). Much of the Alsek drainage was also a priority area. A large area of high catchment importance in the Southern Lakes ecoregion is an area bounded by Lewes Marsh and the M'Clintock River in the south, Lake Laberge in the west, and the Teslin River in the east. In the central part of the study area, an extensive priority area for conservation occurs along much of the Stewart River drainage, from its headwaters in the Selwyn Mountains ecoregion, west across the Yukon Plateau-North ecoregion and linking several existing protected areas. Within the Pelly River watershed, priority areas include Sheldon Lakes along the Ross River and upstream of Pelly Banks to Fortin and Pelly Lakes. Catchments in the lower reaches of the Pelly River are also ranked of high importance, and are connected to priority areas for conservation around the Stewart River through the MacMillan River. A large, contiguous priority area was identified in the Upper Liard watershed including the Frances Lake drainage and the Liard River upstream of the town of Watson Lake. Finally, in southeast Yukon, the Hyland Highland ecoregion is represented by priority areas within the Beaver River drainage.

Notably absent from all top BNs, and thus having low or no catchment importance, are the Upper Yukon and Central Yukon watersheds in the Klondike Plateau ecoregion. These watersheds have extensive anthropogenic disturbance, primarily a long history of mining and associated infrastructure. Given the absence of large, intact landscapes and the continued development

Photo: Hilary Cooke

Photo: John Meikle

The Frances Lake and River drainage in southeast Yukon has been described as one of the most productive regions of Yukon, providing critical habitat for a diverse number of species including moose, caribou, freshwater fish and waterfowl. This area was also identified in this study as a priority for landscape-scale conservation.

activity in the northern part of the Klondike Plateau ecoregion, establishing a large representative conservation area in the central and southern parts of the ecoregion is critical.

Previous conservation assessments by Revel (1981), Theberge (1980), Inukshuk Planning & Development (1994), and Pojar (2007) identified candidate protected areas within my study area. I visually assessed their spatial overlap with priority areas identified in my study. (Spatial overlap was assessed visually because information on the location of candidate protected areas was only available as printed, not digital, maps or text description.)

Of the eight International Biological Programme sites identified within my study area (Revel 1981), five overlap entirely or partly with priority areas identified in this study (Table 10). Nine of the Environmentally Significant Areas described by Theberge et al. (1980) fully overlap with priority areas, three partially overlap, and three have no overlap. For the 15 potential PA identified for the Pelly Ranges and Southwest Interior Landscapes (Inukshuk Planning & Development 1994), four were small (<100 km^2) site-specific reserves; of the larger potential protected areas, seven entirely overlap and two partly overlap with my priority areas for conservation. Of the 14 areas assessed by Pojar (2007) as candidates for a National Park in Park Canada's Region, seven overlap with the YBM study area; while five overlap partly or fully with priority areas of conservation identified in my study (Table 10).

Identifying potential Benchmark Areas (BAs) using parameters similar to those in my study (80% and 95% intactness at catchment and BA scales), Anderson (2009) found that both Kluane National Park and Kusawa Lake NEP qualified as BAs. Based on catchment importance (frequency of occurrence in 10,000 top-ranked networks), Anderson (2009a) also identified a large priority area in the White River drainage (encompassing the Kluane, Donjek, and White Rivers and Wellesley Lake basin), straddling the Klondike Plateau and Ruby Ranges ecoregions. Additional overlaps with my study include: between the Stewart and Yukon Rivers west of the Klondike Highway in the Yukon Plateau Central ecoregion; the Ross River lowlands northeast of the community of Ross River; the Pelly River downstream of Faro; the Nisutlin River drainage east of the South Canol Road; and two areas that overlap existing protected areas – Kusawa Territorial Park and Ddhaw Ghro Habitat Protection Area.

Additional values that should be considered when conducting conservation assessments and designating areas for conservation within land use planning include habitat and area requirements of rare or specialized species and areas of high and/or irreplaceable ecological value.

4.5. Building a comprehensive conservation strategy for Yukon's Boreal Mountains

Protecting the integrity of Yukon's aquatic and terrestrial ecosystems and fish and wildlife populations requires a strategy that draws from the principles of ensuring representation and persistence of biodiversity and includes conserving intact landscapes large enough to accommodate ecological processes and representative of ecological conditions, conserving rare and important habitats, planning strategically for new development and infrastructure, and protecting key habitats and wildlife populations outside conservation areas.

Additional values that should be considered when conducting conservation assessments and designating areas for conservation within land use planning include: habitat and area requirements of rare or specialized (i.e. fine-filter) species; and areas of high and/or irreplaceable ecological value. Types of fine-filter species to be considered include at-risk, rare, endemic, and/or specialized species (Lambeck 1997, Groves et al. 2002). Rare and distinctive species, ecosystems, or land forms will require proportionally higher targets – higher than proportional representation in the region – given that they cover a small area to begin with (Beier and Brost 2010). Examples include rare species (e.g. dune plants) and habitats (e.g. open water migration stopover sites for waterfowl, waterbirds, and shorebirds). Sites with high ecological value, particularly sites with high biological productivity, should also be prioritized and may require higher area targets (Noss et al. 2002). In Yukon's Boreal Mountains, valley-bottom habitats in the boreal low and boreal high bioclimate zones, including wetlands, riparian areas, and old white spruce forests, support high biological productivity and habitat-specialist species (Reid et al. 2010, SLWCC 2012).

Photo: Jukka Jantunen

Photo: Jukka Jantunen

Photo: Hilary Cooke

Additional values to consider in conservation planning include the habitat and area requirements of rare, threatened, endangered, specialized or otherwise valued species. For example, requirements of individual species or groups of species that depend on old forest habitat (e.g. American marten, Martes american*, left), conifer wetlands (e.g. blackpoll warbler,* Setophaga striata*, top right), or large habitat areas (e.g. wood bison,* Bison bison athabascae*, bottom right) may all be considered as additional ecological values in a conservation assessment.*

While the human footprint occurs disproportionately in these zones, the region still supports extensive valley bottoms and floodplains with only minimal human footprint. Areas of high wetland and riparian value should be prioritized for conservation. Several analytical tools (e.g. Marxan) are available to prioritize sites for conservation based on other ecological values.

Protecting large, intact landscapes is insufficient, on its own, to conserve the wild places and wildlife that Yukoners value. Protecting Yukon's biodiversity and ecosystems, both in and out of areas designated for conservation, requires careful management of land outside conservation areas.

A full assessment of threats to biodiversity and ecosystems and effective conservation measures is beyond the scope of this report. However, mechanisms to consider include: a robust environmental assessment process that adheres to thresholds for cumulative effects of disturbance and development; implementation of best management practices, such as spatial buffers and timing windows for key habitats and sensitive sites; and an adaptive management framework that treats management as an experiment with monitoring of ecosystem responses and subsequent improvement of management practices.

The multiple, alternate solutions for both Benchmark Areas and Benchmark Networks in the top scenarios indicates flexibility in meeting the goals of landscape-scale conservation in the study area.

The results of this study suggest that at least 50% of the region should be conserved in large, intact landscapes to ensure representation of basic environmental indicators. Adding critical habitats for focal species (e.g. caribou); rare, threatened, and/or endemic species and habitats (e.g. wetlands, Beringian plants), and ecological processes (e.g. predator-prey relationships for large carnivores) is necessary to ensure persistence of all populations and will undoubtedly increase the land area to be managed for conservation rather than intensive development.

The multiple, alternate solutions for both Benchmark Areas and Benchmark Networks in the top scenarios indicates flexibility in meeting the goals of landscape-scale conservation in the study area. This is a significant advantage for conservation and land-use planning in Yukon, as the flexibility allows for consideration and incorporation of other values (social, cultural, economic) (Kukkala and Moilanen 2013).

