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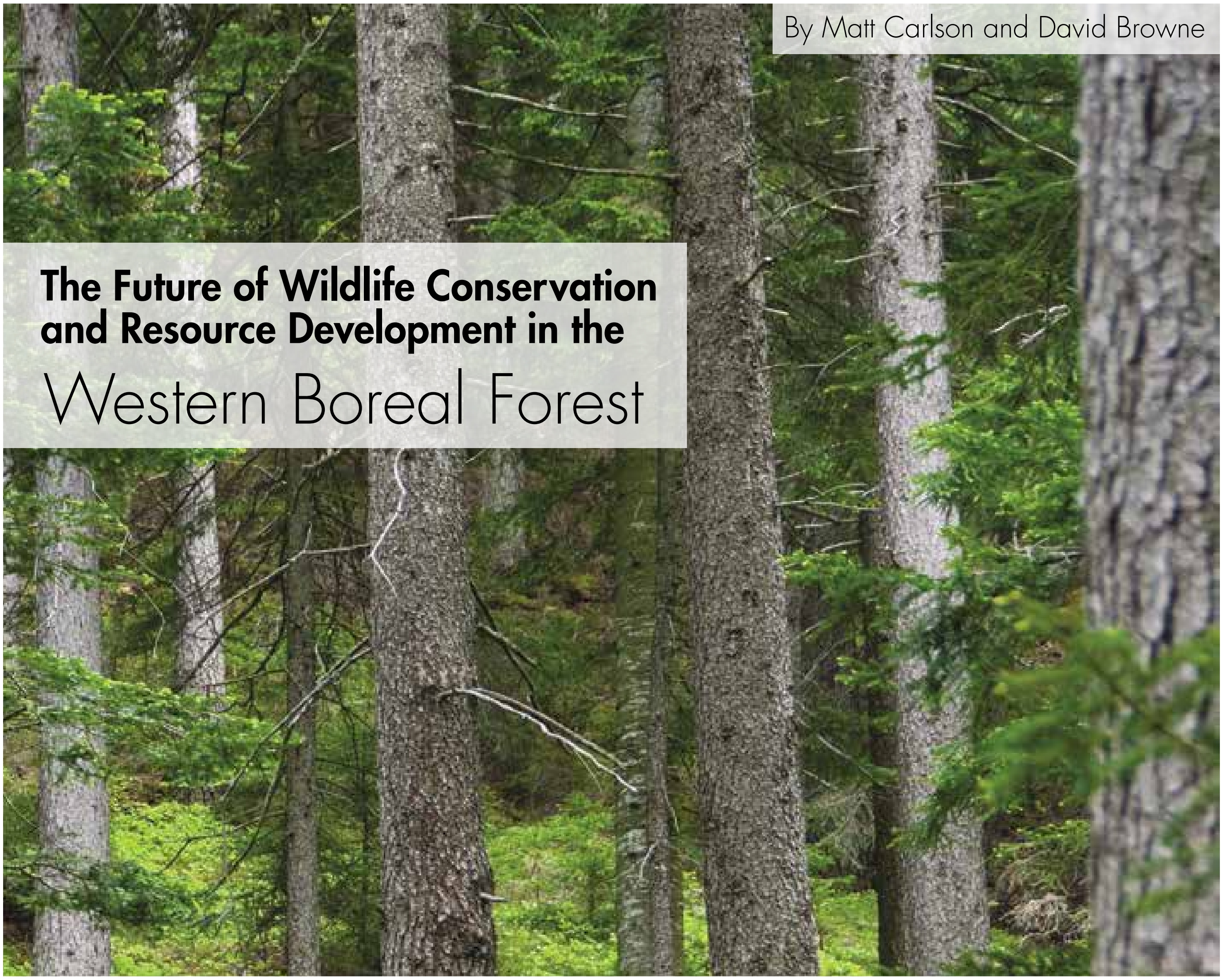

By Matt Carlson and David Browne

The Future of Wildlife Conservation and Resource Development in the
Western Boreal Forest

A technical report on cumulative effects modeling of future land use scenarios

About Canadian Wildlife Federation

The Canadian Wildlife Federation's mission is to conserve and inspire the conservation of Canada's wildlife and habitats for the use and enjoyment of all. For more than 50 years, CWF has stayed true to this mission. CWF conducts its activities through a cooperative approach – working with people, corporations, non-government organizations, and governments to inspire collaboration in achieving wildlife conservation. We use the best available science to develop our policies, programs and communications. We work in collaboration with regional organizations and experts to achieve progress for the conservation of Canada's wildlife from coast to coast to coast. To further this mission, we conduct scientific research, work with governments for strong laws and policies to conserve wildlife, deliver stewardship programming, and further the long-term conservation of Canada's wildlife by increasing youth and general public engagement with the outdoors.

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EXECUTIVE *Summary*

The Challenge

Canada's western boreal forest is a region of national interest due to its impressive economic and environmental assets. Best known for the globally significant oil sands, the region also contains large reserves of other hydrocarbons such as shale gas, as well as expansive tracts of timber and farmland. The region is also a vast wilderness area of forests, bogs, wetlands, and plains that are home to large mammals such as caribou and moose, sport fish such as Arctic grayling and walleye, and over 200 songbird species. Services provided by the region's ecosystems include storage of billions of tonnes of carbon and supply of vast quantities of fresh water. Natural resource production has expanded rapidly in recent decades, with profound implications for these economic and environmental assets. Economic and political power in Canada is shifting westward, propelled by high rates of economic and population growth that are in part due to the development of boreal natural resources. At the same time, the region has become a focal point of environmental concerns due to deleterious effects of resource development such as fragmentation of wildlife habitat and greenhouse gas emissions.

The economic benefits and environmental liabilities of resource development have created a tension that, if unresolved, may undermine future plans for both conservation and resource development. Evidence of this tension includes debates surrounding major infrastructure projects such as the Keystone and Gateway pipelines, and objections from First Nations to resource development that is impacting the ecological integrity of their traditional territories. Increasingly divisive debate suggests that a common vision for the region is lacking. What does the future hold for Canada's western boreal region? Continued expansion of resource development seems likely, but at what cost to regional ecological integrity? Resolving the conflict that surrounds resource development hinges on finding a broadly supported balance between economic growth and conservation.

Identifying opportunities to balance regional economic growth and conservation demands a strategic perspective. Such a perspective is hindered by a planning process that remains focused on individual projects. While a single project in isolation may cause limited environmental impacts, the cumulative effect of many such projects can have major consequences. As a result, project-level planning has limited capacity to chart a regional development path that is consistent with economic and environmental objectives. Canada's western boreal region is prone to cumulative effects due to the potential intensity of development, as well as the presence of multiple overlapping land use sectors each of which has historically been managed in relative isolation. Needed is an evaluation of the potential consequences of all land use activities occurring within large regions (i.e., tens to hundreds of thousands of km^2) and across long timeframes (i.e., decades).

To help inform regional land use planning, we explored the potential consequences of land use in the western boreal region over the next 50 years. To do so, we applied a computer simulation model that incorporated the effects of all major land uses on a range of environmental and economic indicators over a large western boreal landscape. The ambitious scope is commensurate with the scale at which a vision is needed for the region, and the intent of the analysis was two-fold: 1) demonstrate the long-term consequences of current and emerging land-use trajectories to western boreal ecological goods and services; and 2) assess the relative benefits and liabilities of available strategies for balancing development and conservation in the region. We present the analysis as a basis for informed public debate on the desired future for Canada's western boreal region.

Our Approach

The project applied the ALCES® land use simulation software, which provides strategic land use planning guidance by exploring the cumulative effects of multiple land use sectors (e.g., energy, forestry, agriculture, settlements) and natural disturbances (e.g., fire) operating over large regions and across long timeframes. The software was parameterized for a 693,000 km^2 region that includes portions of the Boreal and Taiga Plains ecozones in Alberta, British Columbia, Northwest Territories, and Saskatchewan. The baseline, current condition of the regional landscape was assessed by calculating the area of 26 natural and anthropogenic cover types using spatially explicit land cover inventories. Changes to landscape composition over the next 50 years from seven land uses were simulated, namely, four types of hydrocarbon production (conventional oil, natural gas, shale gas, bitumen), forestry, agriculture, and human settlements. For each land use, plausible rates of growth were based on projections from government and industry as well as historical data. ALCES® tracked the growth and reclamation of anthropogenic footprints associated with the simulated land uses, including roads, pipelines, well sites, seismic lines, industrial plants, mines, cutblocks, towns, rural residences, transmission lines, and farmland. The intensity and spatial distribution of these disturbances and their lifespan were based on various land use assessments and resource inventories relevant to the region, as well as existing land use patterns. Fire was also simulated, again based on available data and research relevant to the region.

The region's future development path is uncertain, and the outcomes of simulations cannot be viewed as predictions. Rather, the utility of the simulations lies in contrasting the implications of alternative land use scenarios that differ in terms of development trajectories and management strategies. Three development rates were simulated: low (i.e., reduced or stagnant commodity prices); moderate (i.e., expected development rates); and high (i.e., robust

and sustained commodity prices). Two scenarios were then used to assess the possible improvement in wildlife and environmental outcomes. The first was the adoption of stringent industry best practices and the second a hypothetical conservation area network based on minimizing foregone development potential. Best practices refer to strategies to minimize the impact of resource development without affecting the rate of commodity production. The consequences of conservation zoning were assessed using scenarios that excluded portions of the region from future development without intensifying resource development in the remaining landscape.

Economic indicators were employment and gross domestic product associated with natural resource production. Wildlife indicators included the threatened woodland caribou, songbirds associated with older forest, the integrity of the fish community, as well as species used for hunting (moose) and trapping (fisher). Impacts to ecosystem services were also assessed, with a focus on carbon and water which account for much of the region's natural capital value.

Our Findings

The outcomes of the moderate development rate simulation suggest that natural resource development in Canada's western boreal region has the potential to generate rapid economic growth at the cost of substantial ecological integrity. GDP and employment were projected to increase almost two-fold over the next 50 years, largely in response to accelerated extraction of bitumen and, of secondary importance, shale gas. Direct environmental impacts of the upward trend in bitumen production included rising emissions and water use. Greenhouse gas emissions more than tripled during the simulation which, if realized, would be a strong impediment to Canada's international obligations to curb emissions. By 2020, simulated GHG emissions from the region accounted for 22% of Canada's total emissions target under the Copenhagen Accord. Also of concern due to potential lake acidification risk were a tripling of sulphur oxide and doubling of nitrogen oxide emissions, although further research is needed to model acid deposition under simulated emission scenarios.

Wildlife that are sensitive to forest disturbance and loss were adversely affected by the expanding development, especially caribou. By the end of the simulation, the majority of watersheds exhibited a high risk of caribou extirpation such that it seems likely that caribou will be lost from the region over the next 50 years if no action is taken to conserve habitat. This conclusion, while dire, is consistent with previous studies including a national assessment of boreal caribou critical habitat which identified all herds in the region outside of the Northwest Territories as not self-sustaining.

Many fish populations in the region are already in decline, and simulation outcomes indicate that degradation of fisheries is likely to continue as development intensity increases in northern watersheds. The spread of linear access corridors, a rapid increase in the number of road stream crossings, as well as a growing human population, were simulated to increase habitat fragmentation and angling pressure and cause a concomitant decline in the integrity of the fish community.

Another impact to aquatic ecosystems was increased phosphorous runoff. The clearing of vegetation to create anthropogenic footprint exposes soil to erosion, which in turn contributes sediment and associated phosphorous to the aquatic system. Phosphorous runoff followed the northwards expansion in development during the simulations, indicating associated impacts such as eutrophication may become more prevalent.

In the southern portion of the study area, an additional change in landscape composition was declining forest age due to the prevalence of timber harvest. A consequence was that biotic carbon storage declined below natural levels due to the lower carbon content of younger forest. The increased abundance of younger forest contributed to the simulated decline in caribou viability, and also elevated risk levels for songbirds and fisher in southern watersheds. In contrast, moose responded positively to the shift towards younger forest, although the population growth effect was partially offset by increased hunter access.

Predictably, simulation outcomes were sensitive to the rate of development, with an accentuated trade-off between economic growth and environmental decline at the higher development rate. Across all simulated rates, however, the intensity and extent of anthropogenic footprint increased, thereby elevating risk to wildlife. Economic growth remained strong even under the low development scenario due to a doubling in energy production, which also caused large increases in emissions and water use.

The application of best practices mitigated some of the undesirable impacts of development in the region. Efforts to minimize the size of industrial footprint and accelerate its reclamation slowed the rate of habitat alteration and loss. Indicators such as caribou,

recreational fish, fisher, and phosphorous runoff exhibited a similar response to best practices as they did to a reduction in development rate. The application of best practices generally slowed the decline in ecosystem indicator performance found in the moderate business as usual scenario, but was insufficient to shift the trend to an improvement in habitat over time. The combination of a low rate of resource development and application of best practices was not explored but would result in even greater improvements in the outcomes for wildlife and the environment while still maintaining significant economic growth. Emissions displayed the greatest sensitivity to best practices, but still increased two-fold under the aggressive best practice assumption of a 50% reduction in emission intensity. For sensitive species such as caribou, the lower disturbance intensities achieved under both the low development rate scenario and the moderate with best practices scenario were still insufficient to significantly reduce risk levels.

In contrast, by preventing future disturbance in a subset of watersheds, conservation zoning scenarios stabilized or reduced risk levels in a portion of the region. The intent of the conservation zoning analysis was not to propose specific conservation zones for consideration, but rather to propose a way of thinking about economic versus ecological benefits and liabilities and to consider the regional consequences of the most simplistic example of the approach; that is, allocation of land to wildlife conservation based solely on prioritizing areas of least economic value first. Zoning 20% of the region's estimated economic resource potential for conservation substantially improved ecological outcomes relative to all three business as usual development rates. In the western boreal region, where overlapping and dispersed natural resource distributions place large regions at risk of cumulative effects, conservation zoning will be necessary to maintain areas of high ecological integrity in the presence of regional economic growth. In practice, the ability to avoid areas of high resource value during the design of protected areas will be constrained by other design criteria such as equitable sub-regional ecological performance and the location of ecologically significant areas. The effectiveness of a conservation area network should be assessed based on its ability to avoid the degradation of areas with high ecological value. Areas of high ecological value will overlap with natural resource potential, requiring that society carefully explore the desired balance between economic growth and wildlife conservation to maintain ecological integrity.

Next Steps

Economic growth is desirable, but so too are abundant wildlife, clean water, and intact wilderness. The western boreal region is vast but finite, and the fixed availability of resources imposes a trade-off between economic growth and ecological integrity. However, the scale of development in the region is already such that it is hampered by practical constraints such as workforce availability and movement of resources to market. Rapid increase of resource production in the short or even medium term may be unrealistic, and impediments that are being encountered in the rush to develop the region's resources provide an opportunity to step back and collectively consider where the region's future should lead and what mix of resource industries should be pursued. In the absence of a coherent land use strategy, continued expansion of development on a project by project and industry by industry basis across the region will diminish options for balancing economic and environmental objectives.

By and large, public engagement in land use planning has been limited, despite public ownership of the natural resources and the environmental and economic importance of the region. Our hope is that this scenario analysis will motivate and inform public discourse around the desired future for the western boreal region and how that vision can be realized. The transformation of Canada's western boreal region has begun, but the end-point of that transformation is yet to be determined. The time to decide the future of the Canada's western boreal region is now.

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INTRODUCTION

Over the past few decades, Canada's western boreal region has transformed from wilderness to an economic engine of national and indeed international importance. The region's oil sands, one of the largest oil deposits in the world, has received massive investment as global oil production transitions to unconventional deposits in the face of dwindling conventional reserves. The story of the western boreal region is about much more than bitumen, however. Recent shale gas discoveries, such as northeastern British Columbia's Horn River Formation, are among the largest in North America and position the region as a major producer of natural gas for decades to come. The hundreds of thousands of square kilometers of forestry tenures in the region contain in excess of a billion cubic meters of timber. Productive soils in parts of the region also support thousands of square kilometers of farmland.

Expansion of these various natural resource sectors has been rapid with profound implications for wildlife and the economy. Bitumen production has increased more than 10-fold over the past three decades[1]. Over the same period, timber production quadrupled in Alberta[2], largely due to the expansion of forestry into northern portions of the province (Schneider 2002). Growth of agriculture has likewise been rapid, with the Peace River Country in boreal Alberta continuing to expand agricultural lands. Over the past decade, economic growth in western provinces has nearly doubled that of central Canada[3]. Likewise, population growth rates in western Canada have been the nation's highest. This growth in economic activity and population, in part facilitated by rising development of boreal natural resources, has caused a westward shift in economic and political power. Proposed megaprojects in the region such as major pipelines are touted as exercises in nation-building.

This national focal point of natural resource production has emerged from a region with stunning ecological assets. Its expanses of peatlands and forests store billions of tonnes of carbon, keeping it from the atmosphere where it would otherwise exacerbate climate change. The region's mosaic of habitat types, a legacy from a dynamic forest fire regime, supports a wealth of biodiversity including more than 200 bird species. The remaining large intact landscapes support populations of large mammals such as caribou that have been extirpated from more heavily developed landscapes to the south (Laliberte and Ripple 2004). A large number of lakes, rivers, and streams contain vast volumes of water and support numerous species, including

[1] http://www.abll.ca/tables/Energy_and_Mining_/Annual_Resource_Production

[2] http://www.abll.ca/tables/Forestry/Annual_Production_m3

[3] Between 2002 and 2011, real GDP growth in Alberta and British Columbia was 2.8% and 2.5%, respectively, whereas in Ontario and Quebec real GDP growth was 1.5% and 1.6% (Lovely and Enenajor 2012).

prized sport fish such as Arctic Grayling, Walleye, and Pike. In the Mackenzie Watershed, a major western boreal drainage basin, these and other ecosystem services have been valued at $483 billion per year (Anielski and Wilson 2007).

In large areas of the western boreal, this natural capital is being traded for expanding resource development. In boreal Alberta, only 38% of the landscape remains as intact forest landscape fragments. Between 1974 and 2010, 20% of the Peace Region in northeastern British Columbia was directly disturbed by land use (Lee and Hanneman 2012). In the southern boreal forest of Saskatchewan, deforestation for agriculture approached 1% per year between 1966 and 1994 (Hobson et al. 2002). As disturbance has expanded, risk to ecosystems has increased. With the exception of the Northwest Territories and Saskatchewan, all boreal caribou ranges in the region assessed during development of the federal recovery strategy exhibited levels of disturbance in excess of the threshold (35%) deemed to present unacceptable risk to caribou persistence. All but one herd for which population data were available were found to be in decline (Environment Canada 2012). Forestry practices that target older stands, may threaten bird species associated with older forest (Schieck and Song 2006). Recreational fisheries in areas of resource development face increased risks of decline in fishing quality due to intensive angling pressure (Post et al. 2001) and the possibility of species introductions. Water contamination (Kelly et al. 2010), acidification (Jeffries et al. 2010), and greenhouse gas emissions (Raynolds et al. 2006) are also of concern.

What does the future hold for Canada's western boreal region? The scale of its economic and ecological assets is such that answering this question is an issue of national importance. It is almost certain that resource production will continue, and likely increase. The Canadian Energy Research Institute projects bitumen production to more than double in the coming decades (Millington and Mei 2011). Continued expansion of resource development will support strong economic growth, but at what cost to regional ecological integrity? Evidence from elsewhere suggests that the ecological cost of wide spread resource development is often severe. Globally, only one fifth of original forest cover is sufficiently intact to support the full range of native species (Bryant et al. 1997), and species are becoming extinct at a rate that far exceeds natural levels (Millennium Ecosystem Assessment 2005). Canada's boreal forests, including parts of the western boreal region, are one of the last strongholds of intact forest ecosystems, accounting for one quarter of remaining frontier forests. Is widespread degradation of western boreal ecosystems in favour of economic development a fixed path? Or are there opportunities for resource development and regional ecological integrity to coexist.

Charting a path towards a sustainable future demands a strategic perspective. Land-use decision making in Canada remains focused on a reactive, project by project approach rather than being guided by any vision of cumulative impacts and conservation opportunities at the landscape scale. The inability of small-scale decision making, alone, to stem regional environmental degradation

INTRODUCTION

has been referred to as the tyranny of small decisions and is deemed a major contributor to the environmental issues we currently face (Odum 1982). Canada's western boreal region is prone to cumulative effects due to the potential intensity of development (i.e., accumulation of numerous development projects), jurisdictional boundaries, and the presence of multiple overlapping land use sectors each of which has historically been managed in relative isolation. Similarly, a lack of coordination between different resource industries and consideration of overlapping development interests can negatively impact the economic potential of the region.

By evaluating activities in combination with past, present, and potential future activities, cumulative effects assessment (Hegmann et al. 1997) provides a mechanism for escaping the tyranny of small decisions and allows for broad scale conservation planning in advance of resource development. The inadequacy of project-level planning is increasingly well recognized, with Joint Review Panels for major projects in Canada such as the Mackenzie Gas Project and Lower Churchill Hydroelectric Generation Project recommending increased attention to regional-level planning and the national recovery strategy for boreal woodland caribou requiring management of impacts at a large landscape level. Regional cumulative effects assessment and conservation planning, of course, demands a regional, multi-industry and multi-project perspective. An evaluation of the potential consequences of all land use activities occurring within large regions (i.e., tens to hundreds of thousands of km^2) and across long timeframes (i.e., decades) is needed as a basis for decision making. This is best done through a scenarios analysis approach that assesses the implications of alternative potential futures to aide in the identification of strategies that are consistent with societal objectives (Peterson 2003).

To help inform regional conservation and land use planning for Canada's western boreal region, we have applied a land use simulation model to explore the consequences of land-use options 50 years into the future. The analysis spans nearly 700,000 km^2 and incorporates the effects of all major land uses on numerous wildlife, ecosystem service, and economic indicators. The ambitious scope is commensurate with the scale at which a vision is needed for the region, and the intent of the analysis is two-fold; 1) demonstrate the long-term consequences of current and emerging land-use trajectories to western boreal wildlife and ecosystem services, and 2) assess the relative benefits and liabilities of potential strategies for resource development and conservation in the region. Rather than advocate a specific position, we present the analysis as an opportunity for informed public debate on the desired future for Canada's western boreal region. The transformation of Canada's western boreal region has begun, but the end-point of that transformation is yet to be determined. The time to decide the future of the Canada's western boreal region is now.

METHODS

To evaluate western boreal cumulative effects and potential management strategies, the project assessed the long-term (50 year) implications of a range of land-use scenarios to ecological and socioeconomic indicators in a portion of Canada's western boreal region. The project applied the ALCES® modelling toolkit (hereafter referred to as ALCES®) which provides strategic land use planning guidance by examining inter-relationships among relevant land-use sectors and natural disturbances, and exploring their environmental and socioeconomic consequences at large temporal and spatial scales.

