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THE HUMAN FOOTPRINT IN THE PEACE RIVER BREAK, BRITISH COLUMBIA

BY
JERRICA MANN AND PAMELA WRIGHT

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

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

Executive Summary

Introduction

Within northeastern British Columbia's Rocky Mountain Cordillera, where the Boreal Plains meet the Northern Boreal Mountains and the Rocky Mountain Hart Range intersects with the Peace River, lies an area referred to as the Peace River Break (PRB). Within the PRB, the Peace River valley breaks through the Rocky Mountains, channeling warm Pacific air into an area otherwise characterized by cold Arctic air. This creates a continental climate that supports an impressive array of six physiographically distinct ecoregions that sustain an abundance of vegetation and wildlife.

This area is the ancestral and traditional home of the Treaty 8 First Nations: the Doig River First Nation, Fort Nelson First Nation, Halfway River First Nation, Prophet River First Nation, Saulteau First Nations, West Moberly First Nations as well as Blueberry River First Nations, Kelly Lake Cree, and Metis peoples. The lands and waters have, and continue to support, continuous use and occupancy in the area by the Nations: communities that depend on the health of the environment and its abundant resources. The PRB was also a desirable location for settlers as the valley provides a route to cross the Rocky Mountains and creates a uniquely temperate climate. Increased access in the 1950s to what was previously a remote and isolated area led to the development of a natural resource industry in the PRB, which promoted the establishment of several communities to support the growing sector.

Contrary to most other Rocky Mountain regions, the PRB is characterized by a substantial human development footprint and little protected area representation. This, in addition to natural constraints, results in a critical "pinch-point" in the continuity of ecologically intact and functioning landscapes along the north-south extent of the Canadian Rocky Mountains. The PRB has become one of British Columbia's most prominent regions for resource-related industry and extraction and is experiencing industrial-caused disturbances at significant rates.

Methods

This project was designed to calculate the extent of the human footprint within the PRB and a priority area along the Hart and Muskwa ranges (Hart/Muskwa Corridor) through to 2016. This analysis was used to inform an understanding of the future human footprint. We used both raster and vector data to calculate land use change and rates of change in our study area. First, the Agriculture and Agri-Foods Canada's Land Use 1990, 2000 and 2010 data was used to quantify coarse land use/cover changes in the PRB between the years of 1990-2000 and 2000-2010. Second, vector data of human disturbances on the landscape was used to create a cumulative human disturbance/ development footprint in the PRB. Third, both vector and raster data were used to create forestry, oil & gas, road, and wind power development potential/suitability maps for the PRB. Data sources used throughout this report are varied although most were sourced from BC government data providers. Data sources vary in accuracy and given the size of the study area the information is more accurate at coarser scales and within shorter frames.

Report Highlights

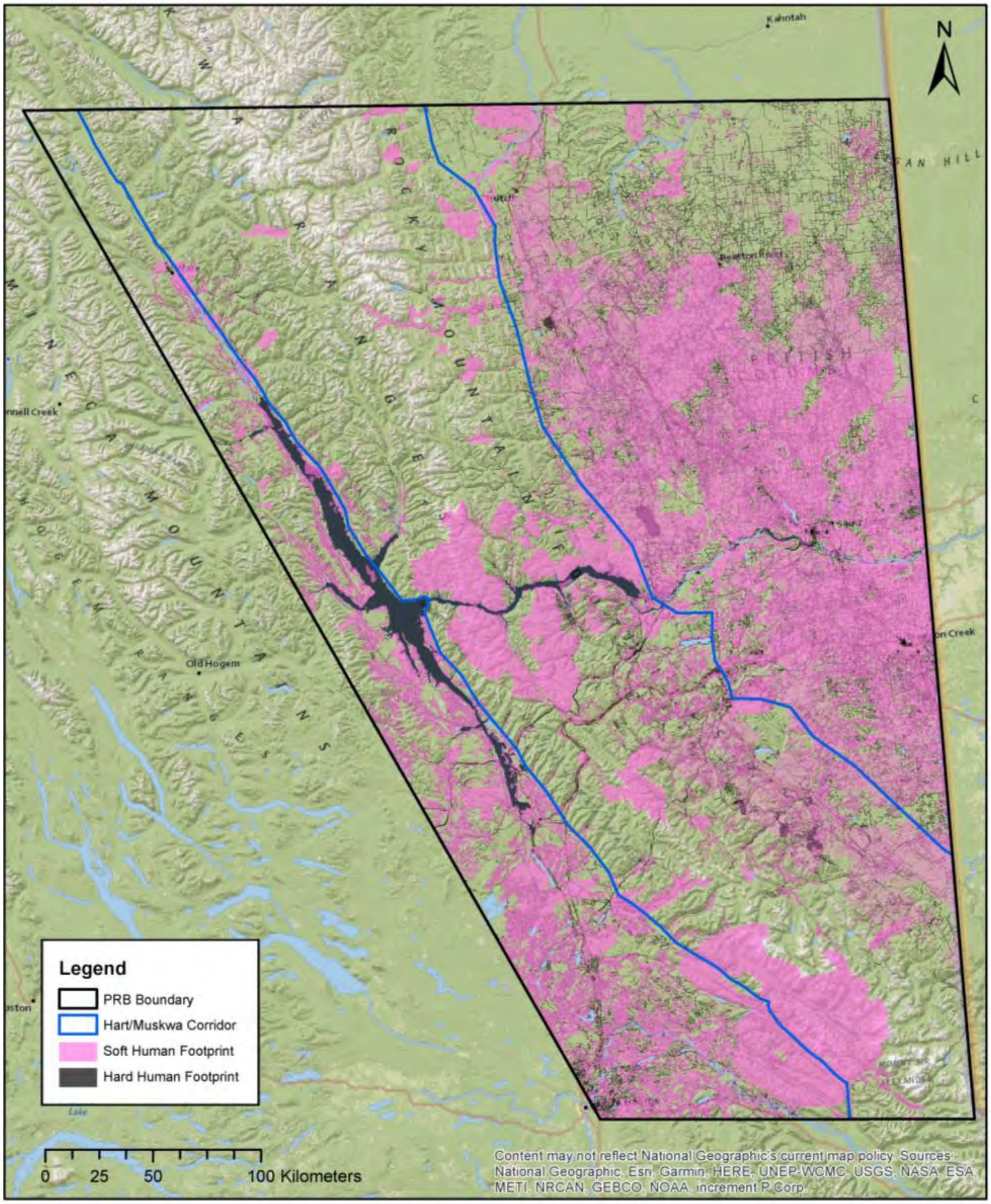
- Current protected area representation both within the broader PRB boundary is low compared to the rest of British Columbia with just 9.5% protected.
- Using the federal ecoregion designations as a method of analysis of representation five of the regions within the study area have less than 3% protected, two are approaching 10% and four others have more than 20% protected.
- Primary sources of semi-permanent (soft) human footprint within the PRB when unbuffered are human-caused fires, cutblocks, recreation areas (including heli-

ski tenures), agriculture and seismic lines amounting to approximately 27% of the PRB. Within the Hart/Muskwa Corridor the semi-permanent footprint consists of 19% of the area but recreation tenures, followed by forestry dominate. Buffered, the semi-permanent footprint rises to 49% (PRB) and 32% (Hart/Muskwa) respectively.

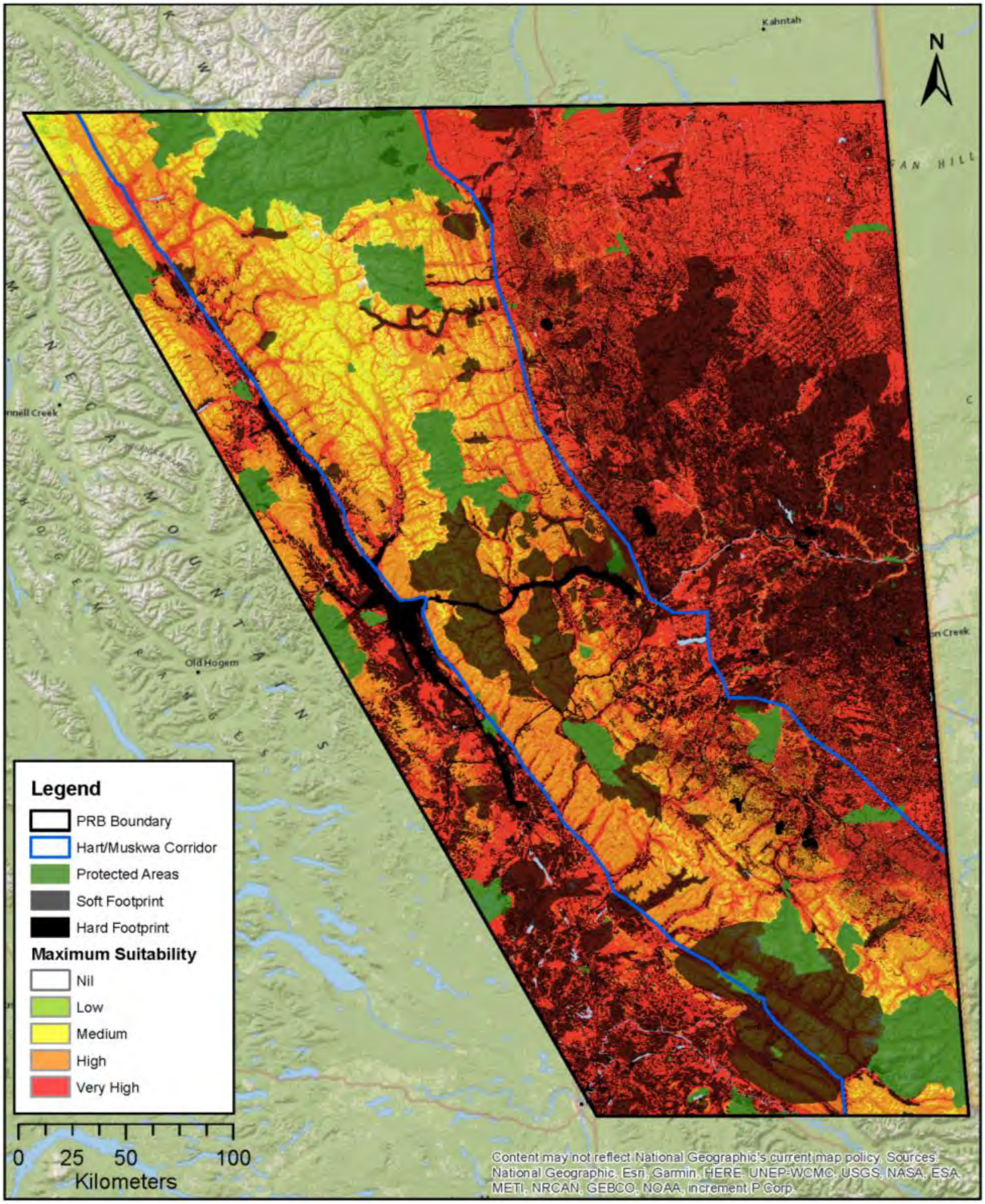
- The permanent (hard) human footprint in the PRB is dominated by roads, reservoirs, and oil and gas infrastructure totally 4 % of the landbase when unbuffered but 68% when buffered. Within the Hart/Muskwa Corridor the permanent footprint accounts for 2% of the landbase unbuffered and 40% when buffered.
- Converted to an index representing the distance to the hard (permanent) footprint 51% of the PRB and 24% of the Hart/Muskwa Corridor is within 0.5 km from the hard human footprint.
- Future resource development potential was examined for four leading resource activities (mineral potential, oil and gas potential, wind power potential, and forestry potential) as well as for roads. Within the Hart/Muskwa Corridor while oil and gas future potential is relatively limited, there is high to very high future potential for forestry and road development. Medium to high future potential for wind and low to medium future potential for mineral development.
- Combining potential developments into an index 43% of the Hart/Muskwa Corridor as medium-high potential for combined resource development and an additional 25% as high-very high potential.

Conclusion

The PRB Region has a significant existing human footprint dominated by linear corridors from roads, seismic lines, transmission/pipeline and utility lines. In spite of the extensive nature of the current footprint and the future resource development potential of the area, there is still a narrow band of intact forest landscapes running from Kakwa Provincial Park and the adjoining mountain park complex to the southeast and north to the Muskwa-Kechika Management Area. The Hart/Muskwa Ranges Corridor is not without a human footprint – particularly in the central and southern portion of the corridor the human footprint is creeping in and future resource development potential suggests that these impacts will only grow. There is still, however, opportunity to conserve a vital landscape before it too disappears.



Executive Summary Map 1. Hard and soft unbuffered human footprint in the study areas



Executive Summary Map 2. Maximum suitability for resource development combined with the existing hard and soft footprint

CONTENTS

List of Maps

List of Tables

List of Figures

The Human Footprint in the Peace River Break, British Columbia

Overview of the Study Area

Within northeastern British Columbia's Rocky Mountain Cordillera, where the Boreal Plains meet the Northern Boreal Mountains and the Rocky Mountain Hart Range intersects with the Peace River, lies an area referred to as the Peace River Break (PRB) – a geographical designation coined by the Yellowstone to Yukon Conservation Initiative (Apps, 2013). Within the PRB, the Peace River valley breaks through the Rocky Mountains, channeling warm Pacific air into an area otherwise characterized by cold Arctic air. This creates a continental climate that supports an impressive array of six physiographically distinct ecoregions that sustain an abundance of vegetation and wildlife (Apps, 2013).

This area is the ancestral and traditional home of the Treaty 8 First Nations: the Doig River First Nation, Fort Nelson First Nation, Halfway River First Nation, Prophet River First Nation, Saulteau First Nations, West Moberly First Nations as well as Blueberry River First Nations, Kelly Lake Cree, and Metis peoples. The lands and waters have, and continue to support, continuous use and occupancy in the area by the Nations: communities that depend on the health of the environment and its abundant resources. The PRB was also a desirable location for settlers as the valley provides a route to cross the Rocky Mountains and creates a uniquely temperate climate (Apps, 2013). By the turn of the 20th century, the fertile soils of the Peace River valley attracted agricultural interests to the region; by the 1950s, two major transportation corridors had been built (the Alaska Highway and John Hart Highway). The increased access to what was previously a remote and isolated area led to the development of a natural resource industry in the PRB, which promoted the establishment of several communities to support the growing sector (Apps, 2013).

Contrary to most other Rocky Mountain regions, the PRB is characterized by a substantial human development footprint and little protected area representation. This, in addition to natural constraints, results in a critical "pinch-point" in the continuity of ecologically intact and functioning landscapes along the north-south extent of the Canadian Rocky Mountains. This pathway, through an otherwise largely impassible physical boundary, allows for critical movements and ecological connections east-west over the Rocky Mountains and north-south between the Canadian Rocky Mountain Parks and the Muskwa-Kechika Management Area (M-KMA).

The PRB has become one of British Columbia's most prominent regions for resource-related industry and extraction (Apps, 2013) and is experiencing industrial-caused disturbances at significant rates. With several large-scale development project proposals on the table (i.e. Northwest Transmission Line and North Montney Mainline project) and the recent approval of the Site C hydroelectric dam, the area could see considerable growth in human population and resource-related infrastructure in the near future. Industrial expansion in the PRB has already created an ecogeographical bottleneck in the region, and further expansions further threaten the vital corridors that connect functional landscapes along the north-south extent of the Canadian Rocky Mountains.

The purpose of this project was to calculate the extent of the human footprint within the PRB and a priority area along the Hart and Muskwa ranges through to 2016 (Map 1). This analysis was used to inform an understanding of the future human footprint. We were informed in the development of our approach by the Atlas of Land Cover, Industrial Land Uses and Industrial-Caused Land Changes in the Peace Region of BC (Lee and Hanneman, 2012). While our tudy focus and lens was slightly different our study area did overlap in part and we frequently consulted this report to identify potential data sources we might be missing or approaches for analysis.

Current protected area representation both within the broader PRB boundary is low compared to the rest of British Columbia. Just 9.5% (12,836.3 km^2) of the PRB is protected, dominated by the southern end of the Muskwa-Kechika Management Area to the north-west and Kakwa Provincial Park to the south-east. Within the Hart/Muskwa ranges, that proportion is artificially at 17.5% because our analysis area purposely included the protected areas of the southern portion of the M-KMA and Kakwa in order to ensure robust analysis. In fact, the proportion of protected land shrinks to just 3.21% (1,904 km^2) of the total PRB area dominated by provincial parks when the adjoining areas to the north and south are excluded (Table 1 and Appendix A).

Identifying the extent to which protected areas meet representation goals varies based on the scale of interest and analysis. There is increased focus on using a common Canadian framework to examine representation. Using the federal Ecoregions as the basis we examined the extent of ecoregions represented in nationally reported protected areas data. Looking just within the ecoregions that intersect with the Hart Muskwa Ranges corridor four ecoregions have more than 20% protected, two are approaching 10% and 5 have less than 3% protected (Table 2 and Map 2).

Methods

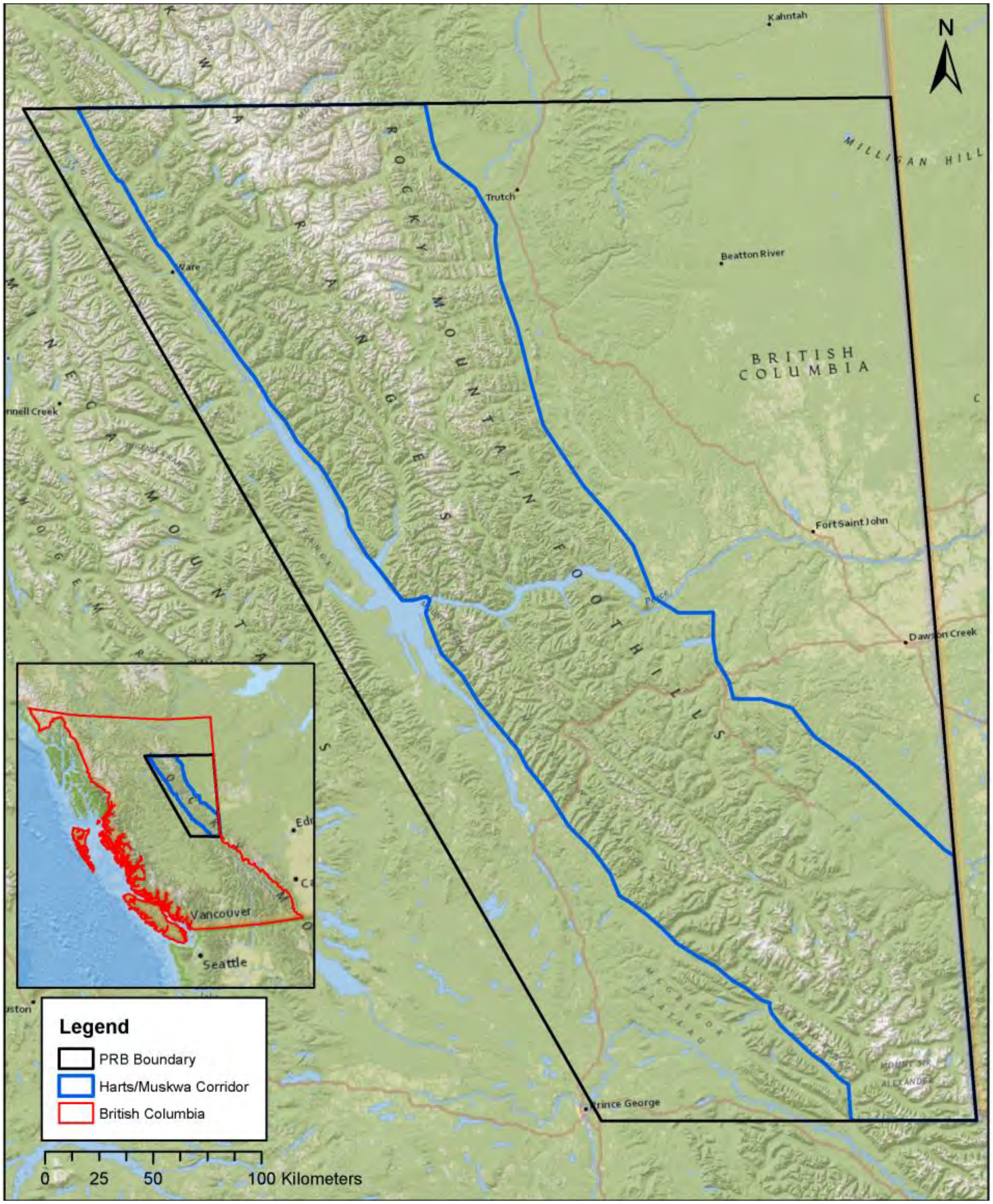
Boundaries for Analysis

The maps used throughout this report display two boundaries which are used for analysis. The biggest boundary, the trapezoid outlined in black and identified as the PRB (PRB) study area is the maximal extent of our scale of analysis. There are numerous boundaries that have been drawn for the PRB itself that all overlap to some extent but differ in other ways. For this project, we selected a much broader boundary consistent with other analyses underway to ensure consistency. The PRB boundary used herein extends north inside the southern part of the Muskwa-Kechika Management Area and south-east to the Alberta border encompassing Kakwa Provincial Park and the beginning of the protected areas complex to the south. We choose to stretch the boundaries to these areas to inform examination of regional connectivity. Located within this is a narrower boundary – a band of relatively intact habitat stretching SE to NW along the spine of the Hart and Muskwa ranges – outlined in blue (labeled the Hart/Muskwa Corridor). This boundary is used as a sub-unit for analysis here because it highlights a focal area for connectivity from the southern to northern aspects of the Rockies.

We used both raster and vector data to calculate land use change and rates of change in our study area. First, the Agriculture and Agri-Foods Canada's Land Use 1990, 2000 and 2010 (LU1990, LU2000, LU2010) data (ISO 19131) was used to quantify coarse land use/cover

Table 1. Proportion of protected areas in the study areas

Protected Area Type	PRB		Hart/Muskwa Ranges (omitting M-KMA/Kakwa)	
	Area (Ha)	Percent (%)	Area (Ha)	Percent (%)
Conservation Areas	4,006.99	0.03	777.00 (777.00)	0.01 (0.01)
Ecological Reserves	6,343.55	0.05	4,281.20 (821.61)	0.07 (0.01)
Protected Areas	23,544.76	0.17	12,140.92 (4,027.36)	0.20 (0.07)
Provincial Parks	1,249,729.83	9.23	1,049,805.12 (190,403.83)	17.22 (3.12)
Total	**1,283,625.14**	**9.48**	**1,067,004.51 (190,403.8)**	**17.5 (3.21)**

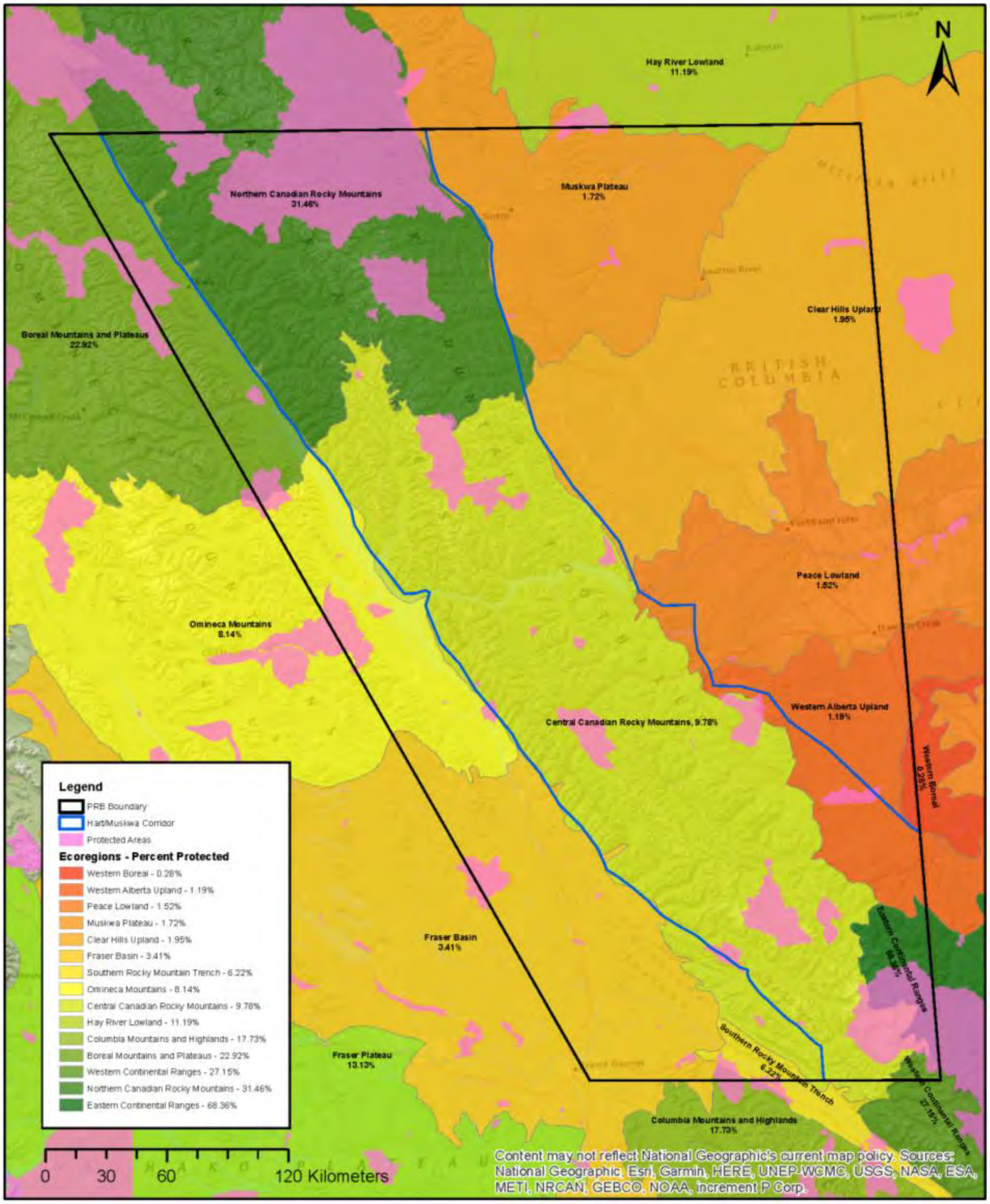


Map 1. Protected areas within the study area boundaries

changes in the PRB between the years of 1990-2000 and 2000-2010. Second, vector data of human disturbances on the landscape was used to create a cumulative human disturbance/development footprint in the PRB. Third, both vector and raster data were used to create forestry, oil & gas, road, and wind power development potential/ suitability maps for the PRB.

Land Use Change with Canada's Land Use Data (ISO 19131)

The Agriculture and Agri-Foods Canada's Land Use 1990, 2000 and 2010 (LU1990, LU2000, LU2010) data (ISO 19131) was used to quantify land use / cover change in the PRB in a meaningful manner between the years of 1990-2000 and 2000-2010. The



Map 2. Ecoregional representation in protected areas in the PRB

1990, 2000 and 2010 Land Use (LU) data cover all of Canada south of 60°N at a spatial resolution of 30 metres. The land use classes follow the Intergovernmental Panel on Climate Change (IPCC) protocol (Penman et al., 2003) and consist of: Forest, Grassland, Water, Cropland, Settlement and Other land (barren land, ice, rock, and unclassified).

The three data sets were converted into vector format then overlaid in order to determine 1) how the land use composition has changed, and 2) which categories were converted into which other categories

Table 2. PRB protected areas representation by ecoregion

Ecoregion Name	Ecoregion Area (Ha)	Protected Area (Ha)	% Protected
Boreal Mountains and Plateaus	10,253,883.02	2,350,529.09	22.92
Central Canadian Rocky Mountains	3,621,519.91	354,073.06	9.78
Clear Hills Upland	4,425,357.41	86,205.15	1.95
Columbia Mountains and Highlands	8,826,967.67	1,565,388.17	17.73
Eastern Continental Ranges	3,867,219.67	2,643,489.54	68.36
Fraser Basin	4,537,833.95	154,710.68	3.41
Hay River Lowland	12,713,772.79	1,423,140.22	11.19
Muskwa Plateau	2,341,114.43	40,340.45	1.72
Northern Canadian Rocky Mountains	3,675,061.11	1,156,214.05	31.46
Omineca Mountains	3,415,912.42	278,180.98	8.14
Peace Lowland	6,821,824.99	103,393.67	1.52
Southern Rocky Mountain Trench	747,761.01	46,496.20	6.22
Western Alberta Upland	7,450,532.73	88,907.94	1.19
Western Boreal	1,147,041.77	3,171.24	0.28
Western Continental Ranges	2,427,779.75	659,235.37	27.15
*** Bold Indicates the Ecoregions intersects the Hart Muskwa Ranges Corridor**			

between the years of 1990-2010. Transition matrices were created in order to display the results of the analyses. The overall accuracies for 1990, 2000 and 2010 were estimated at 84.0%, 87.1% and 92.7%. As some locations can be classified as both Water and Wetland, or Wetland and Forest, overall accuracies for the 1990, 2000 and 2010 data improve to 89.1%, 90.6% and 94.7% if misclassifications between those classes are not considered errors. The greatest amount of misclassification occurs between Grassland and Forest, Other land and Forest, Wetland and Forest and Cropland and Forest, with the majority of errors occurring in boundary pixels. User and producer classification accuracies can be found in (Agriculture and Agri-Food Canada, 2015, ISO 19131 – Land Use 1990, 2000 and 2010 Data Product Specifications). Land cover classifications were recategorized as outlined in Table 3.

Land Disturbance Mapping with Vector Data

Calculating the historic and current human footprint required the acquisition of data, primarily sourced from the BC Data Catalogue, Oil & Gas Commission Open Data Portal, and Natural Resources Canada Open Government Data Portal and the identification and determination of the nature of the impact (parsing, grouping and identifying data layers). Where data were not available in polygon format, a conservative approach was used to calculate area. For example, roads, available only as linear features, were converted to polygons by buffering lines features based on road type and surface type using guidance from the British Columbia Cumulative Effects framework methodology and cross referencing with imagery. Similarly, seismic lines were only available as line features. More recent seismic line data contain a "cut width" attribute. Where older seismic line data did not contain a "cut width" attribute, the average cut width by type (mulcher cut, cat cut, etc.) was applied to each respective cut type (see Appendix D).

Oil and gas well/facility data were obtained from Data BC and the Oil and Gas Commission Open Data Portal in both point and polygon form. The data were compared and duplicates between the sources were deleted before the data were combined. The average area was then calculated for the well/facility sites layer (0.0206 km^2). Well/ facility locations that were available only in point form (pre-Oct 2006 mines) were identified and buffered according to whether or not they were active. Active well / facility point locations were buffered to create 0.0206 km^2 polygons which was the average size of the combined BC Tantalis Crown Tenure and Oil and Gas Commission's well / facility polygons. All well / facility point locations that were not labelled as active were buffered to be 0.0103 km^2 (half the size of the polygon well average). Once all well / facility data were in polygon form they were combined into a single shape file for analysis.

Age of polygons was available for only a limited number of resource (and associated) activities primarily forestry cutblocks, some oil and gas surface holes and forest fires. For some other resource developments (e.g., mineral tenures) a tentative age was available based on authorizations. Still other developments, notably roads, did not have temporal attributes associated with them.

We calculated all original footprints in an unbuffered format first and then repeated calculations using a buffered footprint surface where buffers were derived from numerous sources (Table 4).

We made a distinction between impacts we categorized as semi-permanent or soft versus hard/permanent to indicate that intact habitat could be restored on the former areas or the impact was semi-permeable to species movement.

In analysis, we calculated the percent area of the impacted land (by development). Where

Table 3. Recategorization of land cover types

ISO 19131 Land Use 1990, 2000, 2010 Data Classifications	
Unclassified	Areas not classified due to clouds
Settlement	Built-up and urban
Roads	Primary, secondary and tertiary
Water	Natural and human-made
Forest	Treed areas >1 ha in size
Forest Wetland	Wetland with forest cover
Trees	Treed areas <1 ha in size
Treed Wetland	Wetland with tree cover
Cropland	Annual and perennial
Grassland Managed	Natural grass and shrubs used for cattle grazing
Grassland Unmanaged	Natural grass and shrubs with no apparent use (forest openings, alpine meadows, tundra, etc.)
Wetland	Undifferentiated wetland
Wetland Shrub	Wetland with shrub cover
Wetland Herb	Wetland with grass cover
Rock & Ice	Rock, beaches, ice, barren land
Reclassified Land Use 1990, 2000, 2010 Data Classifications	
Unclassified	Unclassified
Built-Up	Settlement + Roads
Water	Water
Forest	Forest + Forest Wetland + Trees + Treed Wetland
Cropland	Cropland
Grassland	Grassland Managed + Grassland Unmanaged
Wetland	Wetland + Wetland Shrub + Wetland Herb
Rock & Ice	Rock & Ice

disturbances overlapped, impact polygons were dissolved so as to ensure the area was not re-counted. Where time series data were available, we computed linear regressions to look at the rate of change over time on both an annual and cumulative basis.

Methods for Determining Resource Potential

Road Development Potential

We developed a GIS layer of road potential for the PRB based on the 1) relative physical feasibility of road development as a measure of slope, elevation and land cover and 2) relative impact distance, which is a measure of proximity to the existing hard human footprint that could have the potential to encourage road development. These factors were reclassified into ranks and integrated into a weighted analysis. Finally, areas deemed unsuitable for development (namely glaciers and water bodies) were removed from the results via the raster calculator tool (Table 5).

1. Relative Impact Distance

Relative Impact Distance is a measure of the distance from any location in the PRB to the nearest human development (hard human footprint). We assumed that new roads are more likely to be developed in locations that are closer to existing human made features. To determine relative impact distance for 25 m cells across the PRB, we calculated the Euclidean Distance to the Hard Human Footprint from each cell in the study area. We then reclassified the distances in order to

Table 4. Sources for identification of buffers

Development	Buffer Distance	Source
Roads	2 km High 1 km low	Province of BC, 2015; Polfus et al 2011
Wells	1000 m	Polfus et al 2011
Urban	9 km	Based on Polfus et al 2011 - Within 10 km of a municipal boundary developments received an 8000m buffer and beyond that distance they received a 1500m buffer
Mines	2 km	Polfus et al 2011
Dams	9 km	Based on Polfus et al 2011 approach
Windpower	2 km	Based on Polfus et al 2011 approach
Waste Disposal Sites	250m	Based on Polfus et al 2011 approach
O&G Ancillary (sites)	250m	Based on Polfus et al 2011 approach
Power&Telecom Lines	250m	Based on Polfus et al 2011 approach
Pipeline RoW	250m	Based on Polfus et al 2011 approach
Industrial Sites	1 km	Based on Polfus et al 2011 approach
All Crown Tenures	250m	Based on Polfus et al 2011 approach
Cabins/Camps	1.5 km	Polfus et al 2011
Seismic	250m	Removed hand cut seismic & left as actual width – Dyer et al, 2001
Burn Sites	120 m	Laurance et al 2007
Cutblocks	120 m	Laurance et al 2007
Agriculture	1 km	Based on Polfus et al 2011 approach
Rec - Camps	1.5 km	Polfus et al 2011
Rec-Heli	2 km	Recommended by Ecosystems Branch of FLNRO
Rec-Alpine Ski	2 km	Recommended by Ecosystems Branch of FLNRO
Trail Riding	250 m	Based on Polfus et al 2011 approach

rank them from 5 (closest to the hard human footprint) to 1 (furthest from the hard human footprint). The ranked relative impact distance data were then incorporated into the final weighted analysis.

2. Relative Physical Feasibility

To determine the relative physical feasibility of road development in the PRB, we used the general principle that flat, low-elevation land with small change in elevation has a higher physical feasibility for road development than steep, high-elevation land with higher changes in elevation. We first compiled approximate elevations (m) and slopes (°) from the digital elevation model (DEM) for 25 m cells across the PRB. We reclassified the elevation and slope pixels in order to rank them from 5 (most feasible) to 1 (lease feasible). The ranked elevation and slope data were incorporated into the final weighted analysis.