The evidence from regions with a significant human footprint is clear: parks do not work in isolation. Even the large (2,000-7,500 km^2) conservation areas proposed by this study can have ecological processes downgraded by human activity outside their borders – migration disruption (barriers, habitat loss, other threats to survival); aquatic and atmospheric pollution; hydrologic (water) regime disruption; and, climate change.

Regional land-use planning for Yukon must also address climate change, which may be accompanied by changes in the composition of ecological communities and shifts in entire biomes. A recent report by the Yukon Research Centre (Streicker 2016) concluded with high confidence that Yukon's climate is warming rapidly and that winters are warming more than other seasons. Significantly, they note (also with high confidence) that Yukon's climate is warming at twice the rates of southern Canada and worldwide. They also concluded, with medium confidence, that annual precipitation has increased, particularly in the summer, and projections for further warming and increases in precipitation are estimated at 2-2.5C and 10-20% respectively over the next 50 years.

Photo: Lila Tauzer

In central-eastern Yukon, the Pelly Mountains form one wall of the Tintina Trench, which extends 960-km from Watson Lake in southeast Yukon to Dawson City in the west. The Trench formation is a major flyway used by hundreds of thousands of raptors, cranes, shorebirds, waterbirds, and landbirds migrating to and from breeding grounds further north. Such large landscape features shape ecosystems in permanent and profound ways that will persist even in the face of climate change.

Documented changes in Yukon's environment accompanying global warming include decreases in glacier volume with increasing melt (Flowers et al. 2014), increasing permafrost melt (Lyon and Destouni 2010), alpine tree line advance (Danby and Hik 2007), shrub expansion on the arctic tundra (Myers-Smith et al. 2011), range expansion of some butterflies (Leung and Reid 2013), and earlier egg-laying in passerines and shorebirds in response to earlier snow melt (Grabowski et al. 2013).

The majority of Yukon is projected to undergo multiple shifts in climate-biome, or "cliomes" by the 2090s (Rowland et al. 2016). Small protected areas (<100km^2) and those at northern latitudes are projected to undergo the most dramatic changes in cliome composition. Several protected areas (Agay Mene, Lewes Marsh, Tagish River) are projected to experience nearly complete cliome turnover over the next few decades. New combinations of temperature and precipitation parameters are likely to create novel climates, favouring new assemblages of species, which makes the outcomes of climate change uncertain and difficult to predict.

To support climate change adaptation in regional conservation planning, Groves et al. (2012) proposed five strategies: sustaining ecosystem process and function; enhancing regional connectivity; conserving the geophysical stage; protecting climate refugia; and, capitalizing on conservation opportunities emerging in response to climate change. Landscape-scale conservation and management for conservation values in the matrix enables several climate-change adaptation strategies (Krawchuk et al. 2012). By incorporating large-scale

Photo: Hilary Cooke

The Englishmans Range in south-central Yukon is important mountain goat and thinhorn sheep habitat and is part of the roadless Wolf Lake watershed, which has been identified in previous assessments as having high conservation value.

system dynamics and maintaining hydrologic connectivity, a network of large, intact conservation areas will likely provide opportunities for sustaining ecosystem process and function under climate change.

However, climate change is altering natural disturbance regimes in Canada's boreal, including increases in fire frequency and area burned (Balshi et al. 2009, Kelly et al. 2013). Thus, area estimates for minimum dynamic reserves based on historical records may be inadequate under future disturbance regimes. Regional connectivity is necessary to provide opportunities for adaptation of species and ecological communities to climate change (Groves et al. 2012). Landscape-scale conservation, alongside protection of ecological values in the matrix, will support both terrestrial and hydrologic connectivity over space and time (Groves et al. 2012). Proactive planning to achieve these goals will avoid the need to apply retroactive strategies to increase regional connectivity.

Geophysical features, such as bedrock geology and soil type, influence local habitat conditions and variability and are key drivers of species occurrence and diversity (Anderson and Ferree 2010). Conserving the full range of geophysical conditions upon which ecosystems are formed is a fundamental component of systematic planning for conservation of biodiversity under both current and future climate conditions (Groves et al. 2002, Anderson and Ferree 2010).

Finally, the high topographic diversity of Yukon's Boreal Mountains offers a diversity of microclimates in close proximity. In combination with the high level of intactness, which provides opportunities for movement, a network of large, intact, representative conservation areas may provide numerous options for climate refugia (Rowland et al. 2016, (Groves et al. 2012).

5. CONCLUSION

Proactive planning for conservation alongside other values is critical to ensure Yukon's intact ecosystems and watersheds, abundant wildlife populations, wealth of ecosystem services, and cultural and social connections to the land are not eroded by the cumulative impacts of unplanned industrial development. In this report I have presented the results of an analytical approach to identifying gaps in the existed network of conservation areas and opportunities and priorities for conserving areas large enough to accommodate changing landscape conditions under the natural fire regime, while covering enough of the study area to capture its ecological variability. Landscape-scale conservation areas also provide opportunities to study and monitor Yukon's Boreal Mountain ecosystems and thus can act as benchmarks for comparison with areas managed for industrial development.

My results demonstrate that, at a minimum, large (~2,000 to 7,500 km^2), relatively intact (<10% human footprint by area) landscapes covering 50% of the total area of Yukon's Boreal Mountains should be allocated for conservation to achieve long-term protection of biodiversity and ecosystems. I also identified a need to immediately prioritize protection of ecoregions currently lacking any formal protection along with intact valley bottoms and associated ecosystems. Ultimately, what, where, and how much land to dedicate to conservation, to industrial development and human infrastructure and to traditional, cultural, and spiritual values is a decision for Yukoners to make within regional land-use planning processes. This study supports a broader discussion of how much land can be allocated for economic development without compromising long-term conservation of Yukon's boreal biodiversity.

GLOSSARY

Adequacy – A property of the objective of spatial conservation prioritisation. Adequacy is the extent to which a conservation reserve network fulfills the objective of conserving biodiversity (Kukkala and Moilanen 2013). Adequacy requires that high enough targets be given to features (i.e. species, ecosystems, etc.) to ensure a favourable conservation outcome, i.e. persistence of biodiversity features into the future. To be adequate with respect to persistence of biodiversity, the ecological and evolutionary processes that support persistence of biodiversity should be accounted for.

Aichi targets – The 2011-2020 Strategic Plan for Biodiversity, adopted by the Parties to the international Convention on Biological Diversity, is a 'overarching framework on biodiversity, not only for the biodiversity-related conventions, but for the entire United Nations system and all other partners engaged in biodiversity management and policy development' (https://www.cbd.int/sp/). The Plan includes targets, known as the Aichi Biodiversity Targets, to assist in achieving goals. Strategic Goal C is 'To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity'. Under Goal C is Target 11, 'By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes'. Further guidance to Target 11 is provided here: https://www.cbd.int/doc/strategic-plan/targets/T11-quick-guide-en.pdf.

Benchmark Area (BA) – Benchmark Areas are intact landscapes (little or no human development footprint), sufficiently large to encompass the natural disturbance regime (primarily wildfire), and supportive of hydrologic connectivity (by following boundaries of small drainages or catchments). Benchmark Areas are intended to be the core conservation areas in a region and to function as reference or control sites in an adaptive management framework (Schmiegelow et al. 2006, Schmiegelow et al. 2014).

Benchmark Network (BN) – A Benchmark Network is a system of BAs that collectively captures the environmental variability of the study area as measured by coarse-filter indicators of environmental conditions, such as land cover and gross primary productivity (Schmiegelow et al. 2006, Schmiegelow et al. 2014). Systematically planning for a network of BA ensures the full range of environmental conditions occurring across the study area are represented in a conservation network.