ALCES® is designed to track the cumulative effects of ecological processes and human activities under alternative management scenarios (Carlson et al., 2010). By specifying the initial state of the study area and providing quantitative assumptions about forest growth and succession, natural disturbance, resource development, urban expansion, and vegetation regeneration trajectories, the model tracks and updates the state of the landscape in one-year time steps over 50 years (Schneider et al., 2003). A variety of sources were used to parameterize ALCES® including inventories of vegetation types, industrial disturbances and footprints, and human settlement. Assumptions regarding future resource development were based on both the availability of natural resources and either industry predictions or historical rates of resource development. We limited the natural disturbances to wildfire and the land use disturbances to: forest harvesting; conventional oil and gas, bitumen exploration and development (bitumen mining, bitumen extraction using in-situ techniques), shale gas exploration and development, agricultural expansion, transportation in the form or roads, and human settlement expansion. Simulations tracked primary footprint types created by future land use disturbances including: forest harvesting; bitumen mine sites, industrial plants, seismic lines, pipelines, and production and exploration wellsites for hydrocarbon development; major and minor roads (including all forestry and energy access roads) for transportation development; and cities, towns, and acreages for human settlement.

The study area was partitioned into 5km by 5km cells in ALCES®. We proportioned the cells in ALCES® into 14 natural and 12 anthropogenic land cover types based on geospatial analysis of the study area. ALCES® then tracked changes in natural and anthropogenic land cover from development and reclamation of footprint on a cell by cell basis for each annual time step. ALCES® distributed footprint creation based on the expected distribution of development (e.g., due to natural resource availability), and reduced the area of natural land cover in the affected cells to make room for footprint. Conversely, ALCES® distributed footprint reclamation based on footprint age, and increased the area of natural land cover in the affected cells to make up for the reclaimed footprint area. The natural land cover types added in response to reclamation were informed by a cell's natural landscape composition. The outcome of an ALCES®

model run is a 50 year time series of changes in the proportion of natural and anthropogenic land cover for every cell as well as an annual accounting of the natural resource production from various sectors per cell. Wildlife, environmental, and socioeconomic indicators are then calculated on an annual basis using coefficients that relate land cover types and age and resource production to specific outcomes such as habitat suitability or number of jobs.

Parameterization of ALCES® for the scenario analysis required the integration of best information available to:

a) define the study area and assess its existing land cover composition,
b) define assumptions for ecological processes, including natural disturbance and forest succession processes,
c) define development trajectories and associated anthropogenic footprints for the major land use sectors, and
d) select indicators and establish coefficients that relate indicator status to simulated landscape composition and resource production.

An overview of the approach taken is provided below with detailed methods provided in supplementary materials available for download.

2.1 Study area

The project focused on the Boreal Plains ecozone (Ecological Stratification Working Group 1995), a region susceptible to the cumulative effects of natural resource development due to the overlapping distribution of hydrocarbons, timber, and arable land. The overlapping distribution of these resources extends north into the southern portion of the Taiga Plains ecozone, which is accounted for by incorporating the Hay-Slave Lowland ecoprovince in the study area. Areas north of the Hay-Slave Lowland ecoprovince were not included in the study area because they are not suitable for forestry or agriculture, and therefore are not susceptible to the cumulative effects of multiple overlapping land uses. The southern edge of the study area is defined by the northern boundary of the North Saskatchewan watershed. Areas south of this boundary have predominantly been settled and exist either as farmland or settlements. The study area does not include the eastern portion of the Boreal Plains ecozone that overlaps with Manitoba and eastern Saskatchewan due to the low abundance of hydrocarbon reserves in these areas. Instead, the eastern boundary of the study area is formed by the Boreal Plains portion of the following watersheds that are located in western Saskatchewan: Beaver, Upper Churchill, and Clearwater. The western edge of the Boreal Plains forms the western boundary of the study area. Areas further west than this boundary were not included because they are mountainous and therefore ecologically distinct from the Boreal Plains ecozone. The study area spans 693,345 km^2.

METHODS

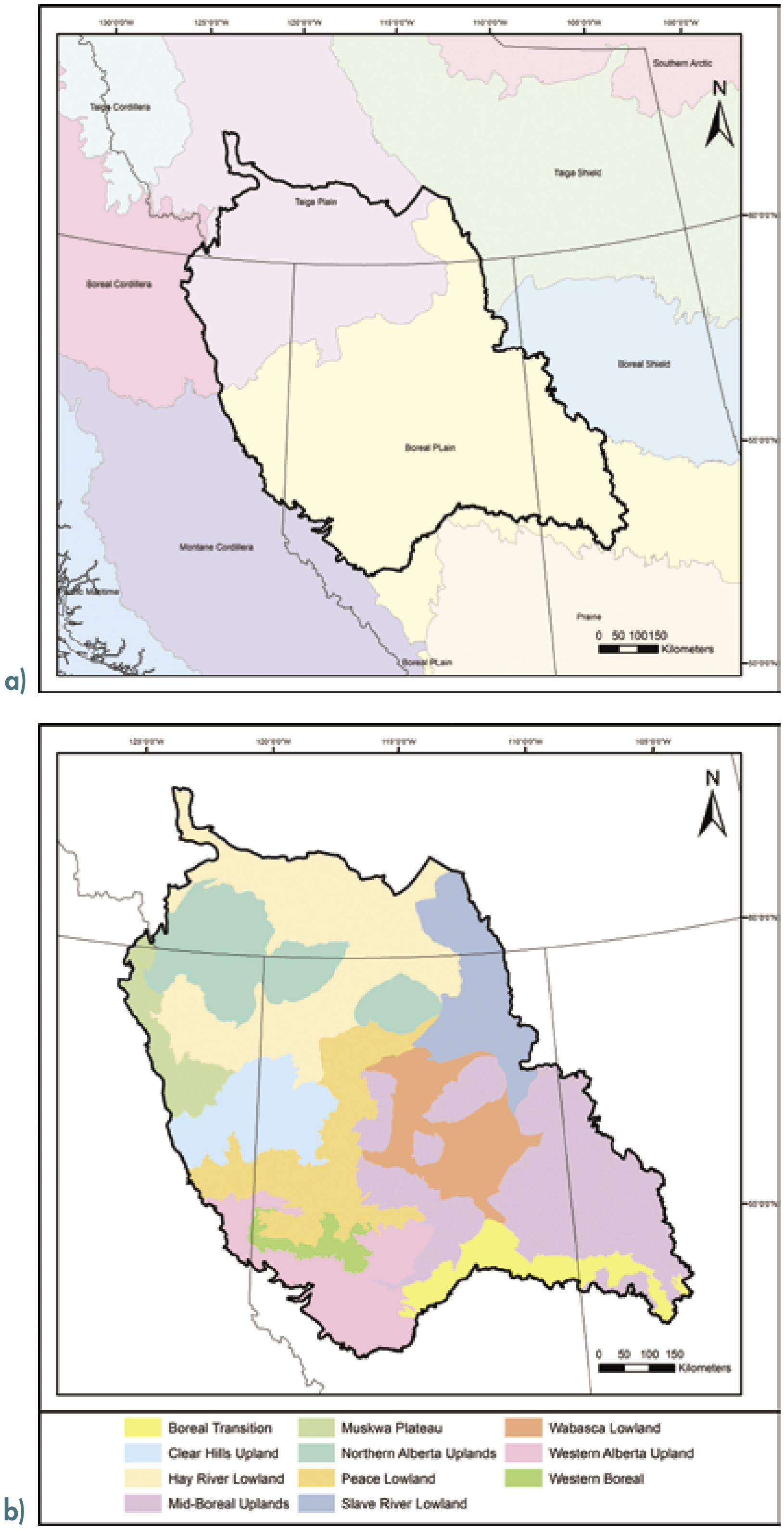

Figure 1. Study area location (outlined in black) relative to a) western Canadian ecozones and b) western Canadian ecoregions.

The study area includes areas of existing and potential future development of all major land uses (energy, forestry, agriculture, settlements) and associated infrastructure, while also providing opportunities for proactive land use planning due to the presence of intact forest landscapes (Figure 2). The project's scope (i.e., study area, scenarios, and indicators) was informed in part by a workshop held at the University of Alberta in December 2010 that was attended by experts in western boreal ecology and land use planning.

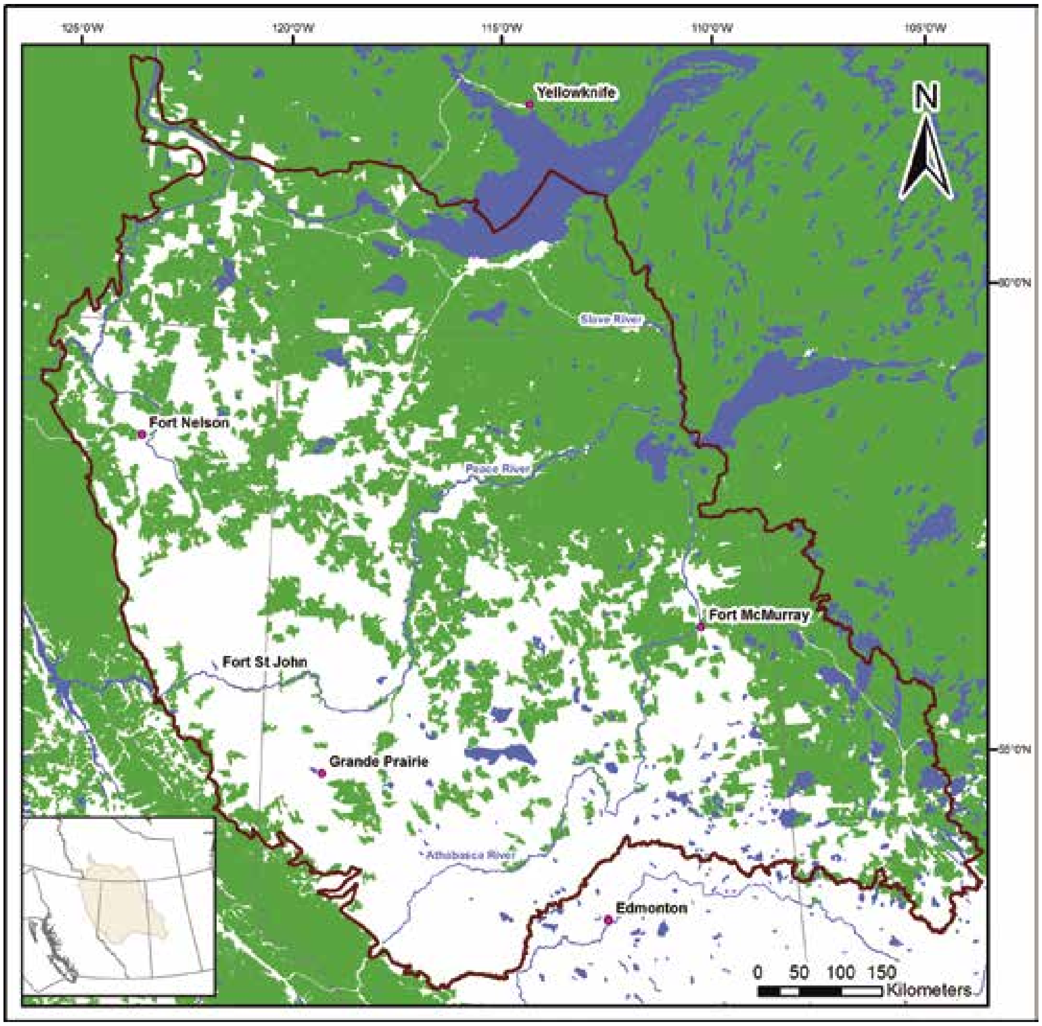

Figure 2. Intact forest landscapes within the study area indicated in green. Data Source: Canada's Intact Forest Landscapes (2010) – acquired in digital format from Global Forest Watch Canada.

2.2 Landscape Composition

In order to model the landscape composition into the future a baseline land cover and anthropogenic footprint needed to be compiled and used to parameterize ALCES®. Natural and anthropogenic land cover was established using existing data sets or applying known rates and patterns of development to estimate footprint as described in detailed methods provided in the supplementary document available online. The resulting land cover types used in the model and their total area within the study region are described in Table 1. Anthropogenic footprint types tracked in the model and their total area and length are described in Table 2.

Table 1. Description and initial area of vegetation land cover types in the study area.

Land cover type	Corresponding GeoBase cover types	Description	Area (ha)
Deciduous forest	Broadleaf Dense, Broadleaf Open, Broadleaf Sparse	Predominantly forested areas with crown closure ≥ 10% and deciduous trees accounting for ≥ 75% of total basal area.	13,973,186
Coniferous forest	Coniferous Dense, Coniferous Open, Coniferous Sparse	Predominantly forested areas with crown closure ≥ 10% and coniferous trees accounting for ≥ 75% of total basal area.	25,748,365
Mixedwood forest	Mixedwood Dense, Mixedwood Open, Mixedwood Sparse	Predominantly forested areas with crown closure ≥ 10% and neither deciduous nor coniferous trees accounting for ≥ 75% of total basal area.	1,103,831
Shrub	Shrub tall, Shrub low, Prostrate dwarf shrub	At least 20% ground cover which is at least one-third shrub.	2,542,251
Bryoids	Bryoids	At least 20% ground cover or 33% total vegetation is bryophyte (mosses, liverworts, hornworts) or lichen	2,819
Herbaceous	Tussock graminoid tundra, Wet sedge, Moist to dry non-tussock graminoid/dwarf shrub tundra, Dry graminoid prostrate dwarf shrub tundra	Minimum of 20% ground cover or one-third of total vegetation is vascular plant without woody stem.	1,727,170
Treed peatland	Wetland – Treed	Peatland where majority of vegetation is tree.	8,441,670

Land cover type	Corresponding GeoBase cover types	Description	Area (ha)
Shrub peatland	Wetland – Shrub	Peatland where majority of vegetation is shrub.	5,034,885
Herbaceous peatland	Wetland – Herb	Peatland where majority of vegetation is herbaceous.	1,145,984
Barren	Snow/ice, Rock/rubble, Exposed land, Sparsely vegetated bedrock, Sparsely vegetated till-colluvium, Bare soil with cryptogam crust – frost boils	Predominately non-vegetated	302,390
Lake	Water	Lentic systems	3,471,470
River	Water	Lotic systems	522,032
Annual cropland	Annual cropland	Annually cultivated cropland	1,978,134
Forage cropland	Perennial cropland and pasture	Periodically cultivated cropland.	2,284,233

Table 2. Area and length of anthropogenic footprint types in the study area and data sources used.

Footprint type	Data source	Area (ha)	Length (km)
Major road	GeoBase national road network	179,382	70,929
Minor road	GeoBase national road network	39,324	16,385
Railroad	CanVec	7,140	3,570
Transmission corridor	CanVec; entities = power transmission line, transmission line	17,709	4,427
Pipeline	Provincial inventories	229,091	152,727
Seismic	Provincial inventory for BC. Corrected CanVec inventory for AB, SK, and NT	430,745	957,211
Wellsite	GFWC national well data set	139,546	57,529
Industrial plant	CanVec (entity = gas and oil facilities) and provincial inventories	56,527	14,757
Oil sands mine	Oil sands surface mining activity in Alberta, Canada up to 2008 (GFWC, provided through databasin)	64,951	785
Gravel pits	CanVec (entities = extraction area, pit)	3,852	775
Settlements	CanVec (entities = residential area)	44,616	1,119
Rural residential	CanVec (entity = building, camp)	60,608	23,481

The resulting land cover and footprint baseline layer, shown in figure 3, was used as the initial state when simulating landscape changes over time under different development rates and management practices.

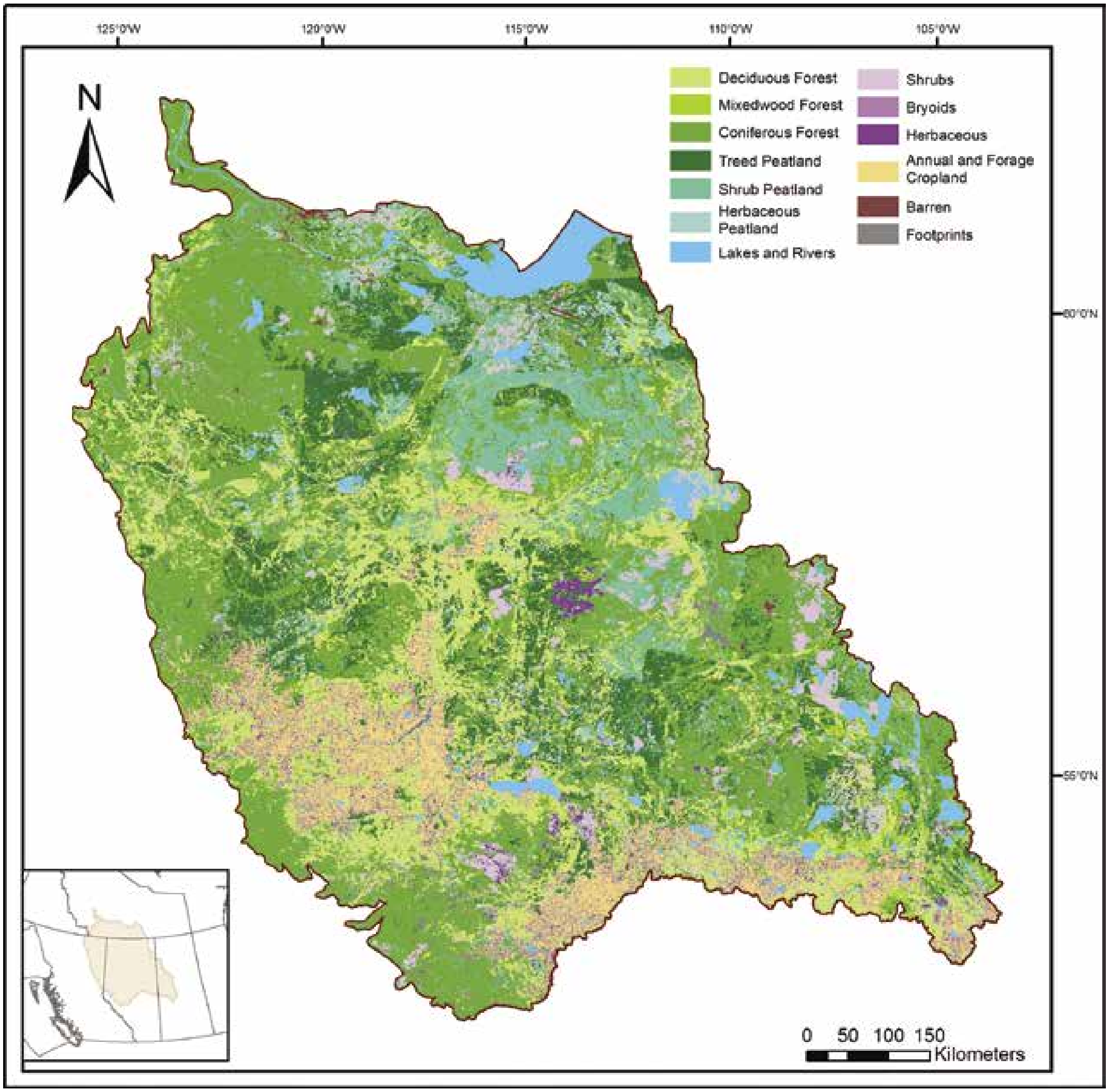

Figure 3. Initial land cover composition of the study area.

2.3 Land-use Scenarios

The scenario analysis did not attempt to predict the future, but rather present a suite of plausible futures that demonstrate logical outcomes of alternative land-use options. The scenarios were selected to assess the strategic benefits and liabilities of land use in the western boreal region, and options for balancing development with conservation. More specifically, the suite of scenarios assessed the implications of manipulating development rates, management practices, and conservation zoning for the five main land uses in the region (oil and gas, forestry, agriculture, settlements, and transportation). The extent of resource development in the simulations was defined using the best available information on resource location and quantity (Figure 4). Settings for development rate, management practices, and conservation zoning are summarized below.

1. Development rate. Three development rates were simulated: low, moderate, and high. The three development rates reflected: reduced or stagnant commodity prices, moderate commodity prices, and robust and sustained commodity prices.
2. Management practices. The effectiveness of best practices at mitigating ecological impacts was explored by applying them to the moderate growth scenario, where best practices refer to strategies to minimize the impact of resource development without affecting the rate of commodity production.
3. Conservation zoning: a suite of scenarios explored the consequences of zoning portions of the landscape for wildlife conservation while elsewhere applying the moderate development rate. It was assumed that the pace of land use outside of protected areas would not intensify to offset the reduction in development caused by protection.

METHODS

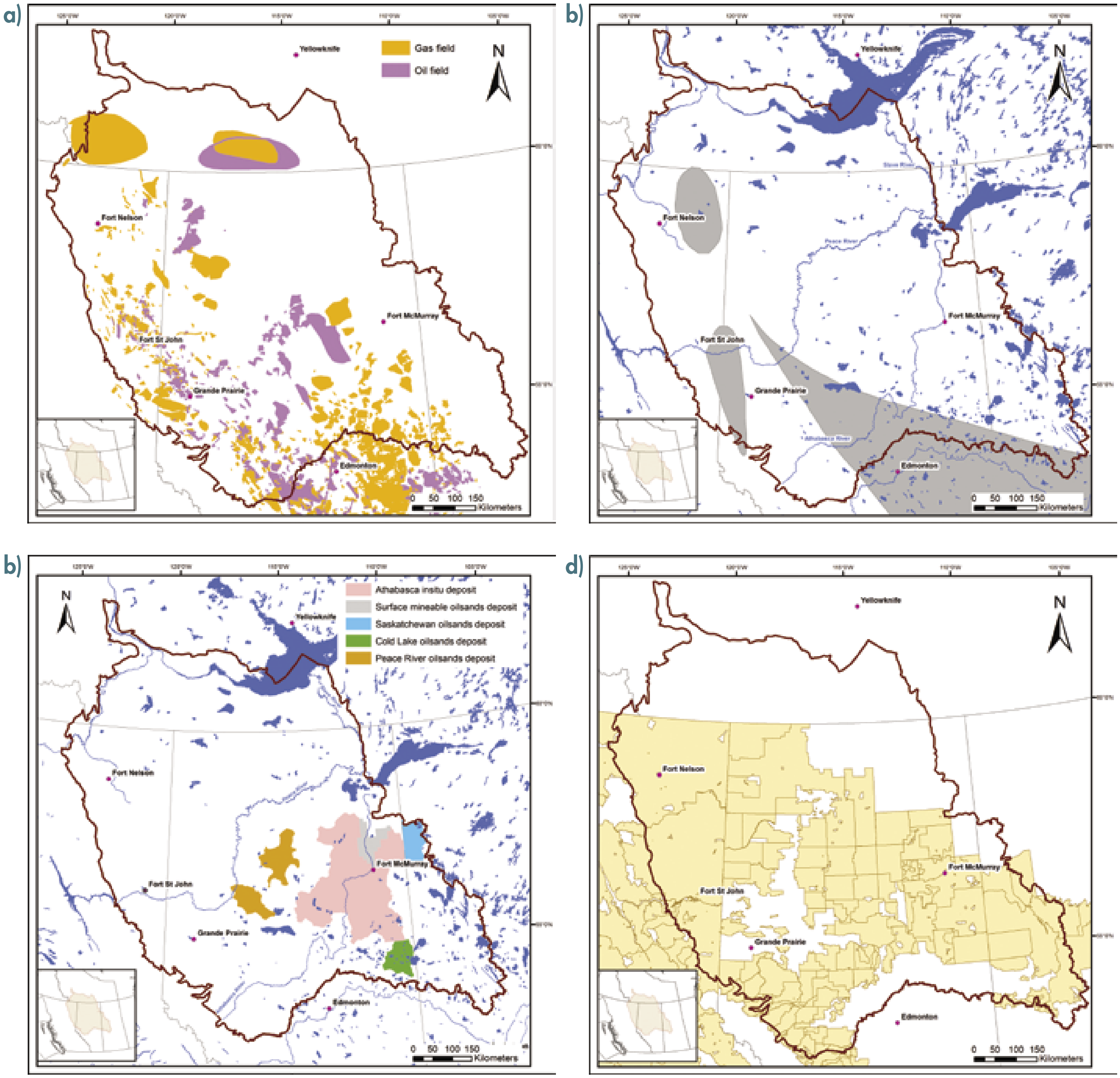

Figure 4. Distribution of a) conventional oil and gas, b) shale gas, c) oil sands and d) forestry resources within the study area. These resource locations were used to define future development scenarios in ALCES®.