3. Calculating Road Development Potential in the PRB

To determine the road development potential for the PRB, we combined the reclassified relative physical feasibility and relative impact distance data into in a weighted overlay analysis using the Weighted Overlay tool. The elevation, slope and distance to the hard human footprint were assumed to have relatively equal influence on road development potential and accordingly, the inputs were given relatively equal weights. As decimals are not possible in the Weighted Overlay tool, slope was weighted 1% more than elevation and distance to human footprint.

Lastly, in order to net out lands unfeasible for road development, lands identified as water or snow were extracted from the BC Vegetation Resource Inventory (VRI – BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017), converted to raster format, and given a value of 0, whereas all other lands in the study area were given a value of 1. Similarly, the Protected Areas were converted into raster format and given a value of 0. The results from the weighted analysis were then multiplied by the land cover and protected area data using the Raster Calculator in order to remove all unsuitable lands (water, glaciers and protected areas) from the results.

Table 5. Road development potential methodology

Layer	Values	Rank	Weight
Elevation (m)	375 - 1000	5	33
	1000 - 1500	4	
	1500 - 2000	3	
	2000 - 2500	2	
	2500 - 3265	1	
Slope (°)	0 - 10	5	34
	10 - 20	4	
	20 - 30	3	
	30 - 40	2	
	40 - 85	1	
Distance to	0 - 10.2	5	33
Hard Footprint (km)	10.2 - 20.4	4	
	20.4 - 30.6	3	
	30.6 - 40.9	2	
	40.9 - 51	1	

Mineral Development Potential

We developed a GIS layer of mineral development potential for the PRB based on 1) BC mineral potential (Mineral Potential - BC Ministry of Energy and Mines, 1998), 2) coal geology (Coal Fields of BC with Coal Bed Methane Potential - BC Ministry of Energy, Mines and Petroleum Resources, 2001), 3) mineral, placer and coal tenures (Mineral, Placer and Coal Tenured Spatial View – BC Ministry of Energy, Mines and Petroleum Resources, 2017), and 4) mineral occurrences (MINFILE Mineral Occurrence Database – BC Ministry of Energy, Mines and Petroleum Resources, 2018).

1. BC Mineral Potential Database

The BC mineral potential database shapefile (Mineral Potential - BC Ministry of Energy and Mines, 1998) includes province-wide information on inventory and distribution for both metallic and industrial minerals. In this database, the BC land-base is divided into 794 tracts of polygons based on common geologic characteristics and are given a rank from 1 (lowest) to 794 (highest) based on the likelihood of discovering new metallic mineral and industrial mineral resources (BC Ministry of Energy and Mines, 1998). The ranking is given separately for metallic mineral and industrial mineral resources. We converted these mineral potential layers into raster format with 25 m cells and rank them from 5 (highest potential) to 1 (lease potential). The ranked mineral potential rasters were incorporated into a final weighted overlay analysis.

2. Coal Geology (Fields with Coal Bed Methane Potential)

The BC Mineral Potential Database does not include inventory information on coal as coal is not strictly considered to be a mineral resource. We decided to integrate a coal resource potential into the combined mineral development potential analysis because the effects of coal mining are likely similar to the effects of metallic and industrial mineral mining on wildlife habitats. To identify areas of coal mining potential, we used the Coal Fields of BC with Coal Bed Methane Potential from Data BC (BC Ministry of Energy, Mines and Petroleum Resources, 2001) and mapped the distribution of the coal fields in the PRB. The PRB contains one large coal field in the middle-eastern portion of the study area with a long arm reaching down the eastern extent of the Hart/Muskwa Corridor boundary as well as one small coal bed (1,512.5 ha) approximately 50 km east of Prince George, just south of Purden Lake. These coal fields comprise 19.9% of the PRB area and 14.6% of the Hart/Muskwa Corridor. Approximately 23.8% of the coal fields in the PRB coincide with existing mineral tenures whereas 42.3% of the coal fields in the Hart/Muskwa Corridor coincide with existing mineral tenures.

As the coal field formation data was not specifically recognized in the BC mineral potential data, we decided to incorporate this data into our analysis by ranking the study area for coal mining potential. To do this we converted the coalfield data into raster format with 25 m cells and then gave coal fields a value of 5 (highest) and non-coal field areas a value of 1 (lowest). We added the coal potential to the final combined mineral development potential weighted overlay analysis to create a combined potential of coal, metallic and industrial mineral development.

3) Mineral, Placer and Coal Tenures

We assumed that previous and current resource tenure sites are more likely to be developed again than areas without a history of mining. To identify mineral tenure locations we displayed the existing mineral tenure sites in the PRB (BC Ministry of Energy, Mines and Petroleum Resources, 2017). Mineral tenured areas cover 6.4% (8,721.8 km^2) of the PRB study area and 9.8% (5,958.5 km^2) of the Hart/Muskwa Corridor. Within the PRB, mineral tenured areas are comprised of 51.2% coal, 48.2%

mineral, and 0.6% placer. Within the Hart/ Muskwa Corridor, mineral tenures cover 9.8% (5,958.5 km^2) of the land-base and mineral tenured areas are comprised of 68.9% (4,209 km^2) coal, 31.0% (1,893.4 km^2) mineral, and 0.1% (6.8 km^2) placer.

Although these data were not included in the final weighted overlay analysis, by displaying their locations within the PRB in relation to the final mineral potential layer, one can deduce which areas are more likely to experience future development.

4) Mineral Occurrences

The mineral occurrence data BC (Ministry of Energy, Mines and Petroleum Resources, 2018) depicts a body of rock containing, or thought to contain, ore minerals or potential ore minerals. A geographic point location identifies the most significant physical reference point to the mineralization. As the data are provided in point location and do not actually depict the information in polygon form, we decided not included this data in the final weighted overlay analysis. Rather, by displaying their locations within the PRB in relation to the final mineral potential layer, mineral occurrence data can be interpreted as potential centers from which future mining activities could be initiated.

5. Calculating Mineral Development Potential in the PRB

To determine the mineral development potential for the PRB, we combined the reclassified industrial and metallic mineral raster datasets with the coal field raster into in a weighted overlay analysis using the Weighted Overlay tool. The metallic, mineral and coal data were assumed to have relatively equal influence on mineral development potential and accordingly, the inputs were given relatively equal weights. As decimals are not possible in the Weighted Overlay tool, and coal tenures are the most prevalent in both the PRB and Hart/Muskwa Corridor study area, the coal data was weighted 1% more than industrial and metallic mineral data.

In order to net out lands unfeasible for mineral development, lands identified as water or snow were extracted from the BC Vegetation Resource Inventory (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017) converted to raster format, and given a value of 0, whereas all other lands in the study area were given a value of 1. Similarly, the Protected Areas (BC Parks, Ecological Reserves And Protected Areas & NGO Conservation Areas - BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development; 2018, 2017) were converted into raster format and given a value of 0. The results from the weighted analysis were then multiplied by the land cover and protected area data using the Raster Calculator in order to remove all unsuitable lands (water, glaciers and protected areas) from the results (Table 6).

Oil & Gas Development Potential

We developed a GIS layer of oil and gas development potential for the PRB by integrating spatial data available from British Columbia government sources on oil and gas geology, oil and gas resource sites, pipelines, wells, elevation, and slope: 1) Geo -Resource Potential, 2) Resource-Site Distance, and 3) Resource Development Feasibility. After these three components were developed, we combined them to create the Oil and Gas Development Potential map for the PRB.

1. Geo-Resource Potential

Geological potential of oil and gas was based on distributions of geological formations known to produce oil and gas. Geo-Resource potential includes two spatial data layers: geological potential for oil and gas in the PRB by oil and gas fields (Oil and Gas Fields - BC Oil and Gas Commission, 2017) as well as unconventional hydrocarbon resource basins (Oil and Gas

Table 6. Mineral development potential methodology

Layer	Values	Rank	Weight
Metallic Mineral Rank	0 - 158.8	1	33
	158.8 - 317.6	2	
	317.6 - 476.4	3	
	476.4 - 635.2	4	
	635.2 - 794	5	
Industrial Mineral Rank	0 - 158.8	1	33
	158.8 - 317.6	2	
	317.6 - 476.4	3	
	476.4 - 635.2	4	
	635.2 - 794	5	
Coal Field	Yes	5	34
	No	1	

Commission, 2017). The PRB contains one polygon of oil and gas geology (the Montney Basin). This dataset depicts the general location and extent of unconventional hydrocarbon resources. The Montney Basin covers 19.61% of the PRB and 3.06% of the Hart/Muskwa Corridor. It contains an estimated 12,719 billion m3 of marketable potential of unconventional natural gas (National Energy Board et al. 2013). Similarly, oil and gas fields (Oil and Gas Fields – BC Oil and Gas Commission, 2017) depict pools, or group of pools, within a specified geographic area that contain oil or natural gas. Oil and gas fields cover 20.62% of the area within the PRB and 6.49% of the Hart/Muskwa Corridor.

Both geo-resource potential datasets were converted into raster format with 25 m cells then reclassified so that oil and gas fields and the Montney basin received a ranked value of 5 while all other areas received a value of 1. We added the resulting data layers to the final combined oil and gas development potential weighted overlay analysis.

2. Resource-Site Distance

The resource site distance contained distance values (km) from each cell in the PRB to the nearest existing oil and gas resource site. Our assumption was that exploration and development of oil and gas would generally expand from the nearest resource sites into areas of the PRB. To determine resource-site distance for 25 m cells across the PRB, we calculated the Euclidean Distance to active oil and gas wells (Well Surface Hole Status - BC Oil and Gas Commission, 2017) as well as to pipeline right-of-ways (Pipeline Right of Way Permits - BC Oil and Gas Commission, 2017). We then reclassified the distances in order to rank them from 5 (closest to resource sites) to 1 (furthest from resource sites). The two ranked resource-site distance datasets were then incorporated into the final weighted analysis.

3. Resource Development Feasibility

To determine the relative physical feasibility of oil and gas development in the PRB, we used the general principle that flat, low-elevation land with small change in elevation have a higher physical feasibility and are thus, more likely be developed than steep, high-elevation land with higher changes in elevation. We first compiled approximate elevations (m) and slopes (°) from the digital elevation model (DEM) for 25 m cells across the PRB. We reclassified the elevation and slope pixels in order to rank them from 5 (most feasible) to 1 (lease feasible). The ranked elevation and slope data were incorporated into the final weighted analysis.

Table 7. Oil and gas development potential methodology

Layer	Values	Rank	Weight
Elevation (m)	375 - 1000	5	10
	1000 - 1500	4	
	1500 - 2000	3	
	2000 - 2500	2	
	2500 - 3265	1	
Slope(°)	0 - 10	5	10
	10 - 20	4	
	20 - 30	3	
	30 - 40	2	
	40 - 85	1	
Distance to Pipelines (km)	0 - 1	5	20
	1 - 2	4	
	2 - 4	3	
	4 - 8	2	
	8 - 231	1	
Distance to Active Wells (km)	0 - 2	5	20
	2 - 4	4	
	4 - 6	3	
	6 - 8	2	
	8 - 185	1	
Oil/Gas Field	Yes	5	20
	No	1	

4. *Calculating Oil and Gas Development Potential in the PRB*

To determine the oil and development potential for the PRB, we combined the reclassified geo-resource potential, resource site distance, and resource development feasibility raster datasets into in a weighted overlay analysis using the Weighted Overlay tool. The geo-resource potential and resource site distance data were assumed to be more relevant than the resource development feasibility layers and they were weighted accordingly.

Lastly, we assumed that all oil and gas development within the PRB would occur within the defined geo-resource potential boundaries within the PRB. In order to exclude lands that did not fall within the geo-resource potential boundary we combined the geo-resource potential layers and reclassified the land outside of oil and gas geology to a value of 0, whereas all other lands within the oil and gas geology were given a value of 1. Additionally, those lands deemed unsuitable for mineral development including water or permanent snow were extracted from the BC Vegetation Resource Inventory (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017), converted to raster format, and given a value of 0, whereas all other lands in the study area were given a value of 1. Similarly, the Protected Areas (BC Parks, Ecological Reserves And Protected Areas & NGO Conservation Areas - BC Ministry of Forests, Lands, Natural

Resource Operations and Rural Development; 2018, 2017) were converted into raster format and given a value of 0. The results from the weighted analysis were then multiplied by the oil and gas geology, land cover, and protected area data using the Raster Calculator in order to remove all unsuitable lands (water, glaciers and protected areas) from the results (Table 7).

Wind Power Development Potential

We developed a GIS layer of wind power potential for the PRB based on the 1) relative physical feasibility of development as a measure of slope, elevation and land cover, 2) relative impact distance, which is a measure of proximity to power grid, and 3) wind power feasibility, which is a measure of the average annual wind in m/sec. These factors were reclassified into ranks and integrated into a weighted analysis (Table 8). Finally, areas deemed unsuitable for development (i.e., glaciers and water bodies) were removed from the results via the raster calculator tool.

1. Relative Physical Feasibility

To determine the relative physical feasibility of wind power development in the PRB, we used the general principle that flat lands with small changes in elevation have a higher physical feasibility for development than steep, high-elevation land with higher changes in elevation. We also assumed that the highest elevations (above 1500 m) would be less suitable for development due to wind turbine freezing. High elevations below the 1500 m threshold were deemed more suitable for wind power development due to increased wind speed with altitude. We first compiled approximate elevations (m) and slopes (°) from the digital elevation model (DEM) for 25 m cells across the PRB. We reclassified the elevation and slope pixels in order to rank them from 5 (most feasible) to 1 (lease feasible). The ranked elevation data were incorporated into the final weighted analysis. Like elevation, slope was deemed an important factor in assessing the site suitability for wind power development because it can affect building and energy producing aspects. The Spatial Analyst Slope tool was used with the PRB Digital Elevation Model to create a slope raster surface (in degrees) with 25 m pixels for the study area. Slopes greater than approximately 200 may result in flow separation over the wind turbines. Therefore, slopes were ranked from 5 (most feasible) to 1 (lease feasible) with a 200 cutoff. The ranked slope data were incorporated into the final weighted analysis.

2. Relative Impact Distance

Relative Impact Distance is a measure of the distance from any location in the PRB to the power grid (nearest transmission line). We assumed that wind turbines are more likely to be developed in locations that are closer to the power grid as it would make connecting wind farms to the power grid less costly. To determine relative impact distance for 25 m cells across the PRB, we calculated the Euclidean Distance to transmission lines from each cells in the study area. We then reclassified the distances in order to rank them from 5 (closest to the power grid) to 1 (furthest from the power grid). The break values were determined subjectively and a break value was applied to cells greater than 100 km away from the power grid as it was assumed that building a transmission line that long would be too costly and might not be justified by the energy output of the wind farm. The ranked relative impact distance data were then incorporated into the final weighted analysis.

3. Wind Power Feasibility

Wind speed was deemed the most important component of our wind power suitability analysis as it determines the energy producing capacity of a proposed wind farm. We used BC's annual wind speed (m/sec) at a height of 50 m, obtained from the Canadian Wind Energy Atlas (Canadian Wind Energy Atlas – Environment Canada,

Table 8. Wind power development potential methodology

Layer	Values	Rank	Weight
Wind Speed	10.5 - 12.5	5	31
(m/sec)	8.5 - 10.5	4	
50m height	6.5 - 8.5	3	
	4 - 6.5	2	
	0 - 4	1	
Distance	0 - 25	5	23
to	25 - 50	4	
Transmission	50 - 75	3	
Lines (km)	75 - 100	2	
	100 - 260	1	
Elevation (m)	375 - 500	3	23
	500 - 1000	4	
	1000 - 1500	5	
	1500 - 2000	2	
	2000 - 3265	1	
Slope (°)	0 - 5	5	23
	5 - 10	4	
	10 - 15	3	
	15 - 20	2	
	20 - 85	1	

2004). Wind travelling at 4 m/s at a height of 65 m is rated at fair wind resource quality (BC Hydro, 2009). Therefore, we chose to use mean annual wind speed data at 50 m height and base our break values of 4 m/sec. The Canadian Wind Energy Atlas data is downloadable in MIF or Map Info file format. The MIF file covering the PRB was downloaded, converted into a shapefile in QGis (QGIS Development Team, 2017), then loaded into ArcMap. Then it was projected into NAD1983 BC Albers using the Project tool, converted to raster format via the Polygon to Raster tool, and finally masked to the PRB study area with the Extract by Mask tool. Wind speeds were reclassified into ranks from 5 (highest wind speed) to 1 (lowest wind speed) with a lower break values of 4m/sec. The ranked wind power feasibility data were then incorporated into the final weighted analysis.

4. Calculating Wind Power Development Potential in the PRB

To determine the final wind power potential for the PRB, we combined the reclassified relative physical feasibility, relative impact distance, and wind power feasibility data into in a weighted overlay analysis using the Weighted Overlay tool. The elevation, slope, and distance to the power grid were assumed to have relatively equal influence on wind farm development potential and accordingly, these inputs were given relatively equal weights. Wind speed was assumed to have to greatest influence on wind power development suitability and was given the highest weighting.

Lastly, in order to exclude lands unfeasible for wind power development, lands identified as water or snow were extracted from the BC Vegetation Resource Inventory (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017), converted to raster format, and given a value of 0 whereas all other lands in the study area were given a value of 1. Similarly, the Protected Areas (BC Parks, Ecological Reserves And Protected Areas & NGO Conservation Areas - BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development; 2018, 2017) were converted into raster format and given a value of 0. The results from the weighted analysis were then multiplied by the land cover and protected area data using the Raster Calculator in order to remove all unsuitable lands (water, glaciers and protected areas) from the results.

Forest Harvest Potential

We developed a GIS layer of forest harvest potential for the PRB based on the 1) resource site / access distance, which is a measure of proximity to existing roads and previously harvested areas, 2) relative harvest feasibility as a measure of slope and land cover, and 3) forestry tenures. These factors were reclassified into ranks and integrated into a weighted analysis (Table 9). Finally, areas deemed unsuitable for harvest (namely non-forested areas and areas under harvest restrictions) were removed from the results via the raster calculator tool.

1. Resource Site / Access Distance

Resource site and access distance consists of two layers; distance from each cell in the PRB to the nearest existing road and distance from each cell in the PRB to the nearest previously harvested area. We assumed that forest harvest was more likely to occur in locations that are closer to existing roads, and therefore more accessible, as well as in areas that have been previously cut and likely replanted for future harvesting. To determine the resource site and access distances for 25 m cells across the PRB, we calculated the Euclidean Distance to roads (Digital Road Atlas FTP – BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017) and then again to cutblocks (Harvested Areas of BC/ Consolidated Cutblocks – BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017) from each cell in the study area, thereby creating two distance layers. We reclassified the distance layers and rank them from 5 (closest to cutblocks or roads) to 1 (furthest from cutblocks or roads). The two resource site and access distance data layers were then incorporated into the final weighted analysis.

2. Relative Harvest Feasibility

We assumed that relative harvest feasibility would be affected by slope, land cover, and forest type. To determine the relative harvest feasibility in the PRB, we used the general principle that flat lands with small changes in elevation have a higher physical feasibility for harvest than steep lands with higher changes in elevation. A slope (°) model was derived from a digital elevation model (DEM) for 25 m cells across the PRB. We reclassified the slope layer and ranked it from 5 (most feasible) to 1 (lease feasible). The ranked slope data were incorporated into the final weighted analysis.

We assumed that Biogeoclimatic Ecosystem Classification (BEC) zones would have an impact on which forested areas were harvested. We initially performed an overlay analysis on the current BEC zones (Biogeoclimatic Ecosystem Classification Map – BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017) and areas previously

Table 9. Forest harvesting development potential methodology

Layer	Values	Rank	Weight
Slope(°)	0 - 10	5	25
	10 - 20	4	
	20 - 30	3	
	30 - 40	2	
	0 - 85	1	
Distance to Roads (km)	0 - 5	5	20
	5 - 10	4	
	10 - 20	3	
	20 - 40	2	
	40 - 52	1	
Distance to Cutblocks (km)	0 - 5	5	20
	5 - 10	4	
	10 - 20	3	
	20 - 40	2	
	40 - 100	1	
Tree Farm License	Inside	5	10
	Outside	3	
Biogeoclimatic Zone	SBS	5	25
	BWBS	4	
	ESSF	3	
	ICH	2	
	SWB & BAFA & IMA	1	

harvested (Harvested Areas of BC/ Consolidated Cutblocks – BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017) within the PRB to determine the forest harvest trends by BEC zone in the PRB. Previously harvested areas in the PRB were comprised of 55.5% Sub-Boreal Spruce (SBS), 32% Boreal White and Black Spruce (BWBS), 9.31% Engelmann Spruce – Subalpine Fir (ESSF), 2.12% Interior Cedar Hemlock (ICH), and 0.04% Spruce – Willow – Birch (SWB). BEC Zones were converted into raster format and reclassified into ranks from 5 (most probable for harvest) to 1 (lease probable for harvest) reflecting historical harvest trends. The ranked BEC data were incorporated into the final weighted analysis.

We used the BC Vegetation Resource Inventory (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017) to identify forested and non-forested areas within the PRB. Forested landscapes were derived from the VRI via level 4 classifications; Treed Coniferous (TC), Treed Broadleaf (TB), and Treed – Mixed (TM). A large portion of the study area where Tree Farm Licenses exist did not contain VRI attributes. To fill tree farm license gaps, the Baseline Thematic Mapping (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 1995) dataset was merged into the data voids. Where the data voids existed in the VRI and BTM attributes were classified as Old Forest, Young Forest, Recently Logged, Selectively Logged or Recently Burned, the land was classified as Forested and merged into the VRI-forest layer. The resulting VRI-BTM merged dataset was used as the "Forested Landscape" layer in the analysis. Areas not classified as forested were removed from the analysis via the Raster Calculator tool after the Weighted Overlay/Suitability analysis.

3. Tenures

We assumed that areas with tree farm license (TFL) tenures (Tree Farm License Schedule A - BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018) were more likely to be harvested than areas not tenured for harvest. The Tree Farm License dataset was converted into raster format and the landscape was reclassified into two ranks; TFL's were given a rank of 5 (most likely to be harvested), whereas forested landscapes outside TFL's were given a rank of 3 (moderately likely to be harvested). The ranked TFL data was incorporated into the final weighted analysis.

4. Calculating Timber Harvest Potential in the PRB

To determine the final timber harvest potential for the PRB, we combined the reclassified resource site / access distance, relative harvest feasibility and forestry tenure data into in a weighted overlay analysis using the Weighted Overlay tool.

Slope and BEC zone were assumed to have the largest influence on forest harvest potential and accordingly, these inputs were given the highest weights. Distance to existing roads and previous cut areas were assumed to have slightly less influence on harvest potential, and tree farm license tenures were assumed to have the least influence on harvest potential.

We assumed that areas classified as Conditional Harvest Zones (CHZ) within the Ungulate Winter Range (Ungulate Winter Range – BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018) and Wildlife Habitat layers (Wildlife Habitat - BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018) would be less likely to be harvested. To account for their reduced harvest suitability without affecting the suitability of the non-CHZ areas in the weighted overlay analysis, a penalty was applied after the weighted suitability analysis. Within the forest harvest potential layer resulting from the weighted suitability analysis, cells classified as conditional harvest zones were given a penalty of -1 to their final score.

Lastly, in order to net out lands inappropriate for forest harvest including protected areas (BC Parks, Ecological Reserves And Protected Areas & NGO Conservation Areas - BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development; 2018, 2017), old growth management zones (Legal Old Growth Management Areas - BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017), ungulate winter range no harvest zones (Ungulate Winter Range – BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018), wildlife habitat no harvest zones (Wildlife Habitat - BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2018), and non-forested lands identified in the VRI (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2017) were converted to raster format, and given a value of 0, whereas all other lands in the study area were given a value of 1. The results from the weighted overlay analysis were then multiplied by the data layers using the Raster Calculator in order to remove them from the analysis results.

Limitations

Limitations and cautions associated with these analyses focus primarily on data sources, data currency, and scale:

Data sources used throughout this report are varied although most were sourced from BC government data providers. However, compilation of some of the data sets was particularly challenging. As noted elsewhere in the report, year of development (e.g., for roads) was not provided for every component, and status (e.g. current, active or restored) was not easily discernible. In addition, for some developments like oil and gas there was no single reconciled database of facilities but rather numerous, overlapping data sets some containing only point data on developments and others a combination of point and vector data. To increase transparency we have documented sources and attempted to detail the methods we used to compile workable layers.

Data sources are updated on different timelines and thus there are some differences between the currency of different parts of our analysis. For example, the Land Use Change analysis conducted from satellite data is done on ten year intervals. Usefully scaled data was available from 1990, 2000 and 2010. However, we would anticipate that the 2020 data will show other increases. The Global Forest Watch Intact Forest Landscape analysis was conducted based on 2013 data. We used these data sources and analysis but later updated that information to demonstrate changes that have occurred since the original analyses was conducted. The majority of the vector data we used for this report was acquired in late 2017, or early 2018, however the data layers themselves may not have been updated since 2016 depending on their source. We hypothesize that this is particularly important for developments that are changing quickly like forest harvesting and associated road building particularly related to spruce beetle salvage.

We also note issues with consistencies of data over time. For example earlier data sets on seismic lines were not given a line width however more recent data sets did ascribe a cut width to the area. We used the method of cut to backcast and assign a line width to these developments.

Some tenures (e.g., mineral) are renewed and the original date of inception isn't provided and those the age of establishment is not readily apparent.

Given that the size of study area is quite large we could not ground truth all of the footprint sources. When developing a mapping approach we did use satellite data to verify our techniques but were unable to verify all developments.

Finally we note important caveats with respect to the scale of data, scale of analysis and scale of interpretation of results. This is particularly noteworthy with respect to our maps of resource development potential. These are maps of resource development potential based on a simplified set of variables and numerous variables such as changing market values that may have a significant influence on development could not be included. Data sources vary in accuracy and given the size of the study area the information is more accurate at coarser scales and within shorter frames.

Results

Land Use/Change from ISO 19131 – Land Use 1990, 2000, 2010

Current (as of the 2010 assessment) land use / land cover in the study areas is dominated by forest cover (Table 10).

The transition matrices display the conversion of land use in hectares from the earlier time period (Y axis) to the later time period (X axis). For the PRB study area (Tables 11-12) in both the 1990-2000 and the 2000-2010 time periods the built-up area converted at a faster rate of change (by percent) than any other land cover area with forestry, cropland and wetland the primary land uses converted (in descending order). Overall the built-up land cover increased by 15% and cropland by just under 3%. Wetland and forest land covers had net decreases that by percentage are relatively small. In the case of forest land cover this smaller percent change is a product of the fact that it by far the dominant land cover. Where the change happens, and how dissected or fragmented the forest environment is, is the critical determinant.

Table 10. Land use/cover as of 2010

Land Use / Cover	% of PRB Study Area	% H/MC Study Area
Built-Up	0.35	0.15
Cropland	3.62	0.02
Forest	84.73	85.48
Grassland	0.8	1.57
Rock & Ice	5	10.49
Unclassified	0	0
Water	2.74	1.72
Wetland	2.76	0.56

Table 11. Land use/cover change in the PRB between 1990-2000

Land Use / Cover Change in the PRB Between 1990 - 2000 (Percent)									
Area (Ha)		Land Use in 2000							
		Unclassified	Built-Up	Water	Forest	Cropland	Grasslands	Wetland	Rock & Ice
Land Use 1990	Unclassified	82.31	0	0	12.31	0	0	0	5.38
	Built-Up	0	100	0	0	0	0	0	0
	Water	0	0	99.91	0.08	0	0	0	0
	Forest	0	0.03	0	99.87	0.09	0	0	0.01
	Cropland	0	0.16	0	0	99.84	0	0	0
	Grasslands	0	0.03	0	0.37	0	99.3	0	0.31
	Wetland	0	0.03	0	0.05	0.2	0	99.72	0
	Rock & Ice	0	0	0	0.12	0	0.06	0	99.82

Table 12. Land use/cover change in the PRB between 2000-2010

Land Use / Cover Change in the PRB between 2000 - 2010 (Percent)									
Area (Ha)		Land Use in 2010							
		Unclassified	Built-Up	Water	Forest	Cropland	Grasslands	Wetland	Rock & Ice
Land Use 2000	Unclassified	100	0	0	0	0	0	0	0
	Built-Up	0	100	0	0	0	0	0	0
	Water	0	0	100	0	0	0	0	0
	Forest	0	0.01	0	99.95	0.03	0	0	0
	Cropland	0	0.11	0	0	99.89	0	0	0
	Grasslands	0	0.02	0	0	0	99.98	0	0
	Wetland	0	0.05	0	0.01	0.14	0	99.81	0
	Rock & Ice	0	0	0	0	0	0	0	100

Intact Forest Landscapes

Using the Global Forest Watch (2013) data we identified the intact forest landscapes within the study areas.

"An Intact Forest Landscape (IFL) is a seamless mosaic of forest and naturally treeless ecosystems within the zone of current forest extent, which exhibit no remotely detected signs of human activity or habitat fragmentation and is large enough to maintain all native biological diversity, including viable populations of wide-ranging species. IFLs have high conservation value and are critical for stabilizing terrestrial carbon storage, harboring biodiversity, regulating hydrological regimes, and providing other ecosystem functions." (Global Forest Watch 2013)

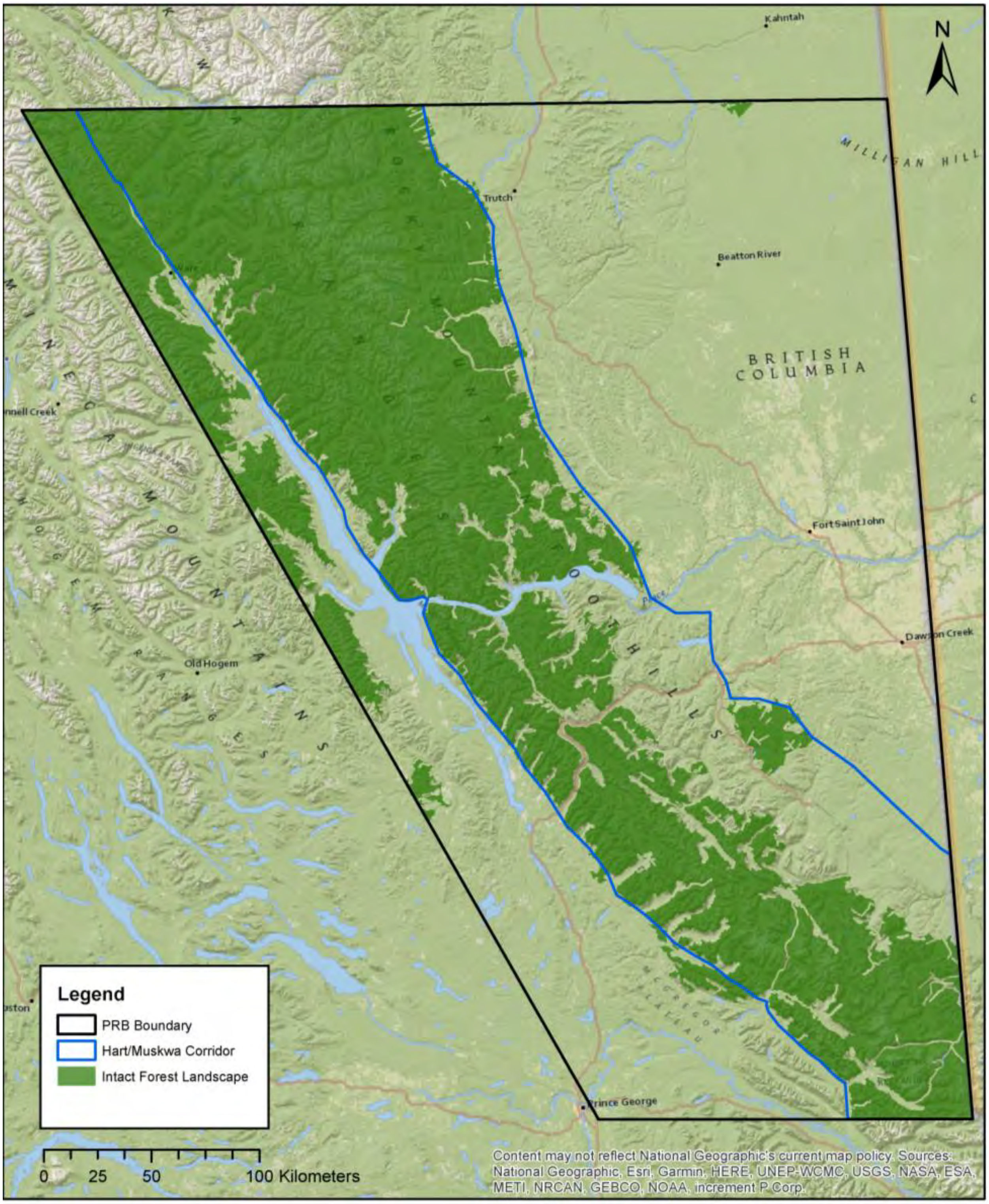
Using the Global Forest Watch definitions, IFLs are located along the spine of the Rocky Mountains narrower in the Hart/ Muskwa Corridor and Peace River area and widest in the north (Map 3). Using the Global Forest Watch methodology and data, 37% of the PRB and 73% of the Hart/ Muskwa Corridor qualify as IFL.

Map 4 displays the overlap of these IFLs with protected areas and other forms of semi -permanent biodiversity conservation on the landscape. Although protected areas are legislated and protect against all associated resource developments Ungulate Winter Range (UWR) and Old Growth Management Areas (OGMA) are management tools that set specific objectives for valued ecosystem components that can be amended by Regional Executive Directors. They do not preclude resource use, but rather set term and conditions for how extraction is to take place. Eighty-nine percent of Protected Areas are rated as IFL, 60% of Ungulate Winter Range but just 2.3% of Old Growth Management Areas qualify as Intact Forest Landscapes.

We calculated the percent of IFL by watershed using two different watershed boundaries. In the first (Map 5), we classified named watersheds by percent intactness (see Table 13 and Appendix C).