Catchment – A catchment is an area of land within which all surface water drains to a common point. In the BEACONs tools, catchments are small drainages that function as the 'building block' units for Benchmark Areas.

Catchment Intactness – Calculated as the%age area of an individual catchment that is free from human footprint (see definitions for intactness and human footprint).

Climate Moisture Index (CMI) – Calculated as annual average precipitation minus annual potential evapotranspiration, climate moisture index describes the annual surplus or deficit of water in the soil (Hogg 1997). Areas of higher precipitation than evapotranspiration have positive measures of climate moisture index, with increasing positive values reflecting increasing humidity. In contrast, negative values indicate a deficit and thus a dry area. CMI units are expressed in cm of water/year. The CMI dataset used in this study was derived by Natural Resources Canada.

Comprehensiveness – A property of the objective of spatial conservation prioritisation. Comprehensiveness is about conserving the full spectrum of biodiversity, including genes, individuals, population, and ecological communities (Kukkala and Moilanen 2013).

Connectivity – Connectivity relates to 'to the ability of species and ecological resources and processes to move through landscapes, not only in the terrestrial domain, but also in aquatic systems and between the two' (Lindenmayer et al. 2008). Within a landscape conservation context, connectivity is generally differentiated into physical connectivity, i.e. the connectedness of habitat patches for a species or other taxonomic group, and functional or ecological connectivity, i.e. the connectedness of ecological processes, such as animal movements and stream networks, at relevant spatial scales.

Conservation area – Broadly defined as any area that supports conservation values and for which there is a conservation plan in effect (Sarkar 2003). In this report, the term conservation area includes any area designated primarily for conservation, including parks (national, territorial), wildlife areas/refuges, Habitat Protection Areas, Special Management Areas, and management zones designated primarily for conservation of ecological values. While protected areas are a type of conservation area, not all conservation areas are formally protected.

Conservation Matrix Model – A proactive approach to planning for landscape-scale conservation that integrates planning for conservation of ecological pattern and process, carefully managing activities in the matrix so ecological values are not compromised, and using control sites (networks of Benchmark Areas, which are also the core reserves in the landscape) within an adaptive management framework (Schmiegelow et al. 2014).

Conservation target – In this report, conservation target refers to the%age area targeted for conservation (rather than the alternate usage of referring to a species, habitat, or ecosystem targeted for conservation).

Ecologically-functional wildlife populations – Whereas a minimum viable population of a species is generally defined as the smallest population necessary for a species to remain viable over the long term despite potential known effects of demographic, environmental, and genetic stochasticity, and natural catastrophes (Shaffer 1981), an ecologically function population is also large enough to maintain ecological interactions with other species (Redford et al. 2011). For example, an ecologically functional population of a keystone species will be that population size that is necessary for it to continue to provide a keystone role in an ecosystem. Similarly, an ecologically functional population of a predator is one that is in the range of natural variability experienced by its prey species, whose population may be regulated or limited by the predator. Redford et al.

(2011) note that maintaining ecologically functional populations is necessary to achieve the conservation goal of species self-sustainability, and further is critical to ensure resilience to change (anthropogenic, climate, or other).

Ecosystem services - Ecosystem services are the output of functioning ecosystems that benefit humans. Ecosystem services may be provisioning (e.g. food, water, fibre, energy), regulating (e.g. climate regulation, water quality and quantity, carbon sequestration, pest and disease control, crop pollination), cultural (e.g. spiritual, aesthetic, recreational, educational), or supporting (e.g. primary (biomass) production, soil formation, nutrient cycling) (Millennium Ecosystem Assessment 2005). In general, intact biodiversity is critical for full ecosystem functioning, which in turn is critical for supporting delivery of ecosystem services.

Efficiency – Efficiency is usually a priority in spatial conservation prioritisation because of the need to balance benefits with costs, which are generally measured by money, land area, and lost economic opportunities. Optimisation spatial planning tools are used to find efficient protected area solutions. In particular, the use of complementarity in site-selection algorithms ensures potential conservation areas meet conservation objectives (i.e. quantitative targets for representation and persistence of biodiversity) as efficiently as possible (Kukkala and Moilanen 2013).

Estimated Maximum Fire Size – Using the Canadian Large Fire Database, the BEACONs Project developed a fire regionalization dataset, which includes estimates of expected fire size, annual burn rate, and maximum fire size.

Flexibility – Flexibility is the degree to which alternative solutions for a reserve network, as identified through spatial conservation prioritisation, can meet the conservation objectives (Kukkala and Moilanen 2013). Flexibility is related to irreplaceability in that there is greater flexibility in design of reserve networks when more sites have low than high irreplaceability, and thus different combinations and spatial arrangements of sites can achieve conservation objectives. Irreplaceability is generally measured at the site level and flexibility is usually measured at the full network or conservation solution level. Flexibility is particularly advantageous within a land use planning context when alternative solutions to achieving conservation objectives within a reserve network can be examined within the context of socio-economic values and political constraints.

Gross Primary Productivity (GPP) – GPP is the total carbon fixed, i.e. absorbed through the process of photosynthesis, by all primary producers within an ecosystem per unit time (measured in kilograms of carbon per day). Net primary production is GPP minus the carbon used by the plant during respiration. GPP is an indicator of the accumulation of biomass over time with, for example, tropical forests have higher annual rates of biomass accumulation (i.e. GPP) over time. The GPP dataset used in this study was derived from MODIS 1-km^2 resolution satellite imagery and represents the mean of 7 years of data (2000-2006).

Habitat – Although habitat is often equated with land cover types, vegetation associations, or ecosystem classes, the term is properly used within a species-specific context, i.e. to describe the environmental, biological, physical or other conditions that are associated with the presence of, and provide the resources required by, a given individual, species, or population (Hall et al. 1997, Lindenmayer et al. 2008).

Human Footprint – Sanderson et al. (2002) define the human footprint as a map of 'human influence of the land surface'. Also termed anthropogenic disturbance or anthropogenic footprint, it is the area of land lost or degraded either directly or indirectly by human development or human activity (Potapov et al. 2008). It includes conversion of land for other uses, e.g. agriculture, resource extraction, urban settlements, roads and infrastructure, and adjacent area not physically converted for human use but with impacts ecosystems and wildlife populations resulting from the area with direct footprint, e.g. through noise disturbance, area avoidance, etc.

Coarse-filter Indicators – A set of environmental variables or ecosystem attributes whose range of conditions is presumed to reflect regional biodiversity and thus used as surrogates in planning for conservation and monitoring success or failure of management activities (Noss 1987, Panzer and Schwartz 1998). This is necessary because knowledge of all levels of biodiversity is lacking. Coarse-filter indicators may include land cover types, ecoregions, or other ecological or biophysical classifications of the environment. Together, coarse-filter and fine-filter indicators are designed to capture, or function as surrogates for, as much of a region's biodiversity as possible (Noss 1987).

Fine-filter Indicators – A species, set of species, or habitats selected to capture elements of regional biodiversity not adequately captured by coarse-filter indicators but considered a priority for conservation or indicative of a species or habitat that is a conservation priority (Panzer and Schwartz 1998). Indicators are selected for a range of purposes, including ecological role (e.g. keystone species), rarity (e.g. endemic plant with limit distribution), conservation status (e.g. threatened species), representative of the occurrence of members of a larger taxonomic or other group (e.g. forest birds), or sensitivity to environmental conditions (e.g. pollution). Together, coarse-filter and fine-filter indicators are designed to capture, or function as surrogates for, as much of a region's biodiversity as possible (Noss 1987).