Accurate forecasting is problematic because uncertain factors such as societal values, government policy, global commodity prices, and technological innovation all affect future land use. However, examining plausible futures using transparent assumptions based on best-available information allows potential benefits and impacts to be understood and evaluated today to identify risks and uncertainties. When faced with uncertainty, we attempted to derive conservative assumptions for the rate of future development and the intensity of associated footprint, so as not to exaggerate future disturbance that can be expected in the region (Table 3). Furthermore, the evaluation of three levels of development (low, moderate, and high) permits the assessment and projected implications of a range of development rates to future indicator condition.

Table 3. Examples of conservative modeling assumptions.

Sector	Examples of conservative assumptions
Hydrocarbon development	• Not including oil shale and coal bed methane development, both of which are intensive with respect to footprint. • Assuming high productivity for in situ and shale gas wells, such that footprint per m^3 of production declines as production shifts from conventional to unconventional hydrocarbons. • Not increasing overall gas production (i.e. conventional plus unconventional) from the region over the simulation period.
Forestry	• Not simulating regeneration delay or shifts in species composition after timber harvest. • Salvaging all merchantable timber from forest cleared for industrial development. • Not simulating a decline in growth and yield for northern portions of the study area. • Not including insect-related forest mortality
Agriculture	• Simulated rate of expansion in agricultural land was lower than the historical rate of expansion
Settlements	• The simulated population growth rate was substantially lower than the long-term historical population growth rates of the study area's two most populous municipalities (Fort McMurray and Grande Prairie)

2.3.1 Development Rate

A moderate development rate scenario was informed by: hydrocarbon production projections from industry, government, and research organizations; annual allowable cuts for commercial forest tenures; estimates of future deforestation due to agricultural expansion; and the recent rate of population growth. The moderate development rate was then modified to create the low and high development scenarios. As oil sands development is the primary economic driver in the region, expert projections of the future of this industry were used to define the difference between low medium and high development rate scenarios. The Canadian Energy Research Institute (CERI; Millington and Mei 2011) provide low ("protracted slowdown"), moderate ("realistic"), and high ("energy security") growth projections of oil sands development in Canada, all of which assume substantially increased production over the next 35 years. These projections translate to a low development rate approximately 17% lower than the 'realistic' or moderate scenario and a high development rate approximately 14% higher than moderate. In order to capture the full range of possible effects of development rate on ecosystem outcomes we used a broader development rate interval of moderate production plus or minus 20%. This was achieved by varying total commodity production up or down by 20% for each resource sector, which the model translated into reduced or increased changes to land cover over time. An exception was agriculture for which low and high development rates were available directly from an analysis exploring future rates of deforestation due to agricultural expansion (ArborVitae 2004).

In all scenarios, the location of simulated land use was based on the spatial distribution of natural resource potential. The intensity and lifespan of footprints associated with land use was based on existing landscape patterns and previous projects.

2.3.2 Best Practices

The best practices scenario was developed to implement strategies for reducing environmental impacts without altering the amount or location of land use. The best practices (Table 4) focused on the main drivers of impacts identified in the business as usual scenario. All other scenario assumptions were equivalent to those assumed for the moderate business as usual scenario.

Table 4. Strategies for reducing environmental impacts modelled in the best practices scenario.

Environmental impact	Best practices
Footprint	Reduce the time required to reclaim well sites and access roads by 15 years through reforestation and minimizing soil disturbance. Double in situ and shale wells per pad through directional drilling Reduce seismic lifespan by 50% by minimizing soil disturbance and installing barriers to motorized access. Barriers to motorized access are also assumed to reduce angler, hunter and trapper access along seismic lines by 50%.
Emissions	Reduce bitumen sector greenhouse gas (GHG) emission intensity by 50% by 2050 through carbon capture and storage and increased efficiency Reduce bitumen upgrading sulphur oxide emission intensity by 50% through flue gas scrubbing
Water	Reduce nutrient and sediment runoff from agricultural land by 50% through careful application of fertilizer, soil conservation, riparian buffers, and separation of livestock manure from streams

2.3.2.1 Habitat loss and disturbance best practices

Best practices to reduce footprint focused on the energy sector which accounted for almost 70% of the industrial footprint in the business as usual scenario, not including cut blocks and agricultural land. Under best practices, well sites and well access roads were reforested after closure and efforts were made to minimize soil disturbance (i.e., through winter drilling, minimizing soil stripping, and leaving slash whole) and avoid the introduction of invasive plant species (Schneider and Dyer 2006). The scenario assumed that these practices reduced reclamation time by 15 years (Athabasca Landscape Team 2009). Increased application of directional drilling doubled the average number of in situ and shale wells per pad (Athabasca Landscape Team 2009). By minimizing disturbance to soil and roots and by including barriers to motorized access, seismic line lifespan was reduced by 50% to 10 years[4]. Barriers to motorized access were assumed to reduce angler, hunter and trapper access along seismic lines to 50% that of conventional seismic. Coordinated planning between the energy and forestry sectors decreased minor road footprint by 34%[5]. Increased monitoring and maintenance of stream crossings increased replacement of problem culverts from 2% to 10% per year.

2.3.2.2 Emissions best practices

The best practice scenario focused greenhouse gas emission abatement on bitumen extraction and upgrading which accounted for 86% of emissions in the business as usual simulation. The best practice scenario assumed that widespread application of Carbon capture and storage, combined with efficiency improvements, can achieve a 50% reduction in GHG emission intensity from bitumen development by 2050 consistent with the government of Alberta's emission intensity reduction target (Government of Alberta 2008).

The best practice scenario also focused sulphur oxide emission abatement on bitumen extraction and upgrading. The bitumen sector accounted for 87% of sulphur oxide emissions during the business as usual simulation. In addition, bitumen sector emissions are in proximity to the Canadian Shield where lakes and soils have a higher sensitivity to acidification than on the Boreal Plains. The main opportunity for reducing bitumen sector sulphur dioxide emission intensity is flue gas scrubbing at upgrading plants (Industry Canada 2004). Syncrude Canada's Emissions Reduction Project is expected to achieve a 50% reduction in sulphur dioxide emissions at an upgrading plant by retrofitting scrubbers. The best practices scenario assumed that industry-wide adoption of scrubbers would achieve a 50% reduction in sulphur oxide emissions associated with upgrading.

[4] Schneider and Dyer (2006) report that low impact seismic with barriers to motorized access may reclaim within five years. Some seismic, however, will persist longer than five years given the increased use of 4D techniques.

[5] A case study in northeastern Alberta determined that coordinated planning between energy and forestry companies could reduce road access by 34% (Schneider and Dyer 2006). Prior to application in the scenario analysis, the level of road reduction had to be adjusted because only a portion of the study area's road network exists in areas of overlap between forestry and energy sector activities. Based on the road network analysis described in the transportation section, approximately 40% of the road network exists in areas of forestry and energy sector overlap. After adjustment to account for the portion of the road network outside of areas of forestry and energy sector overlap, the reduction in road access achievable through coordinated planning is decreased from 34% to 14%.

As with simulated reduction in GHG emission intensity, implementation of the 50% reduction in sulphur oxide was gradual and followed a linear pattern.

2.3.2.3 Water best practices

Best practices to mitigate nutrient and sediment loading focused on minimizing footprint and reducing loading from agricultural land. The best practice scenario assumed that a 50% decrease in nutrient and sediment runoff from cropland and pasture is achievable through careful fertilizer application, improved riparian management, soil conservation, and separation of cattle manure from streams.

Oil sands mining accounted for 70% of water use in the business as usual scenario, and reached levels approaching the maximum wintertime water removals set out in the water management framework for the Athabasca River. As such, abating water consumption by the oil sands mining sector is an important management objective. Opportunities for reducing water use include non-aqueous oil sands extraction and acceleration of fine solids settling in tailings ponds (Griffiths et al. 2006). Such strategies are in the research and development phase, however, and their feasibility and effectiveness remain uncertain. Due to this uncertainty around possible water use reductions in the single largest water use sector, water use was not included in the best practice scenario.

2.3.3 Conservation Zoning

To assess conservation zoning as a land-use strategy, scenarios were completed that excluded development from a subset of tertiary watersheds, a unit of conservation well suited for protecting ecological integrity (Schindler and Lee 2010). As described in section 3.2, numerous conservation zoning scenarios were assessed to explore the relationship between level of protection and wildlife indicator performance. This was achieved through integration of outcomes from: 1) a simulation with moderate development and business as usual practices; and 2) a simulation that excluded all future development. The implications of a conservation zoning scenario was explored by selecting each watershed's output from either the business as usual development trajectory or the conservation zoning trajectory when integrating the simulations to map and report performance across the study area. Conservation of a watershed implied no new footprint, and that existing developments such as hydrocarbon wells completed their productive lifespan and then reclaimed to natural land cover according to the best practice assumptions (described previously). Features assumed to be permanent in other scenarios (farmland, settlements, roads, pipelines) did not reclaim, but also were not permitted to expand. Watersheds that remained zoned for development in a given scenario were assumed to follow the land use trajectory from the moderate development simulation. The approach allows for the examination of the consequences of protecting watersheds from development while not altering the intensity of development in the remaining landscape. This is a conservative assumption as in reality development intensity would be expected to increase in the remaining portion of the landscape allotted for resource development.

In addition to assessing the response of wildlife indicators to a gradient of protection levels, outcomes were assessed for a single conservation zoning scenario that excluded 20% of natural resource value from exploitation. The scenario is not intended as a proposed conservation strategy, but rather is presented to illustrate consequences of conservation as a general land-use strategy. The rationale for the conservation scenario is presented in section 3.2 and is based on the simplistic yet illustrative approach of minimizing natural resource value foregone. This design ignored several considerations that would be central to conservation area network design such as ecosystem representation, protection of focal species habitat, and sub-regional economic impacts. An approach for incorporating such factors into a scenario analysis is discussed in Appendix 1.

2.4 Ecological and Economic Indicators

The scenario analysis assessed a range of ecological and economic indicators (Table 5) to convey trade-offs associated with the land-use scenarios. Ecological indicators encapsulated habitat, wildlife, and ecological processes to provide a succinct but informative assessment of the potential effects of land use to the region’s ecological goods and services. Economic indicators included employment and gross domestic product.

Table 5. Indicators assessed in the scenario analysis.

Indicators
Area of older forest
Area of anthropogenic footprint (total and by sector)
Old forest bird index
Woodland caribou population index
Moose habitat suitability index
Fisher habitat suitability index
Index of native fish integrity
Phosphorus and Phosphorus runoff
Water use
Biotic carbon of upland forests
Industrial emissions (CO_2e, NOx, and SOx)
Employment (total and by sector)
GDP (total and by sector)

Wildlife and environmental indicators are reported as the departure from a model estimated natural range of variation for the indicator in absence of resource development. Natural condition for ecological indicators was estimated by calculating indicator status after removing anthropogenic footprint from the study area and applying a stochastic natural fire regime. Anthropogenic footprint was removed by converting footprint to natural land cover based on the composition of adjacent natural land cover. The annual burn rate was simulated as a random draw from a lognormal distribution with mean of 1.1% (Armstrong 1999). Fifty Monte Carlo simulations were completed, each 200 years in length with the first 100 years used to calibrate forest age to a "natural" distribution. When mapping an indicator's natural condition, indicator status was calculated based on a location's pre-development composition and the average forest age-class distribution resulting from the Monte Carlo fire simulations.

Departure from natural was used to infer risk to species. For wildlife indicators, a risk index was calculated by dividing future status by its estimated natural condition and then applying risk categories. For moose, fisher, and the index of native fish integrity, risk categories are: 1) low risk, defined as a decline of no more than 30% from natural (risk index > 0.7); 2) moderate risk, defined as a decline of 30% to 50% from natural (risk index >0.5); 3) high risk, defined as a decline of 50% to 80% from natural (risk index > 0.2); and 4) very high risk, defined as a decline of more than 80% from natural (risk index < 0.2). For the old forest songbird index, risk categories were informed by a scoring system applied by Partner's in Flight to identify bird conservation objectives from population trends (Rosenberg and Blancher 2005). The risk categories are: low risk, defined as less than 15% decline from natural (risk index > 0.85); moderate risk, defined as 15% to 50% decline from natural (risk index > 0.5); and high risk, defined as more than 50% decline from natural (risk index < 0.5). For the caribou population index, risk was assessed using a set of thresholds developed for assessing risk to caribou ranges in northeastern Alberta (Athabasca Landscape Team 2009). The thresholds incorporate three levels of risk to population persistence: low, defined as index values that are greater than 0.99; moderate, defined as index values that are between 0.95 and 0.99; and high, defined as index values that are below 0.95.

The indicators are intended to report on a range of values that are relevant to the public and decision makers. By reporting biotic carbon and GHG emissions, the scenario analysis assessed the effect of regional land use on global warming. Nutrient and sediment loading assessed the effect of land use on water quality. By reporting the status of woodland caribou and other wildlife species (songbirds, moose, furbearers, fish), the project assessed the effect of land use on wildlife. We attempted to select species that the public may have developed an affinity with through media and campaigns (i.e., caribou), nature viewing (songbirds), hunting (moose), angling (fish), and trapping (fisher). SOx and NOx emissions was assessed as a measure of air pollution.

The indicators were selected to be relevant to potentially influential legislation or agreements including the Species at Risk Act (woodland caribou), the Migratory Birds Convention Act (songbirds), Fisheries Act (fish), the Mackenzie River Basin Transboundary Waters Master Agreement (water quantity and quality), and climate change agreements (greenhouse gas emissions and biotic carbon).

Relationships applied to assess indicator response to land-use scenarios are described in the supplementary methods available online.

SCENARIO OUTCOMES

Four categories of scenario outcomes are presented: socioeconomic benefits, resulting changes to the landscape, implications for fish and wildlife, and implications for ecosystem services.

Graphs are used to summarize future indicator performance on an annual basis at the full study area scale. For a subset of indicators, two series of maps are also presented to show estimated watershed level outcomes. The first series shows an indicator's status averaged across each tertiary watershed at each reporting year (2010, 2020, 2030, 2040, 2050, and 2060) during the moderate scenario to convey changes in the spatial distribution of indicator condition over time. The second series shows indicator status at year 2060 for all five scenarios to allow for comparison of the 50 year outcome for wildlife and the environment under different land use options.

3.1 Projected Benefits of Development

Socioeconomic benefits are presented for low, moderate, and high development scenarios. The best practices scenario is not presented because it was assumed that the improved management practices would be achieved with no loss in resource production and therefore the same socioeconomic benefit as business as usual. The socioeconomic implications of conservation zoning are presented in the following section (3.2) which explores the trade-off between socioeconomic benefits of resource development and wildlife benefits of conservation.

3.1.1 Commodity Production

Total annual energy production[6] more than doubled during the moderate scenario (Figure 5). The relative contribution of each hydrocarbon type to total production shifted during the simulation period, with conventional energy sources declining and unconventional energy sources such as bitumen increasing (Figure 6). The simulated growth in unconventional hydrocarbon production is in concordance with organizations such as the Canadian Energy Research Institute (CERI 2011a) and the National Energy Board (NEB 2011b), which project that annual bitumen production will increase to 12 billion Gigajoules (GJ) over the next 25 to 30 years.

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[6] Hydrocarbon production was converted from m3 to GJ by applying conversion factors used by the National Energy Board (http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/sttstc/nrgycnvrsntbl/nrgycnvrsntbl-eng.html#s4ss1). When calculating conventional oil energy production, the conversion factor for light crude oil was used (1 m3=38.51 GJ). When calculating bitumen energy production, the conversion factor for heavy crude oil was used (1 m3=40.9 GJ). Natural gas and shale gas production was first converted from m3 to thousand cubic feet (1 m3=0.035301 tcf), and then converted to GJ (1 tcf=1.05 GJ).

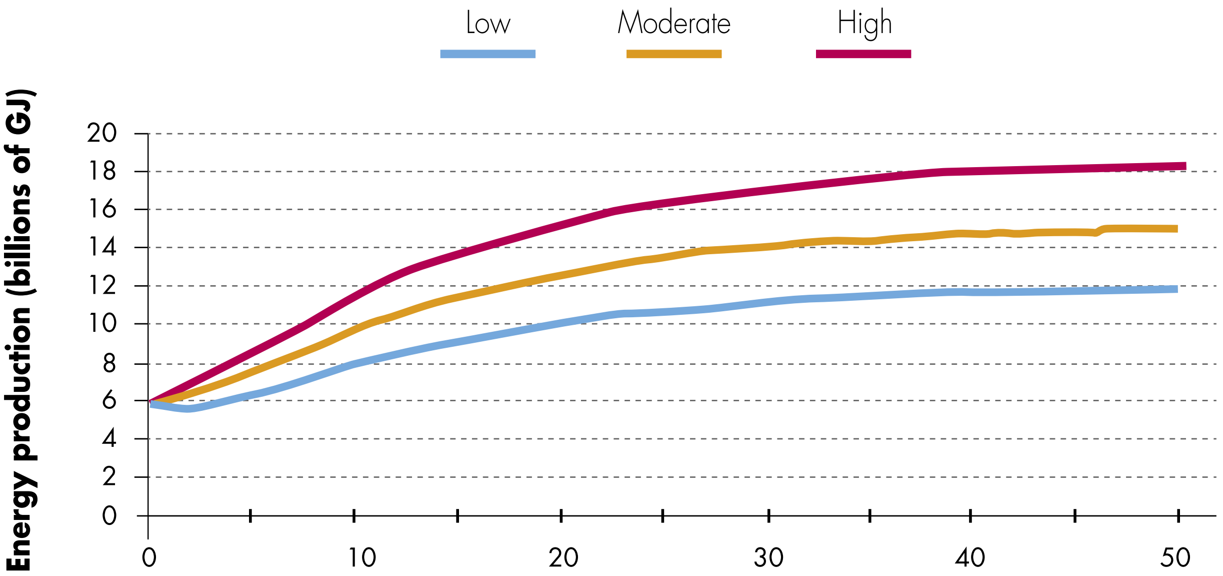

Figure 5. Energy production during simulations of low, moderate, and high development scenarios in gigajoules (GJ) where, for example, 1 barrel of oil equals 5.86 GJ.

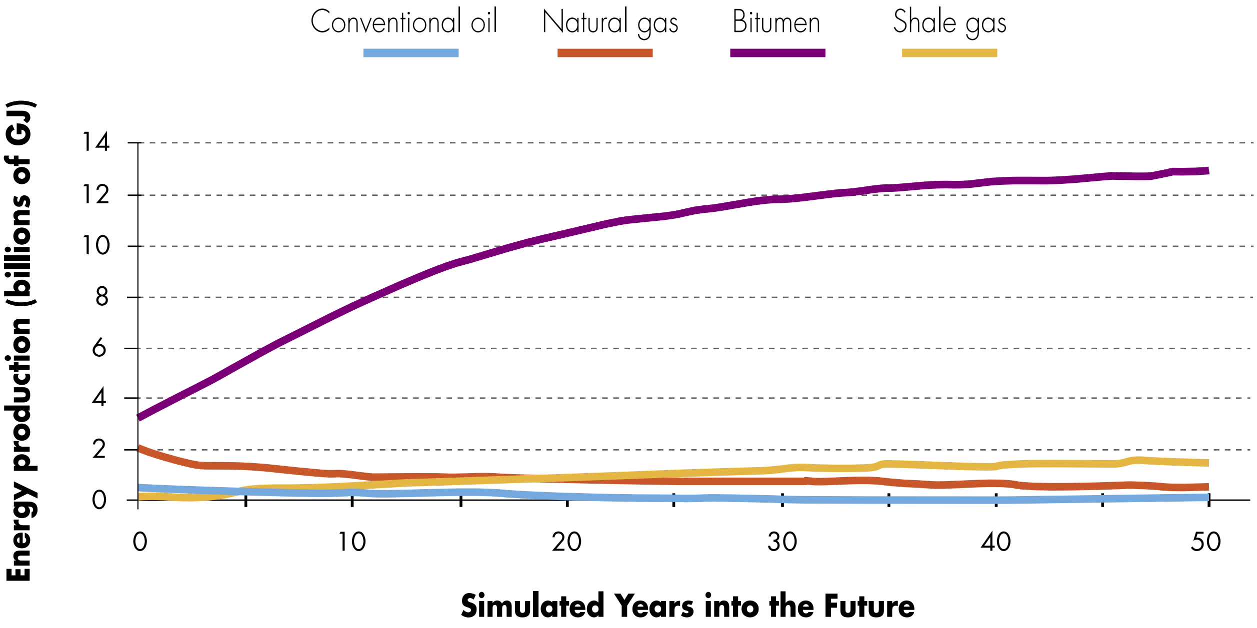

Figure 6. Energy production by hydrocarbon type during simulation of the moderate development scenario in gigajoules (GJ) where, for example, 1 barrel of oil equals 5.86 GJ.