Table 13. Percent intact forest landscape by named watershed in the study areas

% IFL	PRB		Hart/Muskwa Corridor	
	% of Watersheds	% of Area	% of Watersheds	% of Area
0-10	42.22	32.92	17.08	14.37
10-20	0	0	2.32	1.91
20-30	8.89	10.02	2.46	1.96
30-40	13.33	19.82	2.46	2.36
40-50	4.44	6.28	3.69	4.22
50-60	2.22	2.79	3.84	4.15
60-70	2.22	4.13	5.43	5.89
70-80	6.67	10.05	5.43	6.12
80-90	6.67	5.94	6.22	6.38
90-100	13.33	8.05	51.09	52.65

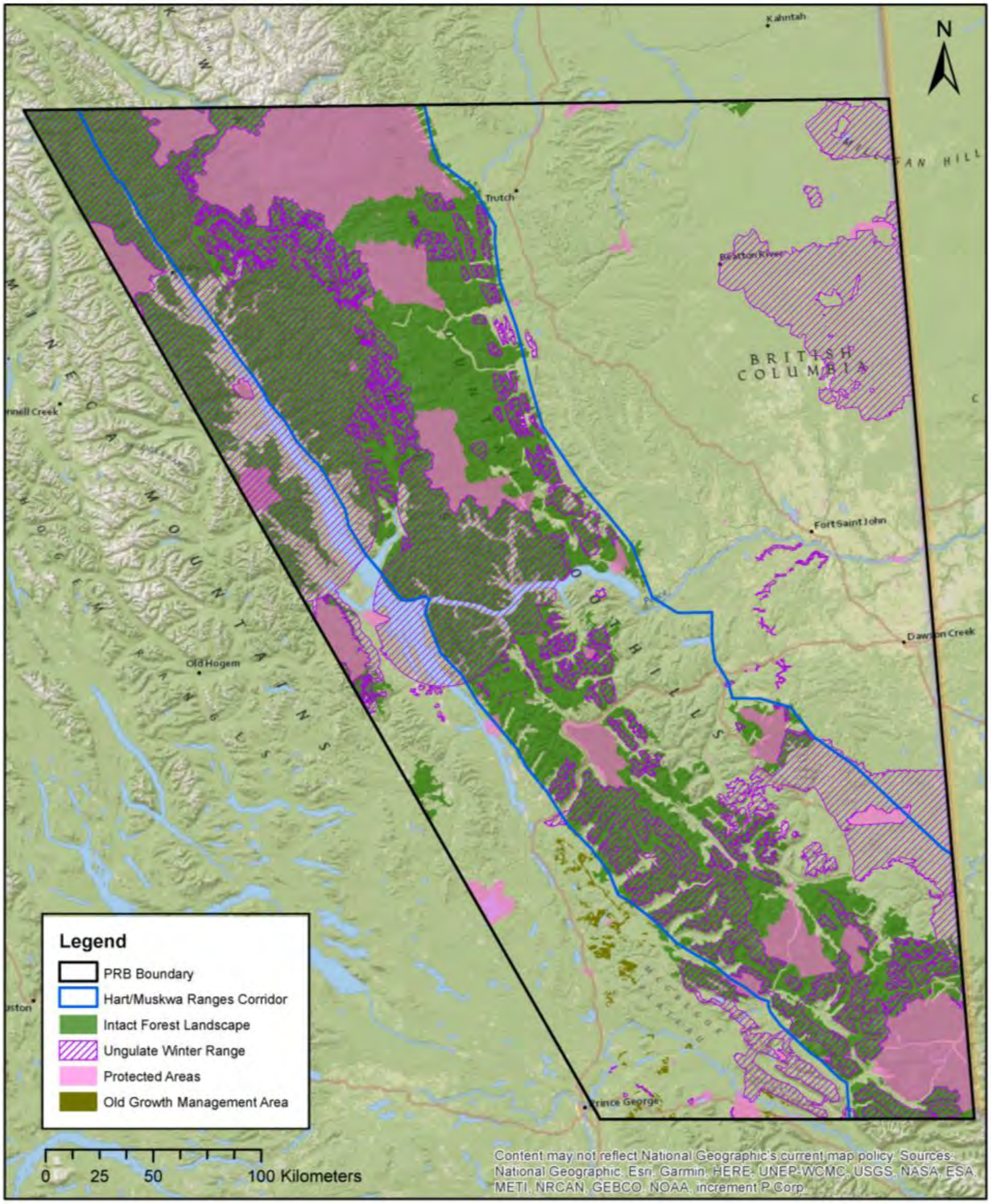


Map 3. Intact forest landscapes in the study areas

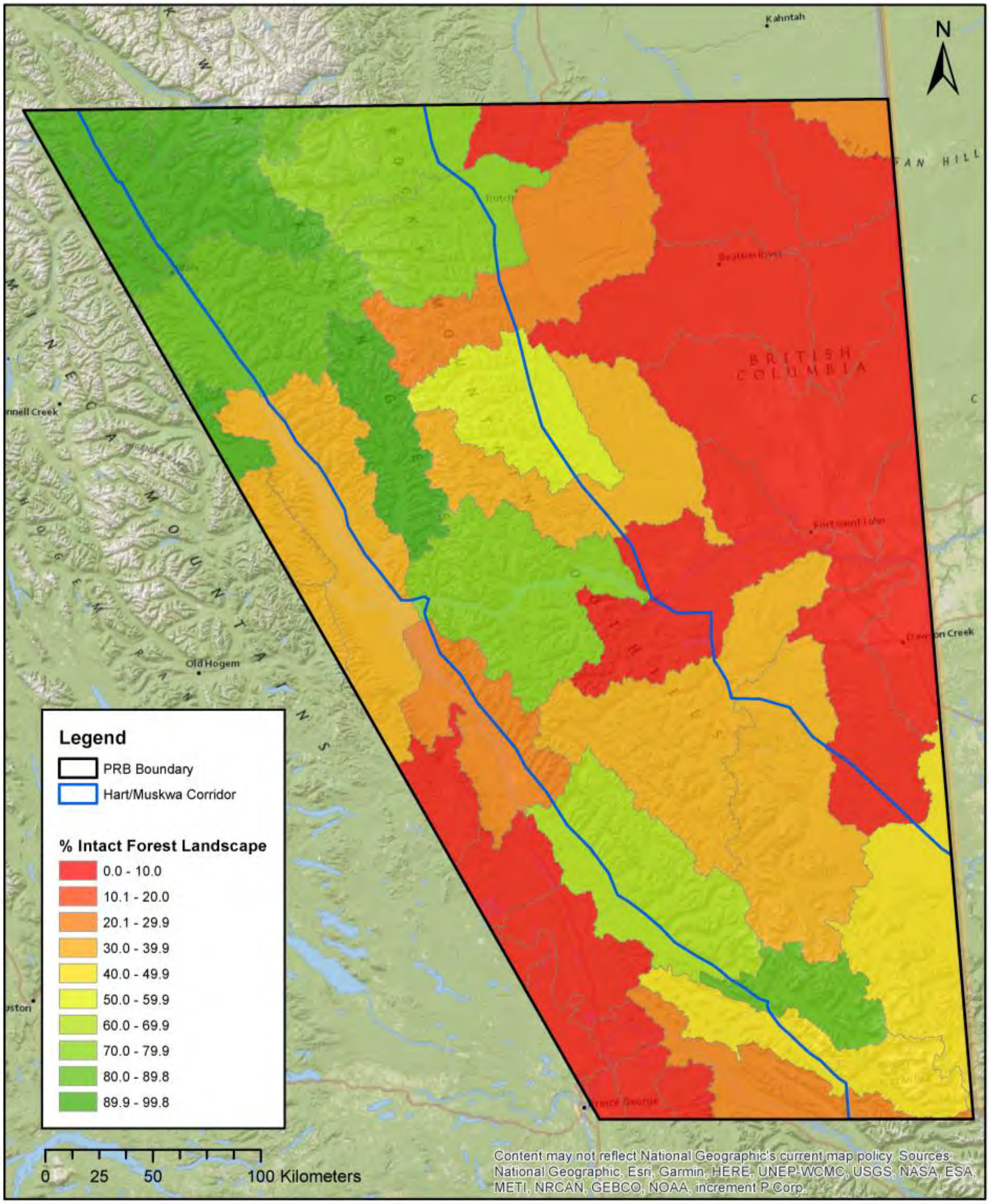
In Map 6 we calculated the percent intact forest landscape within assessment watershed boundaries. The smaller assessment watershed boundaries show a much clearer picture of the least intact landscapes on the east and west sides of the cordillera with decreasing levels of intactness along the margins particularly in the central-southern aspects of the study area (Table 14).

Table 14. Percent intact forest landscape by watershed in the study areas

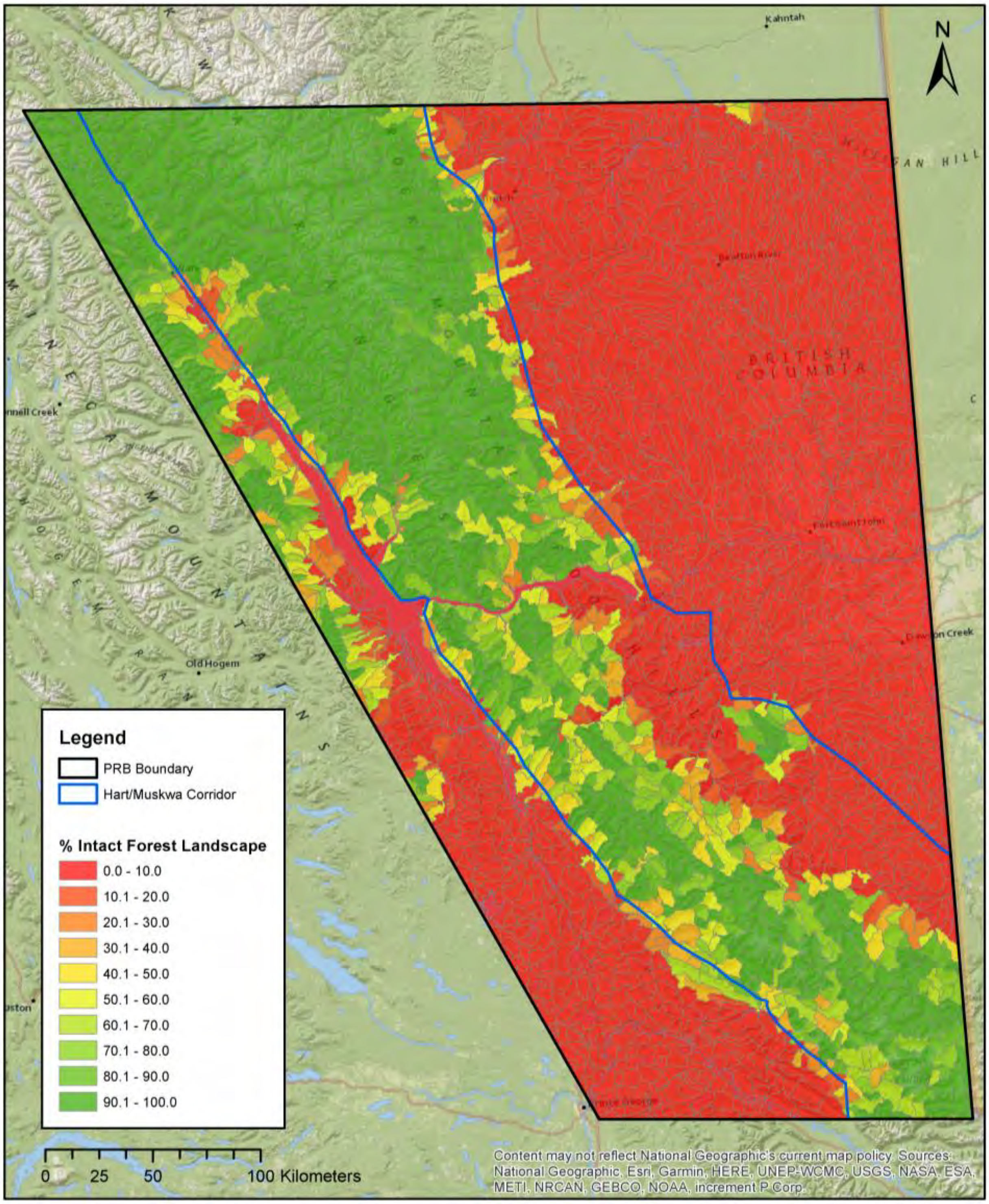
% IFL	PRB		Hart/Muskwa Corridor	
	% of Watersheds	% of Area	% of Watersheds	% of Area
0-10	53.13	53.31	8.7	4.71
10-20	1.58	1.89	0	0
20-30	1.68	1.72	13.04	5.78
30-40	1.55	1.64	17.39	24.9
40-50	2.23	2.66	8.7	10.62
50-60	2.44	2.58	4.35	4.17
60-70	3.19	3.33	4.35	6.55
70-80	3.06	3.25	13.04	19.7
80-90	3.47	3.39	13.04	10.42
90-100	27.68	26.22	17.39	13.16



Map 4. Intact forest landscapes and conservation designations

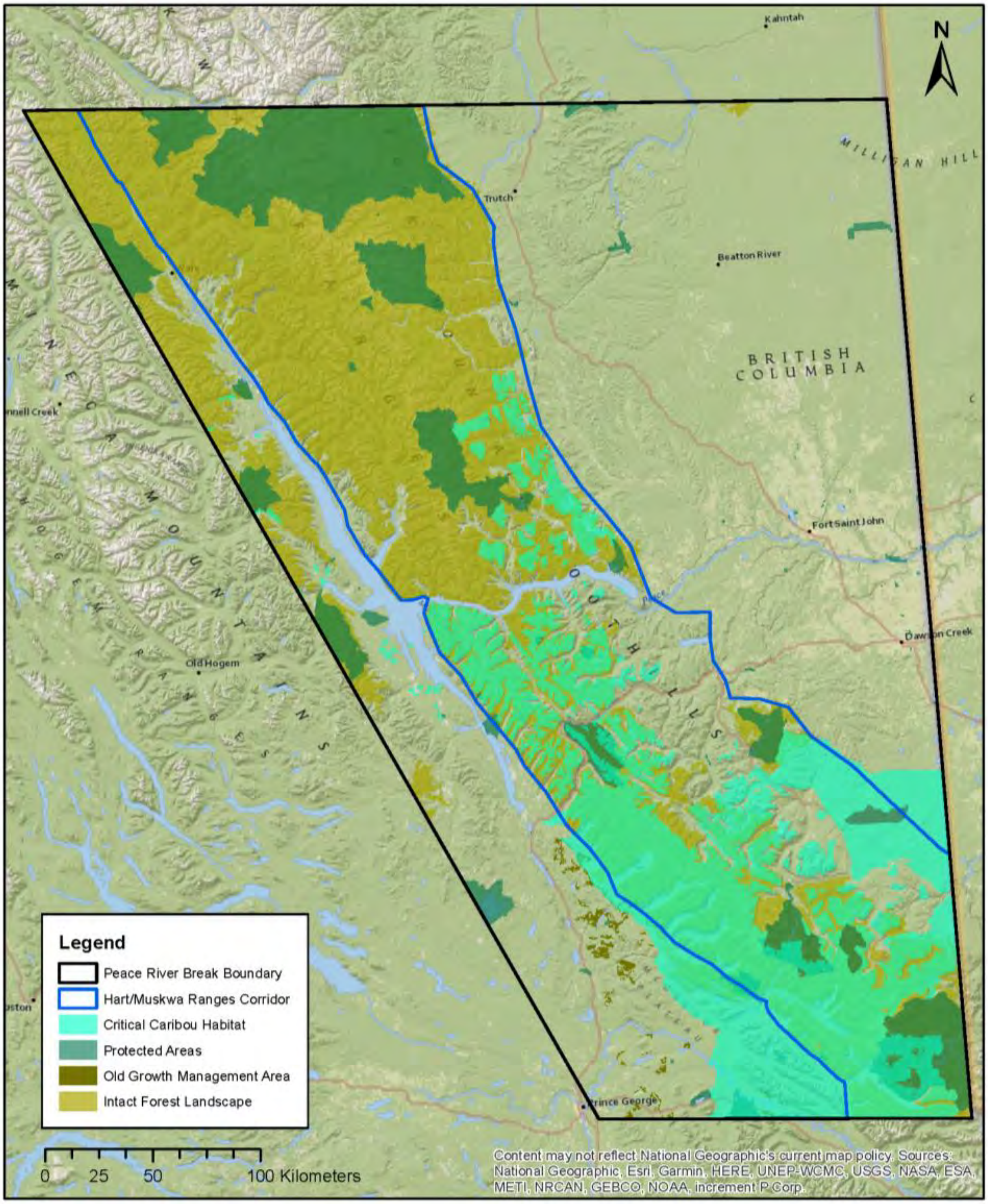


Map 5. Intact forest landscapes by named watershed



Map 6. Intact forest landscapes by assessment watershed

The Hart/Muskwa Corridor area is home to three caribou populations: the Southern, Northern, and Central Mountain caribou. We used the dataset for critical habitat for the Southern mountain population prepared by Environment and Climate Change Canada updated in December 2017 to examine overlap between critical habitat and current levels of protection. Only 6% is currently represented in protected areas, 58% is in intact forest landscapes and 55% is within designated ungulate winter range (Map 7).



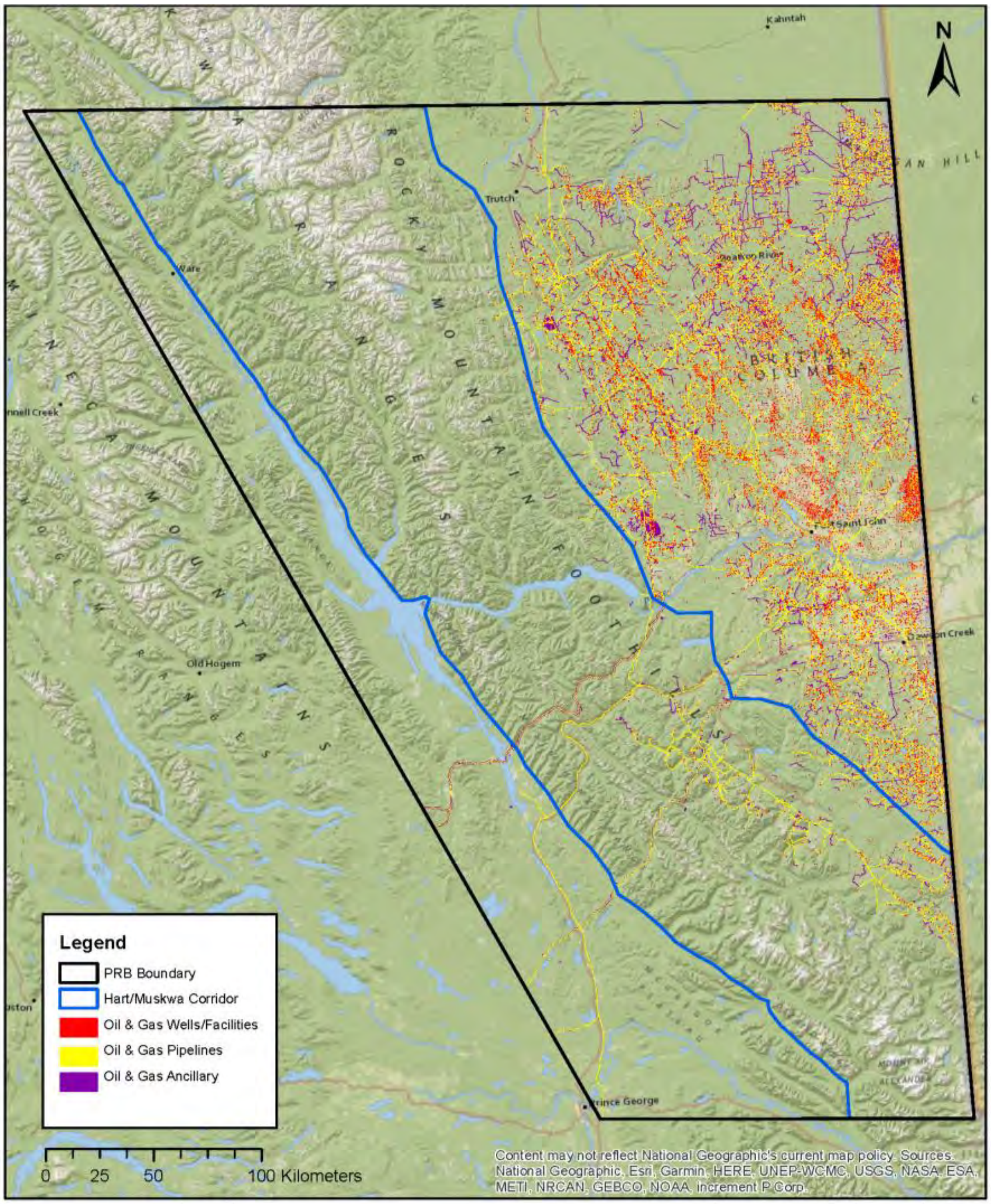
Map 7. Southern Mountain Caribou critical habitat by IFL

Land Use/Change by Resource Sector

Land use and resource development in the study areas consists of forestry, mining, oil and gas development, wind power, agriculture, recreation, roads, other industrial developments and utility corridors. In addition, human caused fires have a significant footprint on the area.

Oil and Gas

The impacts from oil and gas are associated both with the oil and gas well sites (surface holes), associated infrastructure (e.g., pumping stations, pipelines), pipelines and seismic lines (Map 8). Any single hole or pump station has a relatively small footprint. Within the PRB the total footprint outside of seismic lines represents 0.87% of the PRB



Map 8. Oil and gas activity in the study areas

study area unbuffered but buffered they represent 23.31% of the study area. For the Hart/Muskwa Corridor, the footprint is smaller representing 0.27% unbuffered rising to 4.86% buffered.

In addition, seismic lines, which are cut in a grid like pattern across the landscape to identify areas optimal for development are a significant component of the footprint associated with oil and gas development. Seismic lines can be cleared in a variety of different way from those cut and scraped with machinery to those cut by hand leaving varying degrees of human footprint (see Appendix D). The direct footprint (unbuffered) from seismic line developments is just 0.26% of the PRB and 0.06% of the Hart/Muskwa Corridor. Buffered, however, the impacts from seismic line development result in a significantly greater footprint from 20.49% for the PRB and 5.66% of the Hart/Muskwa Corridor. The 241,471 km of seismic lines in the PRB are enough to wrap around the Earth just over six times. Within the Hart/Muskwa Corridor boundary there are 37,599 km of seismic lines – enough to almost circle the Earth (94%).

Oil and gas surface holes (e.g., well sites) have been recorded since 1918 in the PRB and starting in 1940 in the Hart/Muskwa Corridor. Oil and gas development is characterized by cycles of exploration and development. Although there are wide swings in the level of development the annual level of development of new surface holes is on a strong growth curve (r2 = 0.7). The level of development peaked in the mid2000s with a secondary peak in the early 2010s. The average rate of surface hole development is currently at about 800 new wells per year (Fig. 1).

The rate of establishment of oil and gas surface holes within the Hart/Muskwa Corridor is currently much lower (R=0.35) with a peak in the mid-2000s of 30 wells established in 2006 but averaging around 25 wells in the past decade (Fig. 2).

Pipelines, or the right of ways associated with them, represent a significant portion of the footprint of oil and gas development. Although unbuffered they represent just 0.30% of the PRB study area and 0.07% of the Hart/Muskwa Corridor study area, when buffered they represent 6.25% and 1.45% respectively.

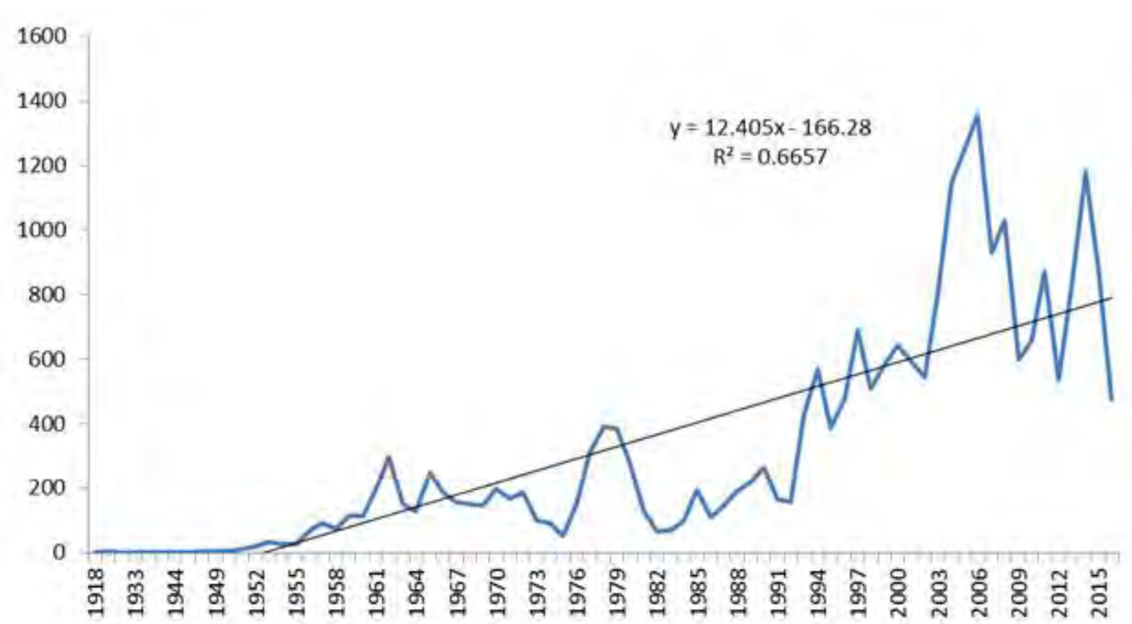


Figure 1. Annual oil/gas surface holes for the Peace River Break between 1918-2016

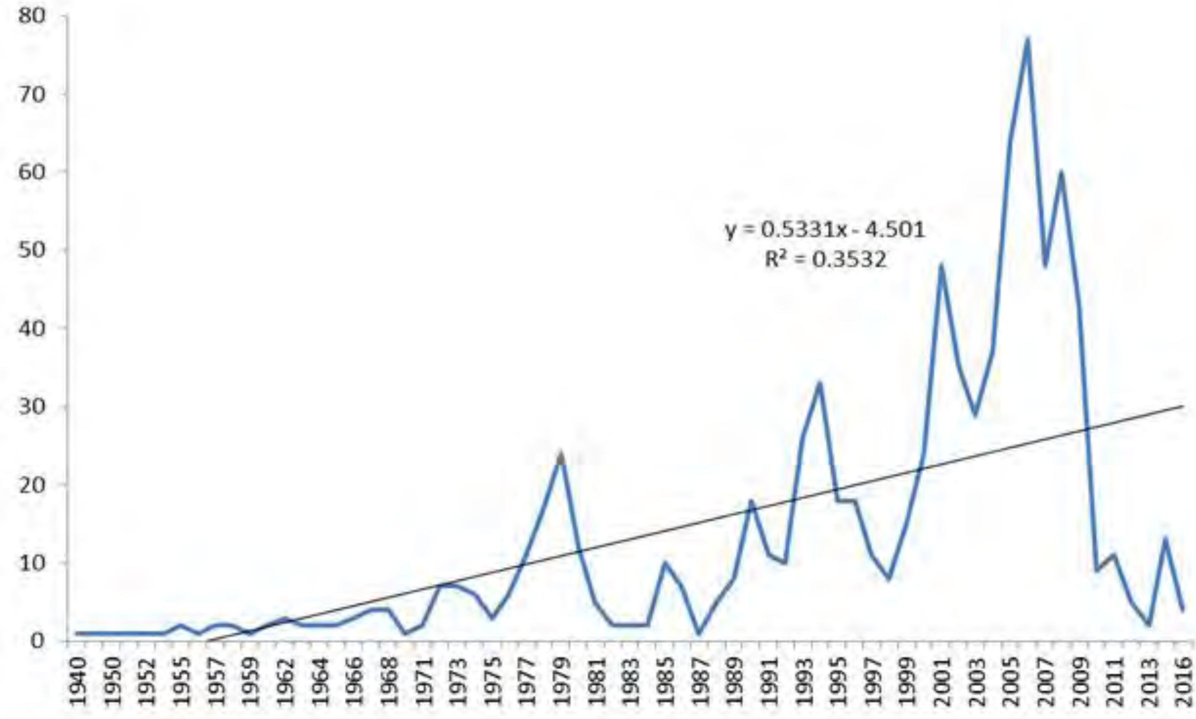


Figure 2. Annual oil/gas surface holes for the Hart/Muskwa Ranges between 1918-2016

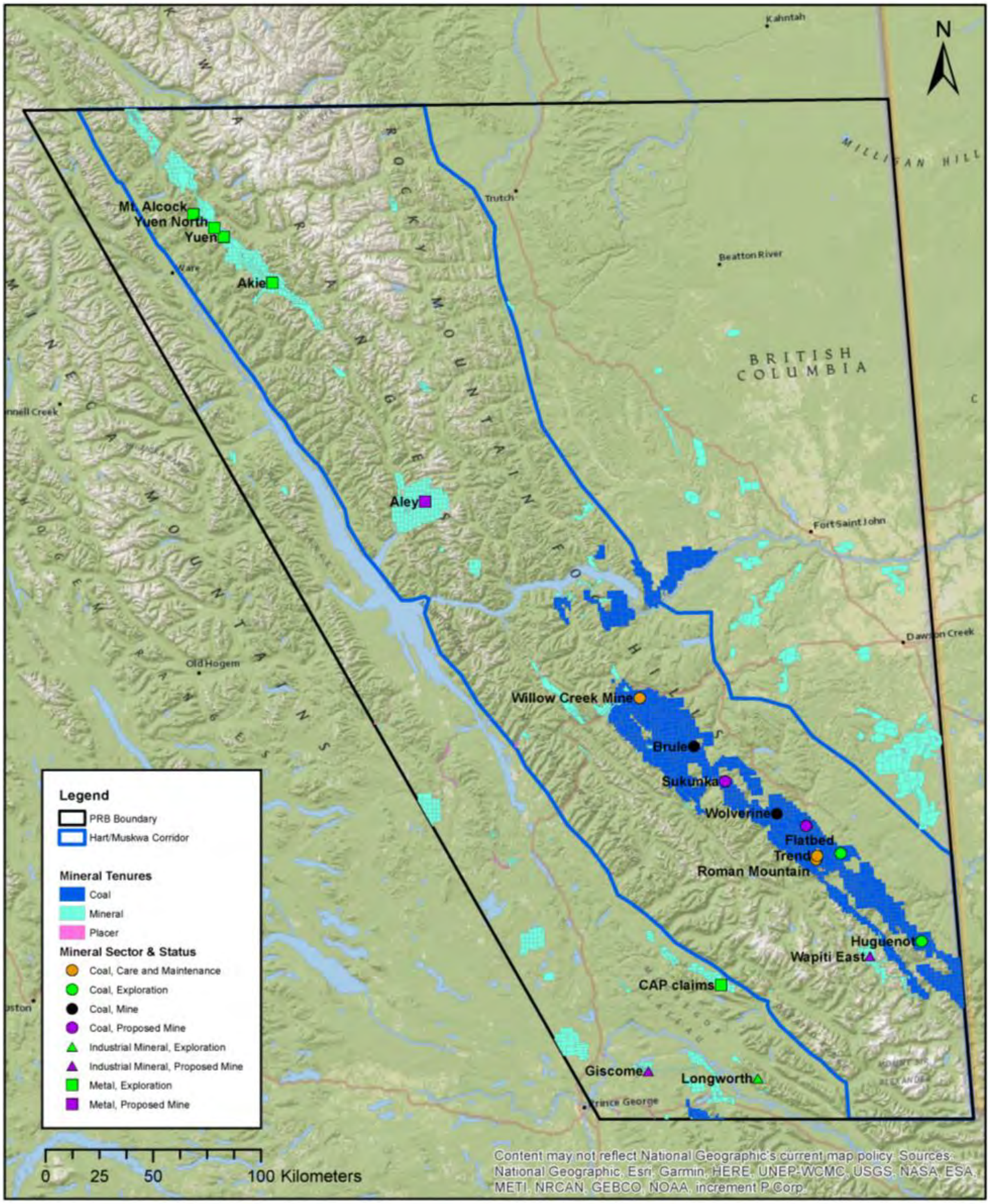
Mining

Mining development and associated tenures in the PRB and Hart/Muskwa study areas can be divided into coal, mineral and placer mining categories. Coal, mineral and placer tenures cover just 6.44% of the PRB study area but 9.77% of the Hart/Muskwa Corridor, where a large coal bed dominates the landscape particularly in the central and southern part of the study area (Table 15). A number of active mines as well as mines in care and maintenance are scattered across the landscape with even more in the exploration and proposal stage (Table 16). Map 9 displays the tenures and the existing and proposed mines.

Mineral tenures awarded over time are, like other resource sectors, cyclical. In the PRB, mineral tenures awarded peaked in the early 2000s but are still at higher than historic levels (Fig. 3). Although the volume of mineral tenures awarded is lower in the Hart/Muskwa Corridor the trends remain the same (Fig. 4). While mineral and placer mine tenures in the Hart/Muskwa Corridor is at significantly lower levels than within the PRB, it's important to note that the majority of coal tenures are located within the Hart/Muskwa Corridor.

Table 15. Total amount tenured in the study areas as of 2016

Mineral	PRB		Hart/Muskwa Corridor	
Type	Area (Ha)	Percent (%)	Area (Ha)	Percent (%)
Coal	451,158.97	3.33	420,904.78	6.9
Mineral	424,500.72	3.13	189,337.70	3.11
Placer	5,436.13	0.04	677.88	0.01
Total	**872,178.29**	**6.44**	**595,849.97**	**9.77**



Map 9. Mining activity in the study areas

Table 16. Current mines in the study areas

Mines in the PRB		
Project	**Sector**	**Status**
Roman Mountain	Coal	Care and Maintenance
Trend	Coal	Care and Maintenance
Willow Creek Mine	Coal	Care and Maintenance
Akie	Metal	Exploration
CAP claims	Metal	Exploration
Flatbed	Coal	Exploration
Huguenot	Coal	Exploration
Longworth	Industrial Mineral	Exploration
Mt. Alcock	Metal	Exploration
Yuen	Metal	Exploration
Yuen North	Metal	Exploration
Brule	Coal	Mine
Wolverine	Coal	Mine
Aley	Metal	Proposed Mine
Giscome	Industrial Mineral	Proposed Mine
Murray River	Coal	Proposed Mine
Sukunka	Coal	Proposed Mine
Wapiti East	Industrial Mineral	Proposed Mine
Mines in the Hart/Muskwa Ranges Corridor		
Project	**Sector**	**Status**
Roman Mountain	Coal	Care and Maintenance
Trend	Coal	Care and Maintenance
Willow Creek Mine	Coal	Care and Maintenance
Akie	Metal	Exploration
Flatbed	Coal	Exploration
Huguenot	Coal	Exploration
Mt. Alcock	Metal	Exploration
Yuen	Metal	Exploration
Yuen North	Metal	Exploration
Brule	Coal	Mine
Wolverine	Coal	Mine
Aley	Metal	Proposed Mine
Murray River	Coal	Proposed Mine
Sukunka	Coal	Proposed Mine
Wapiti East	Industrial Mineral	Proposed Mine

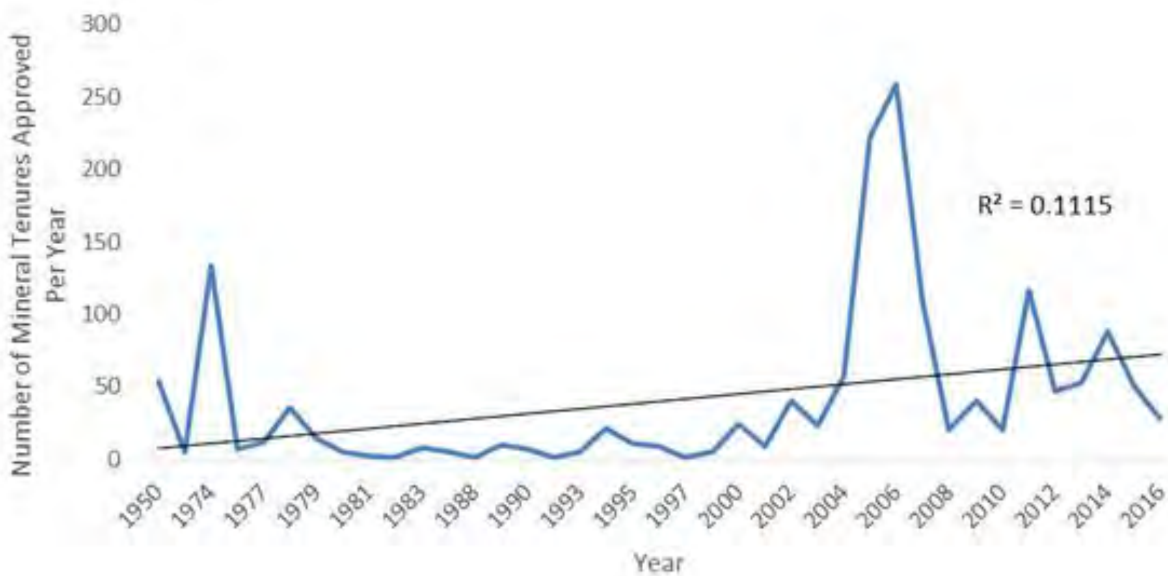


Figure 3. Mineral tenures per year in the PRB for 1950-2016

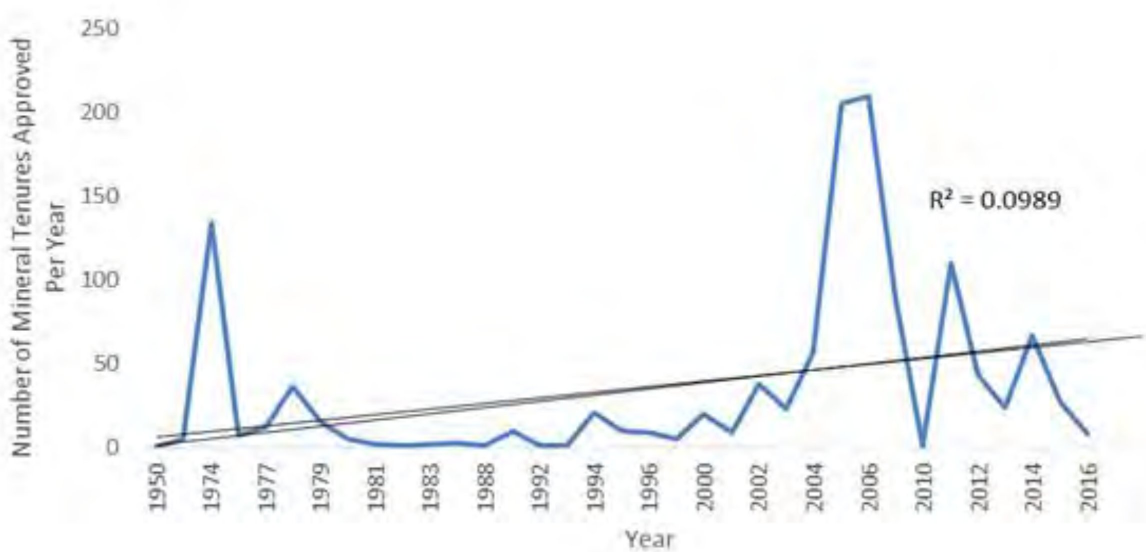


Figure 4. Mineral tenures per year in the Hart/Muskwa Ranges for 1950-2016

Forest Harvesting

The study area contains both volume (timber supply areas (TSA)) and area-based tenures (tree farm licenses (TFL)). A series of TFLs are located primarily within the boundaries of the Hart/Muskwa Corridor (Map 10).