Intactness – In this study, intactness is defined in physical terms by the absence of human footprint (see definition). Intactness does not mean the absence of humans, but the absence of human activity that has a degrading impact on biodiversity, including land conversion but also disturbance. Note that other definitions and usages incorporate ecological integrity into definitions of intactness, e.g. the full complement of native species.

Irreplaceability – Irreplaceability is a measure of the relative contribution of an individual area for meeting conservation objectives, relative to the other areas within the conservation network (Kukkala and Moilanen 2013). An area with high irreplaceability is essential for meeting conservation objectives whereas one with low irreplaceability can be substituted by other areas.

Lake Edge Density (LED) – Derived by the BEACONs Project to characterize density of riparian habitat, measured as kilometres of lake edge per square kilometre within 100 km2 units. They used 1:1,000,000 lakes coverage available from the National Scale Frameworks Hydrology (version 6.0, Atlas of Canada).

Land Cover Class (LCC) – This indicator was derived from an interpretation of 250-m resolution MODIS satellite imagery (available from Natural Resources Canada) with 39 different cover types including forests, shrubs, herbs, lichen, burns and non-vegetated areas (urban, water bodies, wetlands and snow/ice). It was reclassified into 13 classes for this study:

Minimum Dynamic Reserve – A conservation area sufficiently large to accommodate the natural disturbance regime. In boreal systems, representation and persistence of boreal biodiversity is thought to be best achieved if conservation areas are designed to accommodate the scale of natural disturbance regimes, i.e. the size, frequency, and intensity of disturbance events and the resultant spatial and temporal patterns of ecosystems (Leroux et al. 2007a, Leroux et al. 2007b).

Persistence – Broadly, maintenance of biodiversity features into the future. Related to adequacy, in that the adequacy of a reserve network relates to both its representativeness and likelihood of supporting persistence of biodiversity features into the future (Kukkala and Moilanen 2013). The concepts of threat and vulnerability also have implications for persistence of biodiversity.

Representation – Representation is a property of an individual reserve, or reserve network. Representation is generally a measurement (e.g. abundance, density, area) of the occurrence of a feature or features in a reserve or reserve network (Kukkala and Moilanen 2013).

Representation Value – Within the context of assessing representation of environmental indicators within networks of conservation areas (including existing protected areas and Benchmark Networks), the representation value is a measure assessing the congruence of the distribution, i.e. the range and relative frequencies of classes or conditions, of an environmental indicator within the network to its distribution across entire area of interest, e.g. study area (Canadian BEACONs Project 2011). The more similar the two distributions, the more representative the network is of the study area. Representation values are rescaled between 0 and 1, with 0 indicating complete agreement, i.e. minimum distance or difference, between the distribution of an environmental indicator in the network and the study area, and 1 indicating complete disagreement, i.e. maximum distance or difference, between indicator distribution in the network and study area.

Threshold – Within the context of landscape-scale conservation, a threshold is generally defined as an amount of a particular habitat or land cover type, or conversely the level of anthropogenic disturbance or human footprint across a landscape, that, when crossed, results in marked changes in the abundance of species or the functioning of ecosystems (Lindenmayer et al. 2008). These 'non-linear responses to landscape modification' (Lindenmayer et al. 2008) are difficult, and often impossible, to identify in advance of dramatic change, but can have significant implications for conservation if, upon crossing the threshold, the change in the population or ecosystem is difficult to reverse.

APPENDICES

Appendix 1. Reclassification of the national Land Cover Class for the Yukon Boreal Mountains Study region.

Yukon Boreal Mountain Class		National Land Cover Class	
0	Vegetation not dominated	33	Rock outcrops
		37	Water bodies
		38	Mixes of water and land
		39	Snow/ice
1	Closed coniferous	1	Coniferous closed canopy (high density)
2	Open coniferous lichen-shrub	6	Mature coniferous with lichen-shrub understory (med density)
3	Open coniferous moss-shrub	7	Mature coniferous with moss-shrub understory (med density)
4	Sparse coniferous	8	Mature coniferous with moss-shrub understory (low density)
		13	Mature mixed, low to medium density
		20	Sparse coniferous with herb-shrub cover
5	Sparse coniferous shield	9	Mature coniferous with lichen/rock understory (low density)
6	Mature mixed & deciduous	2	Deciduous closed canopy (high density)
		3	Mature mixed closed canopy (high density)
		5	Mature mixed deciduous-coniferous closed canopy (high density)
		11	Mature deciduous, low to medium density
		14	Mature mixed deciduous-coniferous (low-med density)
7	Young mixed	4	Young mixed closed canopy (high density)
		15	Low regenerating young mixed cover
8	Open young deciduous	12	Young deciduous, medium density
		16	High-low shrub dominated (wet and dry)
9	Poorly drained (wetlands and treed bogs)	10	Coniferous low density, poorly drained (wet treed bogs)
		19	Wetlands
		31	Lichen-sedge-moss-low shrub wetland (lichen bogs)
		32	Lichen-spruce bog (wet lichen dominated treed bogs)
10	Open herb/grass	17	Grassland
		18	Herb-shrub-bare-cover (thinly develop soils with barren patches)
11	Open northern	21	Polar grassland, herb-shrub (generally non-tussock tundra)
		22	Shrub-herb-lichen-bare (mesic to dry tundra)
		23	Herb-shrub poorly drained (wet tundra)
		24	Lichen-shrub-herb-bare-soil (mesic, lichen dominated tundra)
12	Lichen and rocky barrens	25	Low vegetation cover (barrens dominated by rock outcrops and bare soil)
		30	Lichen barren (treeless barren land with shallow soils)
13	Burns	34	Recent burns
		35	Old burns
R	Removed	26	Cropland-woodland
		27	High biomass cropland
		28	Medium biomass cropland
		29	Low biomass cropland
		36	Urban and built-up

Appendix 2. Representation values, and ranking based on representation values, for networks of Benchmark Areas (BA) identified for 24 scenarios using the National intactness map (see Table 6 for results using the Yukon intactness map). Of the 500,000 Benchmark Networks produced for each scenario, the best was the Benchmark Network most representative of four environmental indicators, i.e. greatest similarity between the environmental indicators within the Benchmark Network and the study area as a whole. Representation index values close to 0 indicate the Benchmark Network is similar to the study area; values close to 1 indicate dissimilarity in environmental indicators between the Benchmark Network and area. All scenarios were ranked based on overall representation of their best Benchmark Network (top 8 are in bold). Subsets of scenarios were also ranked within groups of similar intactness threshold (8 scenarios in 3 groups); network composition (12 scenarios in 2 groups); and area target (6 scenarios in 4 groups).