Timber harvest targets for the low, moderate, and high scenarios were achieved throughout the 50-year simulations (Figure 7), in part due to the large proportion (57%) of tenured forest that is of merchantable age in the study area today. The abundance of mature and older forest reflects the relatively early stage of forestry in parts of the region, and below-natural levels of natural disturbance in recent decades due to fire suppression (e.g., Cumming 2005). As the simulation proceeded, however, the volume of merchantable timber declined in response to an expanding forestry footprint (Figure 8).

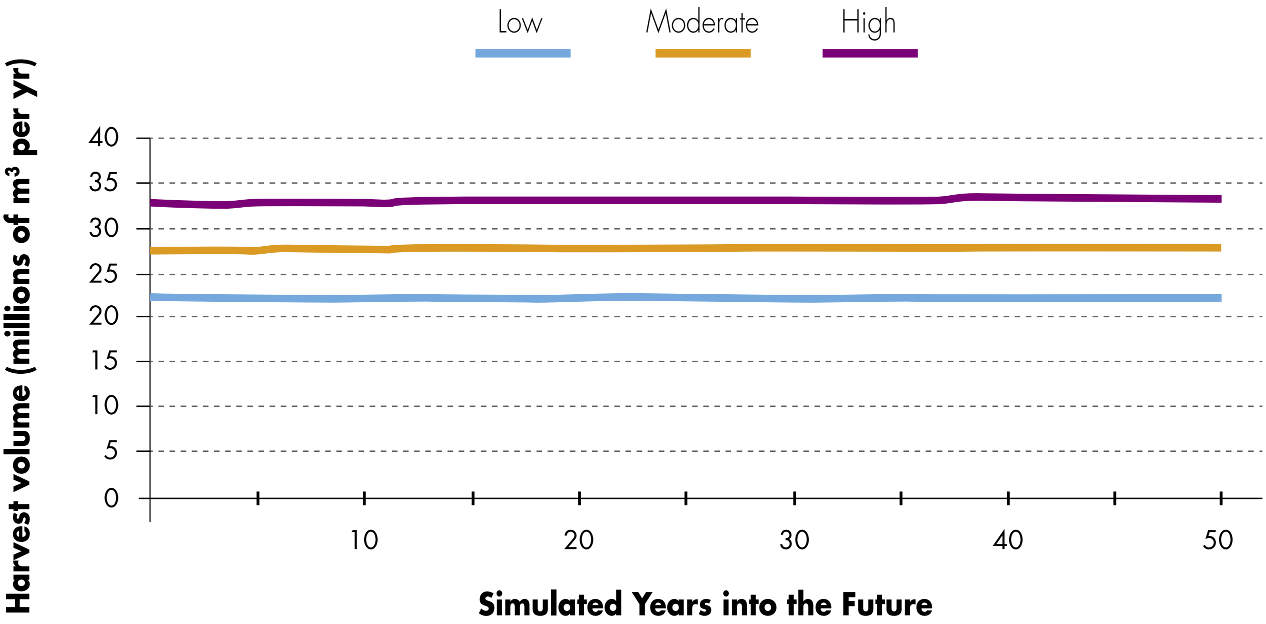

Figure 7. Timber harvest during ALCES simulations of low, moderate, and high development scenarios for the Western Boreal study area.

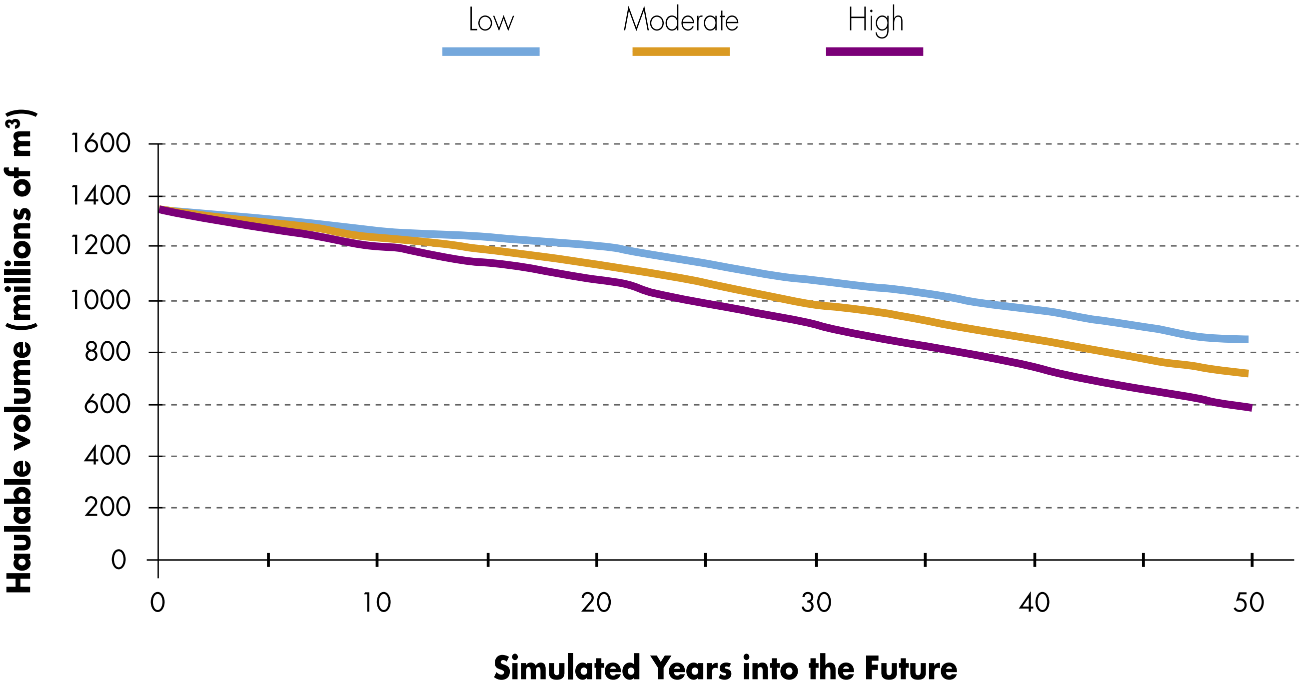

Figure 8. Haulable volume during simulations of low, moderate, and high development scenarios.

3.1.2 Economic Output

Employment (Figure 9) and GDP (Figure 10) directly related to natural resource production increased more than two-fold during the simulations. The increase in economic output was due to rising energy production, where the energy sector was responsible for 85% of direct employment (Figure 11) and 95% of direct GDP (Figure 12) by the end of the moderate scenario. By focusing on direct consequences of land use in the region, the scenario analysis only captured a portion of the economic benefits of simulated natural resource production. When national direct, indirect, and induced impacts of bitumen production are taken into account, employment associated with the bitumen sector is expected to increase to 905,000 jobs by 2035 (CERI 2011b).

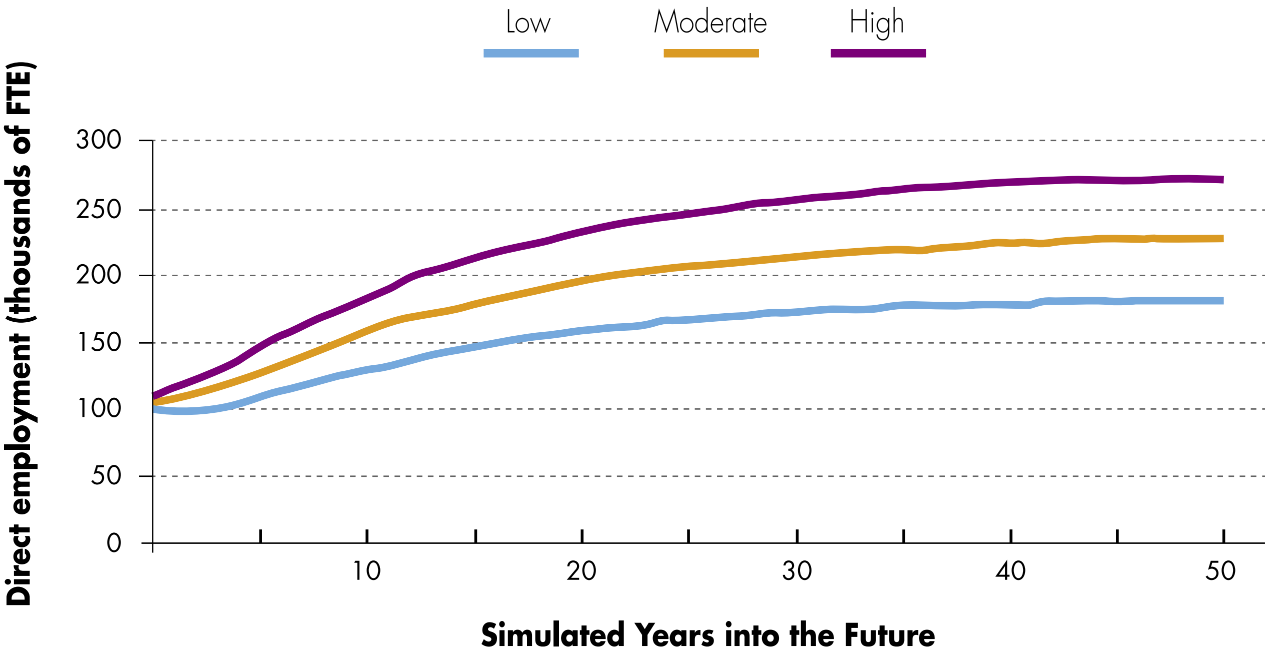

Figure 9. Annual full-time employment (FTE) in the natural resource sector during simulations of low, moderate, and high development scenarios.

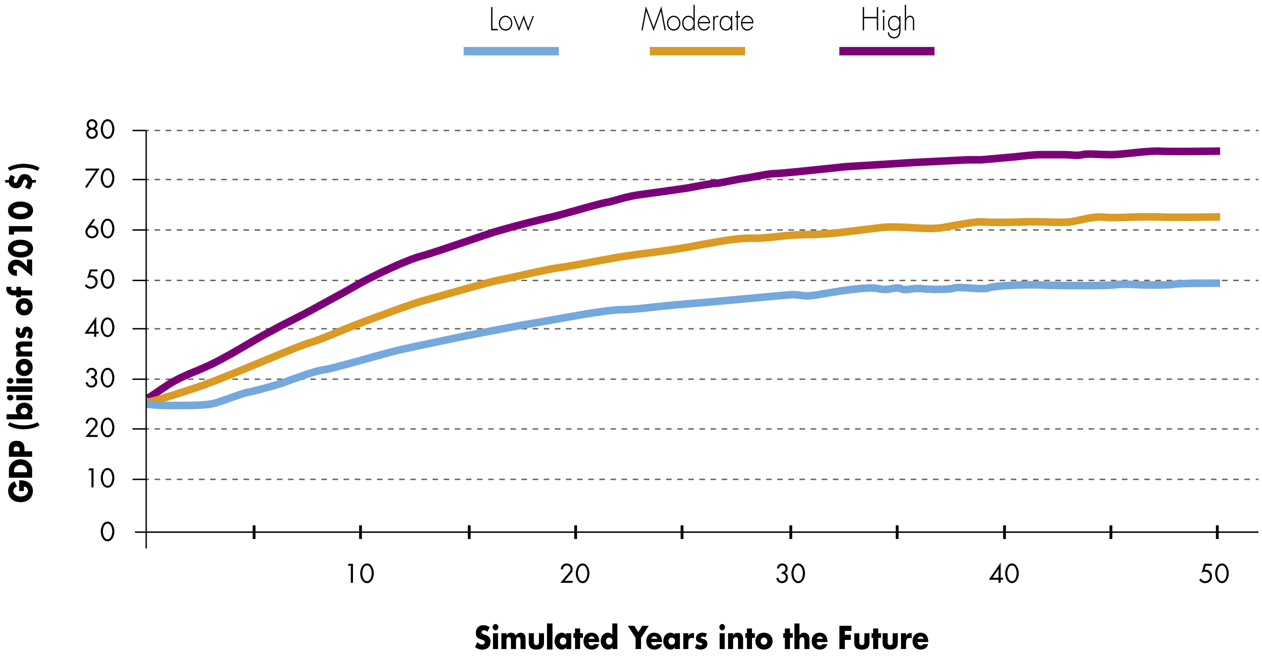

Figure 10. Response of gross domestic product (GDP) generated by the natural resource sector to low, moderate, and high development simulation scenarios.

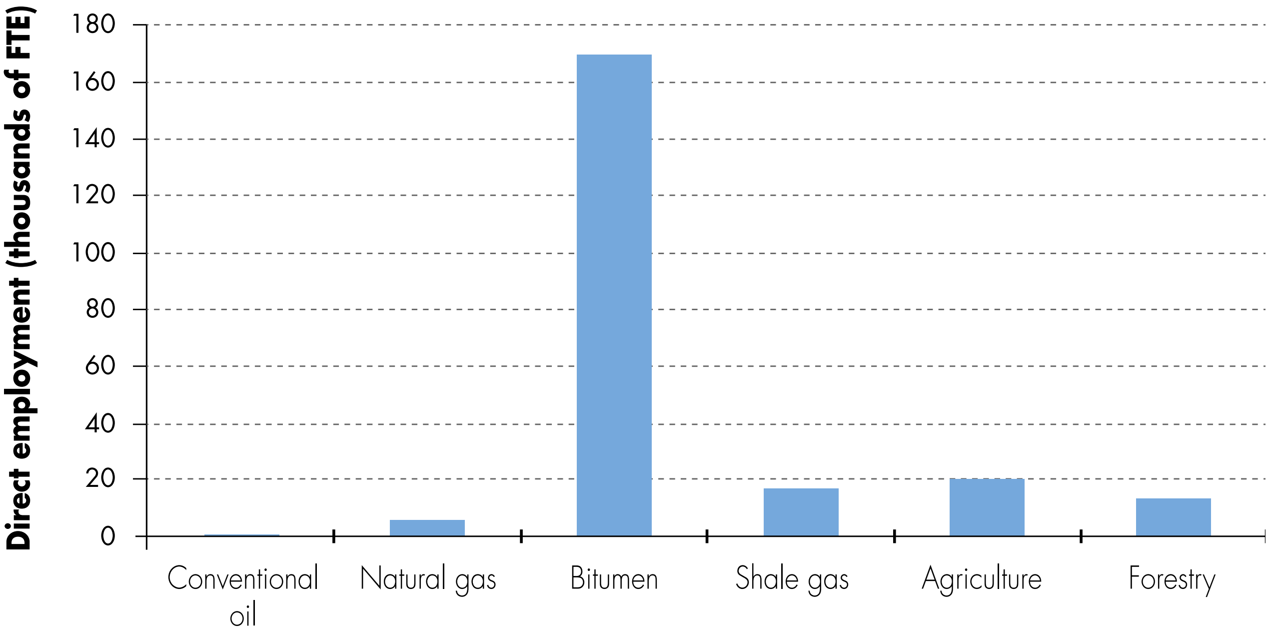

Figure 11. Full-time employment (FTE) by natural resource sector at year 50 of the moderate scenario.

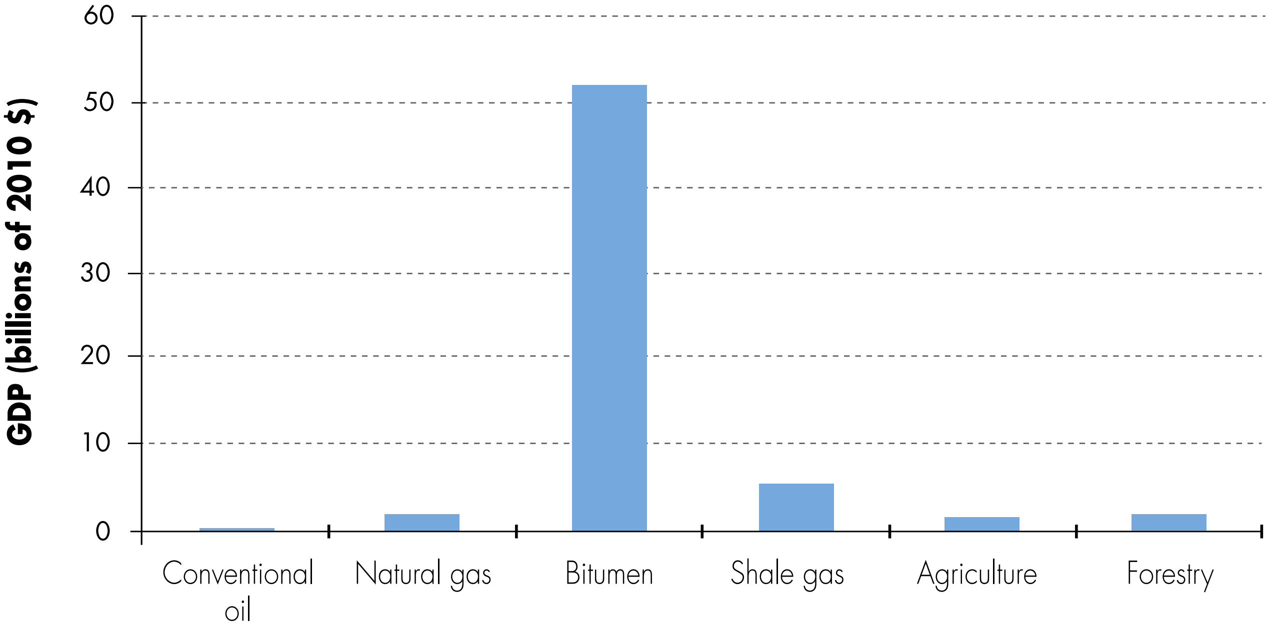

Figure 12. Gross domestic product (GDP) generated by each natural resource sector at year 50 of the moderate scenario.

3.1.3 Human population

The regional population was simulated to expand by 78% during the moderate scenario (Figure 13). The low and high scenarios exhibited smaller (47%) and larger (117%) increases in population in response to different levels of employment growth. The simulated rate of population growth is consistent with Statistics Canada's (2010) projection that Alberta's population will increase by 24-45% over the first half of our simulation period (i.e., by 2035).

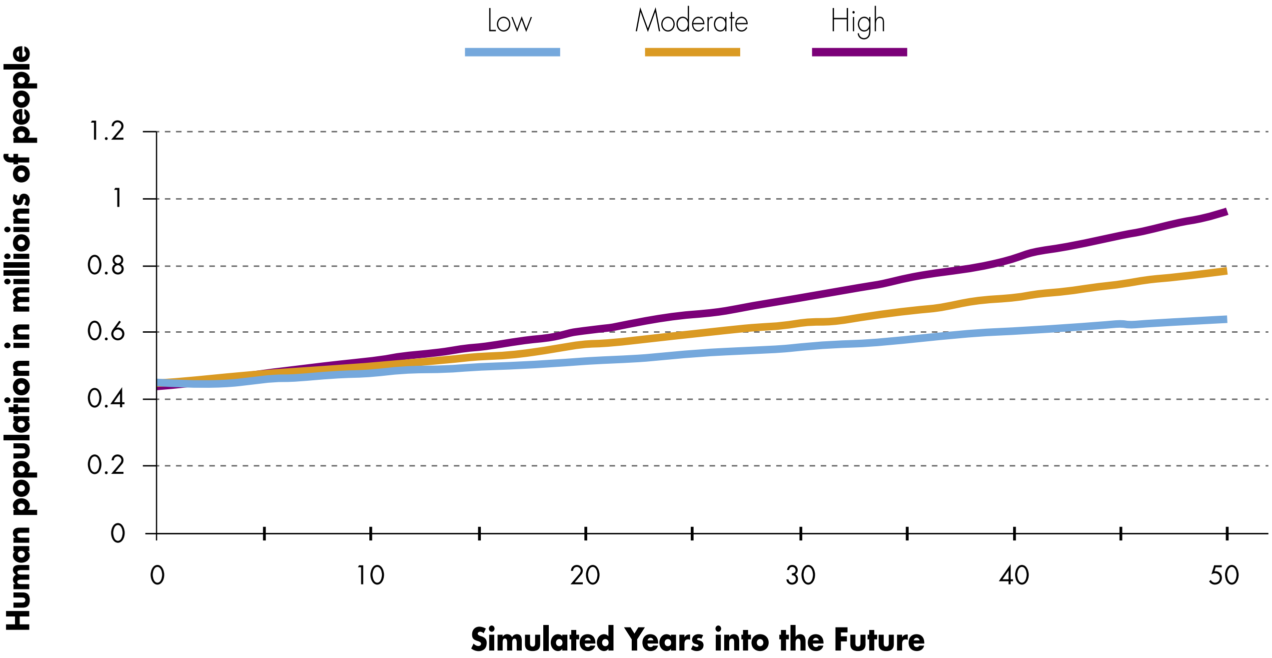

Figure 13. Human population growth during simulations of low, moderate, and high development.

In summary, potential economic benefits are substantial. Direct employment and GDP more than doubled during the moderate development simulation and were in the order of hundreds of thousands of jobs and tens of billions of dollars GDP annually. Even under a lower development rate, economic benefits from the region would remain a major contributor to national economic growth.

3.2 Economic Trade-Offs and Conservation Zoning

The intent of the conservation zoning analysis was not to propose specific conservation zones for consideration, but rather to illustrate a way of thinking about economic versus ecological benefits and liabilities and to consider the regional consequences of the most simplistic example of the approach; that is, allocation of land to wildlife conservation based solely on prioritizing areas of least economic value first.

Watersheds were first ranked by the economic cost of reducing anthropogenic disturbance through conservation. Avoided habitat disturbance in each watershed was calculated as the difference in the final area of anthropogenic footprint (i.e., in 2060) between the moderate growth and full protection scenarios. The gross domestic product (GDP) generated by resource development within each watershed during the moderate development scenario was then divided by the area of avoided habitat disturbance to calculate the cost per ha of avoided disturbance. The rationale for this ranking is that an important benefit of conservation zoning is reducing anthropogenic impact and that an important liability of conservation is inhibiting opportunities to develop natural resources. The outcome of this economic ranking analysis is presented in Figure 14.

The ranking was then applied to create a spectrum of conservation zoning scenarios using the simplistic approach of successively protecting watersheds beginning with the lowest cost per unit of avoided disturbance (Figures 15 and 16). As each additional watershed was zoned for conservation, the performance of ecological indicators across the region was reassessed. The end result was an assessment of ecological performance across a gradient of foregone resource development. Ecological performance was expressed in terms of the portion of the study area for which risk to an ecological indicator was limited to low after 50 years (Figure 15). We also examined the relationship between the proportion of the landscape that presented a high risk to wildlife after 50 years and the proportion of resource development foregone as a secondary conservation zoning outcome (Figure 16).

Ecological integrity initially increased rapidly as additional resource potential was protected from development (Figure 15). The rapid improvement was in part due to the aggregated distribution of natural resource value in the region. Economic value is concentrated in areas with large reserves of hydrocarbons, including the oil sands region and the Horn and Montney shale gas deposits As such, a large portion of the study area can be protected without substantially impacting potential economic growth.