The total harvested area unbuffered represents 8.2% of the PRB study area and 3.8% of the Hart/Muskwa (Map 11). Forestry activities have been concentrated on the southwest side of the Hart/Muskwa Corridor and in the flatter lands on the northeast side. It is important to note that forest harvesting ancillary to oil and gas development, while significant, is not recorded.

Although the logging history in the area undoubtedly predates it, there is reliable spatial data for the study areas on the logging harvest history since 1941. Although cyclical in nature, forest harvesting in the PRB has been on an accelerated trajectory since the late 1950s (Fig. 5).

Within the Hart/Muskwa Corridor the volume harvested over that time represents under one-quarter of the total harvested area of the PRB and the trajectory, while still accelerating is much more variable with peaks through the 1980s and 1990s and troughs in the mid-1990s and late 2000s (Fig. 6).

1. Forest Pests and Salvage Harvesting

Outbreaks of various forests pests associated with warming temperatures, fire suppression and forest management practices amongst other variables have increasing influence on where and how the forest harvest in BC occurs. Salvage harvesting justified by beetle outbreaks changes the dynamic and trends of forest harvesting and means that current maps of harvest blocks and associated forest access roads are often inaccurate. In the last year there has been an apparent increase in salvage harvest (associated with spruce beetle) in the Hart/ Muskwa Ranges but publicly available mapping and data is not yet readily accessible. On the assumption that high areas of beetle hazard are more susceptible to salvage harvest we assembled information on beetle hazard from DataBC (see Appendix E) and using three main beetle threats, Mountain Pine Beetle (MPB), Spruce Beetle (SB), and Douglas Fir Beetle (DFB) we identified hazard class 1 ranks and then calculated maximum hazard (3 for all 3 beetle types) statistics and maps. A large percentage of the areas is 'unclassified'. This area is within Tree Farm License areas where no VRI data exists.

Although DFB exists in just trace amounts, just about ½ of the Hart/Muskwa Ranges is

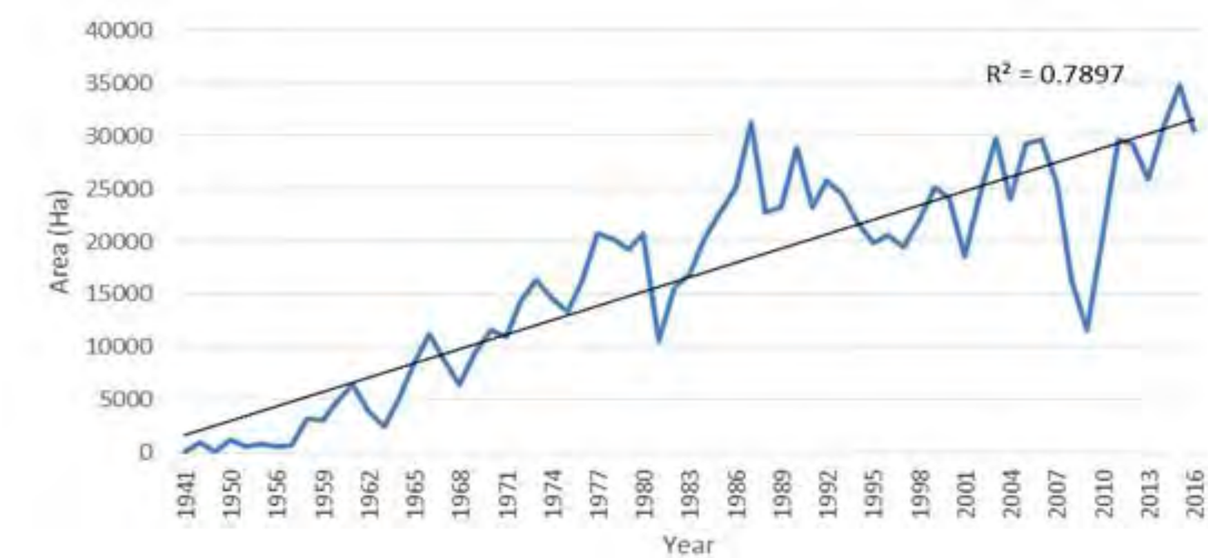


Figure 5. Forest harvest in the PRB for 1941-2016

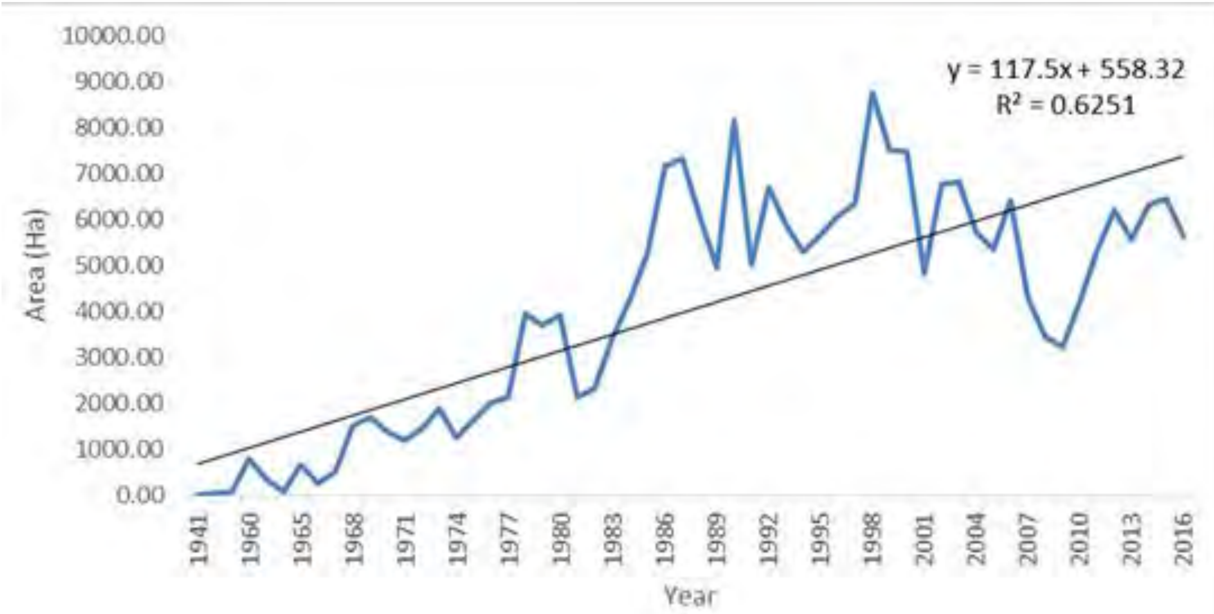
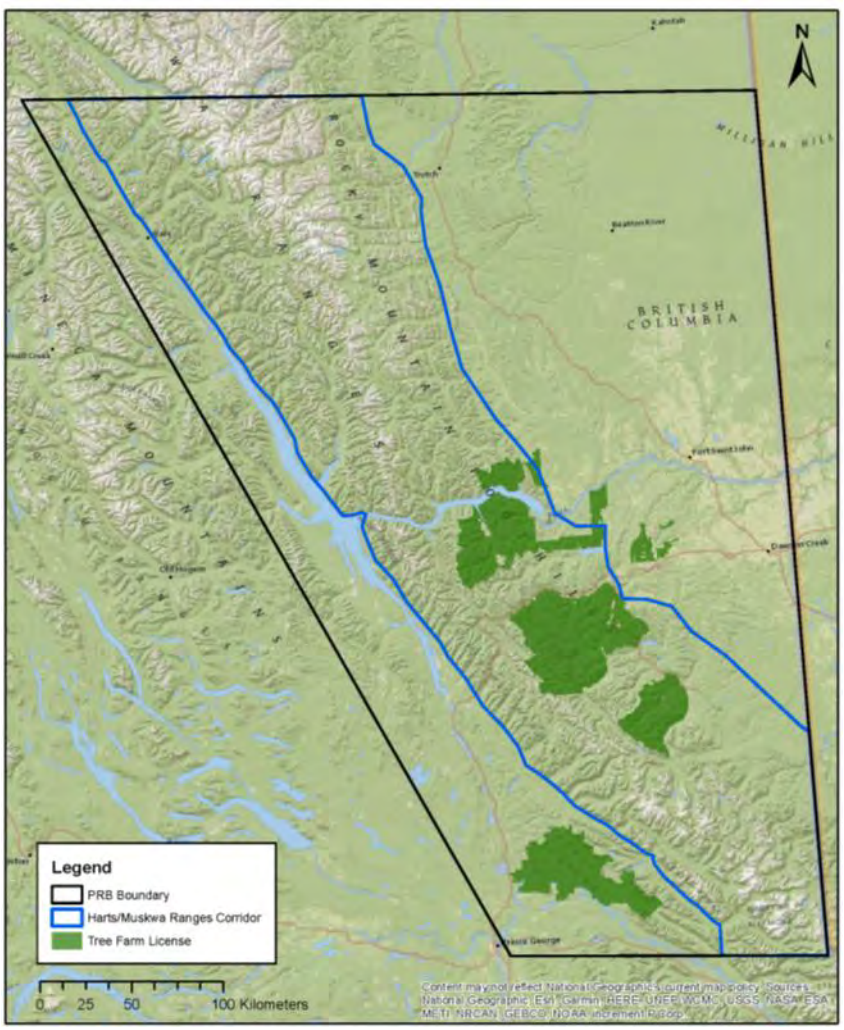
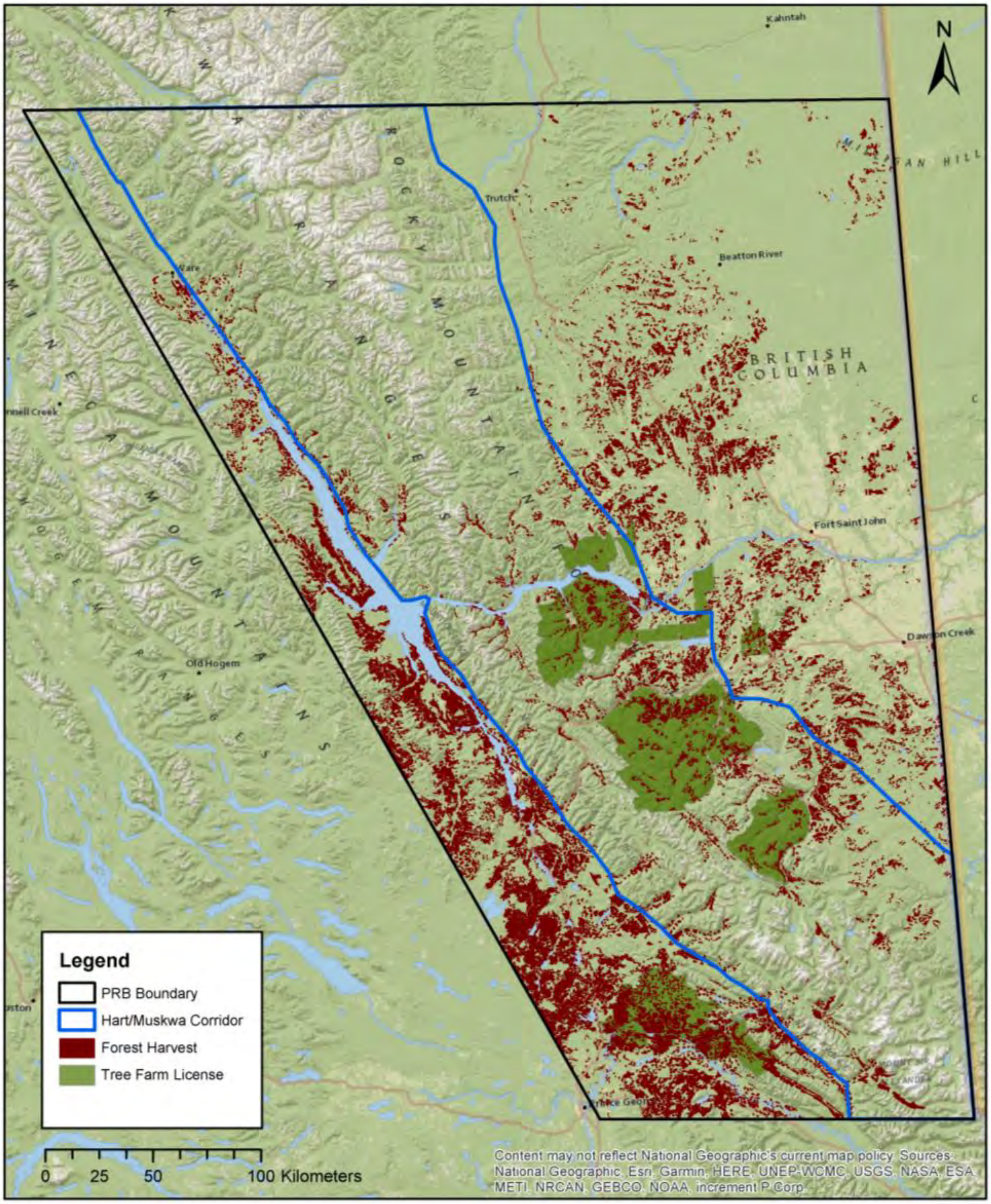


Figure 6. Forest harvest in the PRB for 1941-2016



Map 10. Tree farm licenses in the study areas

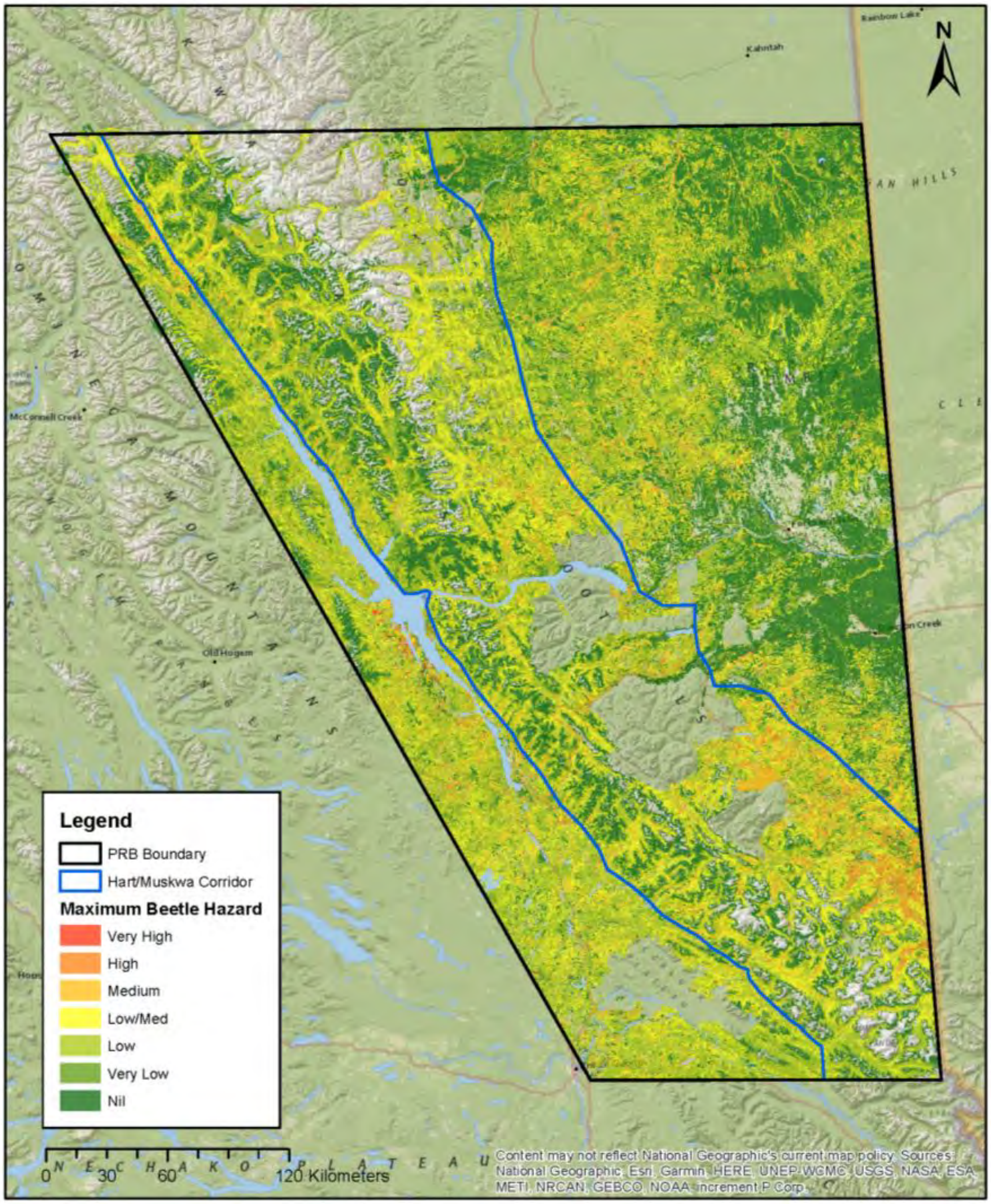


Map 11. Forest harvesting in the study areas (1941-2016)

categorized as low-medium threat for SB (Table 17 and Map 12). The map illustrates that those areas with higher hazard ratings are on the south east side of the study area and we anticipate are likely to have higher priority for salvage harvest.

Table 17. Beetle hazard rating for MPB, SB and DFP

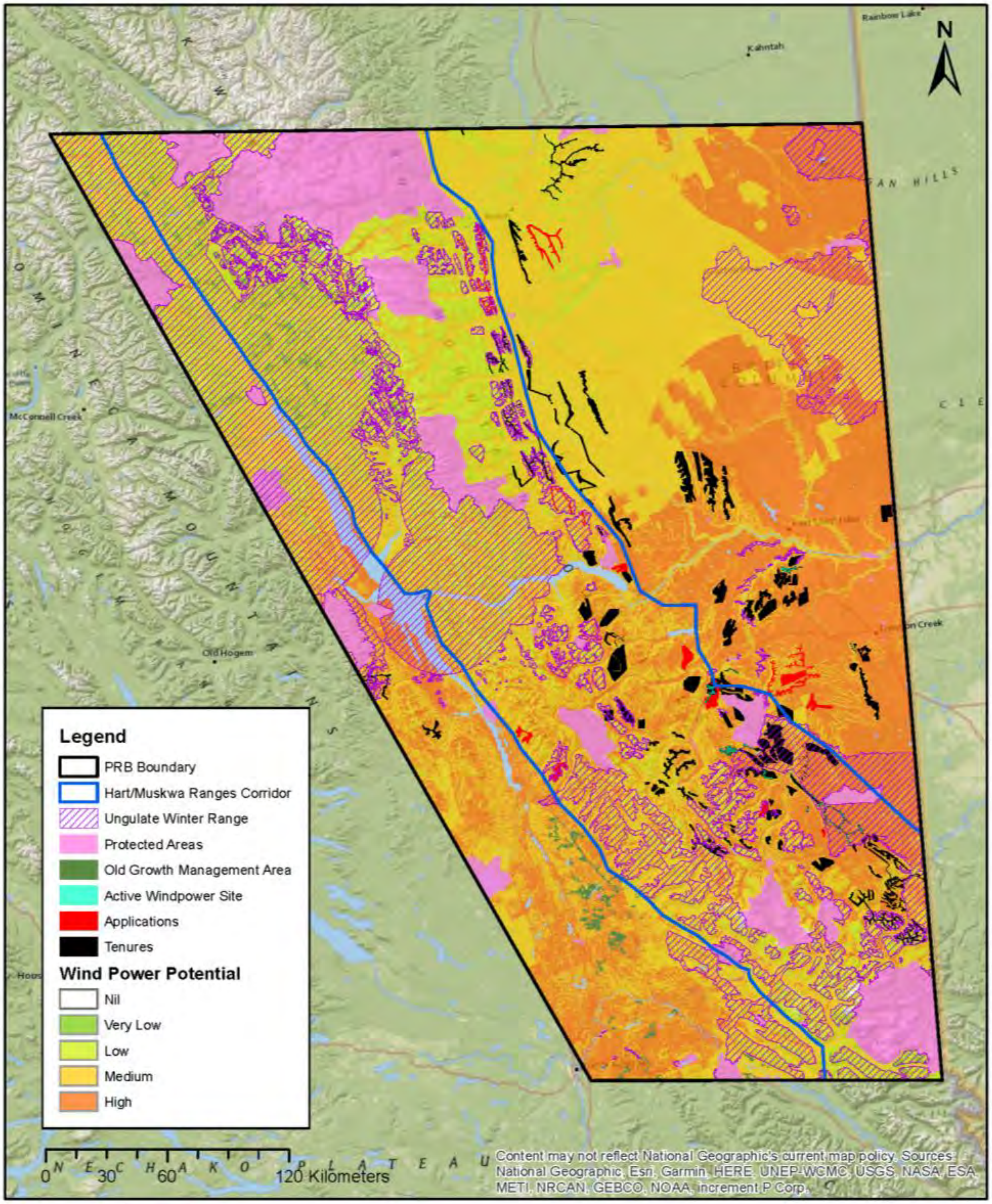
	Peace River Break				Hart/Muskwa Ranges Corridor			
	MPB	SB	DFB	Max	MPB	SB	DFB	Max
Nil	48.51	31.51	79.03	21.25	47.25	20.29	70.6	15.73
Very Low	13.06	5.5	0.3	7.69	9.2	5.09	0.03	5.01
Low	10.99	25.03	0.26	27.12	7.88	25.38	0.05	24.83
Low/Med	4.05	13.67	0.07	16.53	3.05	16.77	0.01	18.63
Medium	2.14	3.21	0.03	5.35	2.01	2.65	0	4.66
High	0.87	0.73	0.01	1.61	1.3	0.51	0	1.81
Very High	0.08	0.05	0	0.14	0.01	0.02	0	0.03
No Data	20.3	20.3	20.3	20.3	29.3	29.3	29.3	29.3



Map 12. Maximum beetle hazard ratings

Wind Power

Wind power is a relatively recent and emerging resource development in the region that while small is concentrated disproportionately in the Hart/Muskwa Corridor correspondent with the high mountain ridges. Although date of initiation is not tracked spatially, wind power is categorized based on its stage in the development (Table 18). Map 13 shows wind tenures and applications in the PRB. We identified active wind power sites as those that have the potential to have active wind towers on the landbase (development, general area, intensive, and operating phases) and are accepted leases or license tenures.



Map 13. Wind power tenures and wind power tenure applications

Table 18. Wind power by stage of development

Tenure Subpurpose/Phase	Area (Ha) Wind Power Tenures and Tenure Applications			
	PRB		Hart/Muskwa Corridor	
	Tenure	Application	Tenure	Application
Development Phase	3,858.52	0	3,858.52	0
General Area (License of occupation)	3,425.32	916.86	2,328.42	0
Intensive	12.14	0	0	0
Investigative and Monitoring Phase	233,710.01	69,810.99	132,368.72	40,939.41
Investigative Phase	12,124.44	8,597.25	1,744.38	3,885.46
Operating Phase	89.34	0	89.34	0

Human-Caused Forest Fires

Fires are natural disturbances and, as a rule, we would not normally report them as a human footprint. However, we have tracked human-caused forest fires as evidence of the human footprint on the land. In the wider PRB study area, human-caused fires are the leading disturbance occupying 10.3% of the landbase but only 2.3% of the Hart/Muskwa Corridor landbase (Map 14).

Human-caused fire in the PRB peaked in the 1940s and 1950s and has been on a general decline (R2 = -0.03) although there was a significant uptick in 2016 with a 50 year high (Fig. 7). In the Hart/Muskwa Corridor human -caused fires peaked in the 1920s with a smaller peak (one-third of the size) in the late 1980s. Area burned has been in a general downward trend (r2= -0.07) since the 1920s (Fig. 8).

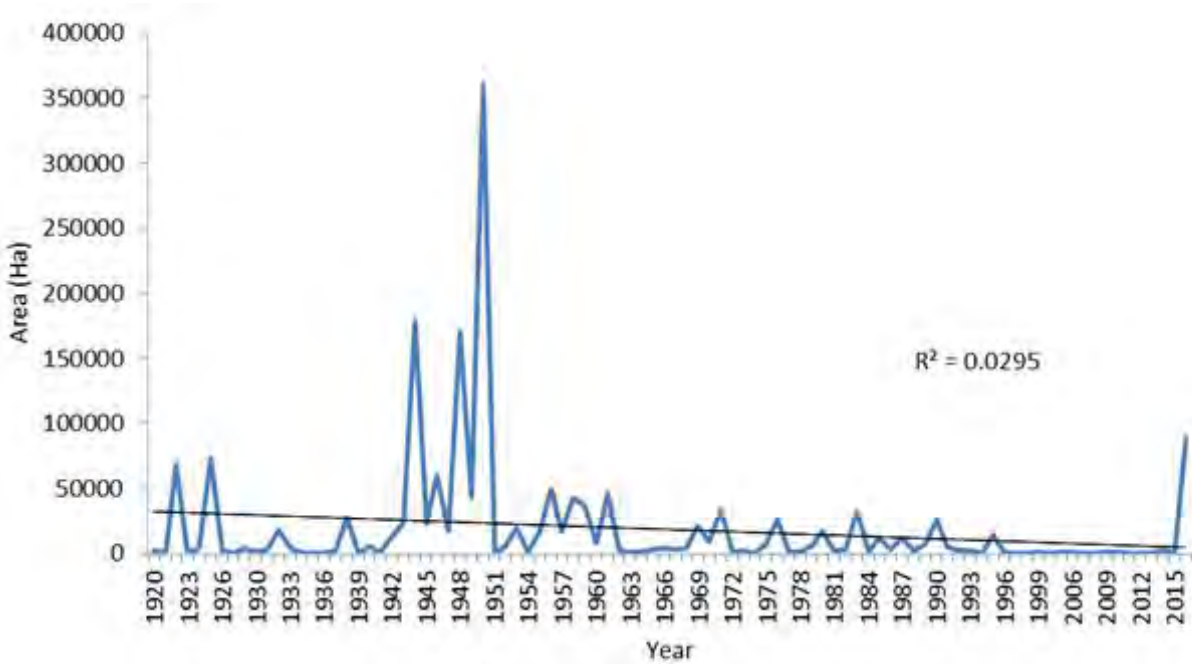


Figure 7. Annual human caused forest fire area in the PRB from 1920 to 2016 where fire area declined annually by .03.

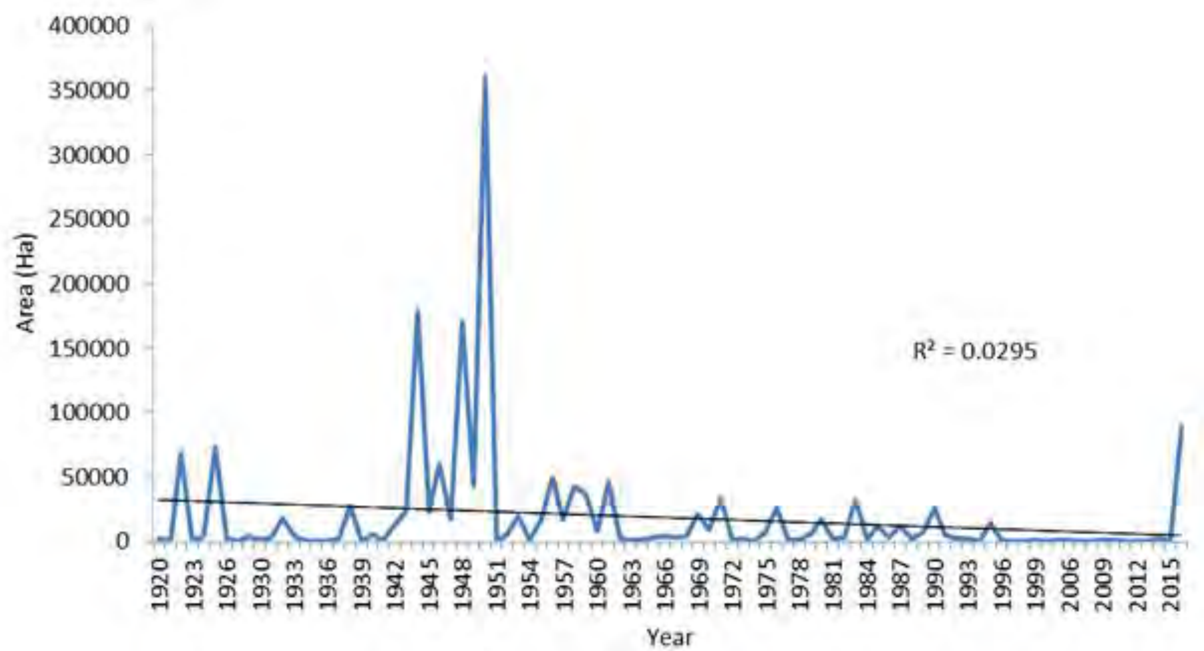
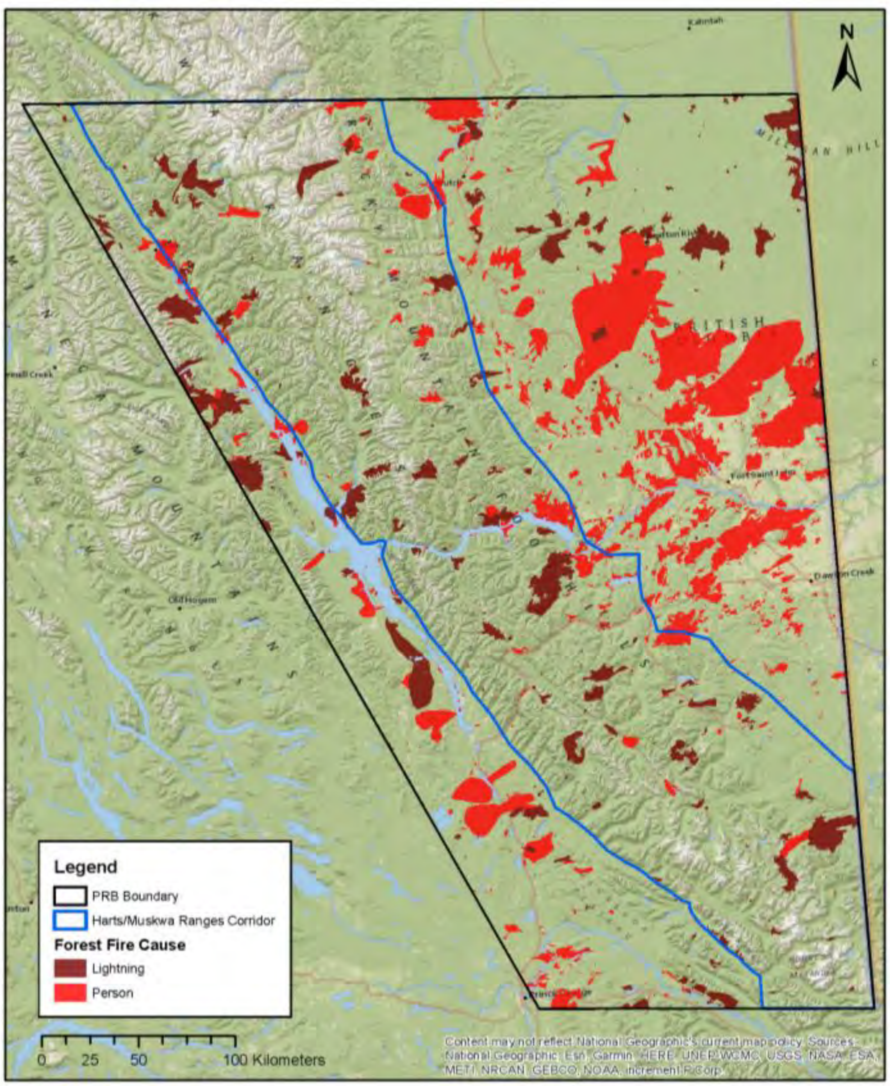


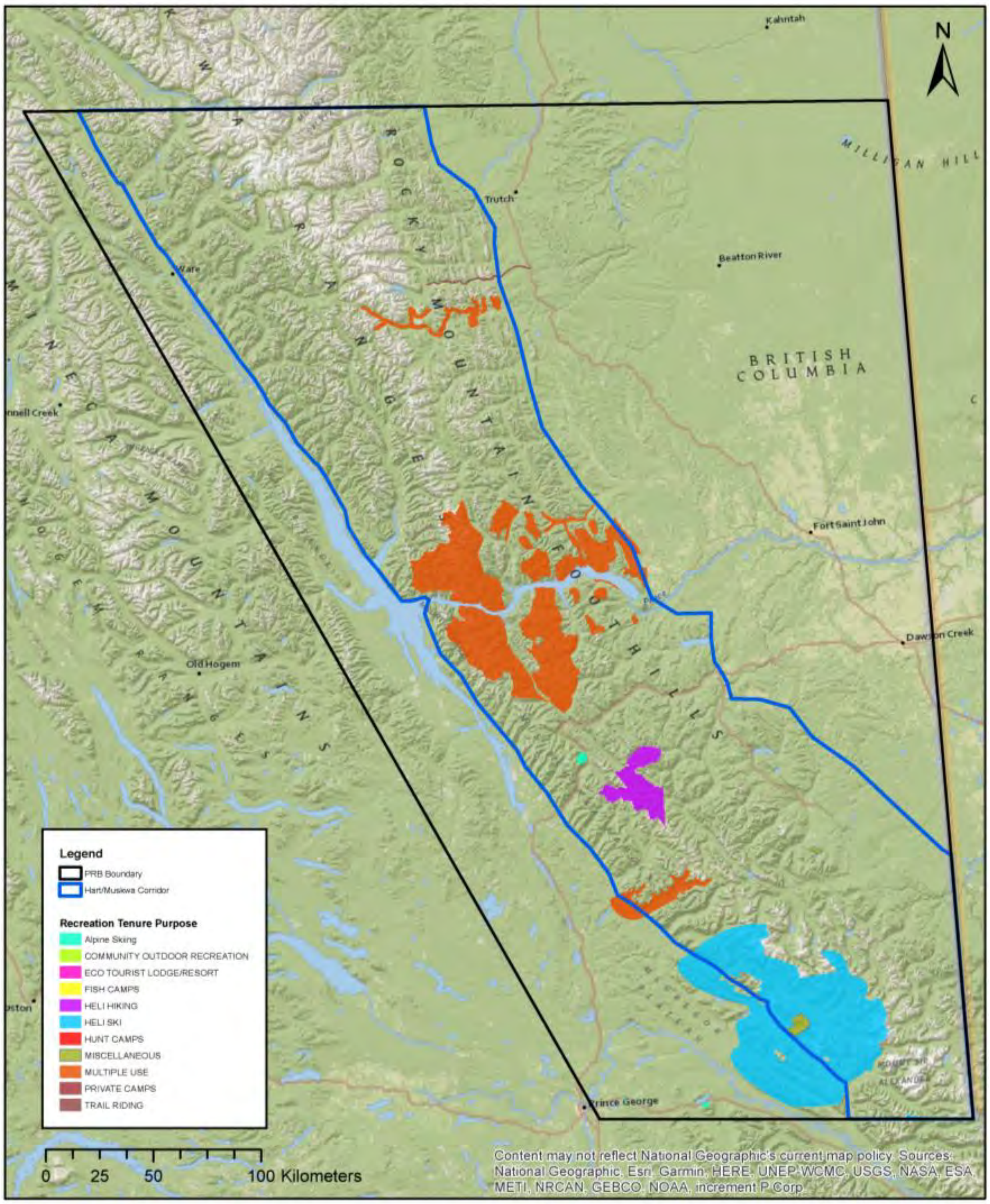
Figure 8. Annual human caused forest fire area in the Hart/Muska Corridor from 1920 to 2016 where fire area declined annually by .07.