Scenario #	Intactness Thresholds	Network Composition	Area Target (% planning area)	Ranking				Environmental indicator representation index				
				Overall	Within Intactness Thresholds	Within Network Construction	Within Area Target	All	GPP[1]	CMI[2]	LED[3]	LCC[4]
1	Catchment=100%, Benchmark Area=100%	Random	15	22	6	11	6	0.079	0.052	0.054	0.026	0.053
2			25	20	4	9	6	0.063	0.037	0.043	0.028	0.070
3			35	21	5	10	6	0.076	0.052	0.046	0.030	0.035
4			50	24	8	12	6	0.139	0.076	0.107	0.047	0.025
5		PA + Random	15	19	3	11	5	0.056	0.018	0.045	0.028	0.059
6			25	13	1	7	5	0.045	0.027	0.033	0.015	0.049
7			35	16	2	8	5	0.049	0.030	0.033	0.021	0.040
8			50	23	7	12	5	0.104	0.046	0.087	0.034	0.022
9	Catchment=80%, Benchmark Area=90%	Random	15	15	7	8	2	0.049	0.025	0.027	0.033	0.060
10			25	11	6	5	3	0.039	0.014	0.030	0.020	0.048
11			35	6	3	3	2	0.030	0.016	0.020	0.016	0.030
12			50	5	2	2	4	0.028	0.016	0.019	0.012	0.023
13		PA + Random	15	17	8	9	3	0.054	0.018	0.047	0.019	0.078
14			25	10	5	6	2	0.038	0.018	0.029	0.017	0.046
15			35	7	4	4	3	0.031	0.014	0.023	0.015	0.040
16			50	2	1	2	2	0.023	0.008	0.018	0.011	0.036
17	Catchment=70%, Benchmark Area=80%	Random	15	14	7	7	1	0.046	0.027	0.030	0.021	0.051
18			25	12	6	6	4	0.042	0.026	0.027	0.020	0.020
19			35	8	4	4	4	0.035	0.016	0.025	0.020	0.035
20			50	3	2	1	3	0.027	0.017	0.017	0.011	0.028
21		PA + Random	15	18	8	10	4	0.055	0.020	0.046	0.023	0.080
22			25	9	5	5	1	0.035	0.013	0.029	0.014	0.059
23			35	4	3	3	1	0.027	0.013	0.017	0.016	0.038
24			50	1	1	1	1	0.022	0.007	0.017	0.011	0.027

[1]GPP=Gross Primary Productivity [2]CMI=Climate Moisture Index [3]LED=Lake Edge Density [4]LCC=Land Cover Clas

LITERATURE CITED

Agriculture Branch 2015. Local Food Strategy: Encouraging the Production and Consumption of Yukon-Grown Food 2015-2020. Agriculture Branch, Energy, Mines and Resources, Government of Yukon. Whitehorse, Yukon. 20 pages

Anderson, L. G. G. 2009b. Quantitative Methods for Identifying Ecological Benchmarks in Canada's Boreal Forest. University of Alberta, Edmonton, Alberta.

Anderson, M. G., and C. E. Ferree. 2010. Conserving the Stage: Climate Change and the Geophysical Underpinnings of Species Diversity. Plos One 5.

Andrew, M. E., M. A. Wulder, and N. C. Coops. 2012. Identification of de facto protected areas in boreal Canada. Biological Conservation 146:97-107.

Arp, C. D., and T. Simmons. 2012. Analyzing the Impacts of Off-Road Vehicle (ORV) Trails on Watershed Processes in Wrangell-St. Elias National Park and Preserve, Alaska. Environmental Management 49:751-766.

Balshi, M. S., A. D. McGuirez, P. Duffy, M. Flannigan, J. Walsh, and J. Melillo. 2009. Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. Global Change Biology 15:578-600.

Bastedo, J. 1979. An Ecological Survey Method for Environmentally Significant Areas in the Yukon with Results from the Frances Lake Study Site. Working Paper Number 5, President's Committee on Northern Studies. University of Waterloo, Waterloo, Ontario.

Bayne, E. M., L. Habib, and S. Boutin. 2008. Impacts of Chronic Anthropogenic Noise from Energy-Sector Activity on Abundance of Songbirds in the Boreal Forest. Conservation Biology 22:1186-1193.

Beier, P., and B. Brost. 2010. Use of Land Facets to Plan for Climate Change: Conserving the Arenas, Not the Actors. Conservation Biology 24:701-710.

Benítez-López, A., R. Alkemade, and P. A. Verweij. 2010. The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. Biological Conservation 143:1307-1316.

Beschta, R. L., and W. J. Ripple. 2016. Riparian vegetation recovery in Yellowstone: The first two decades after wolf reintroduction. Biological Conservation 198:93-103.

Bixler, R. P., S. Johnson, K. Emerson, T. Nabatchi, M. Reuling, C. Curtin, M. Romolini, and J. M. Grove. 2016. Networks and landscapes: a framework for setting goals and evaluating performance at the large landscape scale. Frontiers in Ecology and the Environment 14:145-153.

Blanc, L. A., and J. R. Walters. 2008. Cavity-nest webs in a longleaf pine ecosystem. Condor 110:80-92.

Brandt, J. P. 2009. The extent of the North American boreal zone. Environmental Reviews 17:101-161.

Brandt, J. P., M. D. Flannigan, D. G. Maynard, I. D. Thompson, and W. J. A. Volney. 2013. An introduction to Canada's boreal zone: ecosystem processes, health, sustainability, and environmental issues INTRODUCTION. Environmental Reviews 21:207-226.

Brassard, B. W., and H. Y. H. Chen. 2006. Stand structural dynamics of North American boreal forests. Critical Reviews in Plant Sciences 25:115-137.

Buddle, C. M., D. W. Langor, G. R. Pohl, and J. R. Spence. 2006. Arthropod responses to harvesting and wildfire: Implications for emulation of natural disturbance in forest management. Biological Conservation 128:346-357.

Canadian BEACONs Project. 2011. Benchmark Builder v3.1.26 User Manual. Draft April 1, 2011. The Canadian BEACONs Project, University of Alberta, Edmonton, Alberta. 31 pages.

Canadian BEACONs Project. 2012. Ranker Used Guide Version 1.7.6. The Canadian BEACONs Project, University of Alberta, Edmonton, Alberta. 52 pages.

Cardinale, B. J., J. E. Duffy, A. Gonzalez, D. U. Hooper, C. Perrings, P. Venail, A. Narwani, G. M. Mace, D. Tilman, D. A. Wardle, A. P. Kinzig, G. C. Daily, M. Loreau, J. B. Grace, A. Larigauderie, D. S. Srivastava, and S. Naeem. 2012. Biodiversity loss and its impact on humanity. Nature 486:59-67.

Chetkiewicz, C., and A. Lintner. 2014. Getting it right in Ontario's Far North: the need for a regional strategic environmental assessment in the Ring of Fire [Wawagajing]. Wildlife Conservation Society (WCS) Canadaecojustice Toronto, Ontario.

Coates, K. S., and W. R. Morrison. 2005. Land of the midnight sun: a history of the Yukon. McGill-Queen's University Press, Montreal-Kingston.

Cooke, H. A., and S. J. Hannon. 2011. Do aggregated harvests with structural retention conserve the cavity web of old upland forest in the boreal plains? Forest Ecology and Management 261:662-674.

COSEWIC. 2012. COSEWIC assessment and status report on the Grizzly Bear Ursus arctos in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xiv + 84 pp. (www.registrelepsararegistry.gc.ca/default_e.cfm).

Cote, D., D. G. Kehler, C. Bourne, and Y. F. Wiersma. 2009. A new measure of longitudinal connectivity for stream networks. Landscape Ecology 24:101-113.

Council of Yukon First Nations and the Government of Yukon. 1997. Understanding the Yukon Umbrella Final Agreement - A Land Claim Information Package. Fourth Edition. Whitehorse, Yukon. 81 pages. (http://www.eco.gov.yk.ca/pdf/Understanding_the_Yukon_UFA.pdf)

Canadian Parks and Wilderness Society (CPAWS) -Yukon. 2000. Frances Lake Wildlands Study: A Description of a Candidate Protected Area in the Southeast Yukon. Whitehorse, Yukon.

Danby, R. K., and D. S. Hik. 2007. Variability, contingency and rapid change in recent subarctic alpine tree line dynamics. Journal of Ecology 95:352-363.

Dehcho Land Use Planning Committee. 2006. NDÉH TS'EDÎÎCHÁ: Dehcho Ndéh T'áh Ats'et'î K'eh Eghálats'ênda. RESPECT FOR THE LAND: The Dehcho Land Use Plan. Final Draft Plan – May 2006. Fort Providence, Northwest Territories. 96 pages.