The improvement in ecological integrity with protection was greatest for the fish community (INFI) and fisher, due to their sensitivity to human access. The old forest bird index was also sensitive because protected watersheds retained older forest due to the absence of timber harvest. Moose were less responsive to protection because the benefit of reduced human access was partially offset by reduced availability of younger forests that provide high habitat suitability. Even high levels of protection failed to expand the portion of watersheds where the risk of caribou extirpation is low. However, protection was successful at reducing the percent of the study area where risk to caribou viability was high (Figure 16).

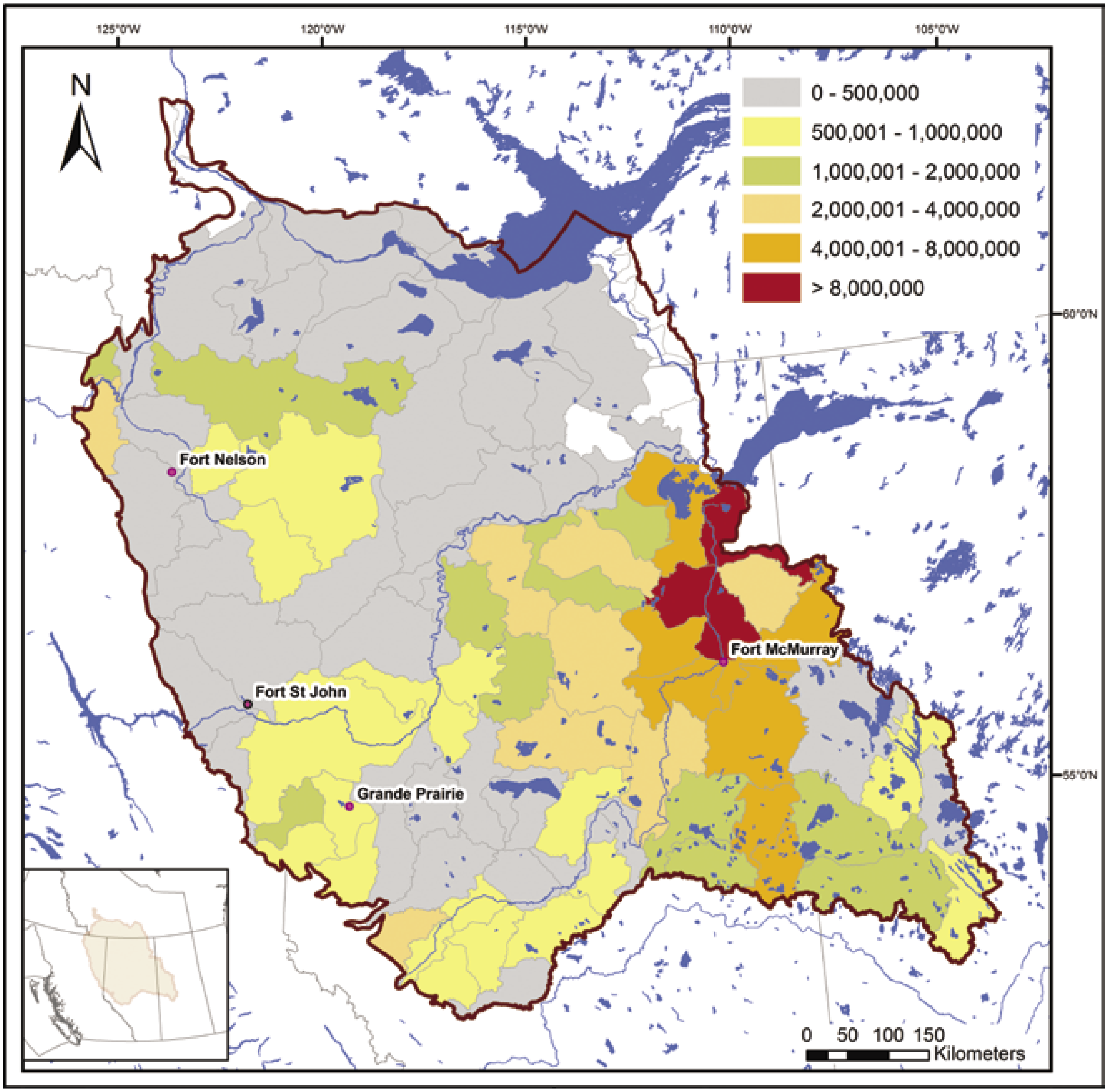

Figure 14. Simulated economic cost (2010 $) per ha of avoided anthropogenic footprint by watershed. Cost per hectare was calculated as simulated GDP in a watershed divided by total area of anthropogenic footprint in the watershed resulting from simulated 50 years of development.

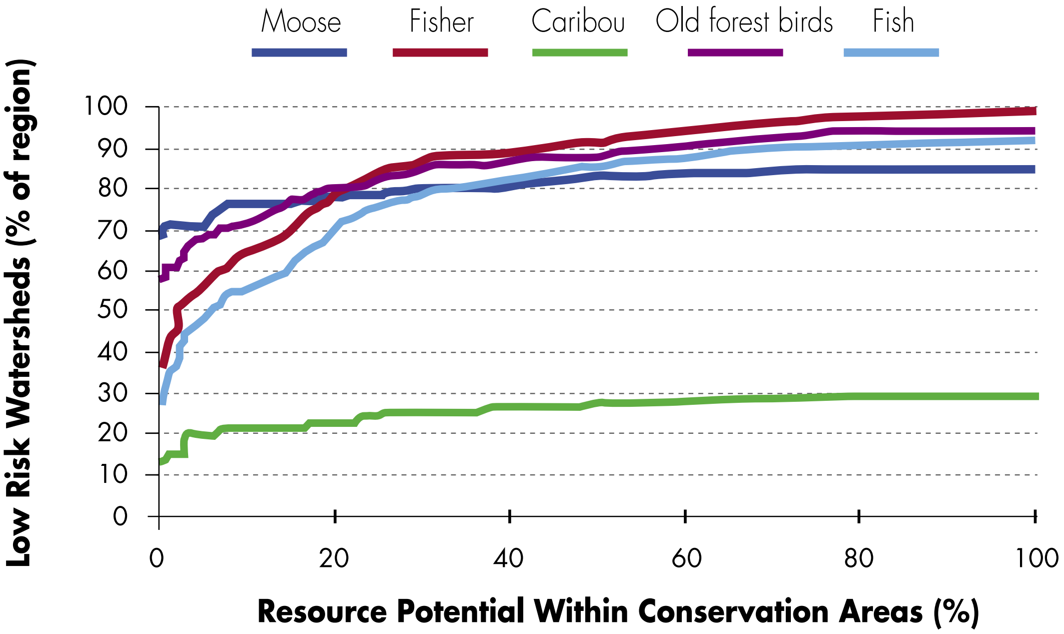

Figure 15. Proportion of the study area covered by watersheds assessed as low risk for wildlife under a range of levels of protection (i.e., % of potential GDP related to future resource production occurring within conservation areas). As described in the methods, the range of protection levels was created by successively selecting watersheds for conservation zoning in both figures 15 and 16 in order of increasing cost of avoided disturbance.

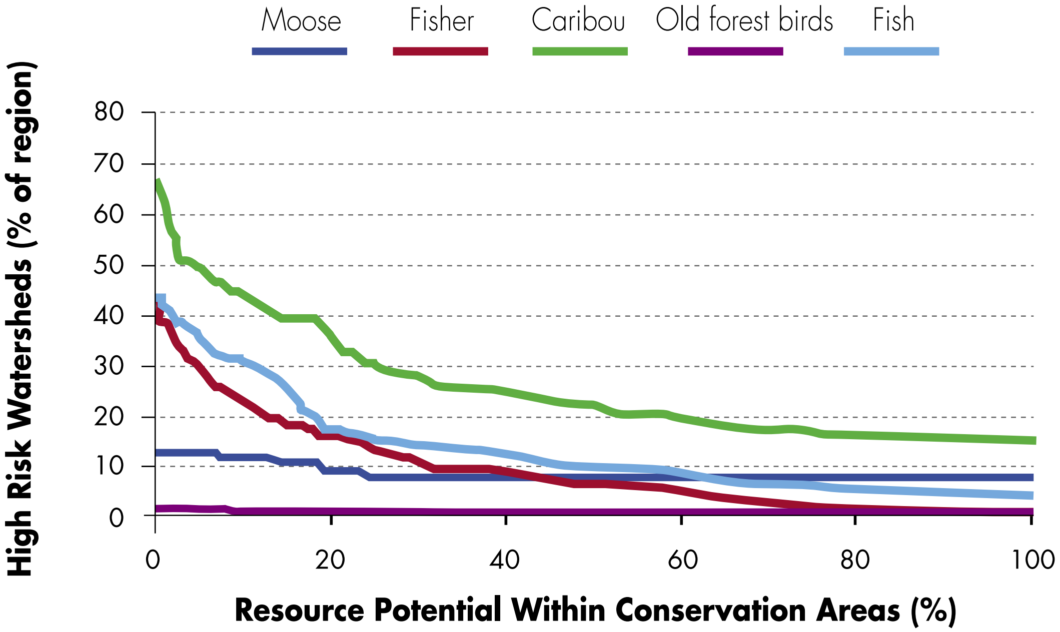

Figure 16. Proportion of the study area covered by watersheds assessed as high risk for wildlife under a range of levels of protection (i.e., % of potential GDP related to future resource production occurring within conservation areas). As described in the methods, the range of protection levels was created by successively selecting watersheds for conservation zoning in order of increasing cost of avoided disturbance.

A single example of a conservation zoning scenario based solely on the approach of conserving the least economically valuable portions of the landscape was used to illustrate the potential consequences of zoning on ecological indicators. Based on the relationships between ecological integrity and resource potential foregone, we selected exclusion of 20% of the region's natural resource value from development as the example scenario as it captured the initial low cost/rapid ecological integrity improvement portion of the relationship and allowed for comparison with the low resource development rate scenario. The selection of watersheds that avoided the most anthropogenic disturbance while excluding 20% of the region's natural resource values from development covered 61% of the region's area in addition to existing protected areas (Figure 17). When comparing landscape and wildlife indicator response across scenarios in the sections below, this scenario is referred to as conservation zoning.

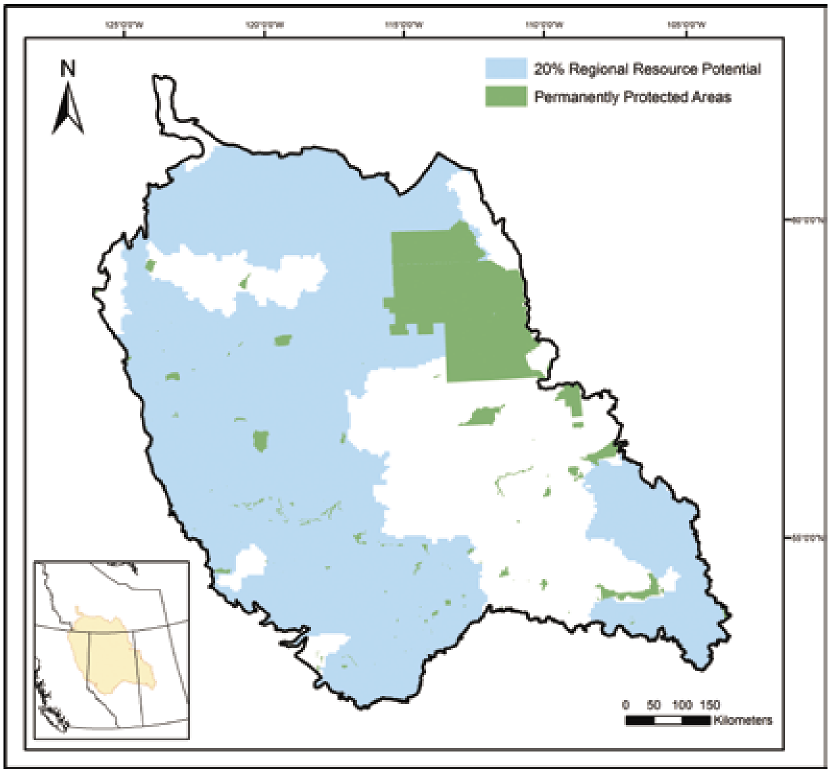

Figure 17. Watersheds designated for conservation (area in blue) in the conservation zoning scenario. Conservation areas cover 61% of the study area in addition to existing protected areas. Hypothetical scenario for exploring ways of thinking about economic versus wildlife conservation trade-offs, not a proposed conservation plan.

3.3 Changes to the Landscape

3.3.1 Total Area Disturbed

Anthropogenic land cover (not including cutblocks) increased during simulations (Figure 18), largely in response to expanding farmland and energy development. The magnitude of the increase in anthropogenic land cover depended on the development rate, with increases of 8%, 24%, and 39% during the low, moderate, and high simulations, respectively. The simulated expansion of anthropogenic land cover is within the bounds of recent experience in areas such as the Peace Region in northeastern British Columbia, where disturbances created between 1974 and 2010 by energy development, forestry, and other industrial land uses cover 20% of the region (Lee and Hanneman 2012). Simulated growth of anthropogenic land cover was focused in regions of high agricultural and energy sector activity. Farmland growth was focused north of Grande Prairie due to the availability of arable land. The spatial distribution of energy sector footprint expanded northwards during the simulation towards shale gas deposits (e.g., around Fort Nelson and Fort St. John in northeastern British Columbia) and bitumen deposits (e.g. around Fort McMurray in northeastern Alberta) as production became more focused on unconventional reserves. The relatively undeveloped conventional gas deposits in the Northwest Territories also received increased footprint as the reserves were

exploited. Best practices such as accelerated reclamation of energy sector footprints slowed but did not eliminate the growth of anthropogenic land cover. The conservation zoning scenario[7], on the other hand, resulted in negligible growth at the scale of the study area and created a patchwork of lower and higher levels of anthropogenic land cover in response to the spatial distribution of protected watersheds.

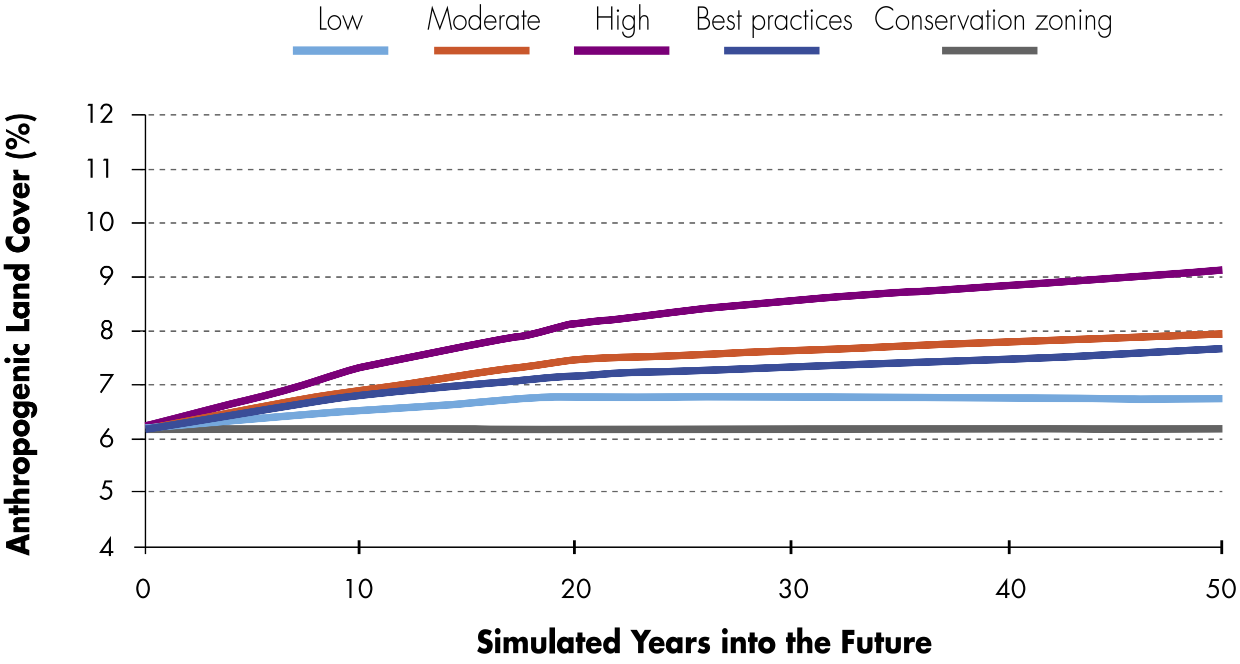

Figure 18. Anthropogenic land cover (not including cutblocks) during simulations of land-use scenarios as a proportion of the entire study area. Anthropogenic land cover made up a much higher proportion of the total area of watersheds with high resource development.

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[7] For the remainder of the report, the conservation zoning scenario refers to protection of 20% of natural resource development value while minimizing the regional cost of avoided disturbance.

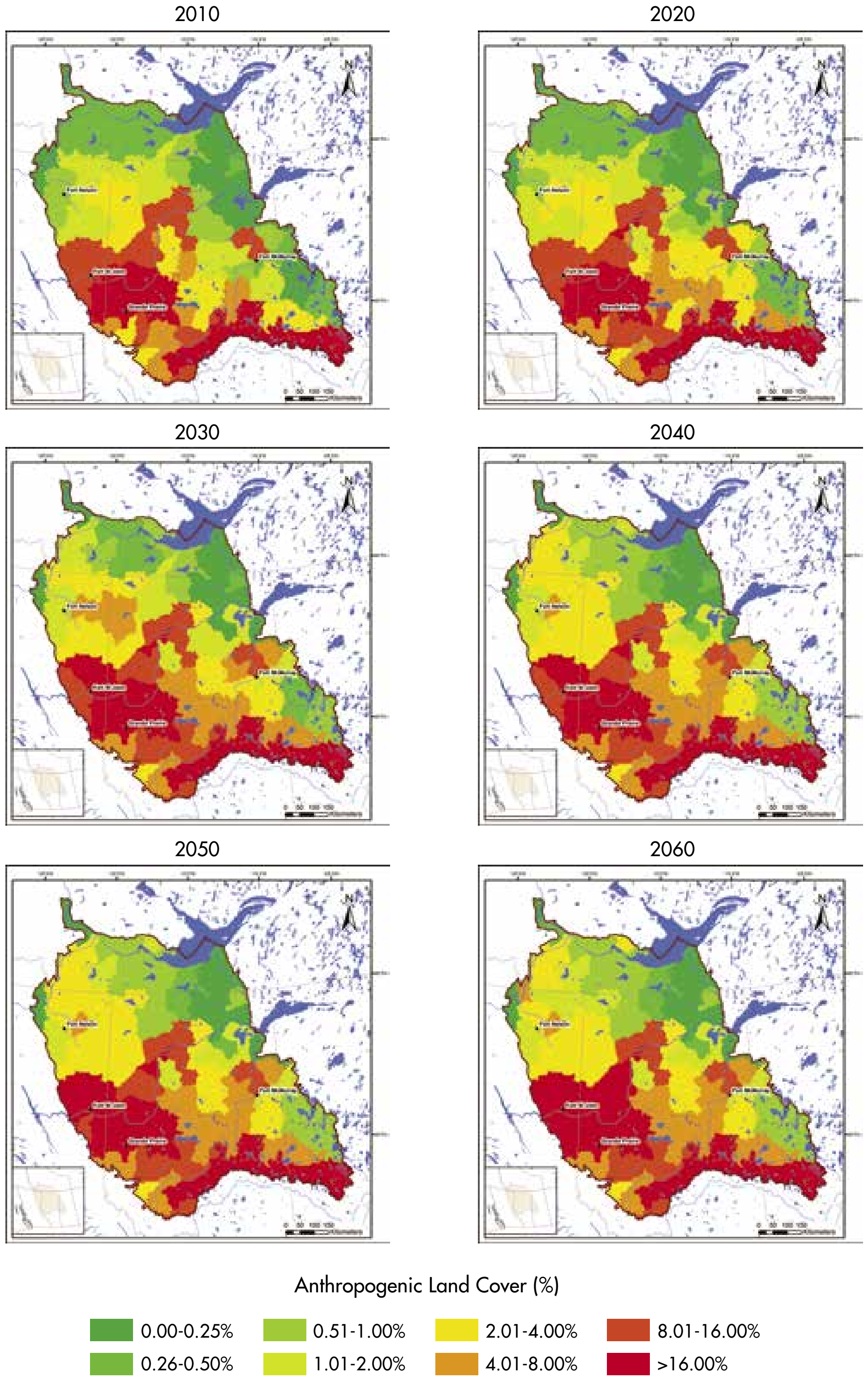
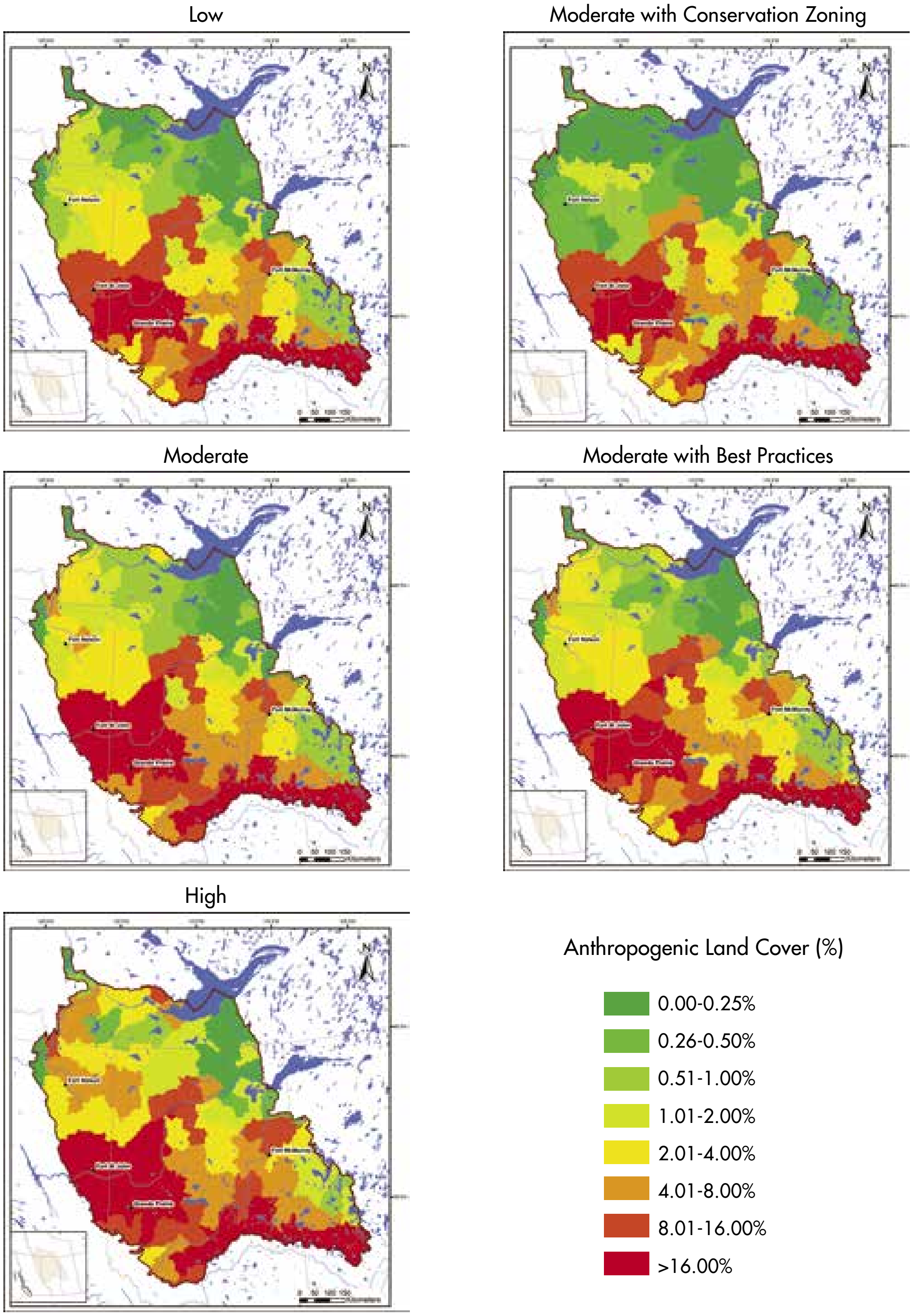


Figure 19. Simulated anthropogenic land cover (not including cut blocks) as a percentage of each tertiary watershed, across reporting years under the business as usual scenario with moderate development rate.