Map 14. Forest fires in the study areas (1920-2016)

Recreation

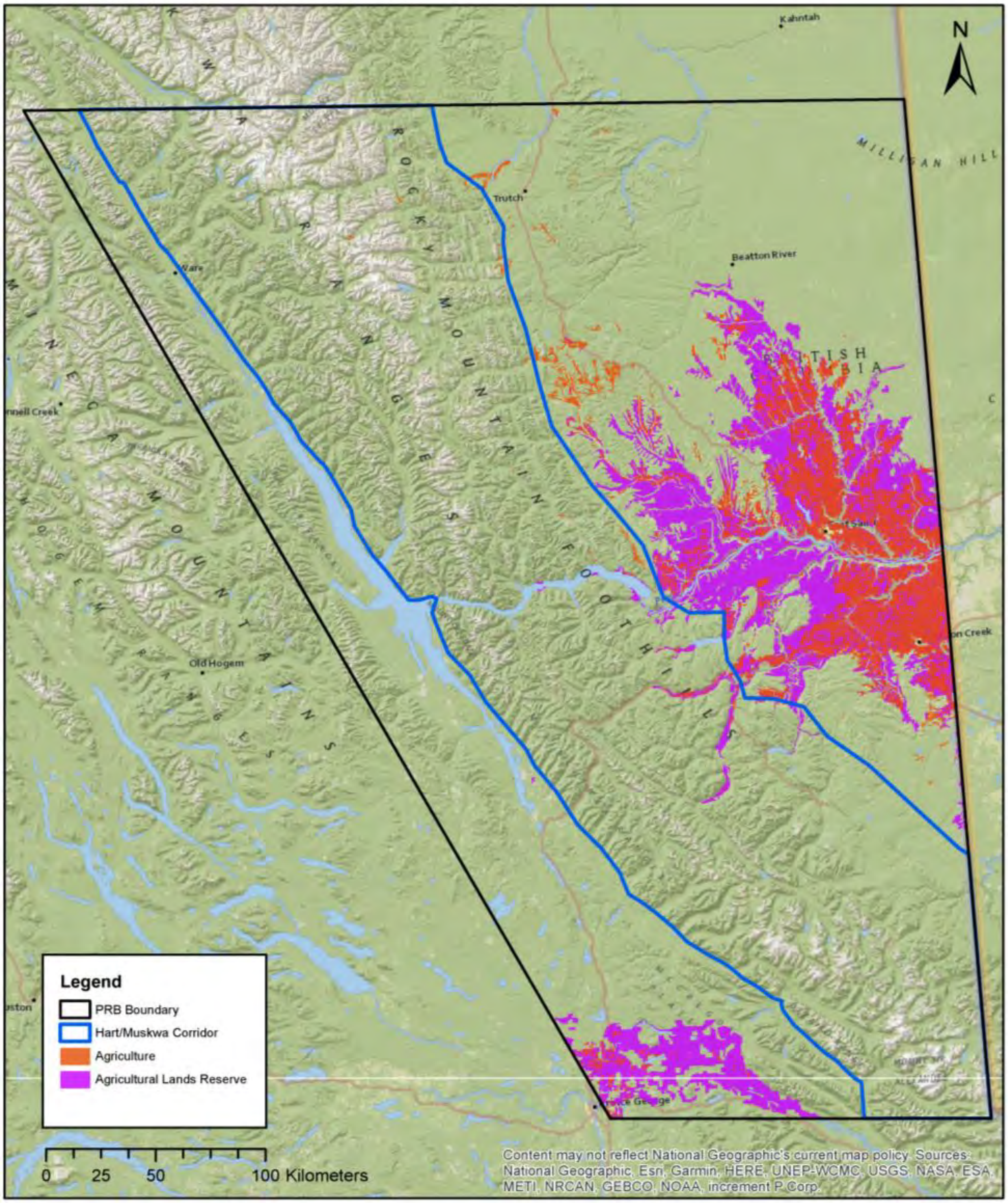
Outdoor recreation activities occur throughout the landbase. We report here on alpine skiing and commercial recreation tenures (e.g., helisking or hunt/fish camps). The impact of these uses varies spatially and temporally but is not tracked. For example, alpine ski tenures often have tenure over an area larger than the relatively concentrated area where they have a permanent footprint. Heli-skiing activities are tenured over large areas but typically have no visible footprint, however, they can have critical disturbance effects particularly over bighorn sheep, mountain goats and caribou (Apps & McLellan, 2006; Harris, Nielson, Rinaldi, & Lohuis, 2014; Stokowski & LaPointe, 2000). Although only 7.1% of the PRB is designated in commercial recreation tenures, 12.7% of the Hart/Muskwa Corridor is tenured (Map 15).



Map 15. Recreation tenures in the study areas

Agriculture

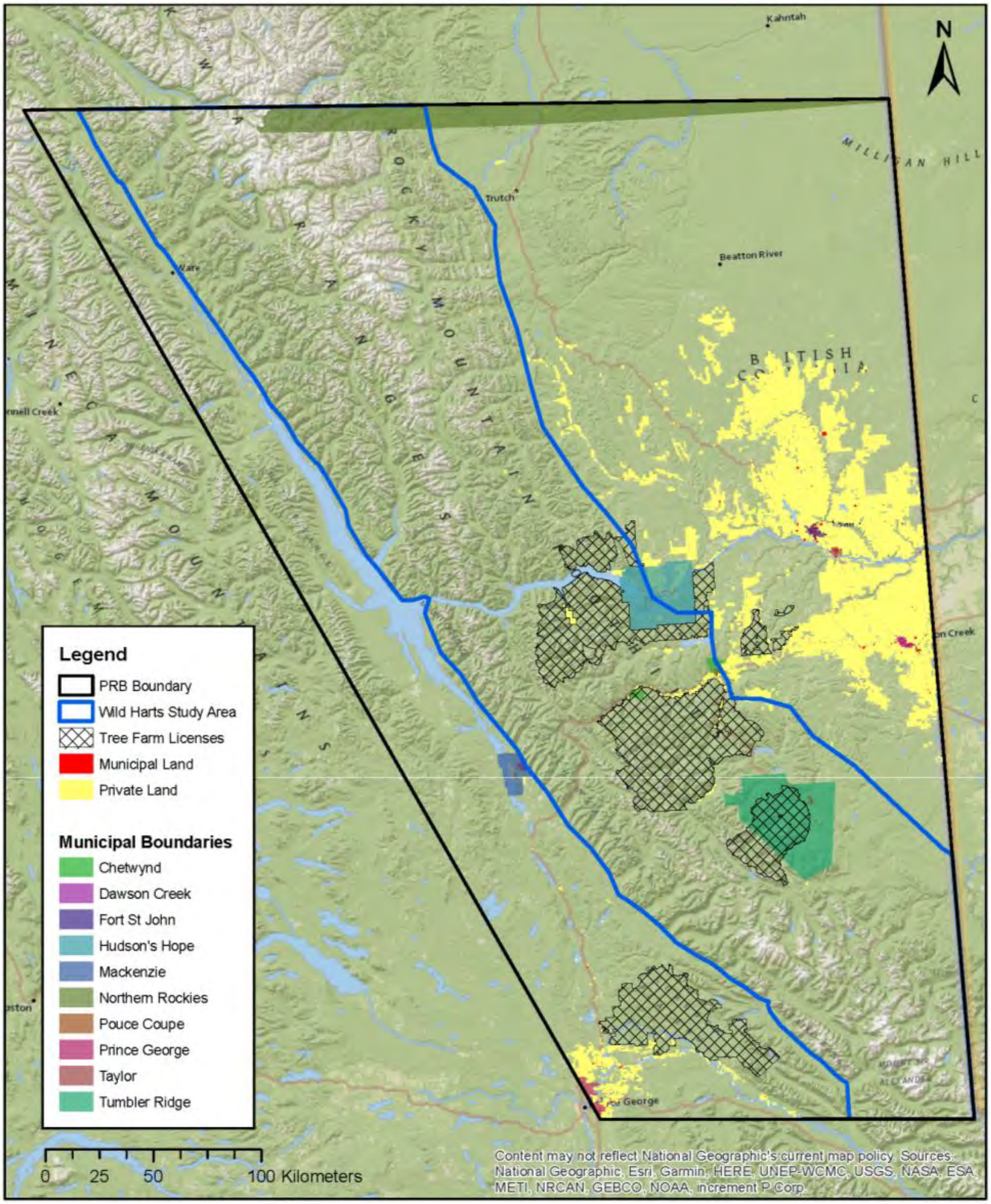
Agricultural lands compromise almost 5% of the PRB but just 0.2% of the Hart/ Muskwa Corridor. Agricultural activities are a mix of cropland, forage land and grassland a significant proportion (83.2%) of which is in the Agricultural Land Reserve (ALR) (Map 16).



Map 16. Agriculture in the study areas

Urbanization

Urbanized areas are relatively limited within the study areas (Map 17). Private lands are dominated by agriculture and not by housing/permanent development. The municipal boundaries of the communities within the region are also typically significantly larger than the current footprint of the community. In total, urban area constitute just 0.15% of the PRB and 0.05% of the Hart/Muskwa Corridor.



Map 17. Land ownership and urbanization in the study areas

Industrial Sites/Utility Corridors/Hydropower

There are a number of other types of developments including industrial and waste disposal sites, utility corridors and hydropower development. Although for most of these developments the total footprint can be quite small the impacts at site levels from industrial sites/waste disposal can be quite significant or the linear nature of the utility corridors can result in fragmentation of significant elements of the landscape.

Within the PRB study area, reservoirs (dominated by the Williston Reservoir) has the largest footprint in the unbuffered footprint analysis, unbuffered but industrial sites dominate in the buffered analysis (Table 19).

Within the Hart/Muskwa Corridor study area, utility corridors dominate in the unbuffered footprint analysis, but industrial sites dominate in the buffered analysis (Table 20).

Table 19. Industrial sites, utility corridors and hydropower in the PRB

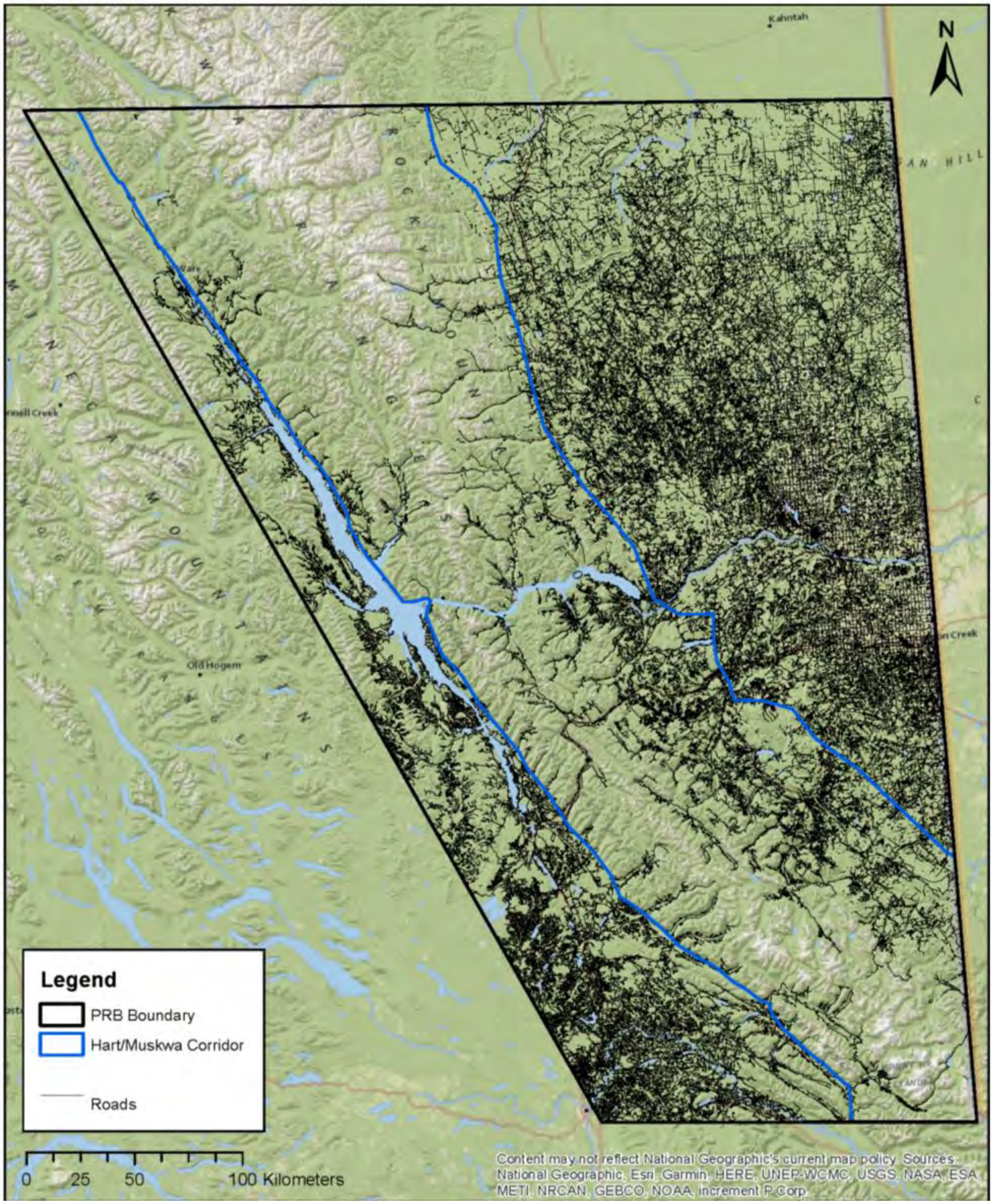
Disturbance Type	PRB Study Area			
	Actual Footprint		Buffered Footprint	
	Area (Ha)	Percent Study Area	Area (Ha)	Percent Study Area
Waste Disposal Sites	7178.7	0.05	70865.51	0.52
Industrial Sites	18230.52	0.13	527610.76	3.9
Power, Water, Telecom Sewage Lines	10740.72	0.08	106653.5	0.79
Active Water Power Sites	1084.71	0.01	1998.43	0.01
Reservoirs*	176475.86	1.3	176475.86	1.3
Dams	44.72	0	177932.73	1.31

Table 20. Industrial sites, utility corridors and hydropower in the Hart/Muskwa Ranges

Disturbance Type	Hart/Muskwa Corridor			
	Actual Footprint		Buffered Footprint	
	Area (Ha)	Percent Study Area	Area (Ha)	Percent Study Area
Waste Disposal Sites	138.91	0	2,669.88	0.04
Industrial Sites	1,295.67	0.02	94,098.17	1.54
Power, Water, Telecom Sewage Lines	4,351.25	0.07	33,966.22	0.56
Active Water Power Sites	0	0	0	0
Reservoirs	37,359.48	0.61	37,359.48	0.61
Dams	41.25	0	73,409.53	1.2

Roads

Roads are one of the most significant sources of human footprint they both provide access to areas for development and for secondary uses (Map 18). The linear disturbance nature of roads means that fragmentation effects are significant. Specific impacts from roads vary depending on the degree of development (e.g., the road surface) and the volume (and timing) of use on the roads. For example rough or seasonal roads that are frequented by snowmobilers



Map 18. Roads in the study areas

can provide access for wolves to the high elevation habitat of caribou (Paquet, Alexander, Donelon, & Callaghan, 2010).

Within both the larger (PRB) and smaller Wild Harts study area rough/loose roads dominate with paved roads a relatively small proportion of the footprint (Fig. 9).

Unbuffered, roads consist of just 1.82% of the PRB. The proportion of the Hart/Muskwa impacted by roads is slightly less (0.78%). When buffered according to the level of road development (2 km for paved roads, 1 km for unpaved roads), the road footprints jump significantly to dominate the study areas at 66.7% and 39.7% of the PRB and Hart/Muskwa Corridor study areas respectively.

The cumulative distance of roads in the PRB (134,580 km) is enough to encircle the Earth 3.3 times. Unfortunately, roads data is not recorded in the government data warehouse by year so we are unable to track the trajectory (or rate of change) of road development over time. Except, however for those roads that have been recorded as decommissioned (less than 10 km) and the small proportion (1.6%) that are overgrown we presume that all roads within the study area are still present.

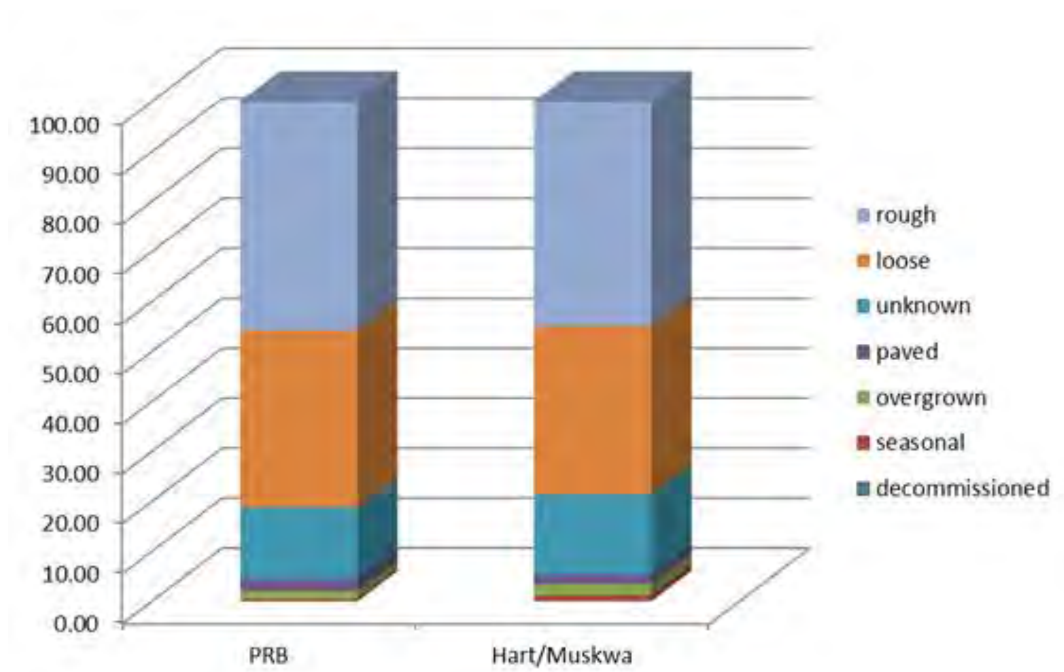


Figure 9. Percent of roads by type

Cumulative Human Footprint

Data from individual resource sector analysis was combined to produce an overall or cumulative human footprint for two areas of analysis, the PRB boundary and the Hart/ Muskwa Corridor. The human footprint is divided into two categories: semi-permanent (or soft) footprint including agriculture, forestry cutblocks and seismic lines; and permanent (hard) footprint activities including roads, industrial sites, wells and pipelines and the like. Overlapping footprints are dissolved together so there are no overlapping features in the calculations.

Semi-Permanent (Soft) Un-buffered Human Footprint

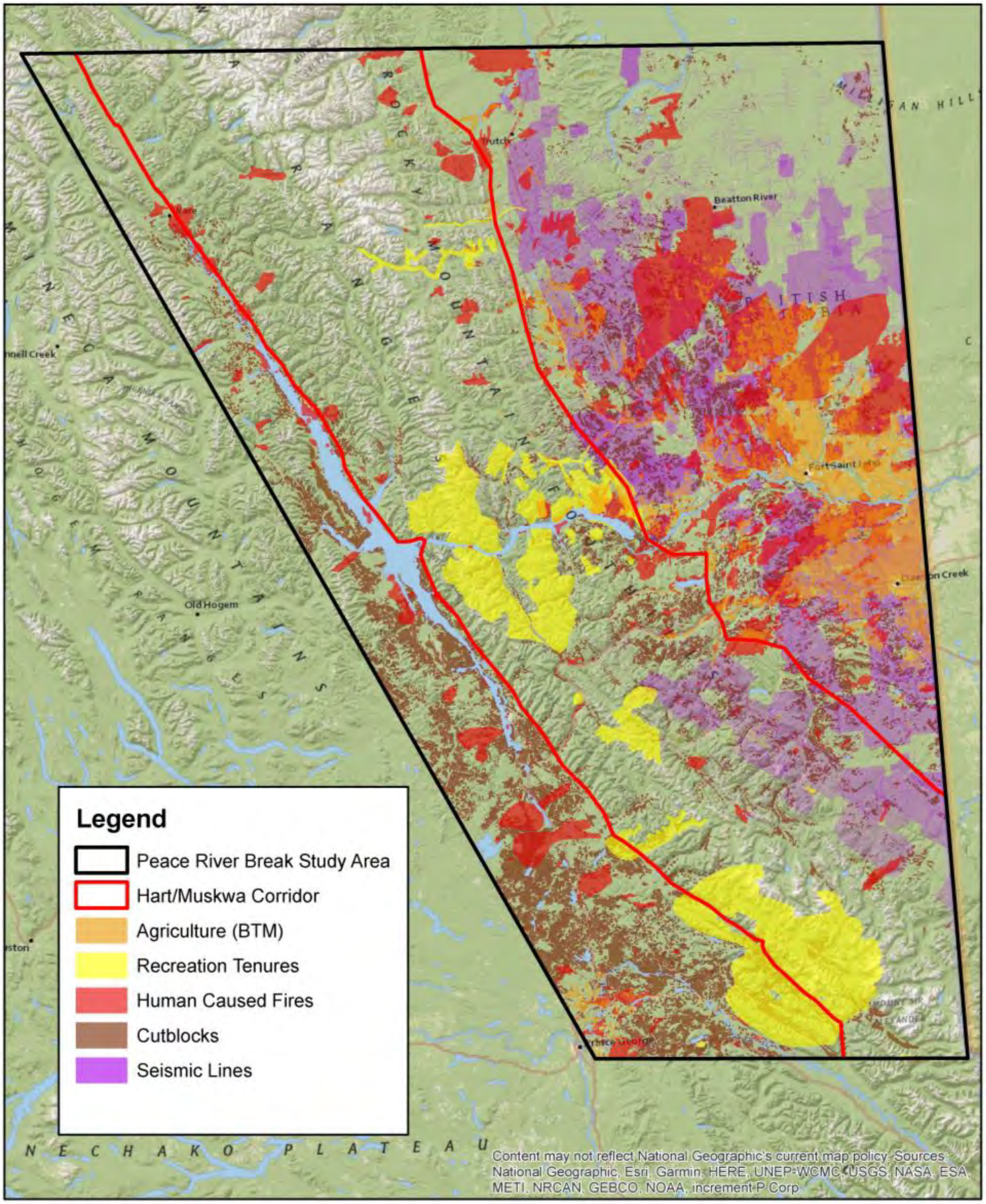
Sorted by descending area within the PRB are human-caused fires, cutblocks, recreation areas (e.g., includes heli-ski tenures), agriculture, and seismic lines (Tables 21 and 22). Approximately 27% of the PRB has a semi-permanent human footprint. Within the Hart/Muskwa Corridor the rank order changes significantly with recreation tenures, followed by cutblocks the primary sources of the footprint. Approximately 19% of the area within the Hart/Muskwa Corridor has a semi-permanent human footprint. Map 19 displays detailed components of the semi-permanent footprint.

Table 21. Soft footprint in the PRB

Disturbance Type	PRB Study Area			
	Actual Footprint		Buffered Footprint	
	Area (Ha)	Percent Study Area	Area (Ha)	Percent Study Area
Agriculture (BTM)	646,596.08	4.77	1,428,825.01	10.55
Cutblocks	1,108,956.52	8.19	1,826,978.69	13.49
Human Caused Fires	1,396,813.47	10.31	1,528,398.66	11.28
Recreation	965,984.92	7.13	1,495,326.28	11.04
Seismic Lines	35,809.60	0.26	2,775,839.86	20.49
Total Footprint	**3,714,317.09**	**27.42**	**6,601,480.64**	**48.74**

Table 22. Soft footprint in the Hart/Muskwa Ranges

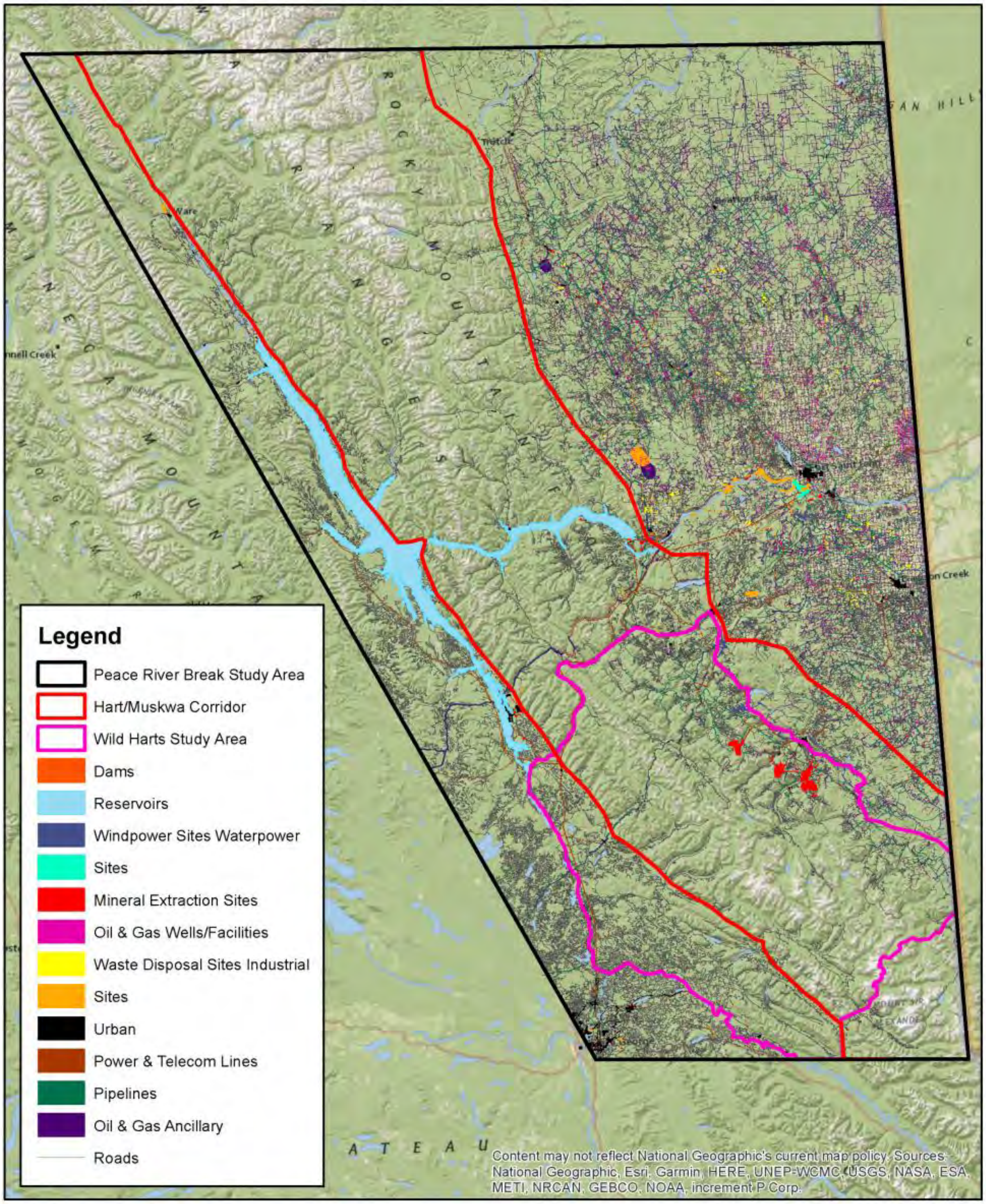
Disturbance Type	Hart/Muskwa Corridor			
	Actual Footprint		Buffered Footprint	
	Area (Ha)	Percent Study Area	Area (Ha)	Percent Study Area
Agriculture (BTM)	13,082.03	0.21	73,815.02	1.21
Cutblocks	233,428.47	3.83	416,751.25	6.83
Human Caused Fires	182,151.32	2.99	207,685.03	3.41
Recreation	771,827.14	12.66	1,209,398.30	19.83
Seismic Lines	3,879.74	0.06	345,203.78	5.66
Total Footprint	**1,141,071.22**	**18.71**	**1,958,179.99**	**32.11**



Map 19. Unbuffered, semi-permanent detailed footprint

Permanent (Hard) Un-buffered Human Footprint

Within the PRB the leading sources of the permanent human footprint (un-buffered) are roads (1.8%), reservoirs (1.3%) and oil and gas and associated infrastructure (0.87%). The total unbuffered human footprint within the PRB is 4.24%. Within the Hart/Muskwa Corridor the permanent human footprint is proportionally much smaller with the unbuffered footprint accounting for just 2.0% of the total landbase. Roads (0.78%), reservoirs (0.61%) followed by oil and gas (0.28%) are the leading sources of the permanent footprint in



Map 20. Detailed unbuffered permanent footprint

the Harts/Muskwa Corridor. Map 20 displays detailed components of the permanent footprint and Map 21 displays the overall permanent footprint.

Within the PRB study area, the total hard human footprint (unbuffered) represents 4.24% of the landbase and 68% when buffered (Table 23). In the buffered analysis, roads and oil and gas development dominate. Within the Hart/Muskwa Corridor, the total hard human footprint (unbuffered) represents 1.96% of the landbase, and 40.39% when buffered. In the buffered analysis roads, urbanization and oil and gas development dominate.

Within the Hart/Muskwa Corridor study area, the total human footprint (unbuffered) represents 2% of the landbase but 40% when buffered (Table 24). Roads also dominate in this landscape followed by oil and gas and mining.