Environment Yukon. 2016. Flynn, N. and Francis. S., editors. Yukon Ecological and Landscape Classification and Mapping Guidelines. Version 1.0. Department of Environment, Government of Yukon. Whitehorse, Yukon. 80 pages.

Estes, J. A., M. T. Tinker, T. M. Williams, and D. F. Doak. 1998. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. Science 282:473-476.

Fahrig, L., and T. Rytwinski. 2009. Effects of Roads on Animal Abundance: an Empirical Review and Synthesis. Ecology and Society 14.

Fisher, J. T., and L. Wilkinson. 2005. The response of mammals to forest fire and timber harvest in the North American boreal forest. Mammal Review 35:51-81.

Florkiewicz, R. 2008. Southern Lakes Regional Wildlife Assessment Species Status Summary: Woodland Caribou. Whitehorse, Yukon.

Flowers, G. E., L. Copland, and C. G. Schoof. 2014. Contemporary Glacier Processes and Global Change: Recent Observations from Kaskawulsh Glacier and the Donjek Range, St. Elias Mountains. Arctic 67:22-34.

Francis, S., and J. Nishi. 2015. Range assessment as a cumulative effects management tool: assessment of the Carcross caribou herd range in Yukon. Whitehorse, Yukon.

Geldmann, J., M. Barnes, L. Coad, I. D. Craigie, M. Hockings, and N. D. Burgess. 2013. Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. Biological Conservation 161:230-238.

Gouvernement du Québec. 2015. The Plan Nord: 2015-2020 Action Plan. Québec, Québec. 28 pages (http://plannord.gouv.qc.ca/wp-content/uploads/2015/04/Synthese_PN_EN_IMP.pdf)

Grabowski, M. M., F. I. Doyle, D. G. Reid, D. Mossop, and D. Talarico. 2013. Do Arctic-nesting birds respond to earlier snowmelt? A multi-species study in north Yukon, Canada. Polar Biology 36:1097-1105.

Groves, C. R., D. B. Jensen, L. L. Valutis, K. H. Redford, M. L. Shaffer, J. M. Scott, J. V. Baumgartner, J. V. Higgins, M. W. Beck, and M. G. Anderson. 2002. Planning for biodiversity conservation: Putting conservation science into practice. Bioscience 52:499-512.

Groves, C. R., E. T. Game, M. G. Anderson, M. Cross, C. Enquist, Z. Ferdana, E. Girvetz, A. Gondor, K. R. Hall, J. Higgins, R. Marshall, K. Popper, S. Schill, and S. L. Shafer. 2012. Incorporating climate change into systematic conservation planning. Biodiversity and Conservation 21:1651-1671.

Habib, L., E. M. Bayne, and S. Boutin. 2007. Chronic industrial noise affects pairing success and age structure of ovenbirds Seiurus aurocapilla. Journal of Applied Ecology 44:176-184.

Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. Wildlife Society Bulletin 25:173-182.

Hauer, F. R., H. Locke, V. J. Dreitz, M. Hebblewhite, W. H. Lowe, C. C. Muhlfeld, C. R. Nelson, M. F. Proctor, and S. B. Rood. 2016. Gravel-bed river floodplains are the ecological nexus of glaciated mountain landscapes. Science Advances 2.

Hayes, R. D., and D. G. Reid. 2014. Avoiding disturbance to Yukon's alpine ungulates and raptors: a summary of scientific knowledge on spatial buffers and timing windows., Wildlife Conservation Society (WCS) Canada, Whitehorse, Yukon.

Hebblewhite, M., C. A. White, C. G. Nietvelt, J. A. McKenzie, T. E. Hurd, J. M. Fryxell, S. E. Bayley, and P. C. Paquet. 2005. Human activity mediates a trophic cascade caused by wolves. Ecology 86:2135-2144.

Hintze, J. 2012. NCSS 8.0.18 NCSS, LLC. Kaysville, Utah, USA. www.ncss.com.

Hogg, E. H. 1997. Temporal scaling of moisture and the forest-grassland boundary in western Canada. Agricultural and Forest Meteorology 84:115-122.

Inukshuk Planning & Development. 1994. Protected Areas Gap Analysis: Pelly Ranges and Southwest Interior Landscapes. Whitehorse, Yukon.

Jeffrey, A., A. Fiser, N. Brender, and B. Dowdall. 2015. Building a resilient and prosperous North: Centre for the North five-year compendium report., The Conference Board of Canada, Ottawa, Ontario.

Joppa, L. N., and A. Pfaff. 2009. High and Far: Biases in the Location of Protected Areas. Plos One 4.

Kelly, R., M. L. Chipman, P. E. Higuera, I. Stefanova, L. B. Brubaker, and F. S. Hu. 2013. Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. Proceedings of the National Academy of Sciences of the United States of America 110:13055-13060.

Kennett, S.A. 2010. Fix It Up: Why and How to Put Northern Land Use Planning on Track for Success. *In* Berger et al. Canada's North: What's the Plan? The Conference Board of Canada, Ottawa, Ontario. 156 pages

Krawchuk, M., K. Lisgo, S. Leroux, P. Vernier, S. Cumming, and F. Schmiegelow. 2012. Boreal forest, Canada.in J. A. Hilty, C. C. Chester, and M. S. Cross, editors. Climate and conservation: landscape and seascape science, planning, and action. Island Press, Washington, DC.

Kreutzweiser, D., F. Beall, K. Webster, D. Thompson, and I. Creed. 2013. Impacts and prognosis of natural resource development on aquatic biodiversity in Canada's boreal zone. Environmental Reviews 21:227-259.

Kukkala, A. S., and A. Moilanen. 2013. Core concepts of spatial prioritisation in systematic conservation planning. Biological Reviews 88:443-464.

Lambeck, R. J. 1997. Focal species: A multi-species umbrella for nature conservation. Conservation Biology 11:849-856.

Laurance, W. F., and A. Balmford. 2013. A global map for road building. Nature 495:308-309.

Laurance, W. F., G. R. Clements, S. Sloan, C. S. O'Connell, N. D. Mueller, M. Goosem, O. Venter, D. P. Edwards, B. Phalan, A. Balmford, R. Van Der Ree, and I. B. Arrea. 2014. A global strategy for road building. Nature 513:229-+.

Lee, K. N. 1999. Appraising Adaptive Management. Ecology and Society 3.

Lee, P. G., and R. Cheng. 2014. Human access in Canada's landscapes., Edmonton, Alberta.

Lee, P. G., M. Hanneman, J. D. Gysbers, R. Cheng, and W. Smith. 2010. Atlas of Canada's Intact Forest Landscapes. Edmonton, Alberta.

Leroux, S. J., and B. Rayfield. 2014. Methods and tools for addressing natural disturbance dynamics in conservation planning for wilderness areas. Diversity and Distributions 20:258-271.

Leroux, S. J., and J. T. Kerr. 2013. Land Development in and around Protected Areas at the Wilderness Frontier. Conservation Biology 27:166-176.

Leroux, S. J., F. K. A. Schmiegelow, R. B. Lessard, and S. G. Cumming. 2007b. Minimum dynamic reserves: A framework for determining reserve size in ecosystems structured by large disturbances. Biological Conservation 138:464-473.

Leroux, S. J., F. K. A. Schmiegelow, S. G. Cumming, R. B. Lessard, and J. Nagy. 2007a. Accounting for system dynamics in reserve design. Ecological Applications 17:1954-1966.

Leung, M. C., and D. G. Reid. 2013. New species records for butterflies (Lepidoptera) on Herschel Island, Yukon, Canada, with notes on natural history. Canadian Entomologist 145:227-234.