Low

Moderate with Conservation Zoning

Moderate

Moderate with Best Practices

High

Figure 20. Simulated anthropogenic land cover (not including cut blocks) as a percentage of each tertiary watershed at year 2060 across all scenarios.

3.3.2 Forest age

Average forest age declined in all scenarios except for the conservation zoning scenario (Figure 21). The decline in average age was greatest in the high development scenario due to increased timber harvest. Across all scenarios, however, average forest age stayed within the range of natural variation. The relative stability of forest age was in part due to the large portion (35%) of forest that is presently mature (defined here as being within two seral stages of becoming older forest). Aging of this large mature forest dampened the effect of timber harvest on average forest age. Another contributing factor was that one-third of the forest landscape is not tenured for timber production. Forests in the southern portion of the study area tended to become younger due to higher levels of timber harvest (Figure 22). Reducing the development rate caused a marginal increase in forest age relative to the moderate scenario. A larger increase in forest age was caused by the conservation zoning scenario due to the exclusion of timber harvest across much of the western portion of the study area (Figure 23).

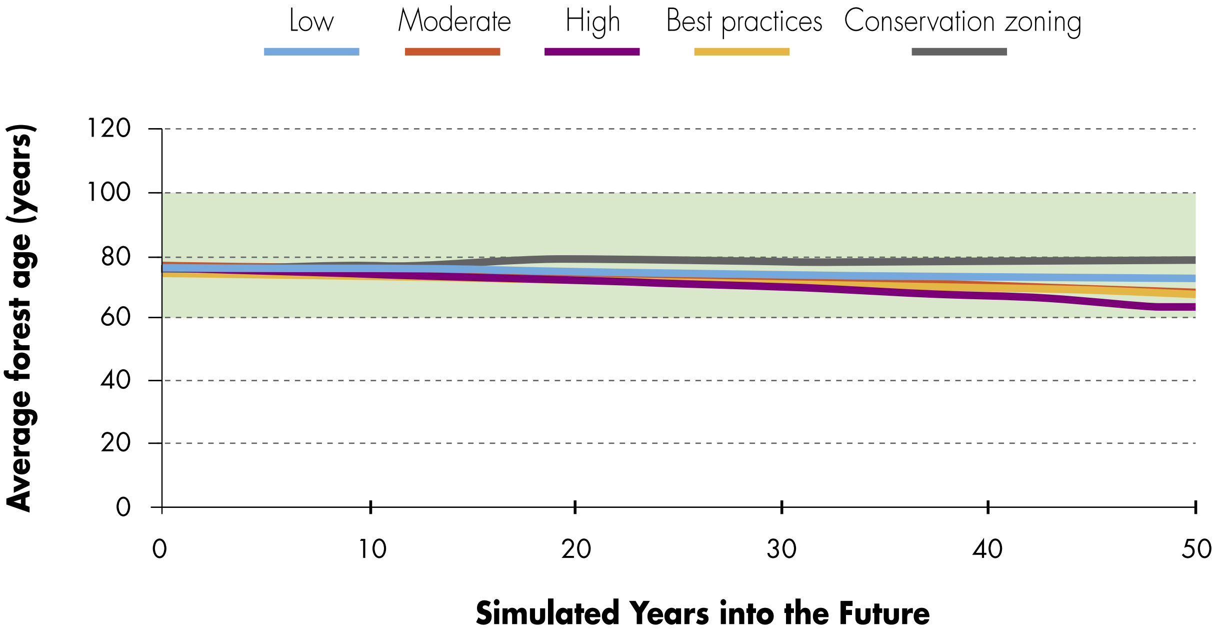


Figure 21. The average age of the forest during simulations of land-use scenarios. The green band identifies the estimated range of natural variation.

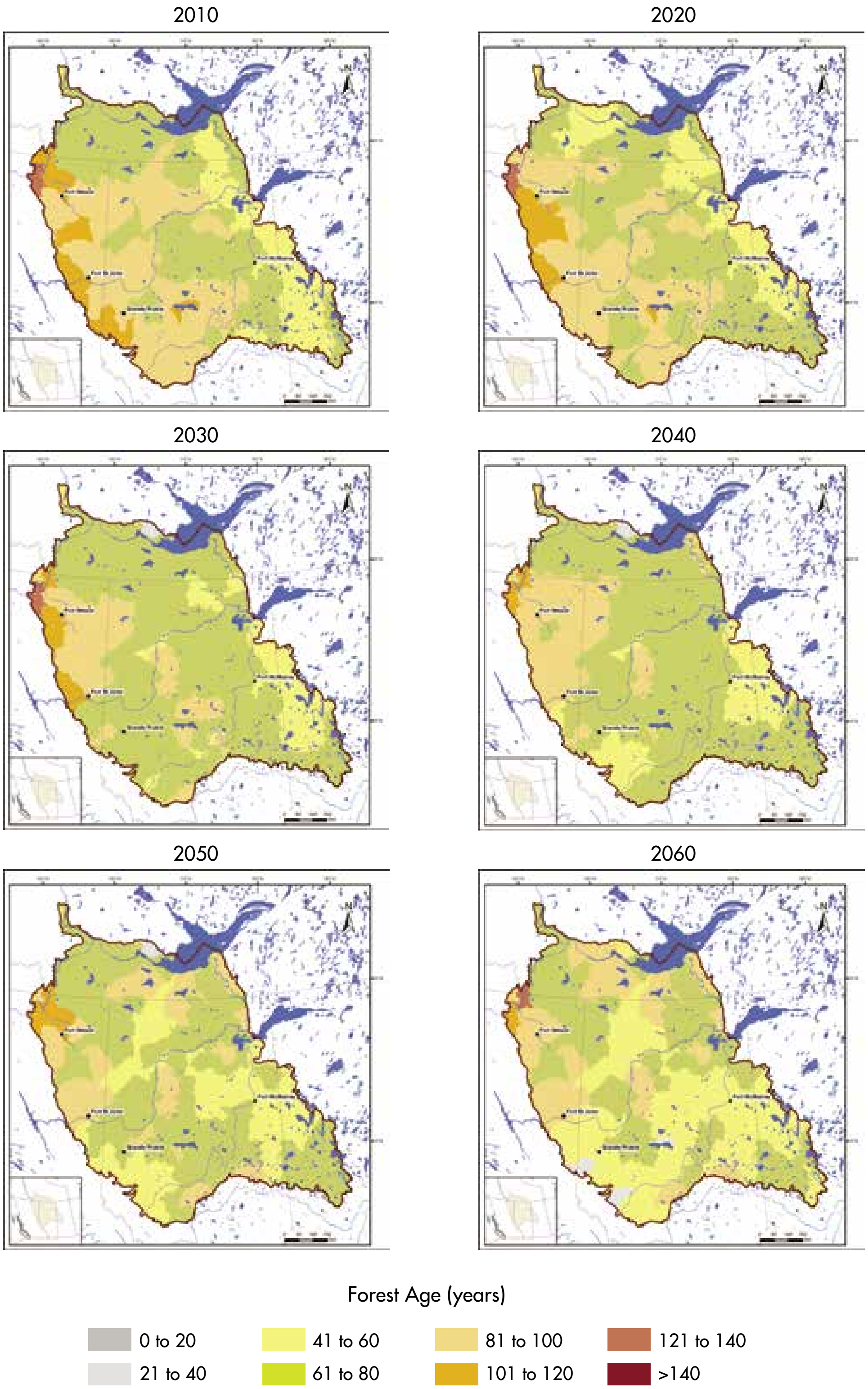


Figure 22. Simulated average forest age of each tertiary watershed from 2010 to 2060 under the business as usual scenario with moderate development rate.

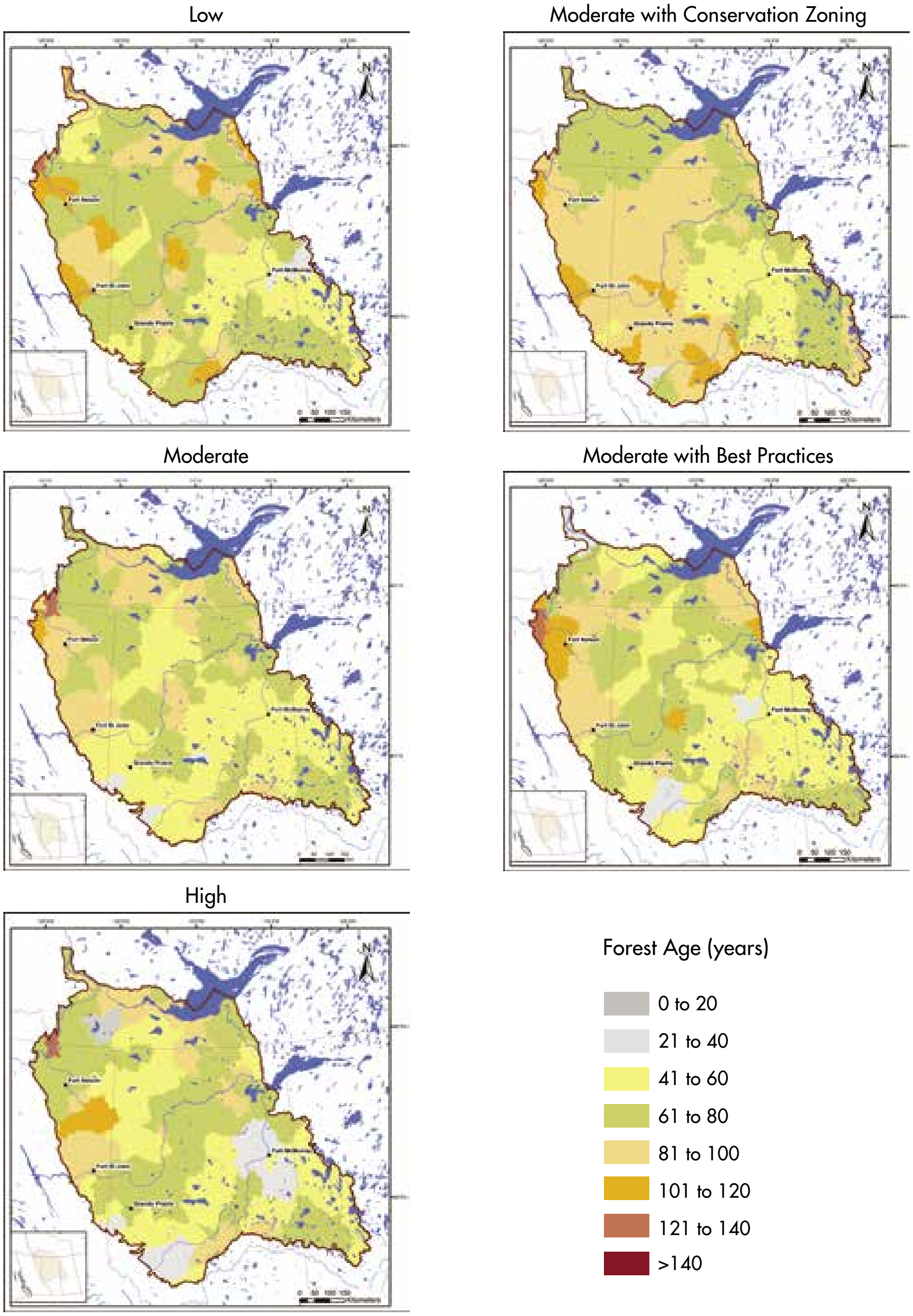


Figure 23. Simulated average forest age at year 2060 across all land use scenarios.

3.4 Implications for Fish and Wildlife

3.4.1 Moose

Averaged across watersheds, the moose habitat risk index is currently within the "moderate risk" category. Moose prefer younger forest due to the availability of browse, and the current abundance of older forest in part explains the lower than natural habitat suitability of the current landscape. Also important is the prevalence of roads and other anthropogenic footprints that facilitate hunter access. Moose habitat suitability increased during later decades of the simulation as reclamation of footprint began to outpace the creation of new footprint and younger forest became more abundant. Moose habitat suitability was insensitive to development rate, likely because the negative influence of footprint growth was offset by the positive influence of more abundant younger forest in the high development scenario.

Initially, the moose habitat risk index was low in the western portion of the study area due to the abundance of hydrocarbon footprint (e.g., south and west of Grande Prairie) and, in British Columbia, the abundance of older forest. As footprint associated with conventional hydrocarbon development reclaimed and as forest age declined during simulations, habitat suitability improved. An exception was areas that continued to receive energy development, including the oil sands region around Fort McMurray in the east, shale gas deposits around Fort Nelson and Fort St. John in the west, and natural gas deposits in the Northwest Territories. Towards the end of the simulations, however, reclamation of footprint in these regions also causes moose habitat to improve. The effect of best practices on footprint was insufficient to substantially alter the spatial

distribution of moose habitat suitability. The impact of the conservation scenario was somewhat larger, although still limited, in part because the benefits of reduced access were counteracted by decreased availability of young forest due to the absence of timber harvest.

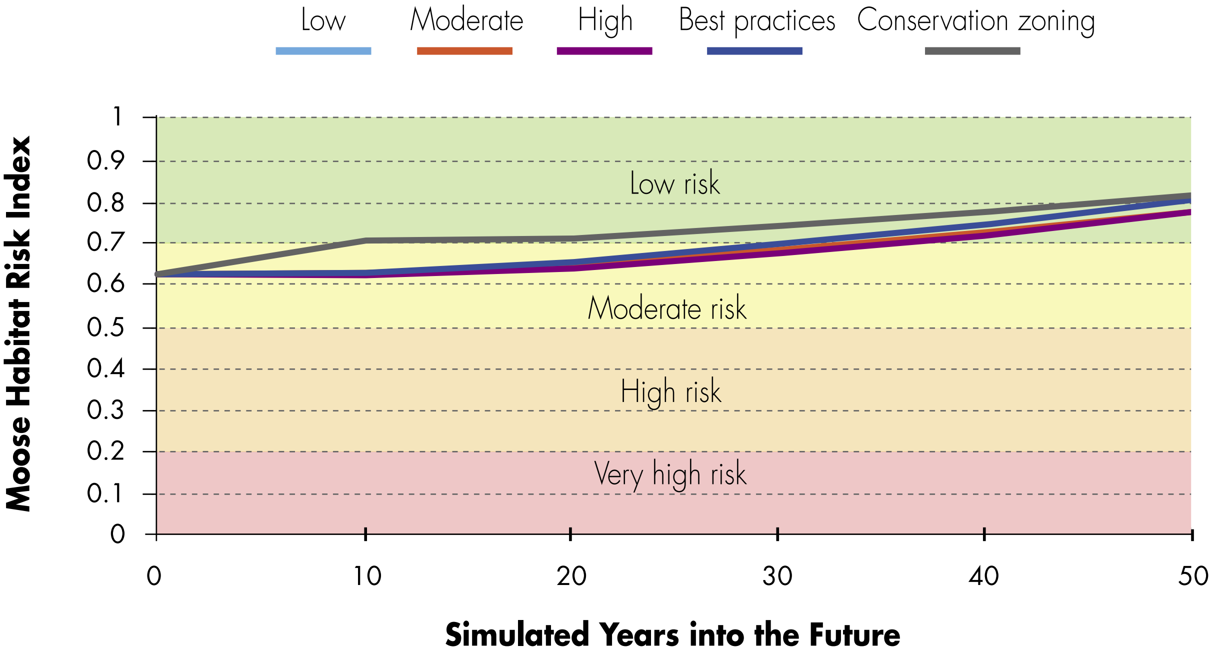


Figure 24. Trend over time of the moose habitat risk index during simulations for all land use scenarios. The horizontal bands of colour refer to levels of risk expressed as the ratio of future status to estimated natural condition, as described in section 2.4.

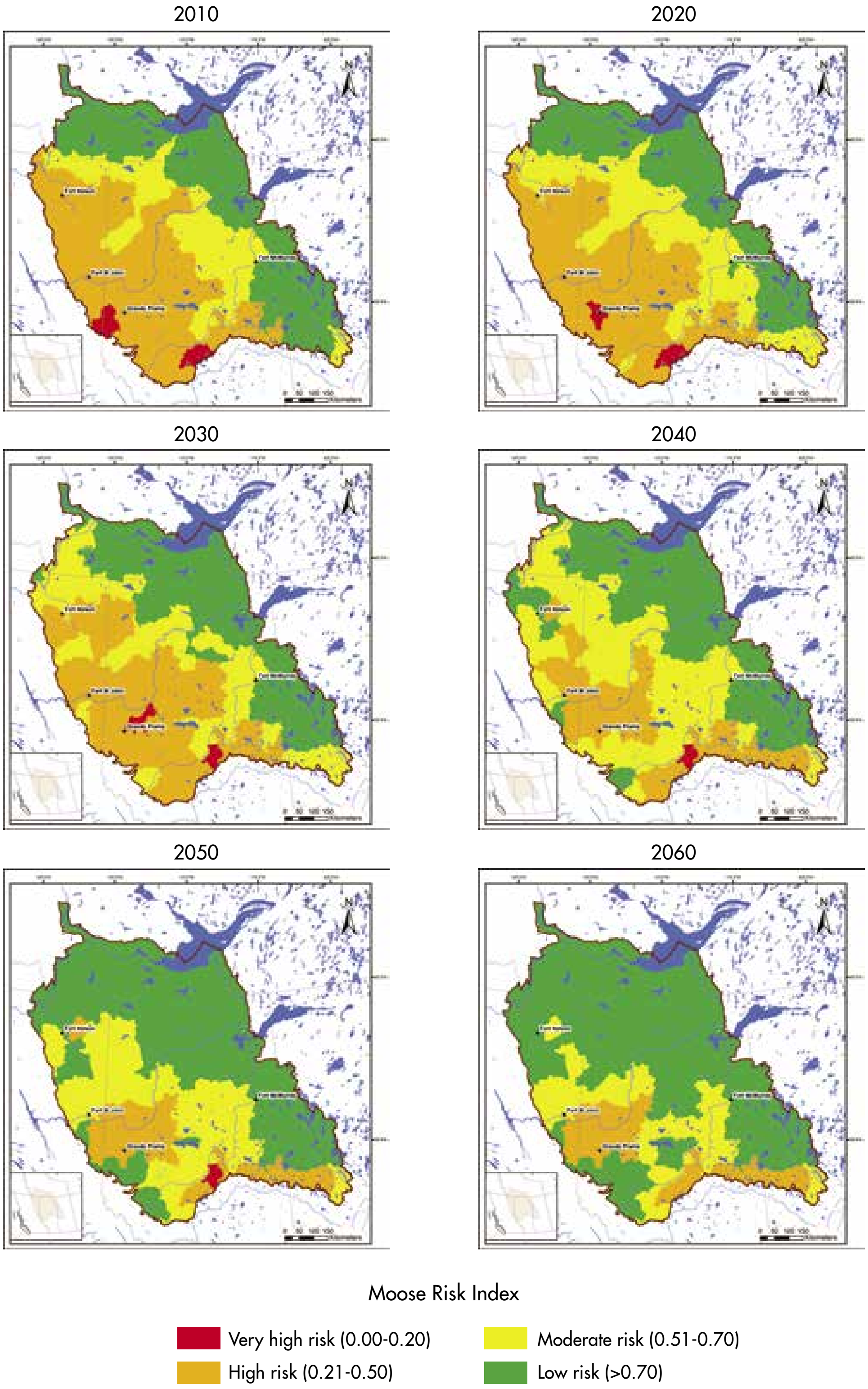


Figure 25. Moose habitat risk index of each tertiary watershed based on the moose habitat suitability index from 2010 to 2060 under the business as usual scenario with moderate development rate.