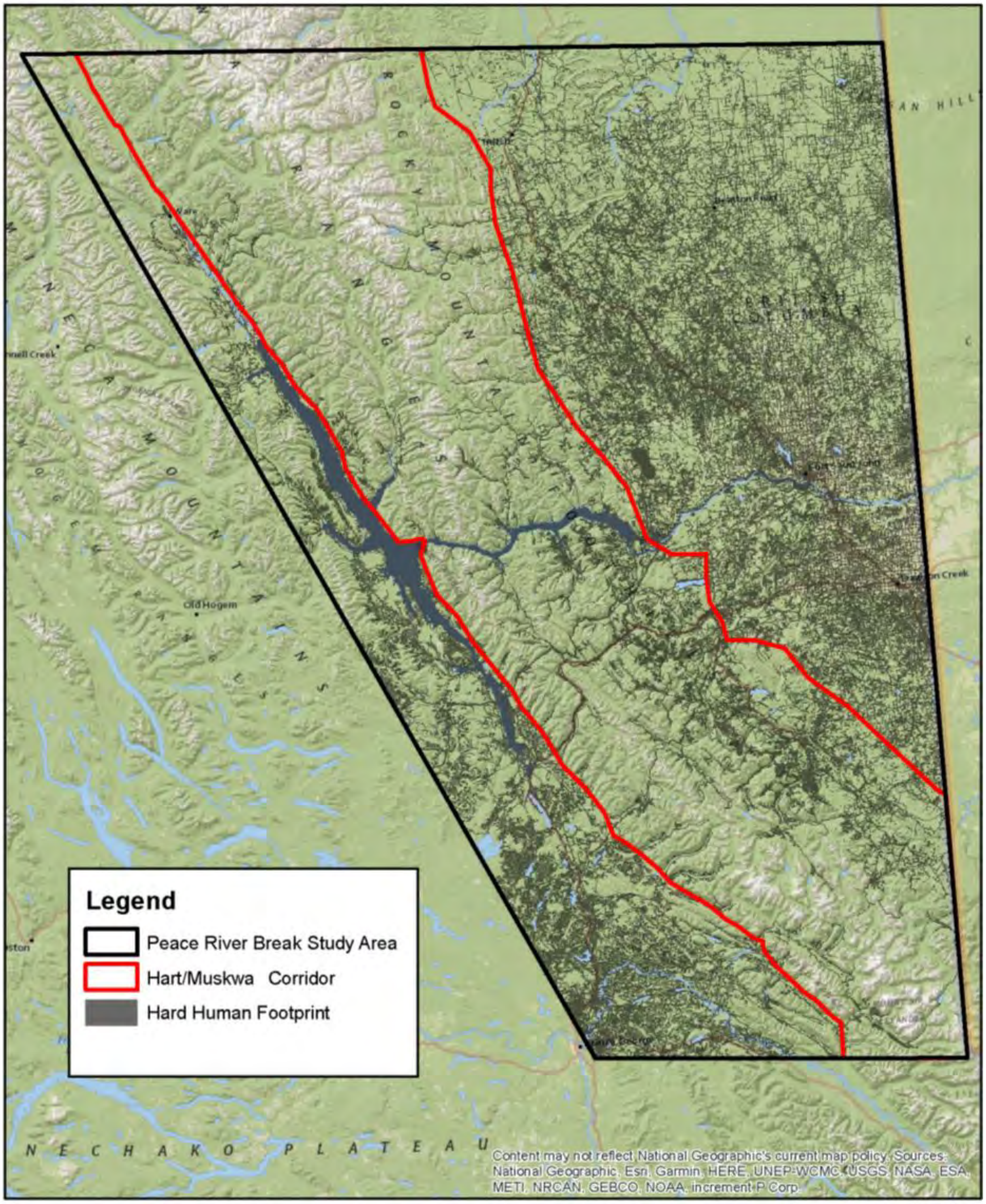
Converted to an index representing the distance to the hard (permanent) footprint 51% of the PRB and 24% of the Hart/

Table 23. Hard footprint in the PRB

Disturbance Type	PRB Study Area			
	Actual Hard Footprint		Buffered Hard Footprint	
	Area (Ha)	Percent Study Area	Area (Ha)	Percent Study Area
Urbanization	19,962.44	0.15	913,400.60	6.74
Road Development	246,899.79	1.82	9,034,537.84	66.7
Oil & Gas Wells & Facilities	28,979.23	0.21	2,897,503.38	21.39
Oil & Gas Ancillary	55,380.65	0.41	840,421.97	6.2
Pipeline Right of Way	40,015.36	0.3	847,011.95	6.25
Waste Disposal Sites	7,178.70	0.05	70,865.51	0.52
Mineral Extraction Sites	13,358.24	0.1	485,582.44	3.59
Industrial Sites	18,230.52	0.13	527,610.76	3.9
Power, Water, Telecom Sewage Lines	10,740.72	0.08	106,653.50	0.79
Active Water Power Sites	1,084.71	0.01	1,998.43	0.01
Active Windpower Sites	6,649.39	0.05	106,295.08	0.78
Reservoirs	176,475.86	1.3	176,475.86	1.3
Dams	44.72	0	177,932.73	1.31
Total Footprint	**574,850.42**	**4.24**	**9,152,155.75**	**67.57**

Table 24. Hard footprint in the Hart/Muskwa Ranges

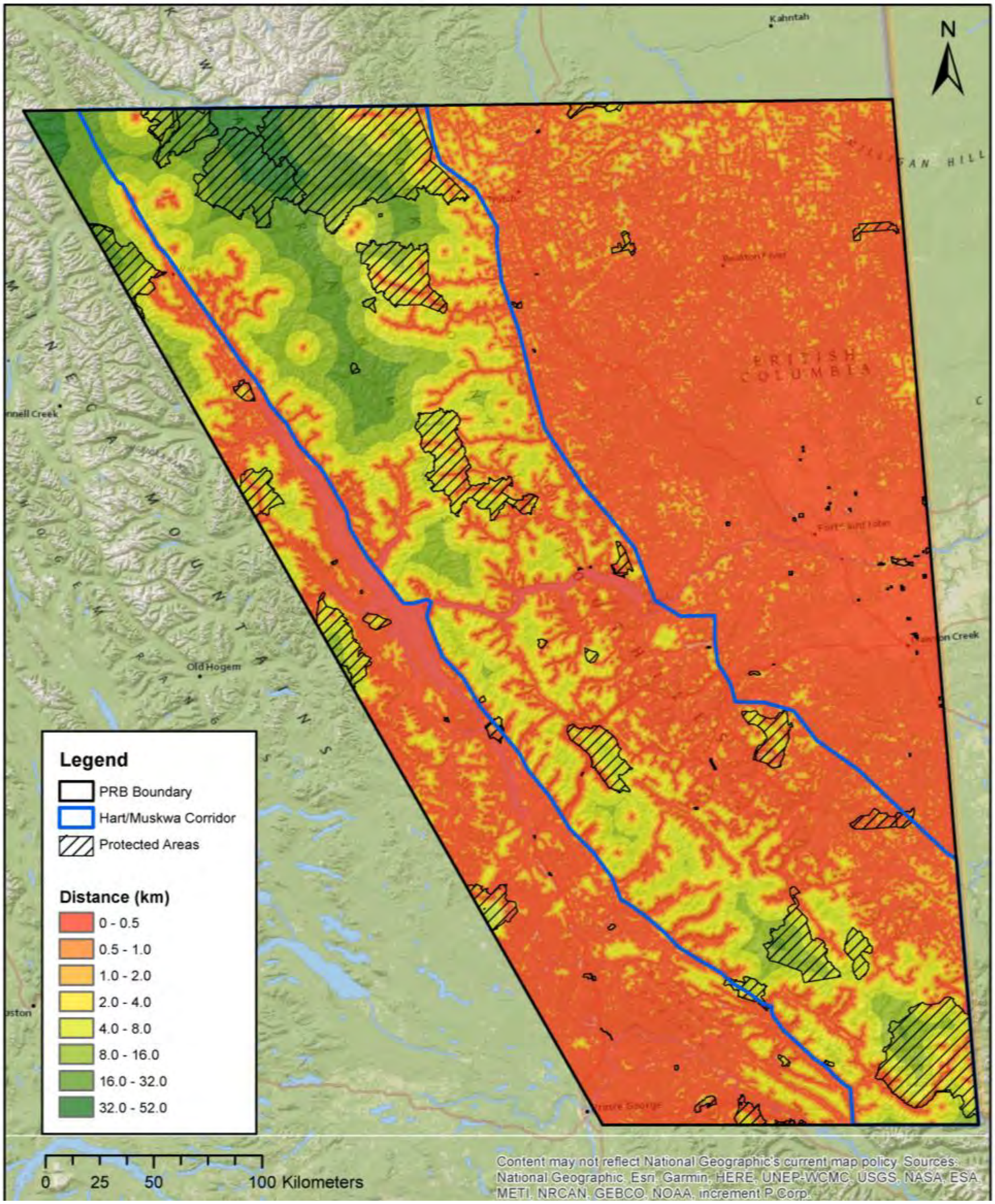
Disturbance Type	Hart/Muskwa Corridor			
	Actual Footprint		Buffered Footprint	
	Area (Ha)	Percent Study Area	Area (Ha)	Percent Study Area
Urbanization	3,073.49	0.05	302,591.54	4.96
Road Development	47,499.57	0.78	2,419,248.65	39.68
Oil & Gas Wells & Facilities	1,347.74	0.02	225,919.53	3.71
Oil & Gas Ancillary	11,480.75	0.19	76,589.96	1.26
Pipeline Right of Way	4,410.17	0.07	90,906.39	1.49
Waste Disposal Sites	138.91	0	2,669.88	0.04
Mineral Extraction Sites	10,782.44	0.18	141,724.25	2.32
Industrial Sites	1,295.67	0.02	94,098.17	1.54
Power, Water, Telecom Sewage Lines	4,351.25	0.07	33,966.22	0.56
Active Water Power Sites	0	0	0	0
Active Windpower Sites	5,540.35	0.09	89,513.98	1.47
Reservoirs	37,359.48	0.61	37,359.48	0.61
Dams	41.25	0	73,409.53	1.2
Total Footprint	**119,718.96**	**1.96**	**2,462,524.00**	**40.39**



Map 21. Overall unbuffered permanent footprint

Table 25. Distance to the hard human footprint

Km	PRB %	Hart/Muskwa %
0 - 0.5	51.04	24.23
0.5 - 1.0	11.91	10.13
1.0 - 2.0	9.18	12.55
2.0 - 4.0	8.59	15.59
4.0 - 8.0	7.81	15.34
8.0 - 16.0	6.21	12.21
16.0 - 32.0	4.13	7.97
32.0 - 50.0	1.13	1.98



Map 22. Distance to hard human footprint

Muskwa Corridor is within 0.5 km from the hard human footprint (Table 25 and Map 22).

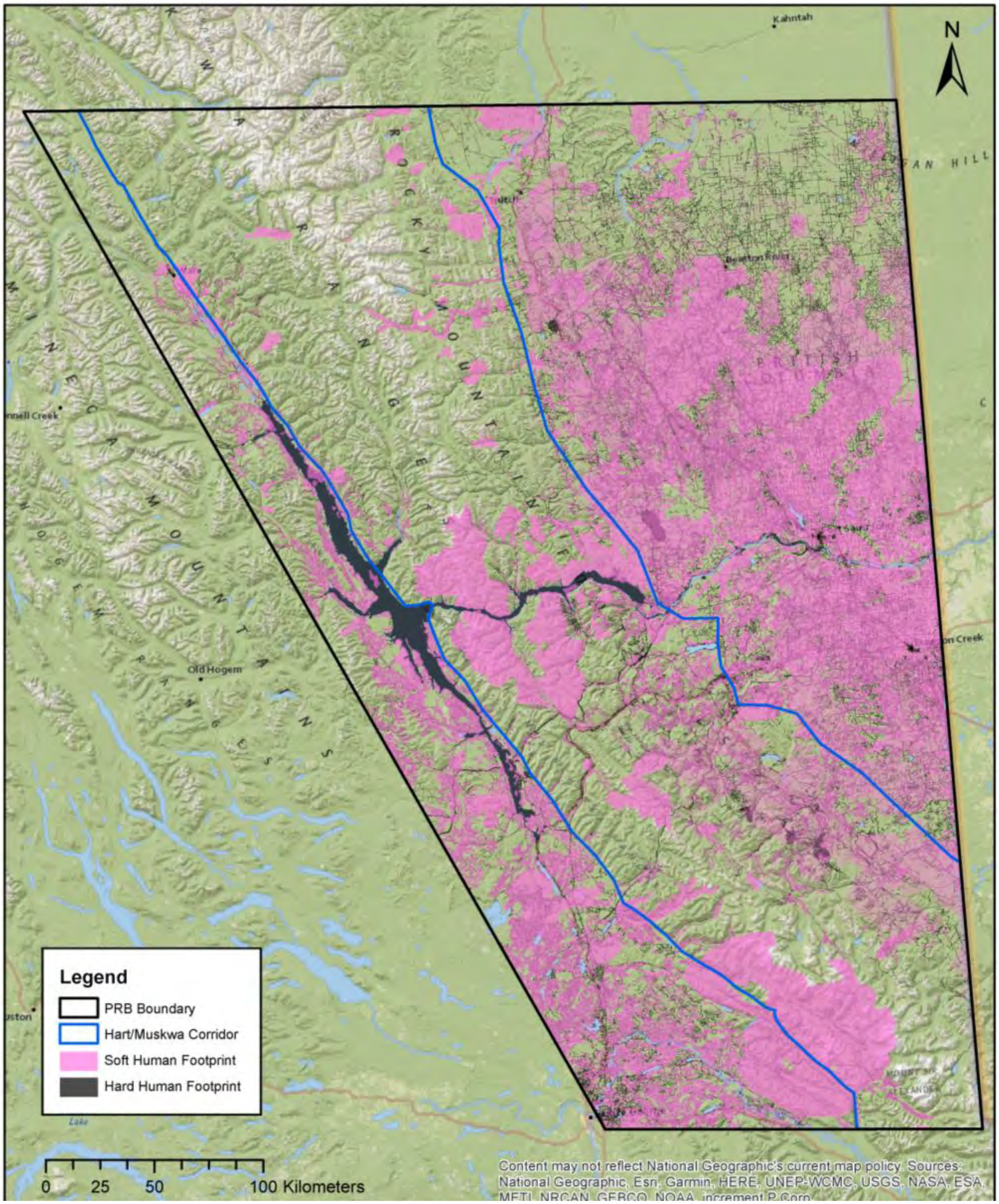
Overall Footprint

When combined, the hard and soft footprints tell a compelling story of the impact of human use and development on the landscape. Within the PRB, road development, oil and gas, seismic lines are the top ranked developments by area. Within the Hart/Muskwa ranges while roads remain the primary development by area, recreation and forestry cutblocks are next (Table 26).

Note that these footprint maps are presented unbuffered given that there can be disagreement over the appropriate width of buffers and because buffering these footprints at scales reproducible in a report makes fairly solid blocks of color thus rendering it less useful (Map 23).

Table 26. Ranked area of development

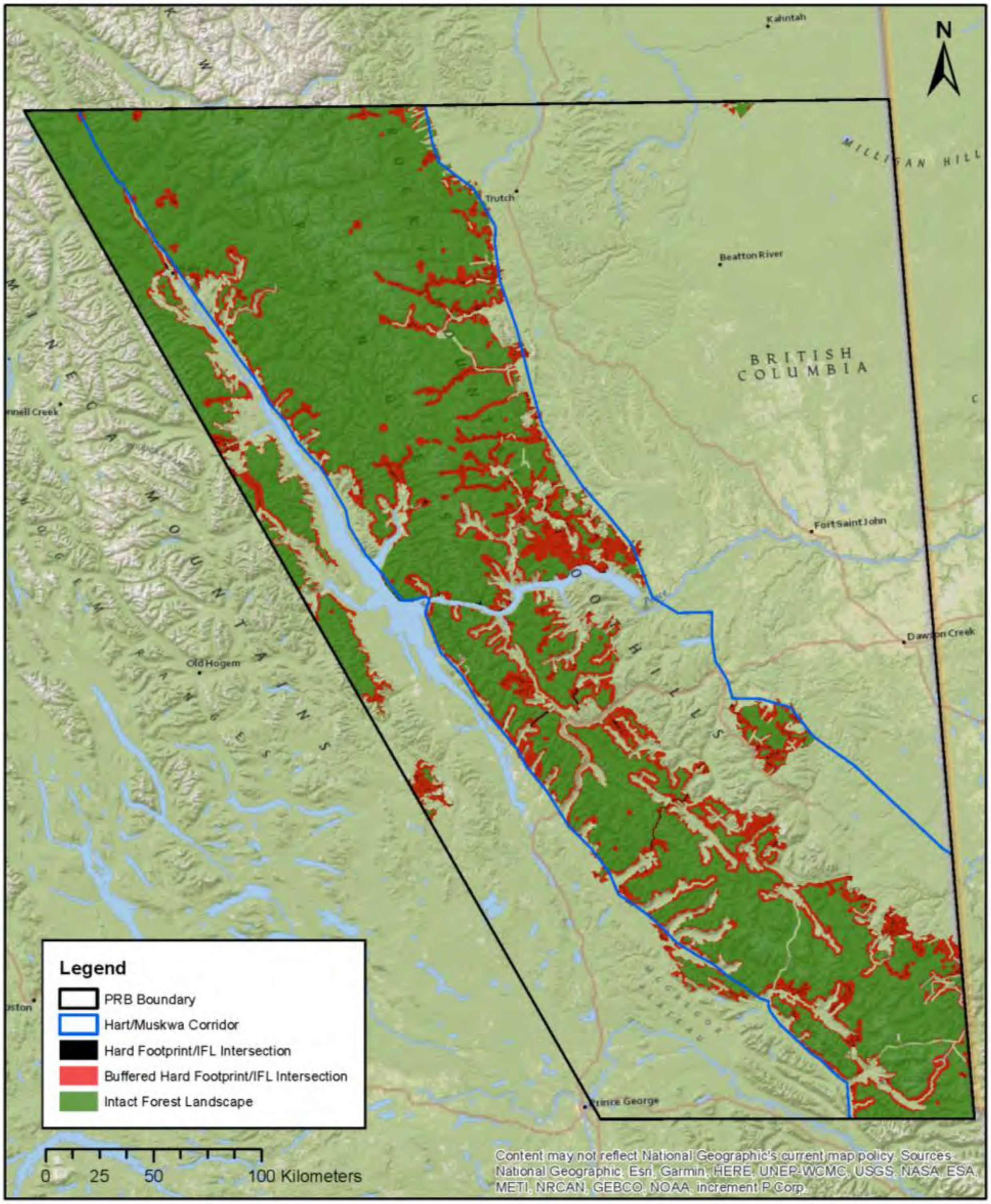
Development	Peace River Break	Hart/Muskwa Ranges
	Rank Order	Rank Order
Road Development	1	1
Oil & Gas Wells & Facilities	2	6
Seismic Lines	3	4
Cutblocks	4	3
Human Caused Fires	5	7
Recreation	5	2
Agriculture (BTM)	6	12
Urbanization	7	5
Pipeline Right of Way	8	10
Industrial Sites	9	9
Mineral Extraction Sites	10	8
Dams	11	13
Reservoirs	12	14
Power, Water, Telecom, Sewage	13	15
Active Windpower Sites	14	11
Waste Disposal Sites	15	16
Active Water Power Sites	16	17



Map 23. Hard and soft unbuffered human footprint

Intact Forest Landscape Analysis Revisited

Using the final permanent footprint we developed, we revisited the intact forest landscape (IFL) mapping produced in 2013 by Global Forest Watch (see maps 3-6). We performed an intersection between the GFW map and our footprint data to identify what changed over that time period. We note that while some differences are a result of on the ground development others are the result of slightly different buffering distances or data sources in contributing layers. Map 24 shows the original IFL in green with the area in red the area of net loss of IFL since 2013.



Map 24. Intact forest landscapes revised

Changes to the unbuffered hard human footprint within the PRB show a 0.17% loss of IFL and a 0.16% within the Hart Muskwa Ranges. The buffered footprint changes by approximately 20% in both study areas (Table 27).

Future Development/Resource Potential

Future resource development potential was examined for four leading resource activities (mineral potential, oil and gas potential, wind power potential, and forestry potential) as well as for roads (Table 28).

Table 27. Intersection of hard human footprint with IFL

Hard Human Footprint (2018) / IFL (2013) Intersection	PRB		H/MRC	
	Hectares	% Area	Hectares	% Area
IFL Original	5079769	100	4459029.75	100
Unbuffered Hard Human Footprint	8583.621	0.17	7278.7	0.16
Buffered Hard Human Footprint	1018529	20.05	887768.56	19.91

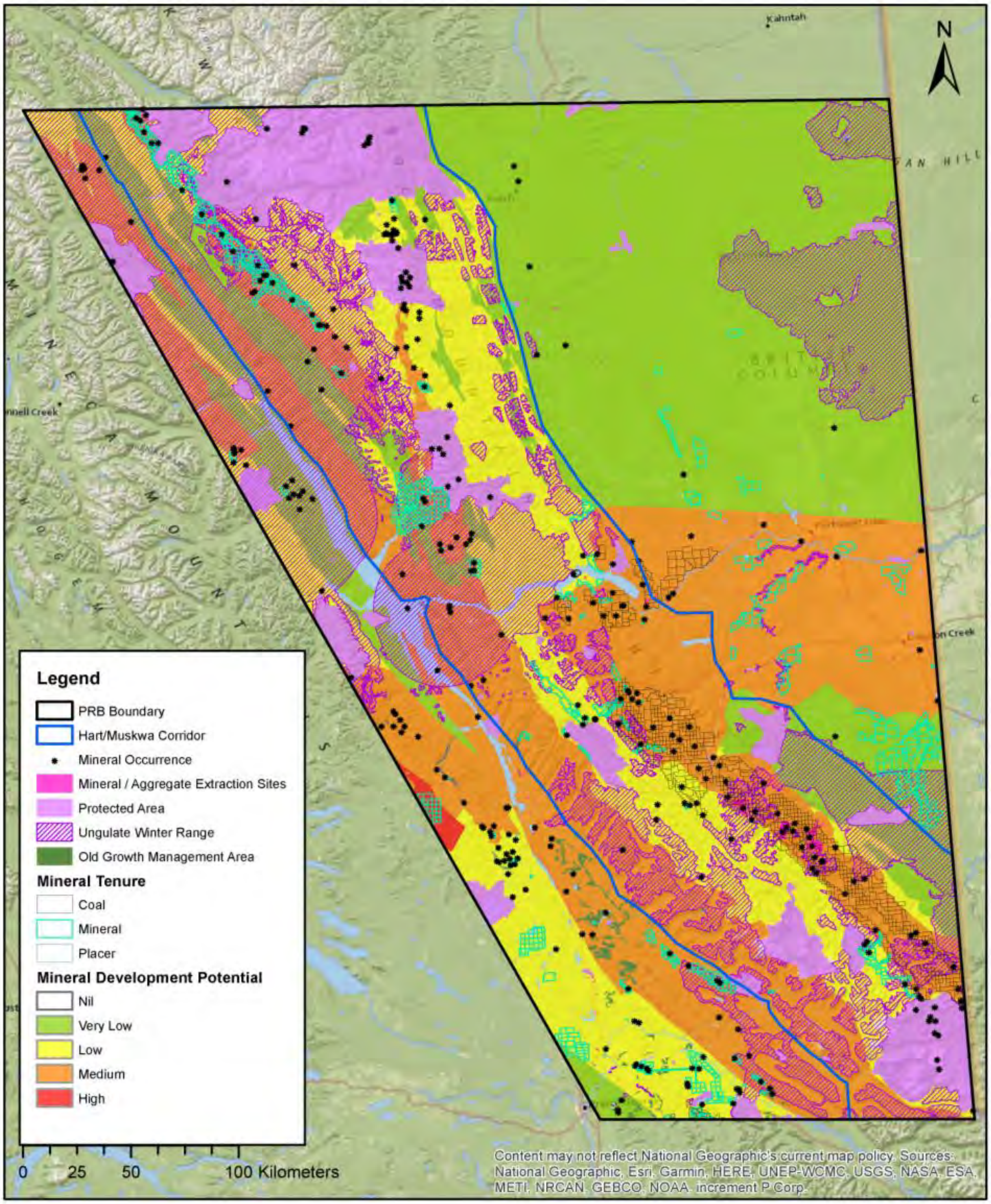
Table 28. Ranked potential suitability of study area by resource development

Ranked Potential		Road Potential		Mineral Potential		Oil & Gas Potential	
Rank #	Potential	PRB	H/MR	PRB	H/MR	PRB	H/MR
0	Nil	11.84	18.98	11.84	18.98	69.74	91.52
1	Very Low	0.01	0.02	36.4	13.66	0	0
2	Low	0.36	0.67	19.43	31	0.3	0.55
3	Medium	6.26	12.25	32.08	36.36	7.94	3.68
4	High	25.57	44.58	0.26	0	15.16	3.88
5	Very High	55.96	23.49	0	0	6.87	0.37

Ranked Potential		Wind Potential		Harvest Potential	
Rank #	Potential	PRB	H/MR	PRB	H/MR
0	Nil	11.84	18.98	37.15	49.84
1	Very Low	0.65	1.29	0.62	0.61
2	Low	16.74	28.77	2.53	5.01
3	Medium	42.9	37.16	9.68	13.72
4	High	27.87	13.81	22.28	20.22
5	Very High	0	0	27.75	10.59

Mineral Development Potential

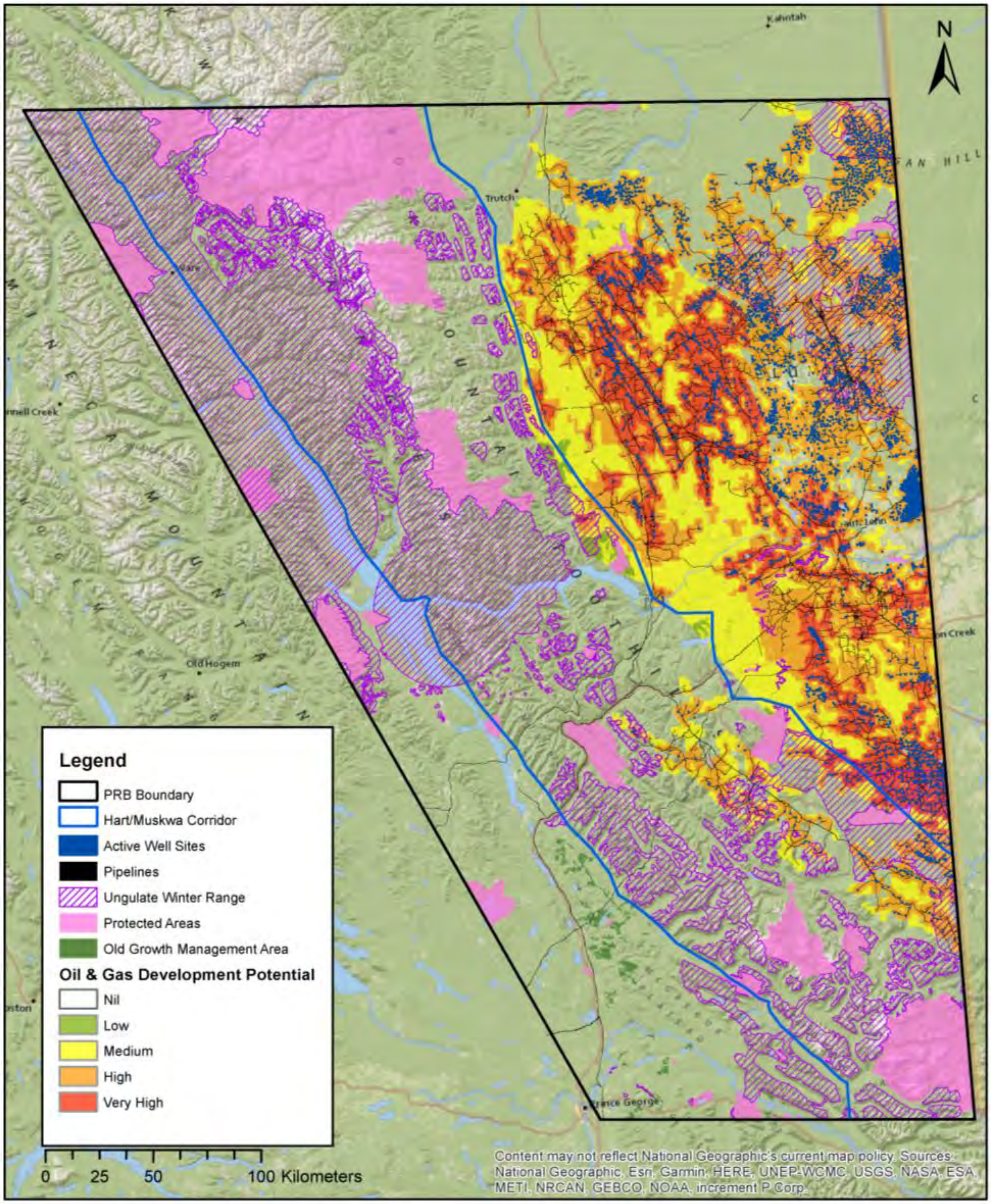
Identifying mineral development potential involved combining data from four sources: 1) BC mineral potential, 2) coal geology, 3) mineral, placer and coal tenures, and 4) mineral occurrences. The results of the analysis ranged from 0 = Nil to, 5 = Very High. Within the PRB, more than three-quarters of the area is ranked between Very Low to Medium. No area within the PRB was classified as Very High. Within the Hart/Muskwa Corridor the biggest proportion (36%) of the area was rated as medium potential followed by 31% with low potential. No area was classified as High or Very High within the Hart/Muskwa Corridor (Map 25).



Map 25. Mineral development potential

Oil and Gas Development Potential

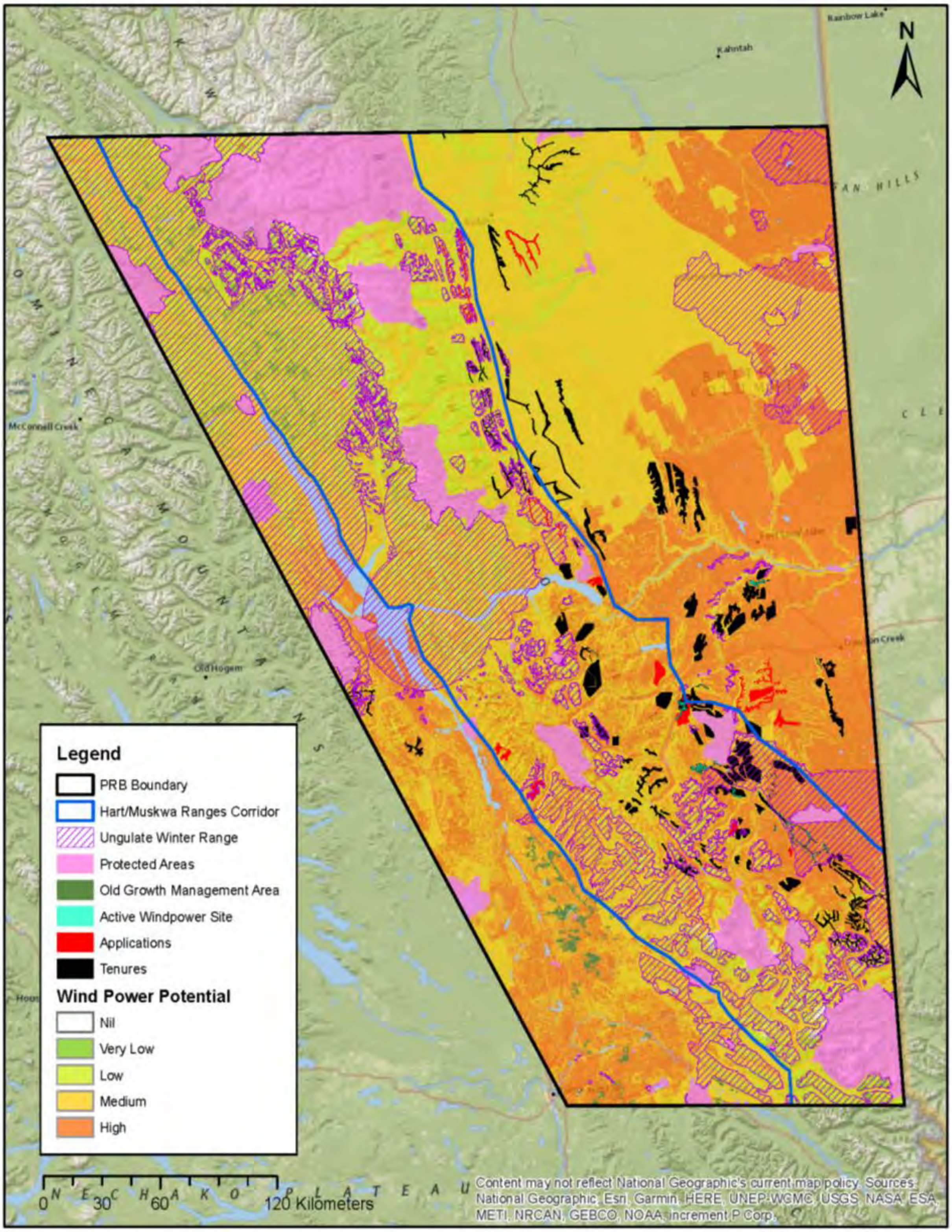
Potential for oil and gas development for the PRB was developed by integrating spatial data available from British Columbia (BC) government sources on oil and gas geology, oil and gas resource sites, pipelines, wells, elevation, and slope. Within the PRB, 70% of the total area has no oil and gas potential but the areas that do have medium to very high potential. Within the Hart/Muskwa Corridor little of the land base (less than 9%) has oil and gas potential with areas of potential having medium and high rankings (Map 26).



Map 26. Oil and gas development potential

Wind Power Development Potential

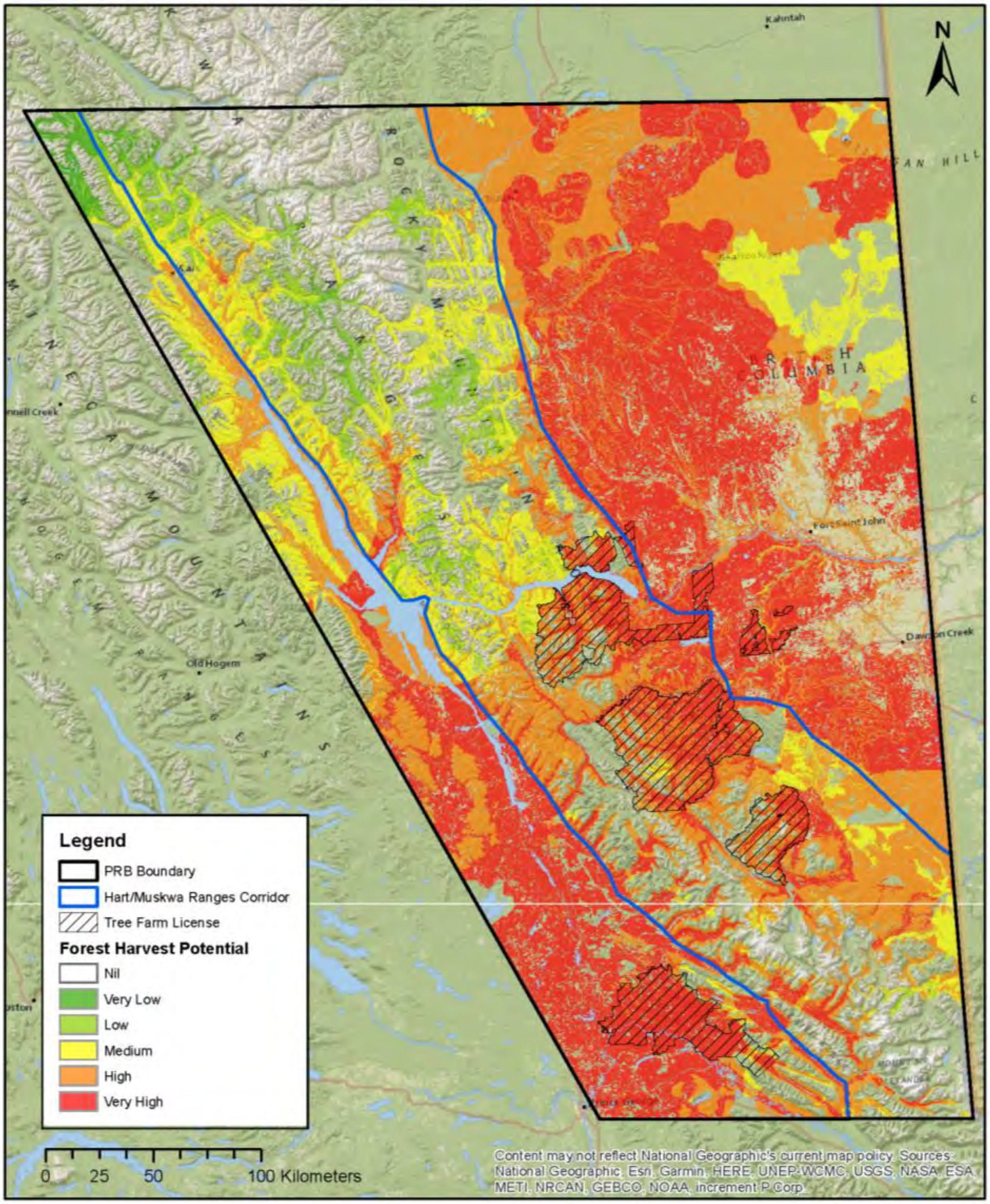
The results of the analysis were divided into 5 categories: 0 = Nil, 1 = Very Low, 2 = Low, 3 = Medium, 4 = High, 5 = Very High. A significant proportion (71%) of the PRB has medium to high wind potential. Within the Hart/Muskwa Ranges the potential wind power development ratings identified 66% of the landbase with a low to medium wind potential (Map 27).



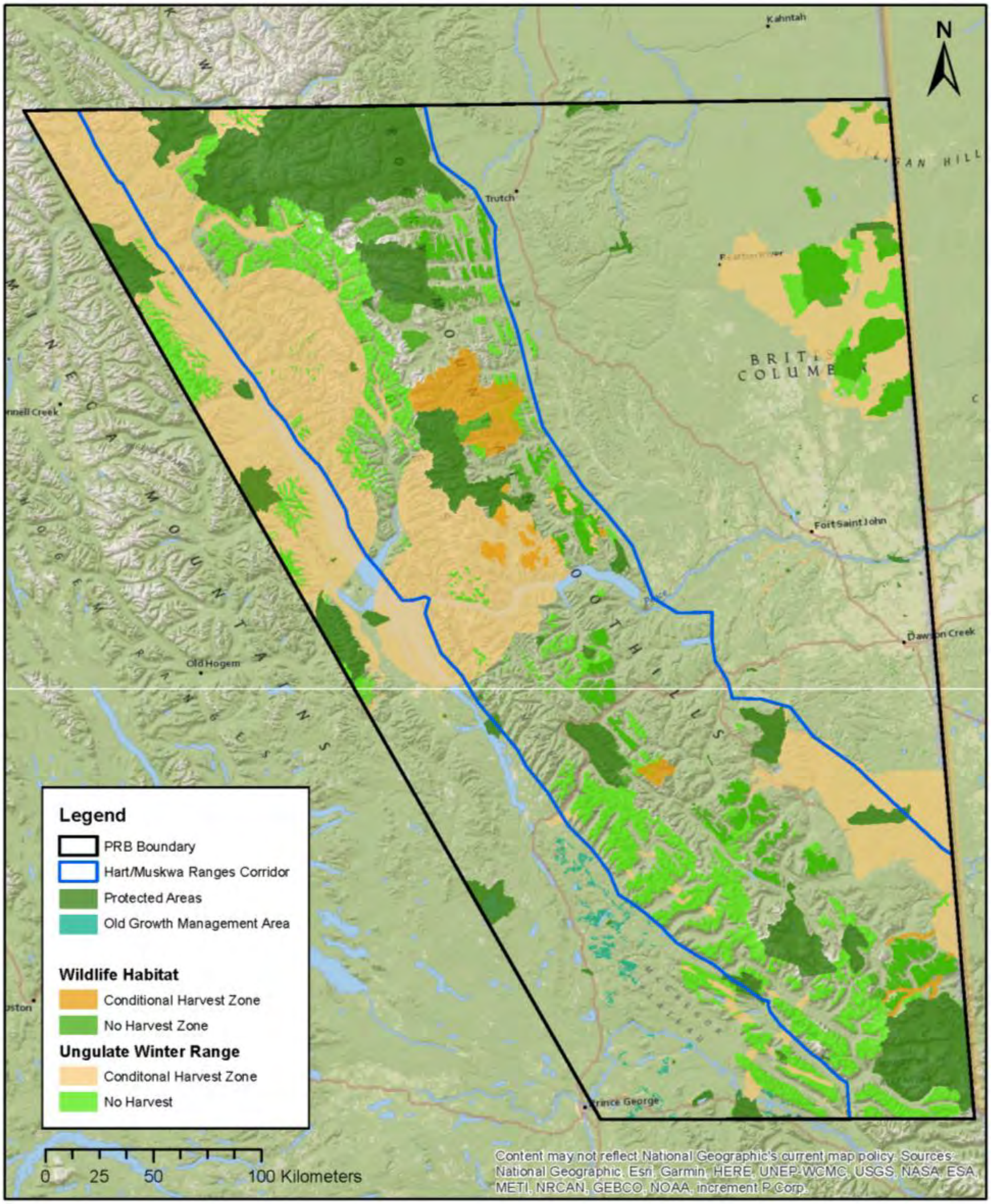
Map 27. Wind power development potential

Forestry Development Potential

Forest development potential in the PRB was bimodal with 37% having no potential but 50% ranked as high to very high potential. There was a similar but opposite trend for the Hart/Muskwa Corridor with 50% ranked as no potential and approximately 30% with high to very high potential. Map 28 identifies forest development potential on the landscape while Map 29 identifies current forest harvest restrictions that will affect the harvest potential.