Lindenmayer, D. B., and J. F. Franklin. 2002. Conserving forest biodiversity: a comprehensive multiscaled approach. Island Press, Washington, DC.

Lindenmayer, D., R. J. Hobbs, R. Montague-Drake, J. Alexandra, A. Bennett, M. Burgman, P. Cale, A. Calhoun, V. Cramer, P. Cullen, D. Driscoll, L. Fahrig, J. Fischer, J. Franklin, Y. Haila, M. Hunter, P. Gibbons, S. Lake, G. Luck, C. MacGregor, S. McIntyre, R. Mac Nally, A. Manning, J. Miller, H. Mooney, R. Noss, H. P. Possingham, D. Saunders, F. Schmiegelow, M. Scott, D. Simberloff, T. Sisk, G. Tabor, B. Walker, J. Wiens, J. Woinarski, and E. Zavaleta. 2008. A checklist for ecological management of landscapes for conservation. Ecology Letters 11:78-91.

Linke, J., G. J. McDermid, M.-J. Fortin, and G. B. Stenhouse. 2013. Relationships between grizzly bears and human disturbances in a rapidly changing multi-use forest landscape. Biological Conservation 166:54-63.

Lyon, S. W., and G. Destouni. 2010. Changes in Catchment-Scale Recession Flow Properties in Response to Permafrost Thawing in the Yukon River Basin. International Journal of Climatology 30:2138-2145.

Margules, C. R., and R. L. Pressey. 2000. Systematic conservation planning. Nature 405:243-253.

Margules, C. R., and S. Sarkar. 2007. Systematic conservation planning. Cambridge University Press.

Margules, C. R., R. L. Pressey, and P. H. Williams. 2002. Representing biodiversity: data and procedures for identifying priority areas for conservation. Journal of Biosciences 27:309-326.

Martin, K., K. E. H. Aitken, and K. L. Wiebe. 2004. Nest sites and nest webs for cavity-nesting communities in interior British Columbia, Canada: Nest characteristics and niche partitioning. Condor 106:5-19.

Martin, T. G., and J. E. M. Watson. 2016. Intact ecosystems provide best defence against climate change. Nature Climate Change 6:122-124.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Biodiversity Synthesis., Washington, D.C.

Minister of Environment and Climate Change (MECC). 2016. 2020 Biodiversity Goals & Targets for Canada. Online at : http://biodivcanada.ca/9B5793F6-A972-4EF6-90A5-A4ADB021E9EA/3499%20-%202020%20Biodiversity%20Goals%20&%20Targets%20for%20Canada%20-%20%20Final%20Web_ENG.pdf

Myers-Smith, I. H., D. S. Hik, C. Kennedy, D. Cooley, J. F. Johnstone, A. J. Kenney, and C. J. Krebs. 2011. Expansion of Canopy-Forming Willows Over the Twentieth Century on Herschel Island, Yukon Territory, Canada. Ambio 40:610-623.

Naylor, L. M., M. J. Wisdom, and R. G. Anthony. 2009. Behavioral Responses of North American Elk to Recreational Activity. Journal of Wildlife Management 73:328-338.

Newbold, T., L. N. Hudson, A. P. Arnell, S. Contu, A. De Palma, S. Ferrier, S. L. L. Hill, A. J. Hoskins, I. Lysenko, H. R. P. Phillips, V. J. Burton, C. W. T. Chng, S. Emerson, D. Gao, G. Pask-Hale, J. Hutton, M. Jung, K. Sanchez-Ortiz, B. I. Simmons, S. Whitmee, H. B. Zhang, J. P. W. Scharlemann, and A. Purvis. 2016. Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. Science 353:288-291.

North Yukon Planning Commission. 2009. Final Recommended North Yukon Land Use Plan. Whitehorse, Yukon.

Noss, R. F. 1987. FROM PLANT-COMMUNITIES TO LANDSCAPES IN CONSERVATION INVENTORIES - A LOOK AT THE NATURE CONSERVANCY (USA). Biological Conservation 41:11-37.

Noss, R. F., A. P. Dobson, R. Baldwin, P. Beier, C. R. Davis, D. A. Dellasala, J. Francis, H. Locke, K. Nowak, R. Lopez, C. Reining, S. C. Trombulak, and G. Tabor. 2012. Bolder Thinking for Conservation. Conservation Biology 26:1-4.

Noss, R. F., C. Carroll, K. Vance-Borland, and G. Wuerthner. 2002. A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone Ecosystem. Conservation Biology 16:895-908.

Panzer, R., and M. W. Schwartz. 1998. Effectiveness of a vegetation-based approach to insect conservation. Conservation Biology 12:693-702.

Pearce, J. L., D. A. Kirk, C. P. Lane, M. H. Mahr, J. Walmsley, D. Casey, J. E. Muir, S. Hannon, A. Hansen, and K. Jones. 2008. Prioritizing avian conservation areas for the yellowstone to Yukon Region of North America. Biological Conservation 141:908-924.

Peel Watershed Planning Commission. 2011. Final Recommended Peel Watershed Regional Land Use Plan. Whitehorse, Yukon.

Poiani, K. A., B. D. Richter, M. G. Anderson, and H. E. Richter. 2000. Biodiversity conservation at multiple scales: Functional sites, landscapes, and networks. Bioscience 50:133-146.

Pojar, J. 2007. National park in Parks Canada's natural region #7 (Northern Interior Plateaux & Mountains). Vancouver, British Columbia.

Potapov, P., A. Yaroshenko, S. Turubanova, M. Dubinin, L. Laestadius, C. Thies, D. Aksenov, A. Egorov, Y. Yesipova, I. Glushkov, M. Karpachevskiy, A. Kostikova, A. Manisha, E. Tsybikova, and I. Zhuravleva. 2008. Mapping the World's Intact Forest Landscapes by Remote Sensing. Ecology and Society 13.

Potapov, P., M. C. Hansen, L. Laestadius, S. Turubanova, A. Yaroshenko, C. Thies, W. Smith, I. Zhuravleva, A. Komarova, S. Minnemeyer, and E. Esipova. 2017. The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. Science Advances 3:13.

Pressey, R. L., and M. C. Bottrill. 2009. Approaches to landscape- and seascape-scale conservation planning: convergence, contrasts and challenges. Oryx 43:464-475.

Pressey, R. L., M. Cabeza, M. E. Watts, R. M. Cowling, and K. A. Wilson. 2007. Conservation planning in a changing world. Trends in Ecology & Evolution 22:583-592.

Redford, K. H., G. Amato, J. Baillie, P. Beldomenico, E. L. Bennett, N. Clum, R. Cook, G. Fonseca, S. Hedges, F. Launay, S. Lieberman, G. M. Mace, A. Murayama, A. Putnam, J. G. Robinson, H. Rosenbaum, E. W. Sanderson, S. N. Stuart, P. Thomas, and J. Thorbjarnarson. 2011. What Does It Mean to Successfully Conserve a (Vertebrate) Species? Bioscience 61:39-48.

Reid, D. G., S. R. Francis, and T. Antoniuk. 2013. Application of herd viability models for Boreal Woodland Caribou (Rangifer tarandus caribou) to a Northern Mountain Caribou herd. Canadian Wildlife Biology and Management 2:13.

Reid, D., B. Pelchat, and J. Weaver. 2010. Strategic conservation assessment for the Northern Boreal Mountains site. Toronto, Ontario, Canada.

Revel, R. D. 1981. Conservation in northern Canada – International Biological Program conservation sites revisited. Biological Conservation 21:263-287.

Ripple, W. J., and R. L. Beschta. 2012. Trophic cascades in Yellowstone: The first 15 years after wolf reintroduction. Biological Conservation 145:205-213.