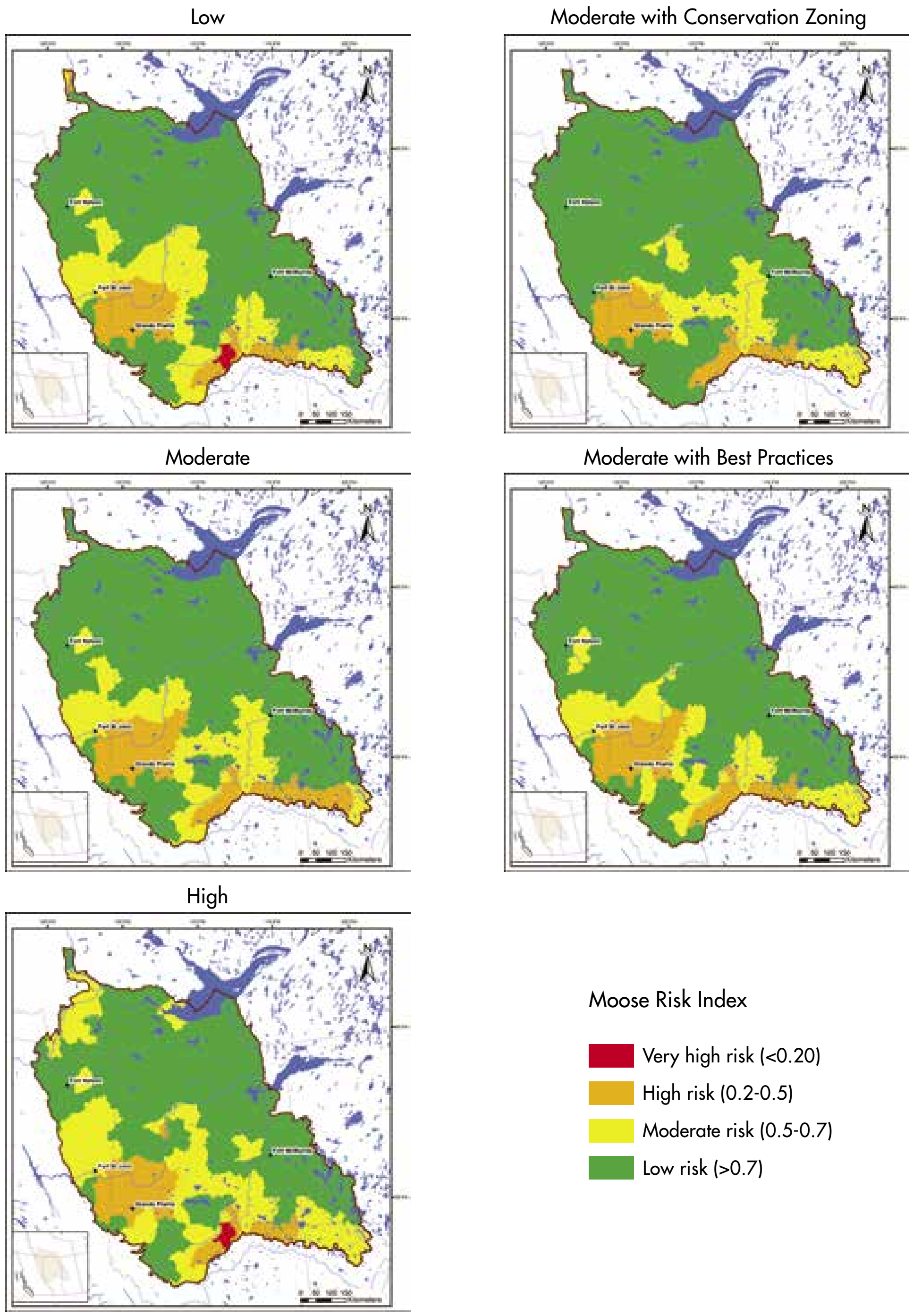


Figure 26. Comparison of habitat risk index for moose across all land use scenarios at year 2060. Simulated risk level of each tertiary watershed based on the moose habitat suitability index.

3.4.2 Fisher

Averaged across watersheds, fisher habitat risk index is currently within the "low risk" category. As the simulations proceeded, however, average habitat suitability declined to the "moderate risk" level in the moderate and high development scenarios (Figure 27). The magnitude of the simulated decline in habitat suitability is similar to that assessed for northeastern Alberta by the Cumulative Environmental Management Association (Wilson and Stelfox 2008), who projected fisher habitat suitability to drop below natural levels in the coming decades. The simulated decline in habitat is also consistent with the species' listing in Alberta as "sensitive" due to potential impacts of forestry activity on habitat and fisher harvest (Alberta Sustainable Resource Development 2010). In our simulations, causes of habitat decline were anthropogenic edge (i.e., trapper access) and the increasing abundance of young forest (i.e., < 40 years) which has negligible habitat value for fisher. The influence of these factors is demonstrated by the effectiveness of the conservation zoning scenario, which limited trapper access and excluded timber harvest from protected watersheds.

The current spatial distribution of fisher habitat suitability is dominated by areas of low risk, with the exception of watersheds where loss of forest cover is substantially larger due to agriculture. As the simulation proceeded, areas of high risk became more prevalent (Figure 28) in response to expansion of energy sector footprint and young forest in areas with forestry (e.g., much of Alberta). High risk areas were more pronounced in the high development scenario relative to scenarios with lower development rates or best practices (Figure 29). In contrast to the other scenarios, fisher habitat suitability increased to natural levels during the conservation zoning scenario due to the exclusion of trapping and timber harvest from large portions of the region.

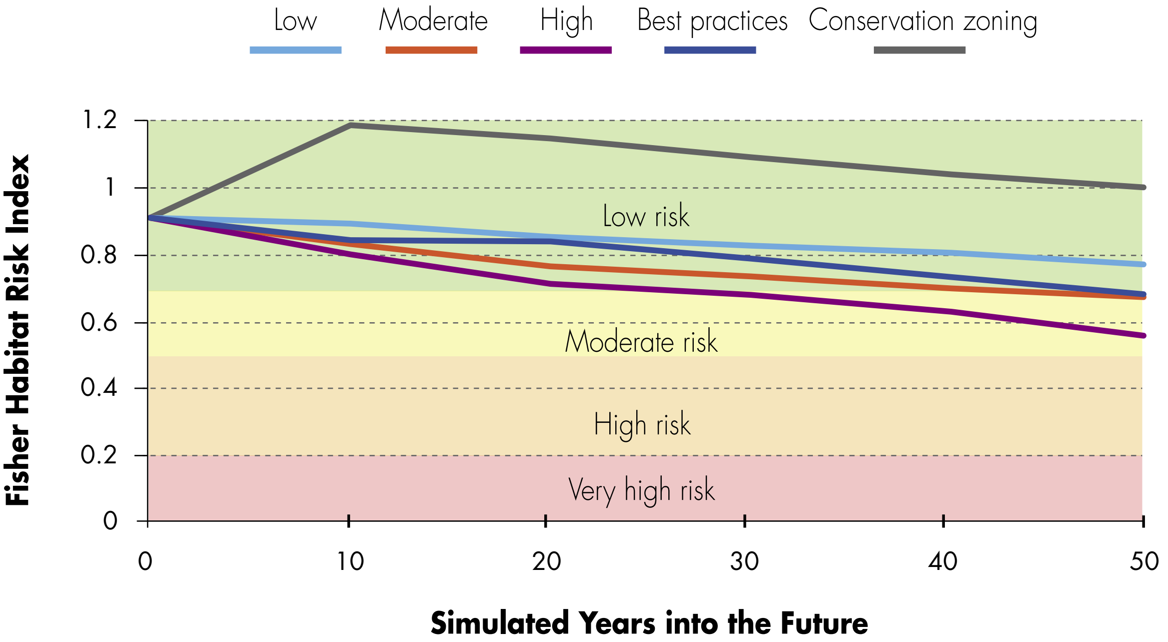


Figure 27. Trend over time of the fisher habitat risk index during simulations for all land use scenarios. The horizontal bands of colour refer to levels of risk expressed as the ratio of future status to estimated natural condition, as described in section 2.4.

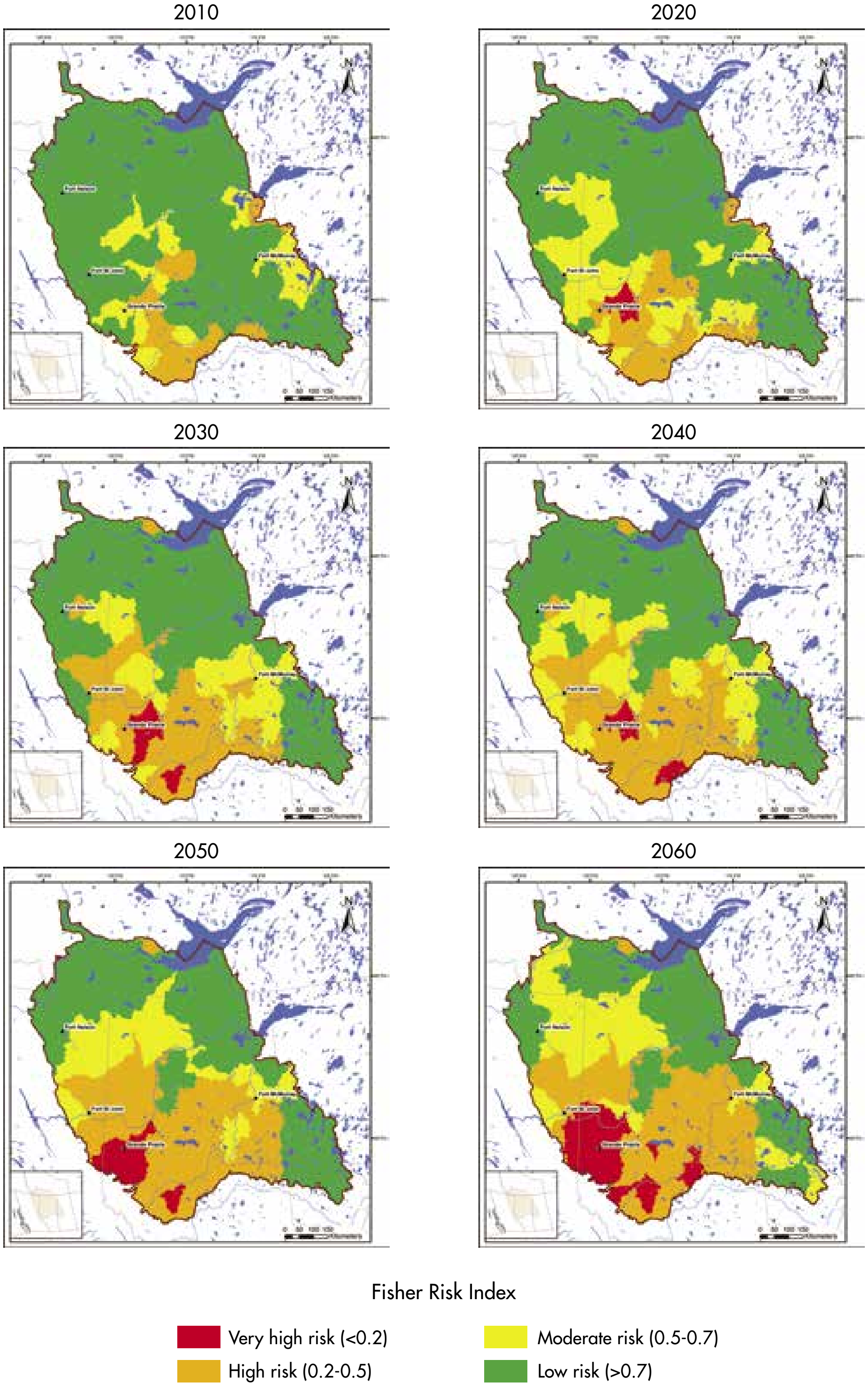
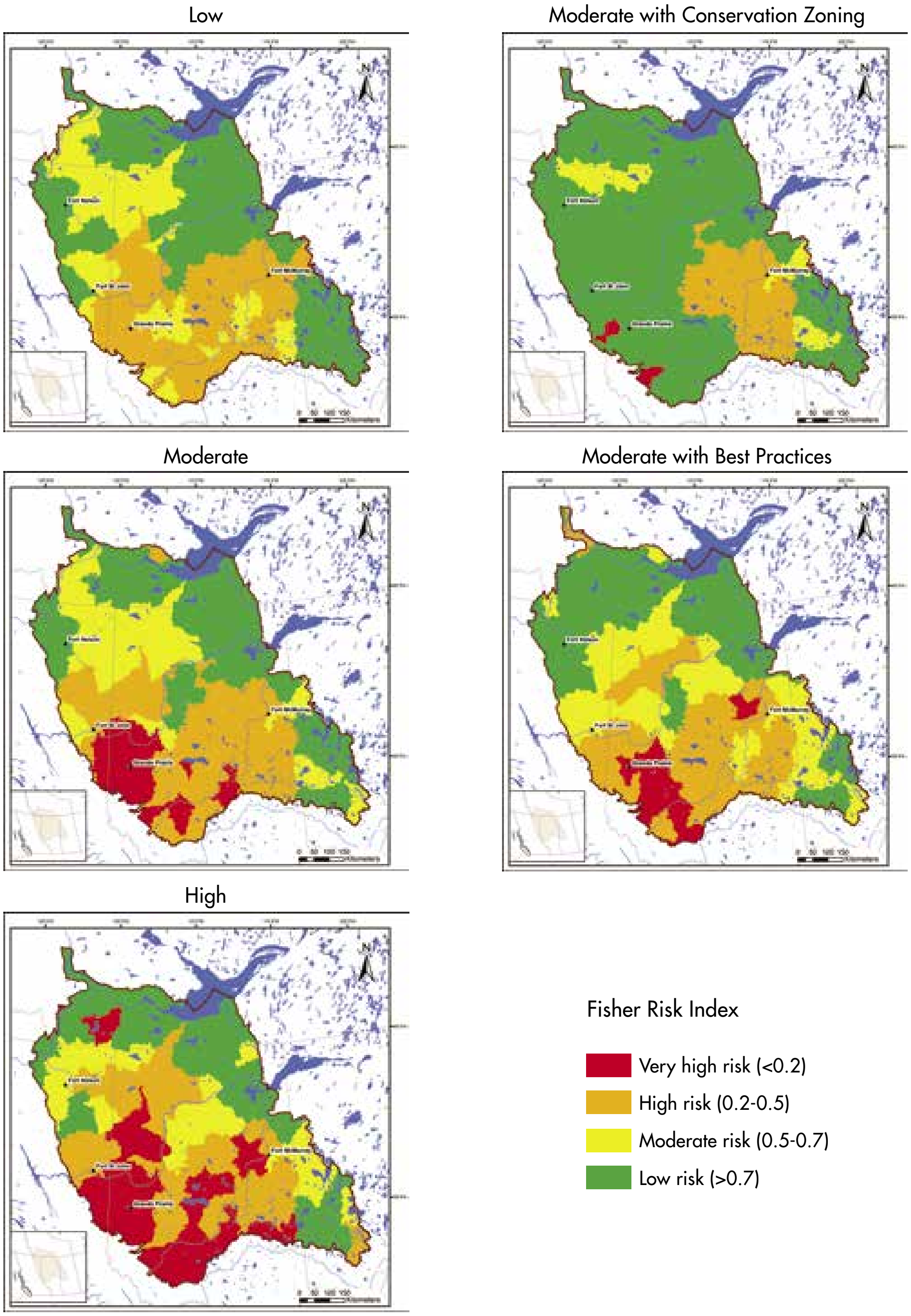


Figure 28. Simulated fisher habitat risk index across reporting years under the business as usual scenario with moderate development rate.



Low

Moderate with Conservation Zoning

Moderate

Moderate with Best Practices

High

Figure 29. Simulated fisher habitat risk index at year 2060 across scenarios.

3.4.3 Woodland Caribou

The potential[8] caribou population growth index was simulated to decline at the regional scale over the next two decades (Figure 30), thereby increasing the average risk to caribou persistence from moderate (0.95-0.99) to high (<0.95). The decline was caused by an increase in young forest and anthropogenic edge, both of which ultimately lead to higher predation pressure on caribou. Younger forest is currently rare in the study area relative to the range of natural variability, but increased steadily throughout the simulations as timber harvest expanded. The density of industrial footprint edge increased initially, but declined in later years when reclamation exceeded footprint expansion. In response to the decline in edge density, the population growth index stabilized and increased towards the moderate risk category during the later decades of the moderate simulation. The decline in the index was greatest in the high development scenario due to higher levels of timber harvest and energy development. The best practices and low development scenarios both improved the index relative to the moderate scenario. The greatest improvement was exhibited by the conservation zoning scenario due to the exclusion of footprint and timber harvest from a greater portion of the landscape.

The current spatial distribution of the caribou population growth index suggests that the species is presently at a moderate to high risk of extirpation in the study area, with the exception of the northern portion of the study area. This is consistent with an assessment of boreal caribou ranges completed as part of the federal recovery strategy for the species, which identified caribou range in the Northwest Territories as the only location in the region where herds are likely to be self-sustaining (Environment Canada 2012). As anthropogenic footprint and timber harvest expanded during the first three decades of the simulation, so too did the number of watersheds exhibiting a high risk of caribou extirpation. By the end of the third decade of the moderate simulation, the majority of watersheds exhibited a high risk of extirpation and the number of caribou herds in the region is very likely to decline. By reducing footprint intensity associated with new hydrocarbon developments, the best practices scenario moder-

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[8] The caribou population growth index is given the word "potential" as a prefix because ALCES simulations assessed the caribou population growth index across the study area, regardless of whether habitat occurred within herd ranges.

ately reduced risk in the northern portion of the study area. The greatest improvement in caribou viability, however, was achieved by the conservation zoning scenario which achieved a substantial reduction in high risk watersheds by excluding new development across much of the study area. Risk remained high, however, in unprotected landscapes such as the oil sands region of northeastern Alberta and areas of high shale gas exploration such as northeastern British Columbia.

The importance of range protection for maintaining the viability of caribou herds in the region is supported by the federal recovery strategy, which calls for a reduction in disturbance across all caribou ranges in the region with the exception of the Northwest Territories. This scenario analysis demonstrates that sufficient reduction in anthropogenic footprint to conserve caribou in the region will require more than just improved management practices. The same conclusion was made by the Athabasca Landscape Team (2009), which recommended the establishment of conservation areas spanning thousands of km2 in northeastern Alberta to maintain caribou in the region.

The level of disturbance in the region and the time required for reclamation are such that 50-years is an insufficient period to reduce disturbance to within sustainable levels for caribou across much of the study area even under a conservation zoning scenario. As concluded by others (Schneider et al. 2010, Athabasca Landscape Team 2009), these results suggest that maintaining caribou in the region is likely to require substantial increases in habitat protection and restoration over a long period of time.

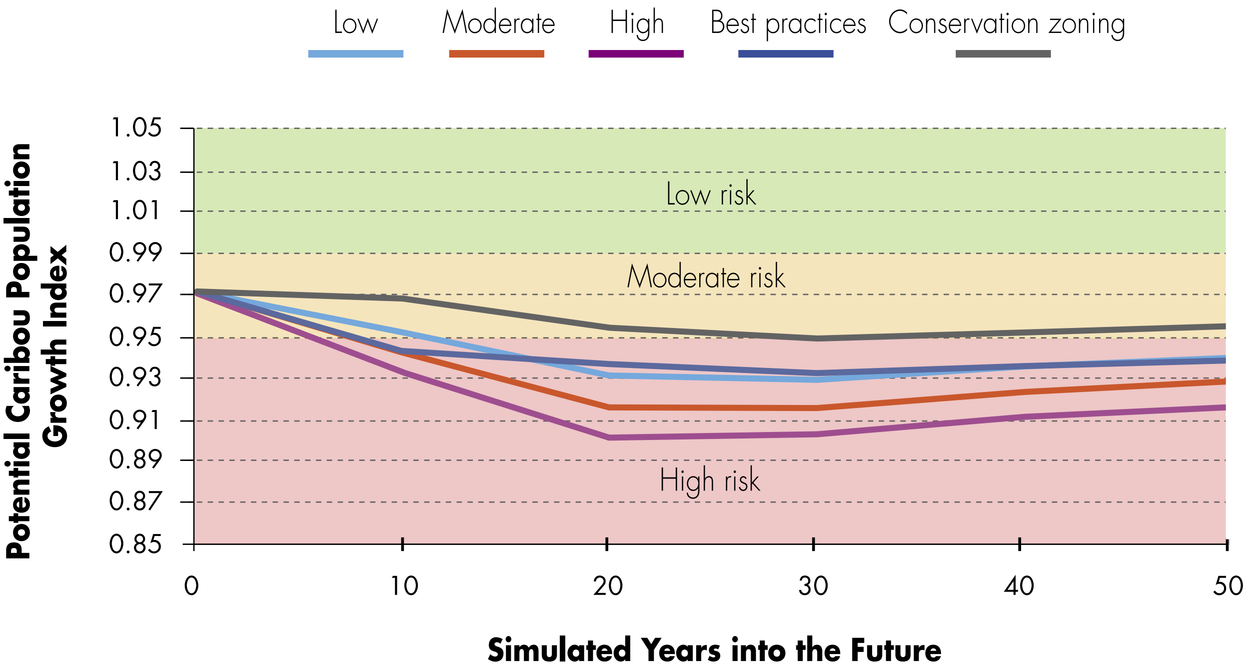


Figure 30. Trend over time of the woodland caribou population growth index during simulations for all land use scenarios. The horizontal bands of colour refer to levels of risk to population persistence, as described in section 2.4.

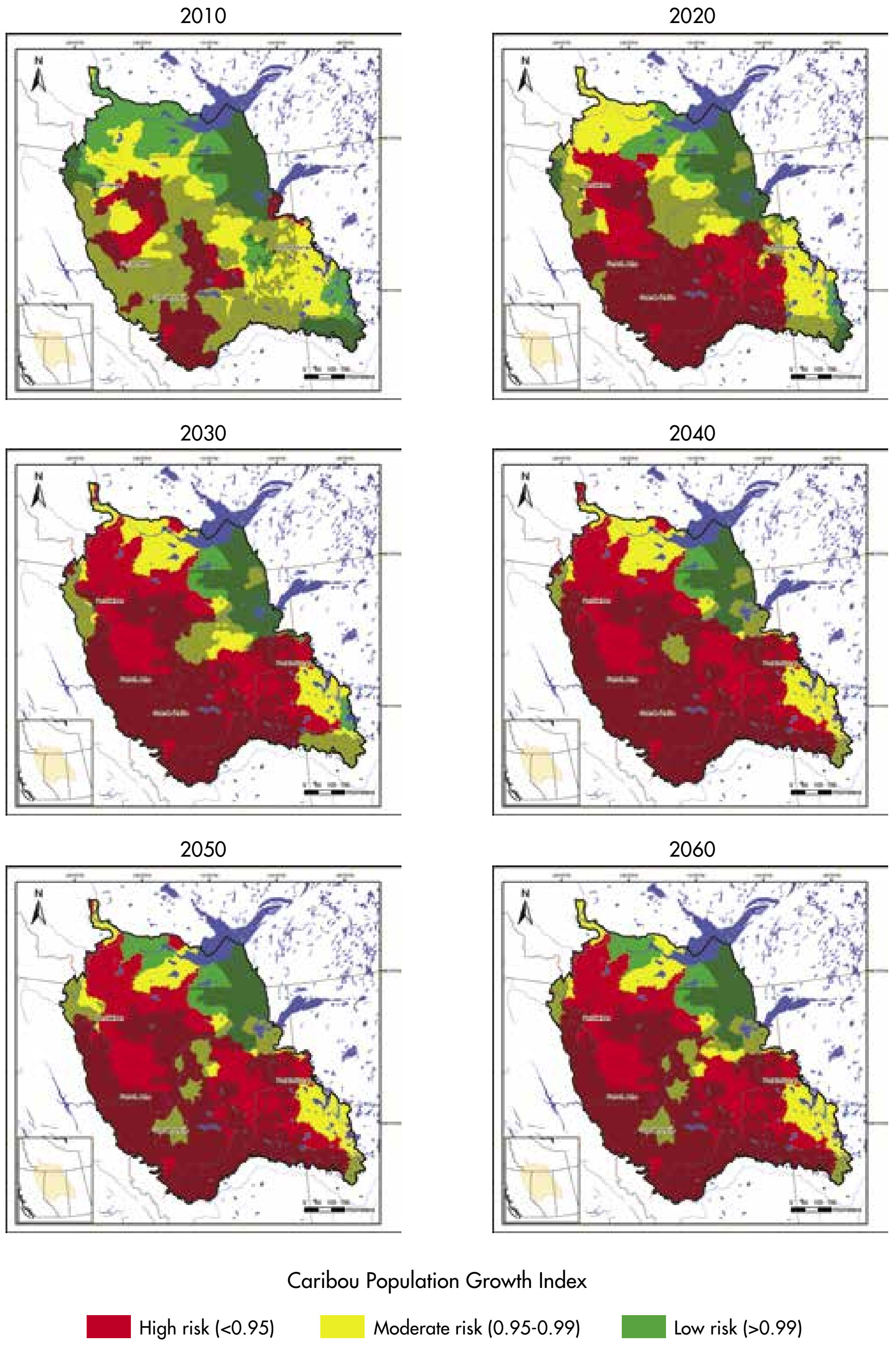


Figure 31. Simulated woodland caribou population growth index of each tertiary watershed from 2010 to 2060 under the business as usual scenario with moderate development rate. Shaded areas indicate portions of the study area where caribou do not occur and habitat is not suitable. Simulations were run for the entire study area as over a 50 time span some unsuitable areas would be expected to regenerate to habitat that can support caribou.