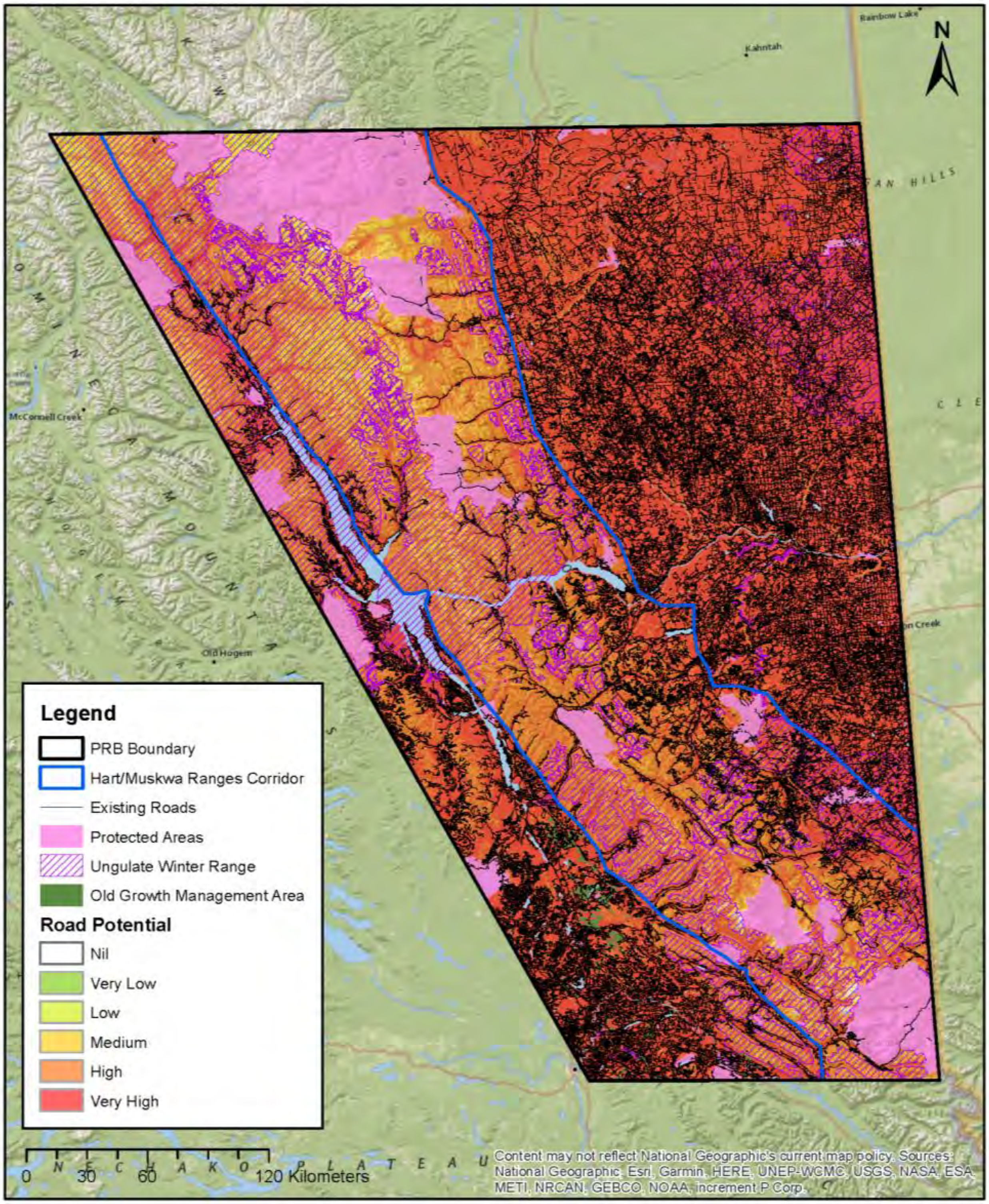
Map 28. Forestry development potential



Map 29. Current forest harvest restrictions

Road Development Potential

Road potential was high in both the PRB and the Hart/Muskwa Corridor with the majority of the area rated as high to very high (Map 30).

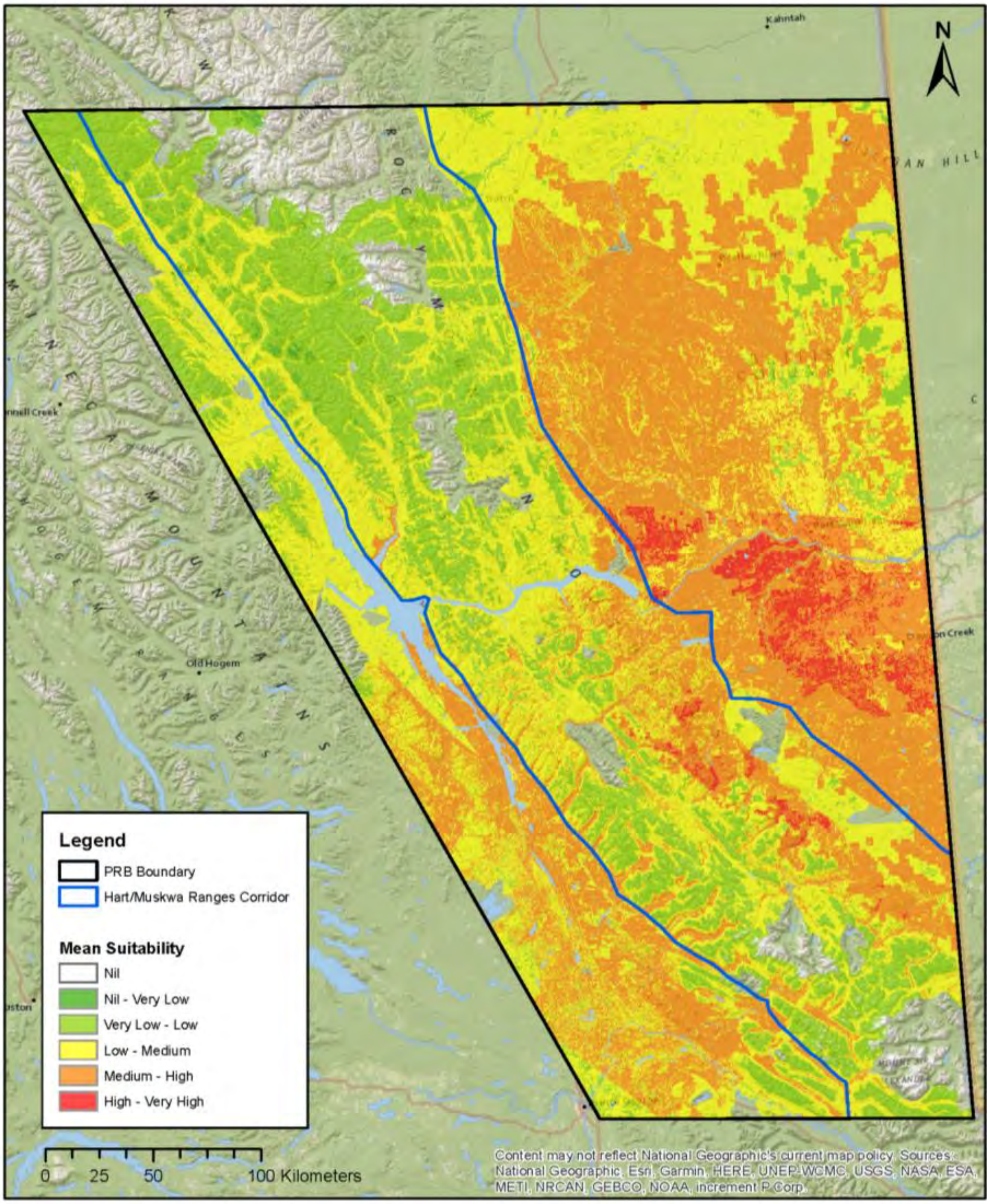


Map 30. Road development potential

Overall Resource Development Potential

Overall resource development potential was calculated on all five of the resource development suitability layers. As various statistics illustrate different phenomena we have presented them visually using three differing statistics: the mean value of all resource potentials combined, the maximum value of all resource potentials, and the sum of all resource potentials (table 29).

Mean suitability shows the average score from Nil (0) to Very High (5) for all resource development potentials combined. It is the most conservative method of calculating overall potential (Map 31).

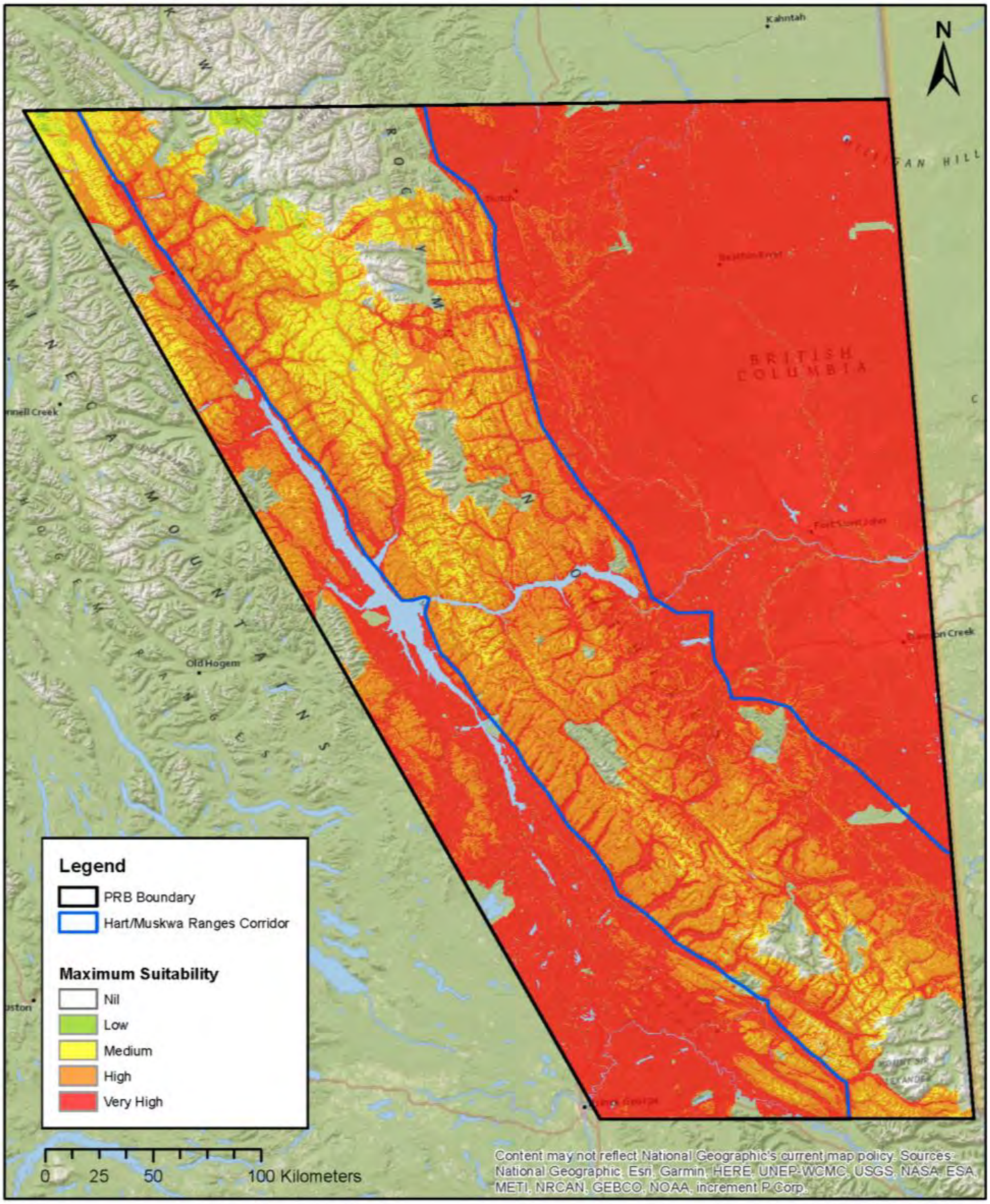


Map 31. Mean suitability/potential for resource development

The maximum suitability approach to assessing resource potential is the least conservative method of rating development potential. In this approach the highest ranking of any of the five resource uses for any raster cell is given (Map 32).

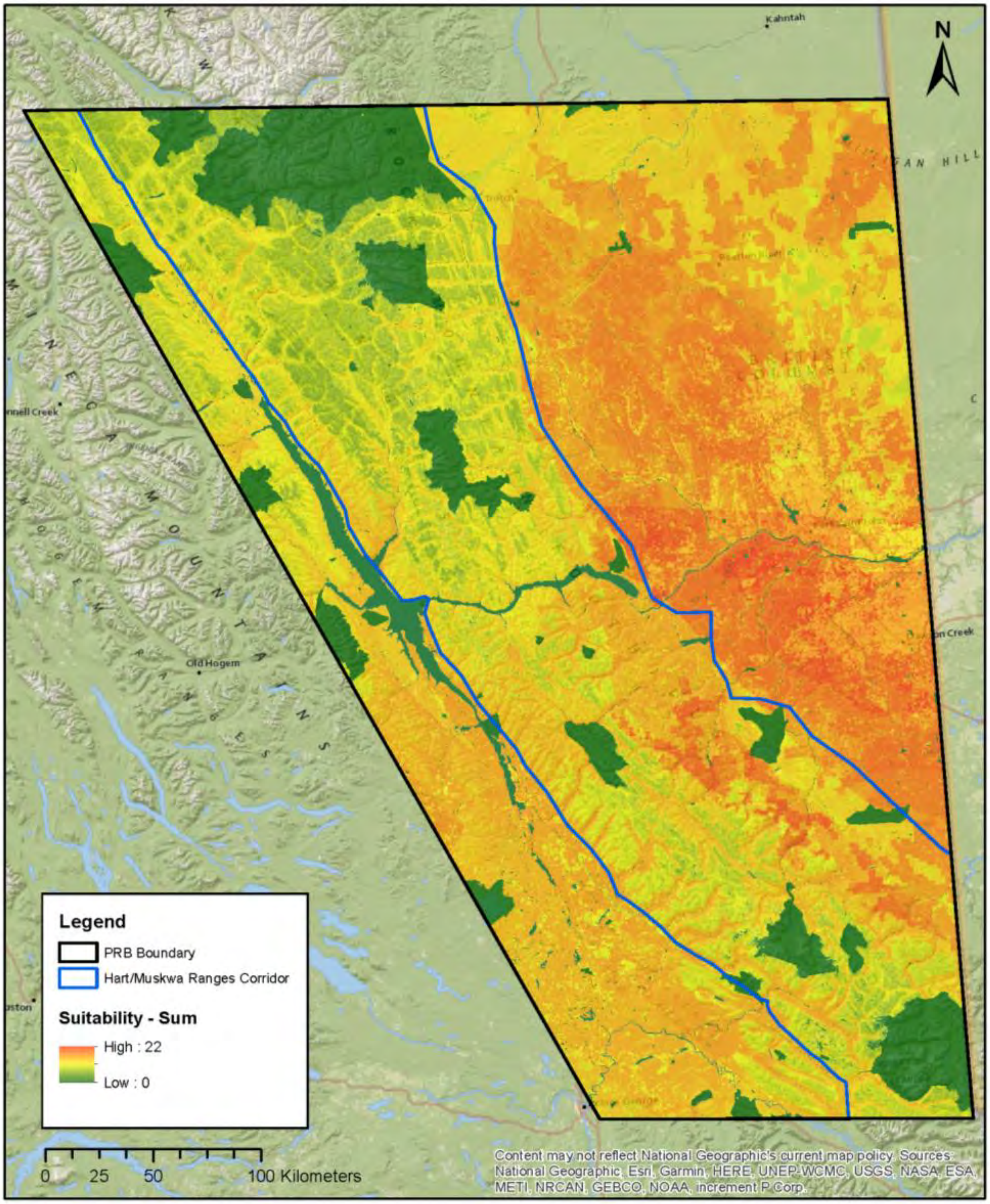
Finally, using an additive model Map 33 displays the sum of all resource potentials in the area.

Examining the overlap between maximum resource development potential and the existing soft/hard permanent footprint

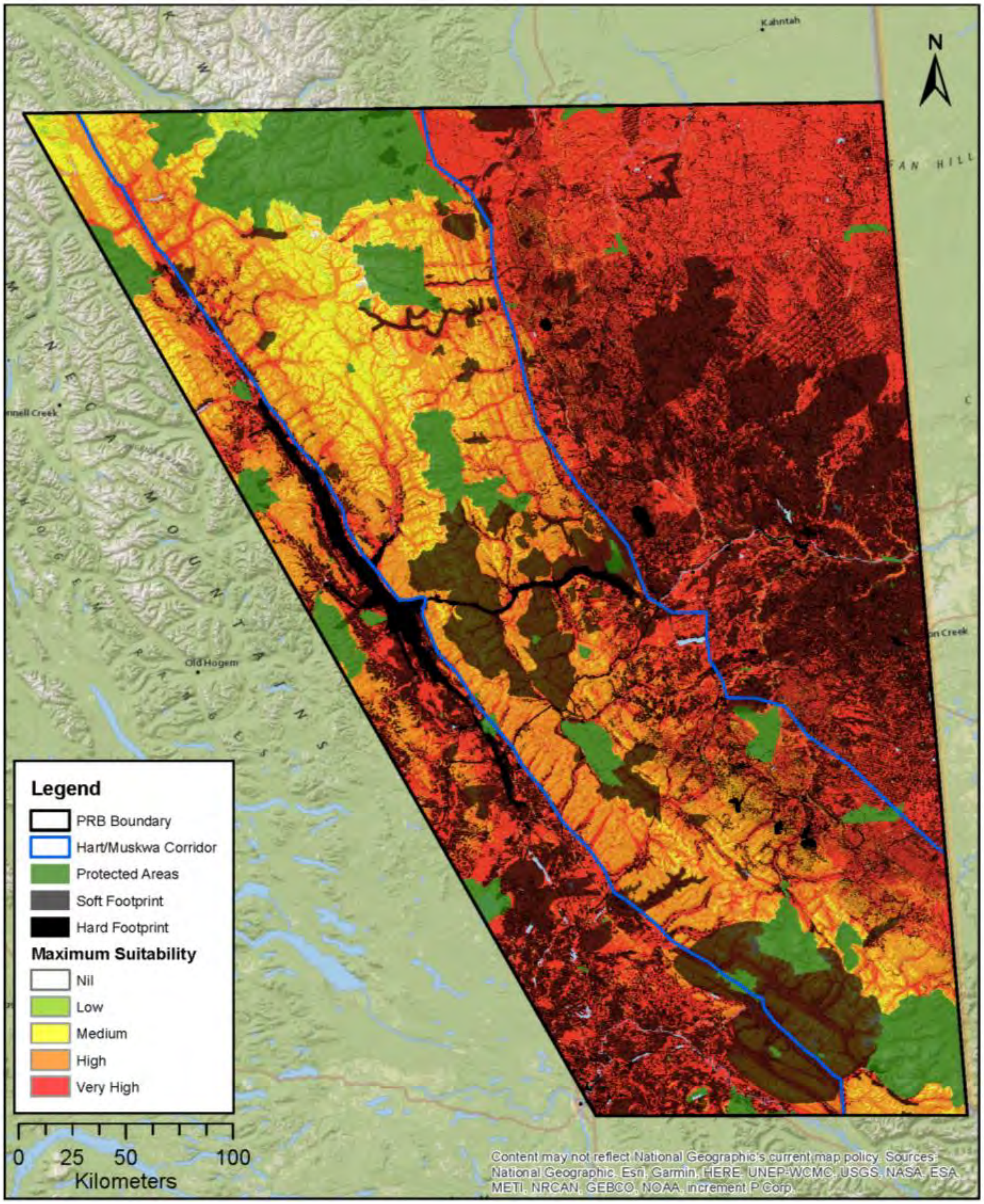


Map 32. Maximum suitability/potential for resource development

identifies potential priority areas where there is no (or minimal) current footprint but strong potential for future development (Map 34). These highlighted areas suggest potential priorities for closer examination and interim protection if conservation is warranted.



Map 33. Sum of suitability/potential for resource development



Map 34. Maximum suitability for resource development combined with existing hard and soft footprint

Table 29. Mean and maximum resource development potential

Suitability	Mean (Average) PRB	Mean (Average) H/MRC	Maximum PRB	Maximum H/MRC
Nil	11.84	18.98	11.84	18.98
Nil - Very Low	0.18	0.4	0	0
Very Low - Low	18.97	32.58	0.31	0.6
Low - Medium	35.75	34.3	6.26	12.22
Medium - High	31	13.14	24.53	43.17
High - Very High	2.26	0.61	57.06	25.02

Climate Change and the PRB

In addition to the already pressing conservation demand in the area, the PRB is projected to experience significant climate change impacts. Climate change models can serve as valuable tools and help planners cope with the challenges of planning for different climate conditions. Furthermore, climate change models can help scientists and planners better understand local climate change hazards such as severe droughts, floods, heat waves, and losses to agricultural productivity. Metrics used to describe climate change potential or susceptibility are numerous. In this section we present a few metrics to help inform discussions of the potential impacts of climate change in the region.

Climate projections for the Peace River region in the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099) are summarized below. Projections are derived from PCIC's online tool, "Plan2Adapt" Projected changes are calculated from the baseline historical period (1961-1990) for average (mean) temperature, precipitation

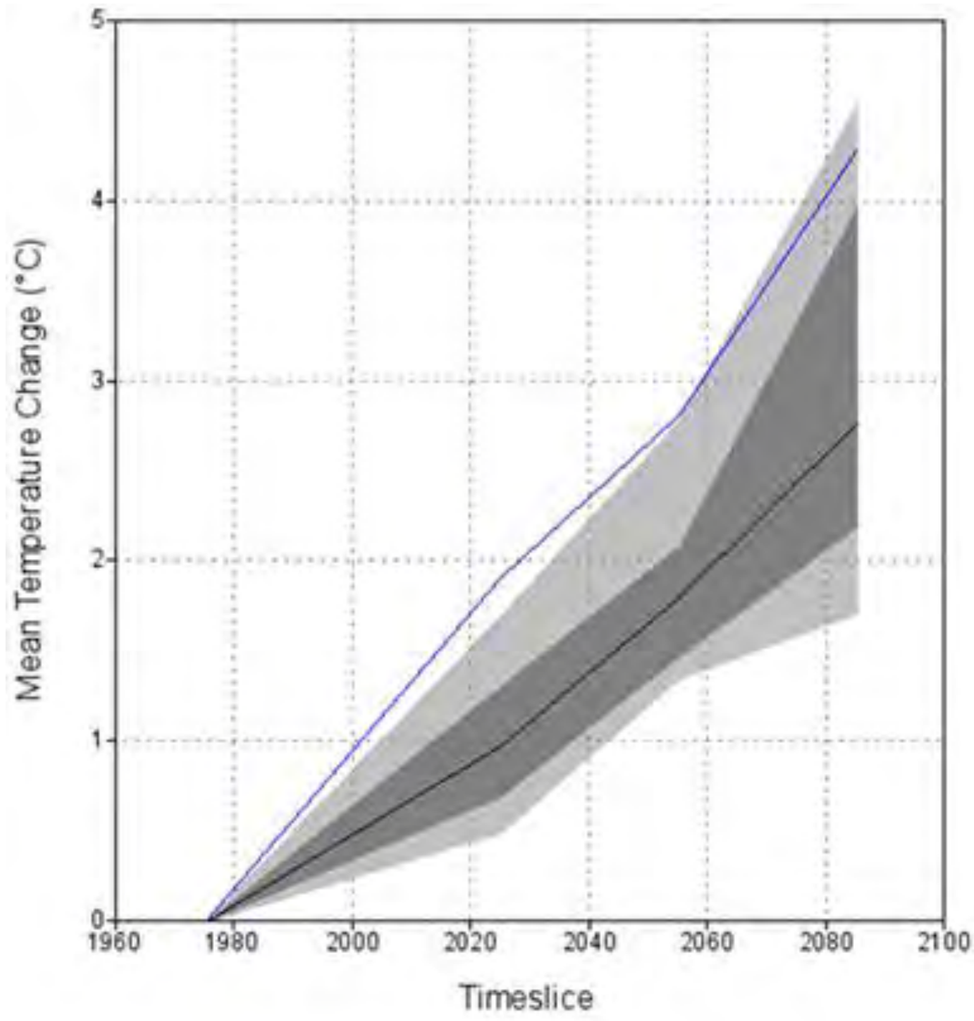


Figure 10. Mean Annual Temperature Change (˚C), for the Peace River Region from 1970 – 2099 where projects are modeled according to a PCIC-standard set of GCM projections using the PCIC online tool 'Plan to Adapt'. The black line indicates the mid-point (median) in the set. The blue line indicates the model used for display purposes (CGCM3 A2 run 4). The dark grey shading shows the middle 50% (25th to 75th percentiles), representing half of the projections in the set. The light grey shading shows the range according to 80% of the climate change projections used (10th to 90th percentiles).

and several climate variables. The projected changes represent the ensemble median, which is a mid-point value, chosen from a PCIC's standard set of Global Climate Model (GCM) projections.

Annual mean temperatures, frost-free days and growing degree-days are all projected to increase in the Peace River region (Fig. 10-15). Annual mean temperatures are projected to increase by 1°C in the 2020s, 1.8°C in the 2050s, and 2.8°C in the 2080s (Fig. 10). Frost-free days are projected to increase annually by 9, 16, and 26 days in

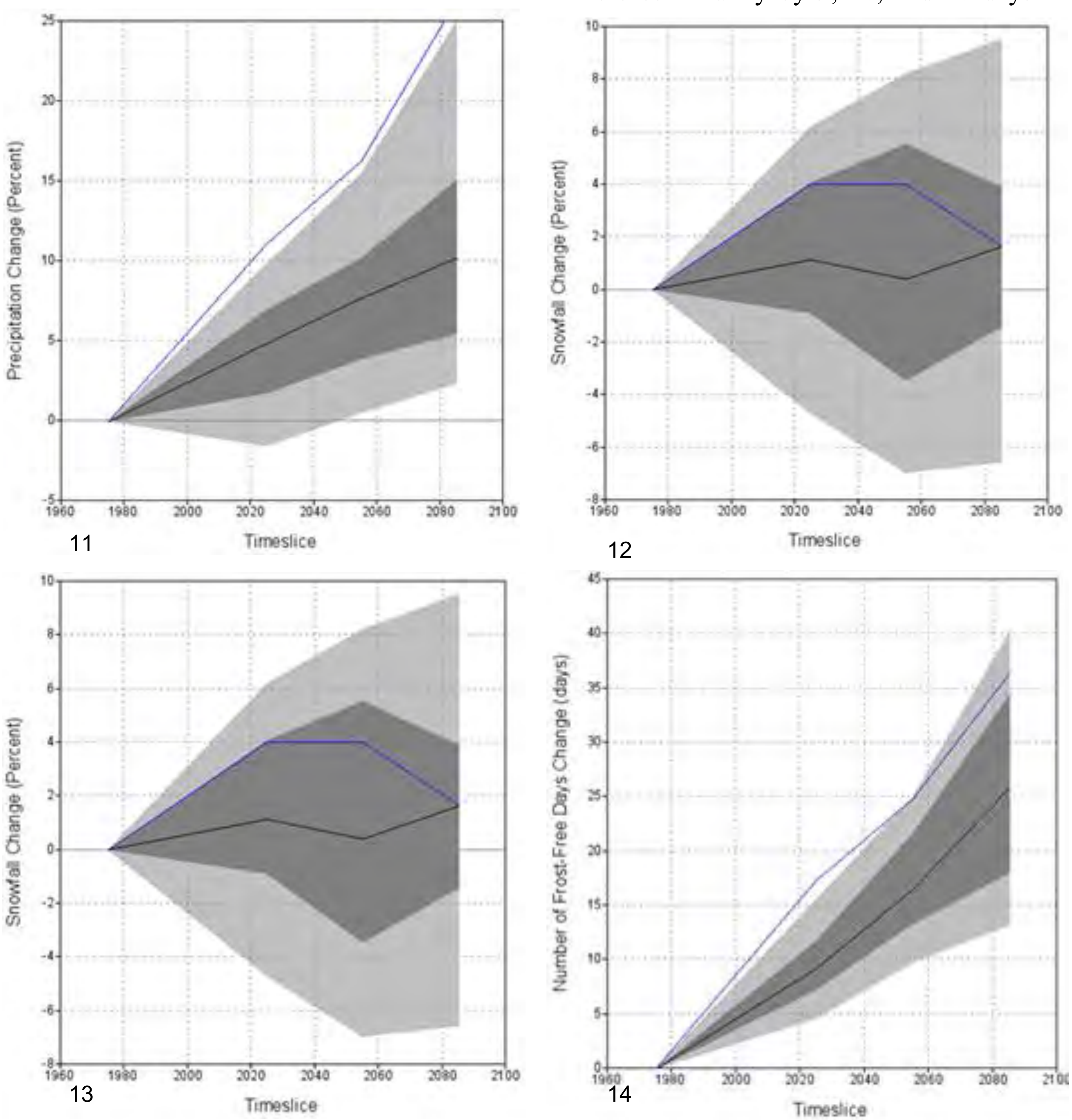
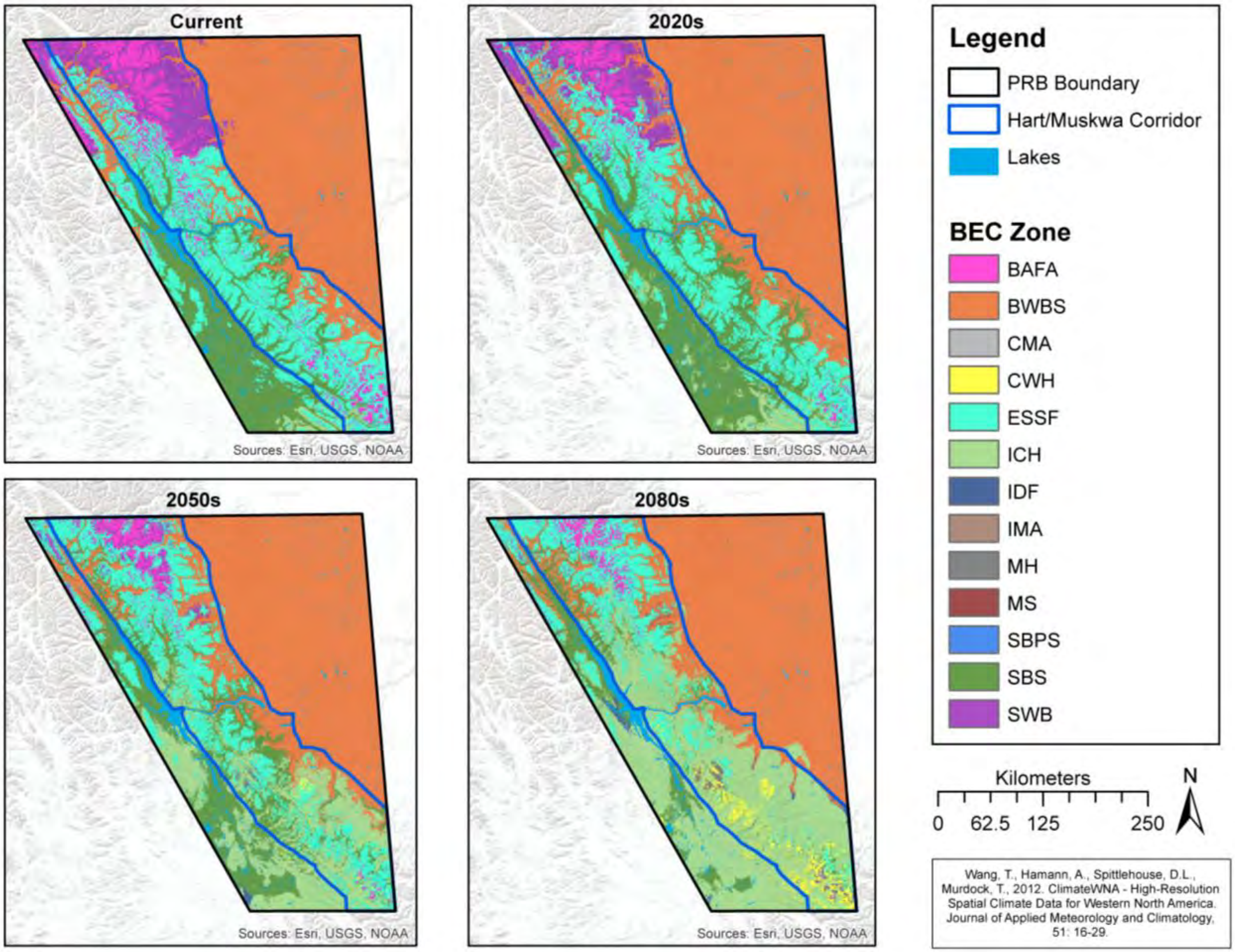


Figure 11-14. Mean annual climate changes in the Peace River from 1970 – 2099 where projections were modeled according to a PCIC-standard set of GCM projections using the PCIC's online tool, 'Plan2Adapt.' The black line indicates the mid-point (median) in the set. The blue line indicates the model used for display purposes (CGCM3 A2 run 4). The dark grey shading shows the middle 50% (25th to 75th percentiles) representing half of the projections in the set. The light grey shading shows the range according to 80% of the climate change projections used (10th to 90th percentiles).



Map 35. Current and projected BEC zones

the 2020s, 2050s and 2080s respectively (Fig. 14). The 2020s, 2050s and 2080 are projected to experience 129, 225, and 364 more growing degree-days annually (Fig. 13).

Although climate models project both increasing and decreasing annual precipitation in the future, the median trend indicates a slight increase (Fig. 11-12). While the amount of summer precipitation is projected to largely remain the same, indicating that a slight increase or decrease is probable, a slight increase in the amount of precipitation falling as snow over the winter is projected. Conversely, a significant decrease in the amount of snowfall is projected in the spring seasons.

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

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

Biogeoclimatic (BEC) zones are a fundamental unit for much of the land use planning, forest management and targets for protected areas representation in British Columbia. Map 35 displays current BEC zones within the study area and projected BEC zones (as per Wang et al., 2016) for 2020, 2050 and 2080.

When examined as a proportion of the landscape, Interior Cedar Hemlock (ICH) forest types are expected to increase the most in both the PRB and Hart/Muskwa Corridor study areas with a corresponding loss of almost all other forest types (Figs 15 and 16).