Rouget, M., R. M. Cowling, A. T. Lombard, A. T. Knight, and I. H. K. Graham. 2006. Designing large-scale conservation corridors for pattern and process. Conservation Biology 20:549-561.

Rowland, E.L., N. Fresco, D. Reid, and H.A. Cooke. 2016. Examining climate-biome ("cliome") shifts for Yukon and its protected areas. Global Ecology and Conservation 8:1-17.

Ross River Dena Council. 2014. Gu Cho Ka-Ka Dee – Our Ancestors Instructions. A Ross River Dena Land Use Plan. Prepared by Ross River Dena Traditional Knowledge Team. Ross River, Yukon.

Sanderson, E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo, and G. Woolmer. 2002a. The human footprint and the last of the wild. Bioscience 52:891-904.

Sanderson, E. W., K. H. Redford, A. Vedder, P. B. Coppolillo, and S. E. Ward. 2002b. A conceptual model for conservation planning based on landscape species requirements. Landscape and Urban Planning 58:41-56.

Sarkar, S. 2003. Conservation area networks. Conservation and Society 1.

Sato, C. F., J. T. Wood, and D. B. Lindenmayer. 2013. The Effects of Winter Recreation on Alpine and Subalpine Fauna: A Systematic Review and Meta-Analysis. Plos One 8:11.

Schieck, J., and S. J. Song. 2006. Changes in bird communities throughout succession following fire and harvest in boreal forests of western North America: literature review and meta-analyses. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 36:1299-1318.

Schindler, D. W., and P. G. Lee. 2010. Comprehensive conservation planning to protect biodiversity and ecosystem services in Canadian boreal regions under a warming climate and increasing exploitation. Biological Conservation 143:1571-1586.

Schmiegelow, F. K. A., S. G. Cumming, S. Harrison, S. Leroux, K. Lisgo, R. Noss, and B. Olsen. 2006. Conservation beyond crisis management: A reverse-matrix model. A discussion paper for the Canadian BEACONs Project. BEACONs, Edmonton, Alberta.

Schmiegelow, F. K. A., S. G. Cumming, K. A. Lisgo, S. J. Leroux, and M. A. Krawchuk. 2014. Catalying large landscape conservation in Canada's boreal systems: the BEACONs Project experience. Page 126 in J. N. Levitt, editor. Conservation Catalysts: The Academy as Nature's Agent. Lincoln Institute of Land Policy, Cambridge, Maine.

Shaffer, M. L. 1981. Minimum population sizes for species conservation. Bioscience 31:131-134.

SLWCC, S. L. W. C. C. 2012. Regional Assessment of Wildlife in the Yukon Southern Lakes Region: Volume 1: Context and Recommendations., Environment Yukon, Government of Yukon, Whitehorse, Yukon.

Smith, C. A. S., J. C. Meikle, and C. F. Roots. 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes. Agriculture and Agri-Food Canada, Summerland, British Columbia.

Southern Lakes Wildlife Coordinating Committee (SLWCC). 2012. Regional Assessment of Wildlife in the Yukon Southern Lakes Region: Volume 1: Context and Recommendations. Environment Yukon, Whitehorse, Yukon. 76 pp.

Stankowich, T. 2008. Ungulate flight responses to human disturbance: A review and meta-analysis. Biological Conservation 141:2159-2173.

Steven, R., C. Pickering, and J. G. Castley. 2011. A review of the impacts of nature based recreation on birds. Journal of Environmental Management 92:2287-2294.

Streicker, J., 2016. Yukon Climate Change Indicators and Key Findings 2015. Northern Climate ExChange, Yukon Research Centre, Yukon College, 84 p.

Svancara, L. K., R. Brannon, J. M. Scott, C. R. Groves, R. F. Noss, and R. L. Pressey. 2005. Policy-driven versus evidence-based conservation: A review of political targets and biological needs. Bioscience 55:989-995.

Theberge, J. B., J. G. Nelson, and T. Fenge. 1979. Environmentally significant areas of the Yukon Territory., Ottawa, Canada.

Tlicho Government 2013. Tilcho Land Use Plan. Behchoko, NWT.

K. Tockner and J. A. Stanford. 2002. Riverine flood plains: Present state and future trends. Environmental Conservation 29: 308–330.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18-30.

van der Ree, R., J. A. G. Jaeger, E. A. van der Grift, and A. P. Clevenger. 2011. Effects of Roads and Traffic on Wildlife Populations and Landscape Function: Road Ecology is Moving toward Larger Scales. Ecology and Society 16.

Venier, L. A., I. D. Thompson, R. Fleming, J. Malcolm, I. Aubin, J. A. Trofymow, D. Langor, R. Sturrock, C. Patry, R. O. Outerbridge, S. B. Holmes, S. Haeussler, L. De Grandpre, H. Y. H. Chen, E. Bayne, A. Arsenault, and J. P. Brandt. 2014. Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests. Environmental Reviews 22:457-490.

Venter, O., N.N. Brodeur, L. Nemiroff, B. Belland, I.J. Dolinsek, I.J. and J.W.A. Grant. 2006. Threats to Endangered Species in Canada. BioScience 56: 903-910.

Venter, O., R. A. Fuller, D. B. Segan, J. Carwardine, T. Brooks, S. H. M. Butchart, M. Di Marco, T. Iwamura, L. Joseph, D. O'Grady, H. P. Possingham, C. Rondinini, R. J. Smith, M. Venter, and J. E. M. Watson. 2014. Targeting Global Protected Area Expansion for Imperiled Biodiversity. Plos Biology 12.

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science 277:494-499.

Ware, H. E., C. J. W. McClure, J. D. Carlisle, and J. R. Barber. 2015. A phantom road experiment reveals traffic noise is an invisible source of habitat degradation. Proceedings of the National Academy of Sciences of the United States of America 112:12105-12109.

Wiersma, Y. F., and D. L. Urban. 2005. Beta diversity and nature reserve system design in the Yukon, Canada. Conservation Biology 19:1262-1272.

Wiersma, Y.F., T.J. Beechey, B.M. Oosenbrug, and J.C. Meikle. 2005. Protected Areas in Northern Canada: Designing for Ecological Integrity. Phase 1 Report. CCEA Occasional Paper No. 16. Canadian Council on Ecological Areas, CCEA Secretariat, Ottawa, Ontario, Canada. xiv + 128 pp. + folded map.

Yukon Bureau of Statistics. 2016. Yukon Statistical Review 2015. Yukon Bureau of Statistics, Executive Council Office, Government of Yukon. Whitehorse, Yukon. 65 pages.

Yukon Department of Renewable Resources. 1998. Wild spaces - protected places, a draft protected areas strategy for the Yukon. Whitehorse, Yukon.

Yukon Development Corp. 2014. Next Generation Hydro - Powering Our Future. Hydroelectric Power Planning. Directive Work Plan. Whitehorse, Yukon. http://nextgenerationhydro.ca/

Yukon Energy, Mines, and Resources (EMR). 2011. Overview of legislation and policies pertaining to regional land use plans in the Yukon. Department of Energy, Mines and Resources, Yukon Government, Whitehorse, Yukon.

Yukon Government. 2016. Yukon Biomass Energy Strategy. Whitehorse, Yukon. http://www.energy.gov.yk.ca/pdf/Yukon-Biomass-Energy-Strategy-Feb2016.pdf

Yukon Land Use Planning Council (YLUPC). 2012. Frequently Asked Questions (FAQs) About Regional Land Use Planning in the Yukon. Whitehorse, Yukon. (http://www.planyukon.ca/index.php/documents-and-downloads-2/reference-documents/107-faqs-sheet/file)

Yukon Protected Area Strategy (YPAS). 1996.

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