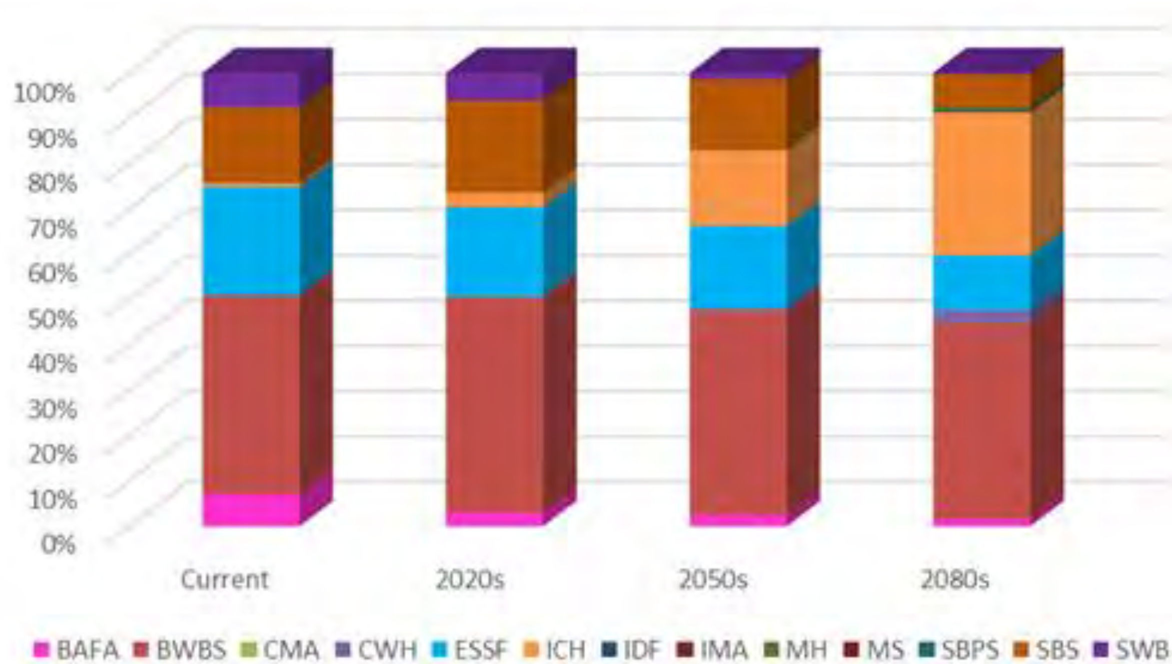


Figure 15. Projected distribution of BEC Zones in the PRB

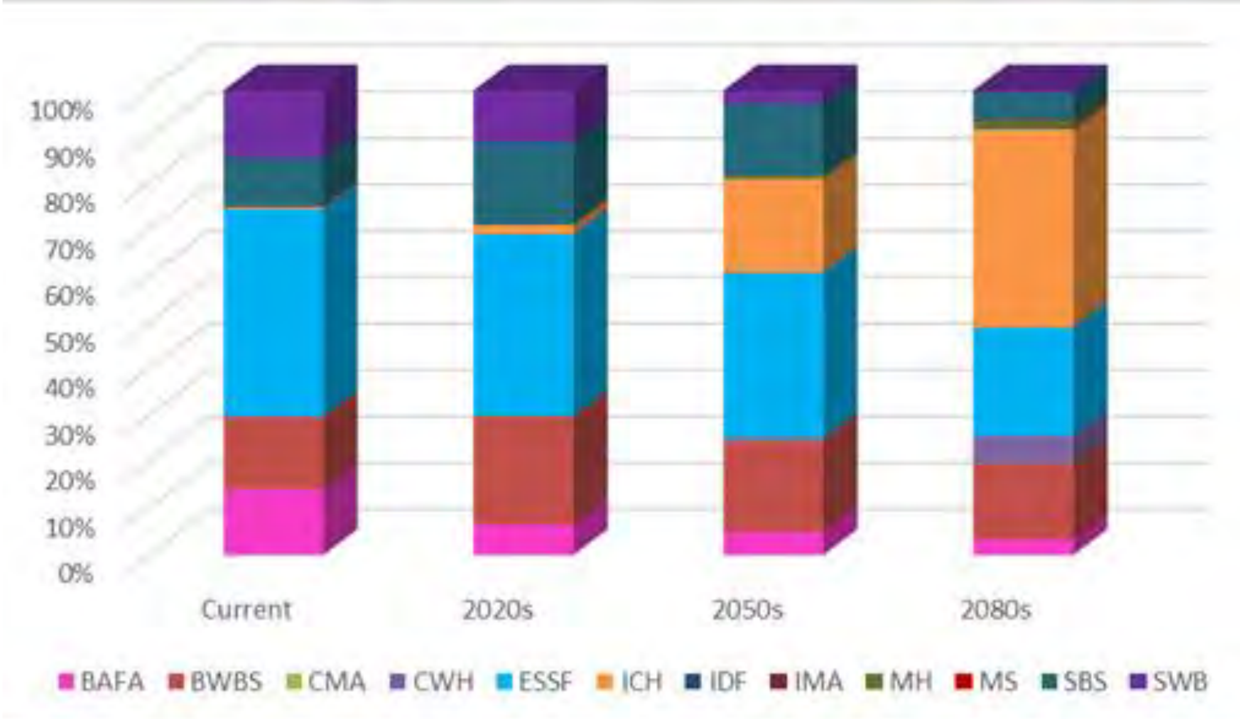


Figure 16. Projected distribution of BEC Zones in the Hart/Muskwa Ranges

Conclusion

Situated at a critical point in north/south continental connectivity from the Yellowstone region north to the Yukon and at a critical point regionally in connectivity east to west, the PRB Region has a significant existing human footprint dominated by linear corridors from roads, seismic lines, transmission/pipeline and utility lines. In spite of the extensive nature of the current footprint and the future resource development potential of the area, there is still a narrow band of intact forest landscapes running from Kakwa Provincial Park and the adjoining mountain park complex to the southeast and north to the Muskwa-Kechika Management Area.

The Hart/Muskwa Ranges Corridor is not without a human footprint – particularly in the central and southern portion of the corridor the human footprint is creeping in and future resource development potential suggests that these impacts will only grow. There is still, however, opportunity to conserve a vital landscape before it too disappears.

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Data Sources

Primary data sources used included:

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Mines, energy and communication networks in Canada – CanVec Series – Resources Management Features: https://open.canada.ca/en/open-data
- Construction & Land Use CanVec: https://open.canada.ca/en/open-data
- Oil & Gas commission: https://data-bcogc.opendata.arcgis.com/
- Mine Locations/Status: http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/OpenFiles/2018/Pages/2018-1.aspx

Urban Areas

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Vegetative Resource Index = Level 5 classification Urban or airport
- Baseline Thematic Mapping = Urban

Roads

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Digital Roads Atlas

Surface Holes (Oil & Gas Wells & Facilities

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Tantalis Crown Tenures =Drill site/Wellsite tenure
  Removed duplicates within the OG well/facility sites layer then combined the layers. Average Area was then calculated for the new well/facility sites layer (0.0206 km^2)
- Oil & Gas commission: https://data-bcogc.opendata.arcgis.com/
- Identified well/facility locations that were only available in point form (pre Oct 2006 mines) and buffered active wells to be 0.0206 km^2 (the average of the polygon dataset), buffered all other wells to be 0.0103km^2 (1/2 the size of the polygon well average).
- Merged new Well Sites Layer with the Buffered Surface Hole Layers
  New final well sites layer was dissolved (to rid of overlapping areas) and clipped to study area

Agriculture

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Baseline Thematic Mapping = Agriculture

Forest Harvest

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Consolidated Cutblocks

Fires

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Fire Perimeters - Historical

Mineral Extraction

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Tantalis Crown Tenures. Tenure stage = tenure; tenure type = lease, license, permit; Tenure purpose = quarrying; Tenure sub-purpose = mineral protection
- BTM = Mining
- Mines, energy and communication networks in Canada – CanVec Series – Resources Management Features: https://open.canada.ca/en/open-data
- Ore extraction
- Aggregate extraction

Industry

- BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset
- Construction & Land Use CanVec
- Dams
- Reservoirs
- Tantalis Crown Tenures.
- Industrial Sites = battery site; campsite; cathodic site/anode beds; combined uses commercial; commercial B; communications sites; compressor sites; dehydrator site; flare site; gas processing site; heavy industrial; industrial camps; inlet site; land farms; light industrial; log handling/storage; meter site; mineral production; water analyzer.
- Power, Telecom Lines = telecommunication lines, electric powerlines, water lines, sewer/ effluent lines.
- Oil & Gas Pipelines = gas & oil pipelines
- Also Mines, energy and communication networks in Canada – CanVec Series – Resources Management Features: https://open.canada.ca/en/open-data) = Pipelines layer
- Water Power = Waterpower
- Windpower = Windpower
- Recreation = Alpine Skiing; Commercial Recreation
- OGC Ancillary Features
- Oil & Gas Ancillary
- Oil & Gas Pipelines = BC Data Catalogue Tantalis Crown Tenures (Oil and gas pipeline) + CanVec Series – Resources Management Features (pipelines)

Intact Forest Landscapes

- Global Forest Watch (http://data.globalforestwatch.org/datasets/f9ee12765aa94ab5a2150ec7e988b66b_5?geometry=-150.57%2C51.568%2C-81.004%2C59.045&uiTab=metadata)

Appendix A - Protected Areas by Size

PRB Study Area		
Provincial Park Name	**Area (Ha)**	**% Study Area**
Ancient Forest/Chun T'oh Whudujut Park	1,595.12	0.01
Arctic Pacific Lakes Park	13,895.00	0.1
Bearhole Lake Park	12,707.49	0.09
Beatton Park	329.34	0
Beatton River Park	193.4	0
Bijoux Falls Park	35.34	0
Bocock Peak Park	1,143.11	0.01
Buckinghorse River Wayside Park	35.92	0
Butler Ridge Park	6,845.21	0.05
Carp Lake Park	26,608.27	0.2
Charlie Lake Park	176.27	0
Chase Park	27,165.26	0.2
Close-To-The-Edge Park	413.73	0
Crooked River Park	970.38	0.01
Dune Za Keyih Park [A.K.A. Frog-Gataga Park]	45,377.16	0.34
East Pine Park	13.99	0
Ed Bird - Estella Lakes Park	5,589.31	0.04
Evanoff Park	1,474.56	0.01
Finlay Russel Park	46,627.27	0.34
Graham - Laurier Park	99,981.63	0.74
Gwillim Lake Park	32,458.02	0.24
Heather - Dina Lakes Park	5,822.88	0.04
Hole In The Wall Park	137.18	0
Kakwa Park	170,082.93	1.26
Kiskatinaw Park	54.47	0
Kiskatinaw River Park	198.35	0
Klin-Se-Za Park	2,670.73	0.02
Kwadacha Wilderness Park	130,335.23	0.96
Milligan Hills Park	7,828.00	0.06
Moberly Lake Park	103.58	0
Monkman Park	62,895.86	0.46
Muscovite Lakes Park	5,711.53	0.04
Northern Rocky Mountains Park	332,639.24	2.46
Omineca Park	43,319.54	0.32
One Island Lake Park	58.93	0
Peace River Corridor Park	2,014.52	0.01
Pine Le Moray Park	43,288.78	0.32
Pine River Breaks Park	614.68	0
Pink Mountain Park	97.69	0
Prophet River Hotsprings Park	184.62	0
Prophet River Wayside Park	113.42	0
Purden Lake Park	3,214.57	0.02
Redfern-Keily Park	80,800.49	0.6
Sikanni Chief Canyon Park	4,710.21	0.03
Sugarbowl-Grizzly Den Park	11,706.90	0.09
Sukunka Falls Park	422.62	0
Swan Lake Park	81.92	0
Taylor Landing Park	0.91	0
Tudyah Lake Park	52.08	0
Wapiti Lake Park	16,836.81	0.12
Whiskers Point Park	95.39	0
Total	**1,249,729.84**	**9.23**

Ecological Reserve Name	Area (Ha)	% Study Area
Aleza Lake Ecological Reserve	269.04	0
Blackwater Creek Ecological Reserve	291.96	0
Cecil Lake Ecological Reserve	129.53	0
Chunamon Creek Ecological Reserve	343.98	0
Clayhurst Ecological Reserve	374.96	0
Heather Lake Ecological Reserve	283.73	0
Ospika Cones Ecological Reserve	1,283.27	0.01
Patsuk Creek Ecological Reserve	538.19	0
Raspberry Harbour Ecological Reserve	121.02	0
Rolla Canyon Ecological Reserve	27.68	0
Sikanni Chief River Ecological Reserve	2,176.33	0.02
Tacheeda Lakes Ecological Reserve	503.86	0
Total	**6,343.55**	**0.05**
Protected Area Name	**Area (Ha)**	**% Study Area**
Ancient Forest/Chun T'oh Whudujut Protected Area	491.67	0
Bearhole Lake Protected Area	5,054.23	0.04
Close-To-The-Edge Protected Area	287.91	0
Dune Za Keyih Protected Area	7,655.38	0.06
Finlay - Russel Protected Area	951.11	0.01
Giscome Portage Trail Protected Area	148.85	0
Kakwa Protected Area	458.19	0
Klua Lakes Protected Area	7,633.22	0.06
Sikanni Chief Falls Protected Area	799.15	0.01
Sugarbowl-Grizzly Den Protected Area	65.05	0
Total	**23,544.76**	**0.17**
Conservation Areas	**Area (Ha)**	**% Study Area**
All	4,006.99	0.03

Appendix A - Protected Areas by Size (continued)

Hart/Muskwa Ranges Corridor		
Provincial Park Name	**Area (Ha)**	**% Study Area**
Arctic Pacific Lakes Park	8905.49	0.15
Bearhole Lake Park	12707.49	0.21
Bijoux Falls Park	35.34	0
Bocock Peak Park	1143.11	0.02
Butler Ridge Park	6845.21	0.11
Close-To-The-Edge Park	413.73	0.01
Dune Za Keyih Park [A.K.A. Frog-Gataga Park]	45377.16	0.74
Graham - Laurier Park	99981.63	1.64
Gwillim Lake Park	32452.86	0.53
Heather - Dina Lakes Park	1545.04	0.03
Hole In The Wall Park	137.18	0
Kakwa Park	170082.93	2.79
Klin-Se-Za Park	2670.73	0.04
Kwadacha Wilderness Park	130335.23	2.14
Moberly Lake Park	103.58	0
Monkman Park	62895.86	1.03
Northern Rocky Mountains Park	332639.24	5.46
Pine Le Moray Park	43288.78	0.71
Prophet River Hotsprings Park	184.62	0
Redfern-Keily Park	80800.49	1.33
Sukunka Falls Park	422.62	0.01
Wapiti Lake Park	16836.81	0.28
Total	**1,049,805.12**	**17.22**
Ecological Area Name	**Area (Ha)**	**% Study Area**
Heather Lake Ecological Reserve	283.42	0
Ospika Cones Ecological Reserve	1283.27	0.02
Patsuk Creek Ecological Reserve	538.19	0.01
Sikanni Chief River Ecological Reserve	2176.33	0.04
Total	**4,281.20**	**0.07**
Protected Area Name	**Area (Ha)**	**% Study Area**
Bearhole Lake Protected Area	3739.44	0.06
Close-To-The-Edge Protected Area	287.91	0
Dune Za Keyih Protected Area	7655.38	0.13
Kakwa Protected Area	458.19	0.01
Total	**12,140.92**	**0.2**
Conservation Areas	**Area (Ha)**	**% Study Area**

Appendix B—Conversion Matrices for Original Classifications of Land Use Change

Summary of Land Cover/Use Changes in the PRB Between 1990 and 2010

Study Area	Time Period	Change	Unclassified	Settlement	Roads	Water	Forest	Trees	Forest Wetland	Treed Wetland	Cropland	Grassland Managed	Grassland Unmanaged	Wetland	Wetland Shrub	Wetland Herb	Rock & Ice
PRB Study Area	1990 to 2000	Area Changed (Ha)	-0.18	4222.62	10.98	-0.09	-12677.3	-600.66	-128.07	-25.83	10124.91	-0.09	-34.2	-779.94	4004.28	-4115.34	-1.08
		Percent Change	-1.54	19.33	0.05	0	-0.12	-2.6	-0.03	-0.06	2.07	-0.01	-0.03	-3.11	1.19	-18.3	0
	2000 to 2010	Area Changed (Ha)	0	1945.8	394.65	0	-4409.28	-33.03	-703.8	-8.64	3598.47	0	-16.74	-573.48	-156.51	-7.2	-30.24
		Percent Change	0	7.46	1.91	0	-0.04	-0.15	-0.15	-0.02	0.72	0	-0.02	-2.36	-0.05	-0.04	0
	Total	Area Changed (Ha)	-0.18	6168.42	405.63	-0.09	-17086.6	-633.69	-831.87	-34.47	13723.38	-0.09	-50.94	-1353.42	3847.77	-4122.54	-31.32
		Percent Change	-1.54	26.79	1.96	0	-0.16	-2.74	-0.17	-0.08	2.8	-0.01	-0.05	-5.47	1.14	-18.34	0

Appendix C—Intact Forest Landscape by Watershed

Intact Forest Landscape by Named Watershed in the Peace River Break							
Watershed	Watershed Total Area (Ha)	Watershed Total % IFL	Area (Ha) within PRB	% Watershed in PRB	IFL Area (Ha)	Area Watershed in H/MRC	% of PRB
Bowron	362,142.80	0.00	57,837.11	15.97	0.00	0.00	0.43
Carp Lake	179,969.23	0.00	153,973.04	85.56	0.00	0.00	1.14
Crooked River	218,529.86	0.00	218,529.86	100.00	0.00	0.00	1.61
Finlay Arm	738,205.57	36.67	645,153.57	87.39	265,725.87	227,140.09	4.76
Finlay River	548,542.31	82.14	546,119.62	99.56	448,131.74	395,659.16	4.03
Fontas River	384,662.24	20.76	86,023.66	22.36	0.00	0.00	0.64
Fox River	429,197.54	98.99	429,197.54	100.00	424,867.13	372,883.44	3.17
Frog River	488,214.75	99.21	98,280.19	20.13	98,280.19	47,238.03	0.73
Gataga River	369,397.61	99.82	83,997.57	22.74	83,997.57	83,997.57	0.62
Herrick Creek	205,597.91	83.59	205,597.91	100.00	171,849.36	186,892.53	1.52
Ingenika River	532,916.74	95.00	73,522.18	13.80	57,938.93	0.00	0.54
Kahntah River	285,215.15	5.63	249,124.08	87.35	0.00	0.00	1.84
Kiskatinaw River	405,169.24	0.00	405,169.24	100.00	0.00	74,441.67	2.99
Lower Beatton River	724,407.55	0.00	723,384.55	99.86	0.00	0.00	5.34
Lower Chilako River	313,884.87	0.00	1,870.87	0.60	0.00	0.00	0.01
Lower Halfway River	556,803.67	32.86	556,803.67	100.00	182,948.20	227,099.62	4.11
Lower Omineca River	401,353.24	37.15	37,087.83	9.24	28,563.86	0.00	0.27
Lower Peace River	331,937.98	0.00	328,453.57	98.95	0.00	0.00	2.42
Lower Salmon River	183,226.31	0.00	83,351.42	45.49	0.00	0.00	0.62
Lower Sikanni Chief River	464,525.45	6.13	390,187.20	84.00	5,766.02	0.00	2.88
McGregor River	346,653.83	47.30	346,600.61	99.98	163,917.60	195,687.10	2.56
Mesilinka River	329,778.83	39.04	96,652.33	29.31	63,026.50	0.00	0.71
Middle Muskwa River	424,645.36	86.21	52,684.04	12.41	52,684.04	52,684.04	0.39
Middle Prophet River	276,323.42	0.50	115,654.66	41.85	0.00	0.00	0.85
Milligan Creek	257,241.14	0.00	256,831.57	99.84	0.00	0.00	1.90
Morkill River	821,116.63	23.19	256,688.36	31.26	26,752.91	30,864.47	1.90
Murray River	651,015.67	36.06	651,015.67	100.00	234,764.55	534,466.03	4.81
Muskeg River	84,709.91	0.00	32,246.63	38.07	0.00	0.00	0.24
Nation River	691,933.47	7.97	134,893.55	19.50	19,740.55	0.00	1.00
Ospika River	298,038.28	94.68	298,038.28	100.00	282,169.36	298,038.28	2.20
Parsnip Arm	373,114.57	29.71	373,114.57	100.00	110,834.24	130,585.93	2.75
Parsnip River	559,660.47	61.88	559,660.47	100.00	346,291.97	399,214.25	4.13
Peace Arm	589,264.68	70.92	589,264.68	100.00	417,928.58	584,410.32	4.35
Pine River	698,285.52	32.03	698,285.52	100.00	223,634.81	529,360.75	5.16
Smoky River	510,936.25	47.56	503,729.44	98.59	239,971.75	451,747.57	3.72
Tabor River	200,452.14	0.00	93,120.31	46.46	0.00	0.00	0.69
Toodoggone River	485,996.11	98.30	107,216.44	22.06	103,076.70	0.00	0.79
Upper Beatton River	520,714.12	0.00	520,714.12	100.00	0.00	0.00	3.84
Upper Fort Nelson River	368,609.89	0.25	43,810.33	11.89	0.00	0.00	0.32
Upper Halfway River	378,252.95	56.43	378,252.95	100.00	213,441.78	253,995.83	2.79
Upper Muskwa River	425,022.77	77.45	359,460.79	84.57	299,417.01	302,293.70	2.65
Upper Peace River	581,994.64	6.96	581,994.64	100.00	40,531.85	212,929.64	4.30
Upper Prophet River	411,958.62	75.11	411,958.62	100.00	309,412.56	314,716.39	3.04
Upper Sikanni Chief River	641,437.56	25.58	641,437.56	100.00	164,103.37	191,117.18	4.74
Willow River	318,129.57	0.00	67,830.55	21.32	0.00	0.00	0.50
TOTAL AREA		-	**13544821.39**	-	**4,052,862.43**		#REF!

Intact Forest Landscape by Named Watershed in the Hart/Muskwa Ranges Corridor							
Watershed		Watershed Total % I	la (Ha) within H/N	Watershed in H/MRC			% of H/MCR
Finlay Arm	738,205.57	36.67	227,140.09	30.77	3.73		3.73
Finlay River	548,542.31	82.14	395,659.16	72.13	6.49		6.49
Fox River	429,197.54	98.99	372,883.44	86.88	6.12		6.12
Frog River	488,214.75	99.21	47,238.03	9.68	0.77		0.77
Gataga River	369,397.61	99.82	83,997.57	22.74	1.38		1.38
Herrick Creek	205,597.91	83.59	186,892.53	90.90	3.07		3.07
Kiskatinaw River	405,169.24	0.00	74,441.67	18.37	1.22		1.22
Lower Halfway River	556,803.67	32.86	227,099.62	40.79	3.72		3.72
McGregor River	346,653.83	47.30	195,687.10	56.45	3.21		3.21
Middle Muskwa River	424,645.36	86.21	52,684.04	12.41	0.86		0.86
Morkill River	821,116.63	23.19	30,864.47	3.76	0.51		0.51
Murray River	651,015.67	36.06	534,466.03	82.10	8.77		8.77
Ospika River	298,038.28	94.68	298,038.28	100.00	4.89		4.89
Parsnip Arm	373,114.57	29.71	130,585.93	35.00	2.14		2.14
Parsnip River	559,660.47	61.88	399,214.25	71.33	6.55		6.55
Peace Arm	589,264.68	70.92	584,410.32	99.18	9.58		9.58
Pine River	698,285.52	32.03	529,360.75	75.81	8.68		8.68
Smoky River	510,936.25	47.56	451,747.57	88.42	7.41		7.41
Upper Halfway River	378,252.95	56.43	253,995.83	67.15	4.17		4.17
Upper Muskwa River	425,022.77	77.45	302,293.70	71.12	4.96		4.96
Upper Peace River	581,994.64	6.96	212,929.64	36.59	3.49		3.49
Upper Prophet River	411,958.62	75.11	314,716.39	76.40	5.16		5.16
Upper Sikanni Chief River	641,437.56	25.58	191,117.18	29.80	3.13		3.13

Appendix D—Seismic Line Buffers

Cut Type	Width (m)	Comment
Existing Access	4.13	
Existing Cat Cut	3.8	
Existing Hand Cut	0.62	no buffer applied to hand cut
Existing Mulcher Cut	2.38	
Existing Push Out	3.36	
Gravity/Aeromagnetic	0	Removed as no impact
New Cat Cut	5.02	
New Cut Access	3.94	
New Cut Push Out	3.31	
New Hand Cut	1.14	no buffer applied to hand cut
New Mulcher Cut	2.9	

Note: Seismic lines received a width attribute in the spatial databases sometime after the year 2000. Older seismic lines had no width. Where seismic lines data did not contain a "cut width" attribute, the average cut width by type (mulcher cut, cat cut, etc.) was applied to each respective cut type. Note buffer distance = ½ cut width as buffers out each side of line.

Appendix E—Mountain Pine Beetle Hazard Rating Documentation Version 1.2

Attribute	Description	Definition	Value Range	Source or comment
Feature_id	Unique ID	Char 32		VRI attribute
Opening_ind	Opening indicator	Char 1		VRI attribute
Non_Productive_CD	Non-productive code	Integer 2		VRI attribute
Species_1	Species 1 (layer 1 rank1)	Char 4		VRI attribute
Species_2	Species 2	Char 4		VRI attribute
Species_3	Species 3	Char 4		VRI attribute
Species_4	Species 4	Char 4		VRI attribute
Species_5	Species 5	Char 4		VRI attribute
Species_6	Species 6			VRI attribute
Species_Pct_1	Species 1 percentage	Integer 2		VRI attribute
Species_Pct_2	Species 2 percentage	Integer 2		VRI attribute
Species_Pct_3	Species 3 percentage	Integer 2		VRI attribute
Species_Pct_4	Species 4 percentage	Integer 2		VRI attribute
Species_Pct_5	Species 5 percentage	Integer 2		VRI attribute
Species_Pct_6	Species 6 percentage	Integer 2		VRI attribute
Proj_Age_1	Stand projected age	Integer 2		VRI attribute
Proj_Height_1	Stand projected height	Numeric 6		VRI attribute
Crown_Closure	Crown closure	Integer 2		VRI attribute
Site_index	Site Index	Numeric 6		VRI attribute
Basal_Area	Stand basal area	Float 4.4		VRI attribute
Pct_Pine	Total percentage of pine in stand	Integer 2		Derived by summing the percentage of pine across all 6 species
Basal_Area_Pine	basal area of stand Pine component	Float 4.4		Derived by multiplying pct_pine by basal_area
VRI_Live_Stems_Per_HA	VRI live stems per hectare at	Float 4.4		VRI attribute
Qmd175_all	Quad mean diameter at 17.5 cm utilization level	Float 4.4		VRI attribute
Lon	Longitude of stand centre point	Float 4.4		Derived from feature geometry
Lat	Latitude of stand centre point	Float 4.4		Derived from feature geometry
Elevation	Stand mean elevation	Integer 2		Obtained from TRIM digital elevation model
Factor_p	Hazard factor P	Float 4.1		Derived from basal area
Factor_a	Hazard factor A	Float 4.1		Derived from stand age
Factor_d	Hazard factor D	Float 4.1		Derived from tree density
l_value	Location value used to calculate hazard factor l	Float 4.1		Derived from lat, long and elevation
Factor_l	Hazard factor L	Float 4.1		Derived from l_value
Haz_rating	Overall hazard rating	Float 4.1		Derived from factor p, factor a, factor d, and facto_l
Haz_range1	The range of hazard rating in the hazard class	Char 6		Example: "20-40"
Haz_class1	Hazard rating class 1 – 20% hazard rating classes	Char 3	Haz_rating	Class Value
			(no input data)	NTA = No Typing Available
			0	NIL = nothing
			0.001 – 4.999	VL = very low
			5-19.999	L = low
			20-39.999	LM = low/med
			40-59.999	M = medium
			60-79.999	H = high
			80-100	VH = high
Haz_range2	The range of hazard rating in the hazard class	Char 6		Example: "20-40"
Haz_class2	Hazard Rating Class 2 – 33% hazard rating classes	Char 3	Haz Rating	Class Value
			(no input data)	NTA = No Typing Available
			0	NIL = nothing
			0.001 – 4.999	VL = very low
			May-33	L = low
			33.0001-66	M = medium
			66.0001-100	H = high
Hectares	Area of stand polygon in hectares	Float 4.2		Derived from feature geometry

Appendix E—Mountain Pine Beetle Hazard Rating Documentation Version 1.2

FLNRO Project #: P13-0052

Last Update: March, 2014

Project Client: Kevin Buxton, FLNRO

GIS Analyst: Chris Steeves, FLNRO

Project Area: Province of BC

Background:

Mountain Pine Beetle is a pest of significant concern in the northern and southern interior due to the mortality of pine species caused by this forest insect.

Hazard rating systems provide an objective framework for evaluating the risk of a particular pest, at the stand level, based on a series of quantifiable factors known to be correlated with hazard.

Overview:

This documentation provides detailed information on the process used to create the Mountain Pine Beetle hazard spatial dataset using the most appropriate information and processes, it will also document the data structure of the resultant dataset.

This document and accompanying spatial dataset is a collaborative project of the Ministry of Forests and Range and the Integrated Land Management Bureau.

Project Scope:

The project involves creating mountain pine beetle hazard rating spatial datasets for the province of British Columbia, on a TSA basis, on non TFL lands.

Data Sources:

Vegetation: VRI exported from the BCGW in December of 2013.

Basal Area: Attribute present in VRI.

Elevation: Derived from 25 metre TRIM digital elevation model data

Process:

The process for creating the hazard rating model was based upon the following resource:

The Mountain Pine Beetle – A Synthesis of Biology, Management and Impacts in Lodgepole Pine. Chapter 8 – Decision Support Systems. Terry L. Shore, Bill G. Riel, Les Safranyik, and Andrew Fa.

This methodology is similar to the one described in the Bark Beetle Management Guidebook , located at the URL below.

http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/beetle/chap3a.htm#Link18

The main difference is the newer methodology is updated to provide continuous functions for age and density, versus the discrete functions of the earlier methodology.

The hazard rating method describes four major hazard factors used to create the final hazard rating:

Hazard Rating = P * A * D * L

Factor P: Proportion of Basal Area

The percentage of susceptible pine basal area equation was modified slightly from the new methodology to take into account the standard utilisation level of 12.5 cm dbh. Basal area data for these utilisation levels are much more readily available than the 7.5 cm and 15 cm dbf utilisation levels described in the new methodology.

$$P = \frac{\text{(Average basal area / ha of pine >= 12.5 cm dbh)}}{\text{(Average basal area / ha of all species >= 12.5 cm dbh)}} * 100$$

Pine basal area was obtained by multiplying the total percentage of pine in the stand (expressed as a proportion) by the stand basal area. Species codes included as pine were {'P','PJ','PF','PL','PLI','PXJ','PY','PLC','PW','PA', 'PM',’PR’,’PS’}.

Factor A: Age

The age factor was implemented as outlined in the newest methodology. The proj_age_1 attribute was used from the vegetation inventory to estimate age.

Age	Factor
40-80	0.1 + 0.1 * [(proj_age_1 - 40) / 10] ** 1.585
81-120	1.0
121-510	1.0 – 0.05 [(proj_age_1 - 120) / 20]
<40 or > 510	0.1

Factor D: Density

The density factor was implemented as outlined in the newest methodology with continuous functions for density factors less than 1. The vri_live_stems_per_ha (all stems) attribute from the VRI was used to estimate tree density.

Density	Factor
<650	0.0824 * [sph125_all/250] ** 2.0
650-750	1.0 – 0.7 * [3 – sph125_all / 250] ** 0.5
751-1500	1.0
>1500	1.0 / [0.9 + [0.1 ** (2.718 * 0.4796 * (sph125_all / 250) – 6.0)]]

Factor L: Location

The location factor was implemented almost exactly as outlined in the new methodology. The formula was modified slightly to use the absolute value of the longitude as GIS systems represents all longitudes west of Greenwich, England as negative, and the formula requires an unsigned value to work correctly.

Y = (24.4 * abs(longitude)) - (121.9 * latitude) - (elevation (m)) + (4545.1)

Y	Factor
>0	1.0
0 to -500	0.7
< -500	0.3

The lat and lon coordinate used is that of the label point of the stand polygon. The elevation was calculated as an average elevation for the stand, based on TRIM digital elevation model data which had been resampled to a 50 metre resolution.

Resultant Data Model:

The overarching goal for the resultant dataset, was to retain all the core VRI attributes which are typically used to characterize a stand, as well as all attributes used as inputs to the hazard rating calculation. In addition it was also considered a goal to retain the individual hazard rating factors within the resultant dataset. This approach would allow individuals to re-calculate the hazard rating based on a modified approach, such as for example, discounting the location factor.

A data dictionary for the resultant dataset is provided below:

Attribute	Description	Definition	Value Range	Source or comment
Feature_id	Unique ID	Char 32		VRI attribute
Opening_ind	Opening indi-	Char 1		VRI attribute
Non_Productive_CD	Non-productive code	Integer 2		VRI attribute
Species_1	Species 1 (layer 1 rank1)	Char 4		VRI attribute
Species_2	Species 2	Char 4		VRI attribute
Species_3	Species 3	Char 4		VRI attribute
Species_4	Species 4	Char 4		VRI attribute
Species_5	Species 5	Char 4		VRI attribute
Species_6	Species 6			VRI attribute
Species_Pct_1	Species 1 percentage	Integer 2		VRI attribute
Species_Pct_2	Species 2 percentage	Integer 2		VRI attribute
Species_Pct_3	Species 3 percentage	Integer 2		VRI attribute
Species_Pct_4	Species 4 per-	Integer 2		VRI attribute

Species_Pct_5	Species 5 percentage	Integer 2		VRI attribute
Species_Pct_6	Species 6 percentage	Integer 2		VRI attribute
Proj_Age_1	Stand projected age	Integer 2		VRI attribute
Proj_Height_1	Stand projected height	Numeric 6		VRI attribute
Crown_Closure	Crown closure	Integer 2		VRI attribute
Site_index	Site Index	Numeric 6		VRI attribute
Basal_Area	Stand basal area	Float 4.4		VRI attribute
Pct_Pine	Total percentage of pine in stand	Integer 2		Derived by summing the percentage of pine across all 6 species
Basal_Area_Pine	basal area of stand Pine component	Float 4.4		Derived by multiplying pct_pine by basal_area
VRI_Live_Stems_Per_HA	VRI live stems per hectare at	Float 4.4		VRI attribute
Qmd175_all	Quad mean diameter at 17.5 cm utilization level	Float 4.4		VRI attribute
Lon	Longitude of stand centre point	Float 4.4		Derived from feature geometry
Lat	Latitude of stand centre point	Float 4.4		Derived from feature geometry
Elevation	Stand mean elevation	Integer 2		Obtained from TRIM digital elevation model
Factor_p	Hazard factor P	Float 4.1		Derived from
Factor_a	Hazard factor A	Float 4.1		Derived from
Factor_d	Hazard factor D	Float 4.1		Derived from

l_value	Location value used to calculate hazard factor l.	Float 4.1		Derived from lat, long and elevation
Factor_l	Hazard factor L	Float 4.1		Derived from l_value
Haz_rating	Overall hazard rating	Float 4.1		Derived from factor p, factor a, factor d, and facto_l
Haz_range1	The range of hazard rating in the hazard class	Char 6		Example: “20-40”
Haz_class1	Hazard rating class 1 – 20% hazard rating classes.	Char 3	Haz_rating:	Class Value
			(no input data)	NTA = No Typ-
			0	NIL = nothing
			0.001 – 4.999	VL = very low
			5-19.999	L = low
			20-39.999	LM = low/med
			40-59.999	M = medium