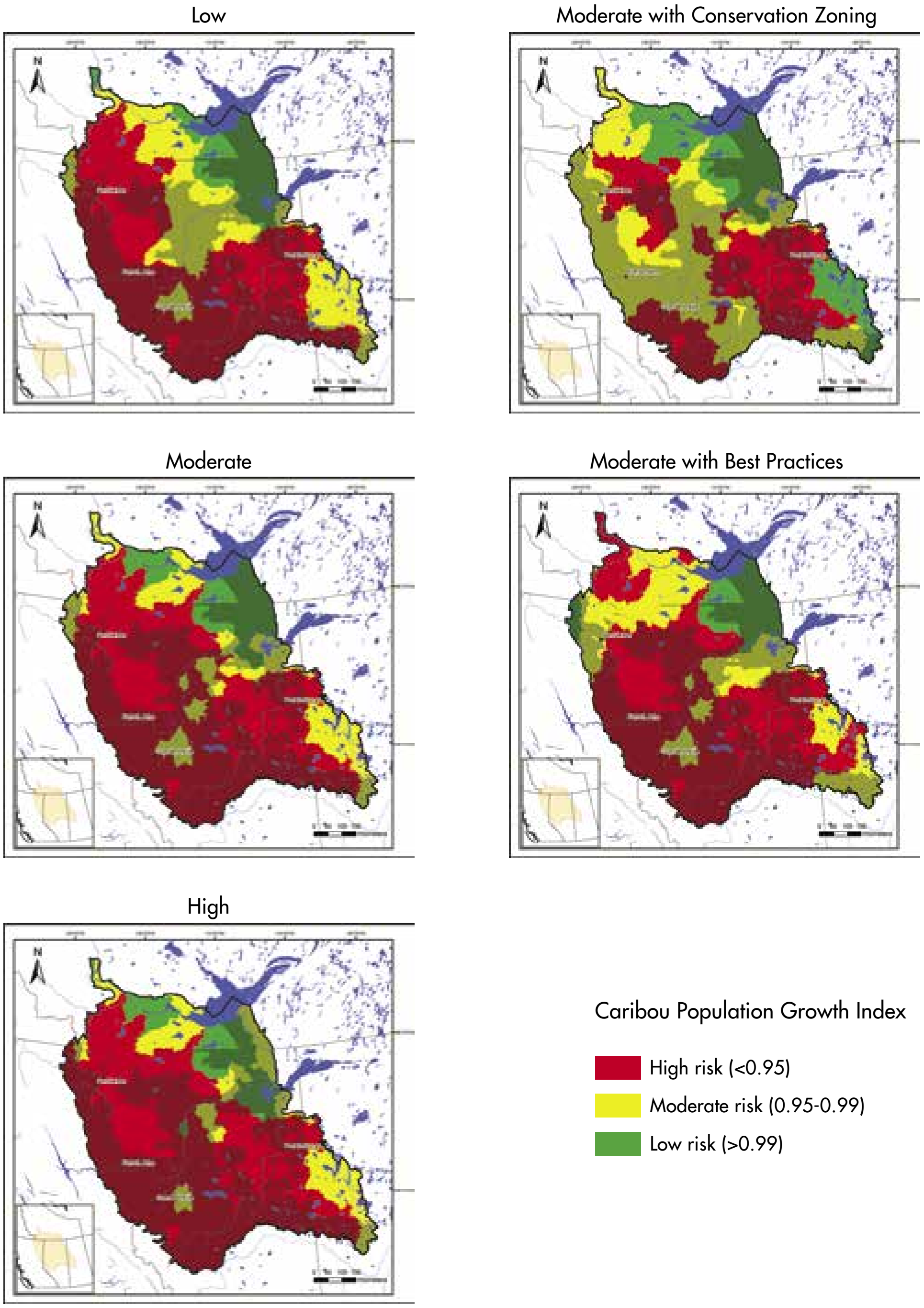


Figure 32. Comparison of caribou population growth index averaged across each tertiary watershed for all land use scenarios at year 2060. Shaded areas indicate portions of the study area where caribou do not occur and habitat is not suitable. Simulations were run for the entire study area as over a 50 time span some unsuitable areas would be expected to regenerate to habitat that can support caribou.

3.4.4 Fish Community

The average index of native fish integrity (INFI) across the region is currently 0.6, which is indicative of a community where most sport fish such as walleye and pike are still abundant but large fish are rare. The index declined during the early decades of the simulations, suggesting that even small fish will become less plentiful and that some species such as arctic grayling will become rare (Figure 33). Angling pressure was the primary cause of the index's poor performance. The region's fish community is sensitive to angling due to the low productivity of cold water ecosystems and the relative scarcity of lakes to accommodate anglers (Sullivan 2003), and many fish populations in the region are in decline or have collapsed due to overfishing (Post et al. 2002). As human population and access density grew during the simulations, angling pressure increased and caused the index to decline. The index stabilized in later decades of the simulation when access began to decline due to reclamation of energy sector footprint. In contrast to angling pressure, habitat disturbance had negligible effect when considered at the regional scale. Fragmentation of aquatic habitat by impassable culverts increased during the simulation, but did not substantially exceed the threshold (10%) beyond which fragmentation is thought to begin to detrimentally affect the fish community.

The current spatial distribution of INFI across the study area indicates a gradient of risk to fish community integrity from high in the developed south to low in the intact north. An exception to the pattern is the Saskatchewan portion of the study area which, although located south, exhibits low risk due to lower levels of hydrocarbon development and associated access. As the simulation proceeded, the region of high or very high risk expanded northwards in response to increased development of northern resources such as the oil sands near Fort

McMurray in northeastern Alberta, shale gas near Fort Nelson and Fort St. John in northeastern British Columbia, and natural gas in the Northwest Territories. The high scenario increased the spread of high or very high risk watersheds due to more rapid population and access growth. Towards the end of the simulation period, fish community integrity began to improve as reclamation of access began to outpace the creation of new access. Best practices reduced the spread of high or very high risk watersheds during the early part of the simulation by reducing the growth of access, but the greatest improvement in fish community integrity was achieved by the expansion of conservation areas. The limitation of footprint expansion and reduction in angler access allowed risk to decline to low within watersheds zoned for conservation. The large improvement in fish community integrity achieved by reducing angler access is consistent with the outcomes of simulations completed for northeastern Alberta, which assessed substantially reduced impacts to the fish community under an access management scenario (Wilson and Stelfox 2008).

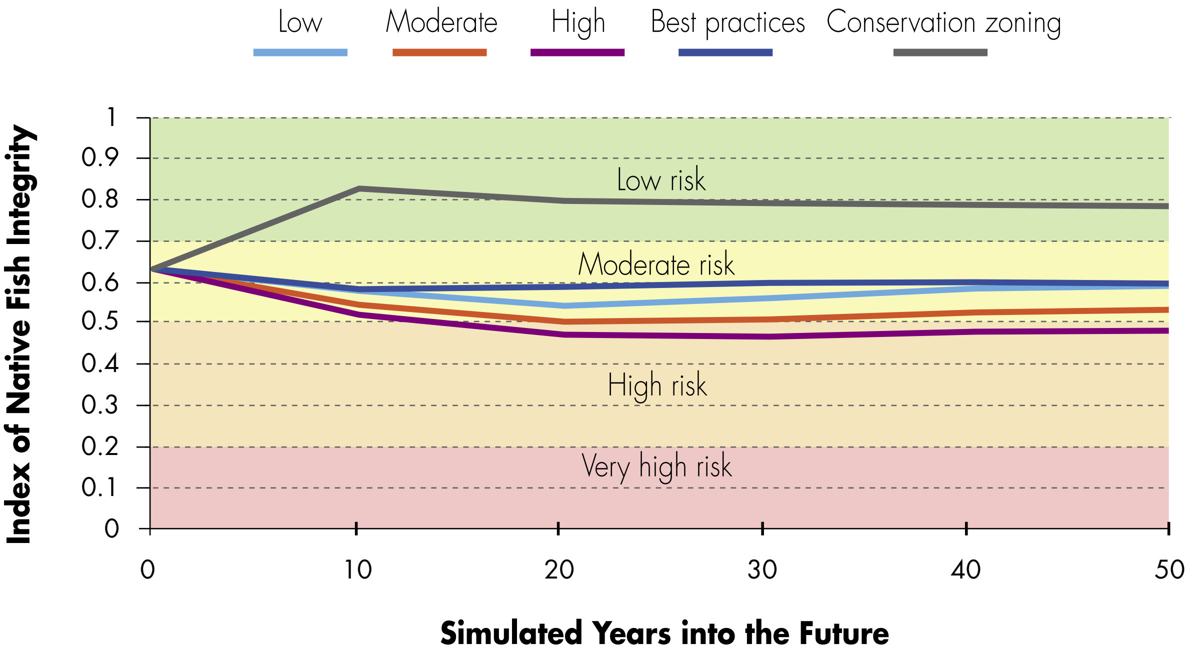


Figure 33. Trend over time of the index of native fish integrity during simulations for all land use scenarios. The index gradient from 1 to 0 implies changes in fish community structure from communities with abundant large sport fish (INFI=1), to common but small sport fish (INFI=0.5), to rare sport fish (INFI=0).

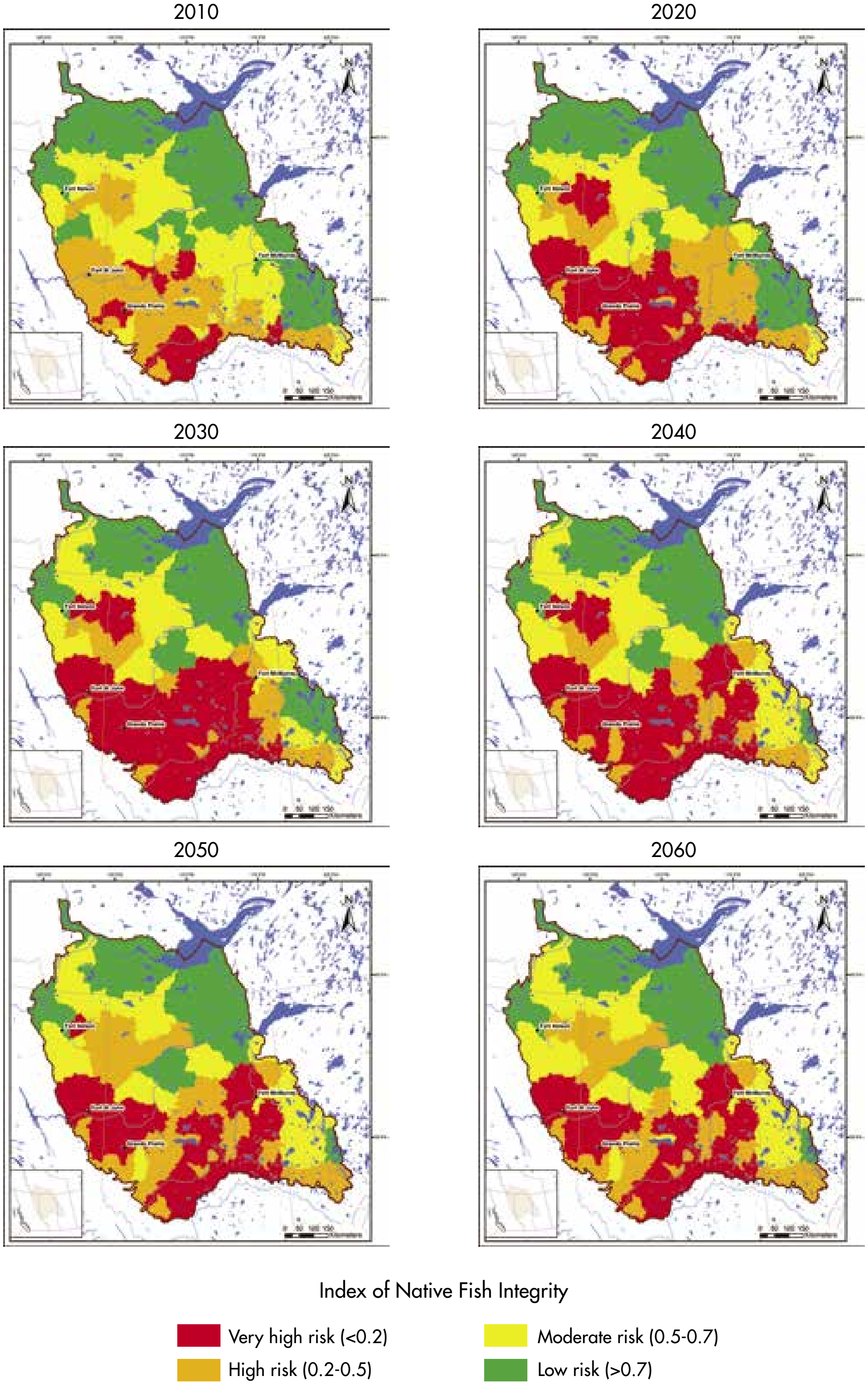


Figure 34. Simulated index of native fish integrity averaged across each tertiary watershed for 2010 to 2060 under the business as usual scenario with moderate development rate.

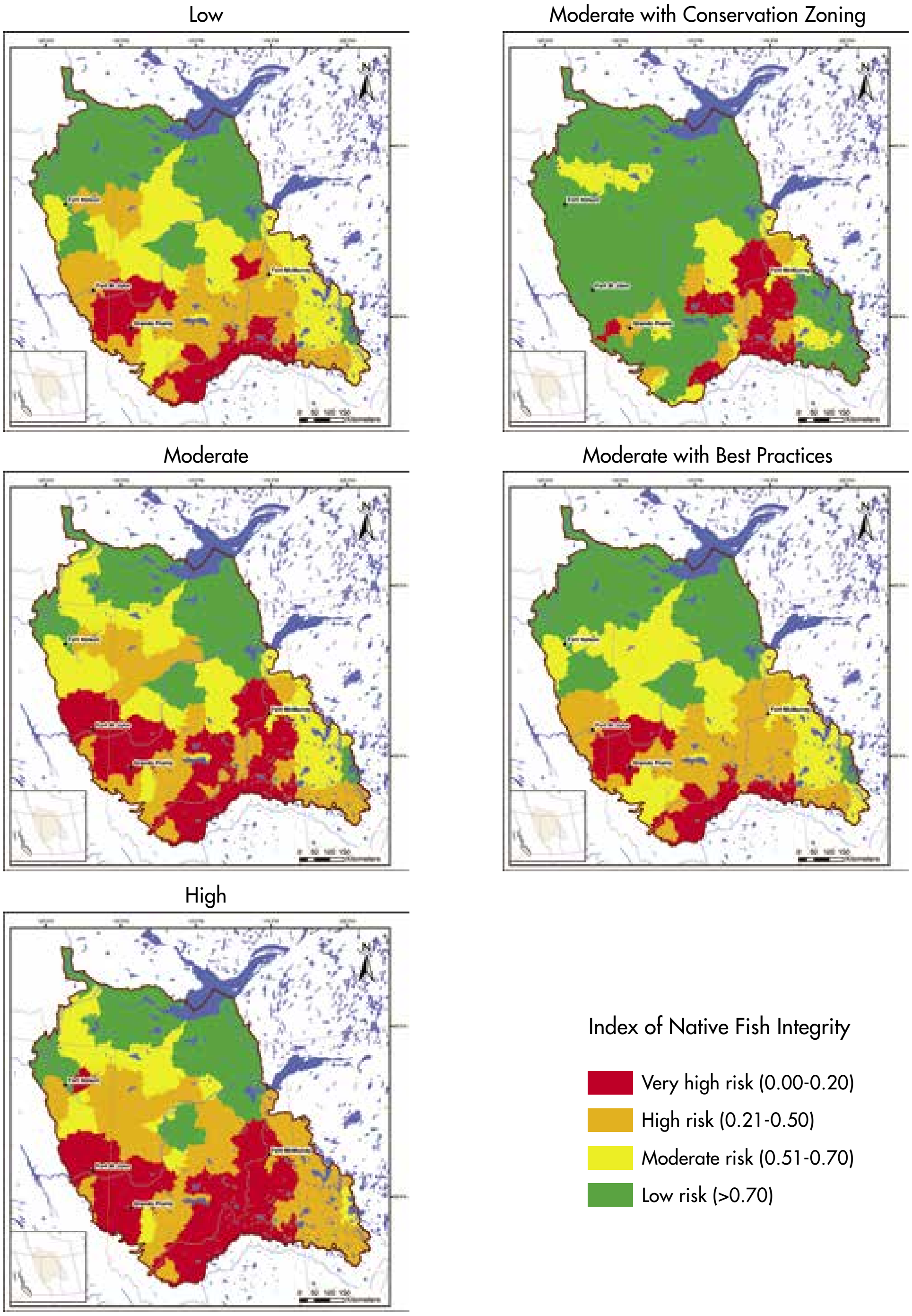


Figure 35. Comparison of the index of native fish integrity averaged across each tertiary watershed for all land use scenarios at year 2060.

3.4.5 Song birds

Old forest songbird risk index increased during the initial decades of the simulations, prior to stabilizing and then beginning to decline (Figure 36). The tendency towards population decline was greatest in the high development scenario due to the impact of a higher timber harvest rate on older forest habitat. Averaged across watersheds, the index stayed within the low risk category during the 50-year simulation period when evaluated at the entire landscape scale. Spatially, however, large portions of the southern half of the landscape shifted into a moderate risk category over time. The higher average risk and increasing risk in the southern portion of the landscape during the final decade of the simulation would likely continue in subsequent decades because older forest should become scarcer as the area harvested continues to expand. The potential for songbirds to be negatively impacted by declining older forest over the longer term is supported by a scenario analysis completed for a portion of the study region located in northeastern Alberta. In that study, a species associated with older forest (black-throated green warbler) exhibited a stable population during the first 60 years of the simulation, but declined by over 40% by the 90th simulation year as older forest became less abundant (Mahon et al. 2014).

The spatial distribution of the old forest songbird risk index reflects that of the forest age distribution (Figure 22), with lower risk to the north and west

(Figure 37). As the simulation proceeded, the index declined in the southern portion of the study area where timber harvest was most prevalent and increased to the north where older forest accumulated in the absence of forestry. By sheltering more land from forestry, the conservation zoning scenario reduced risk to low across much of the study area (Figure 38).

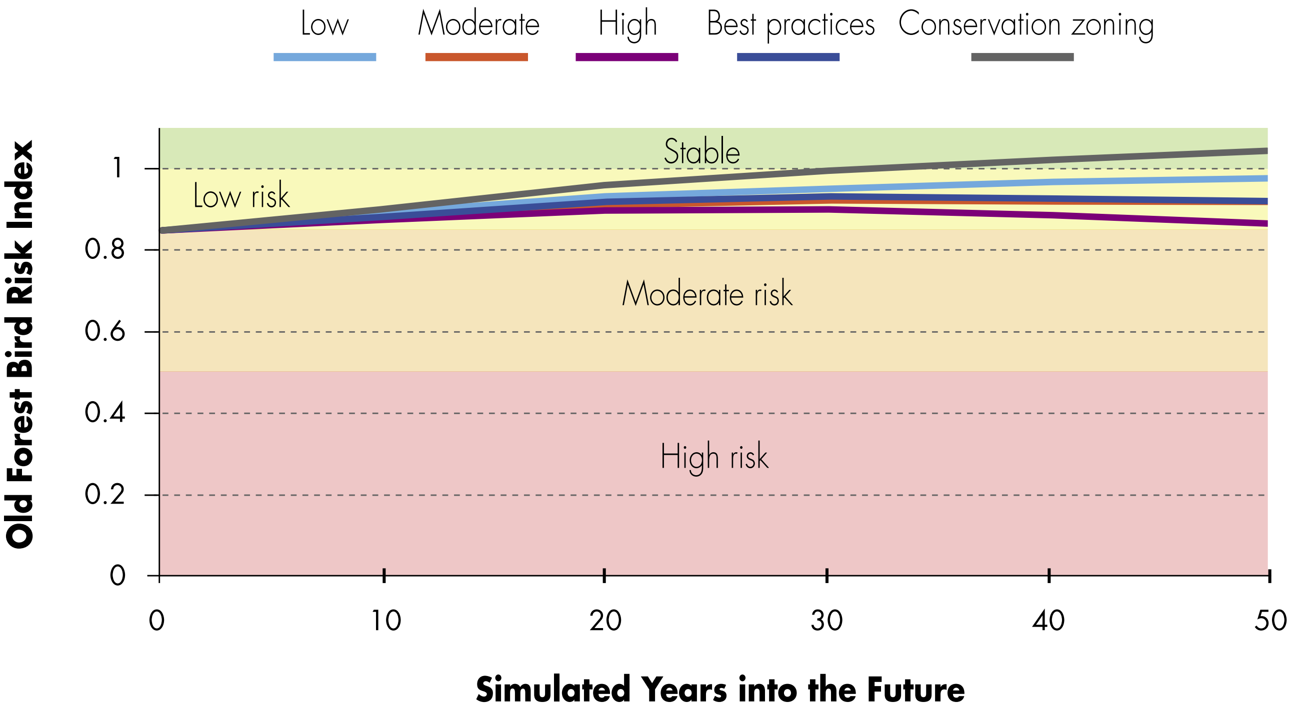


Figure 36. Trend over time of the old forest songbird risk index during simulations for all land use scenarios. The horizontal bands of colour refer to levels of risk expressed as the ratio of future status to estimated natural condition, as described in section 2.4.

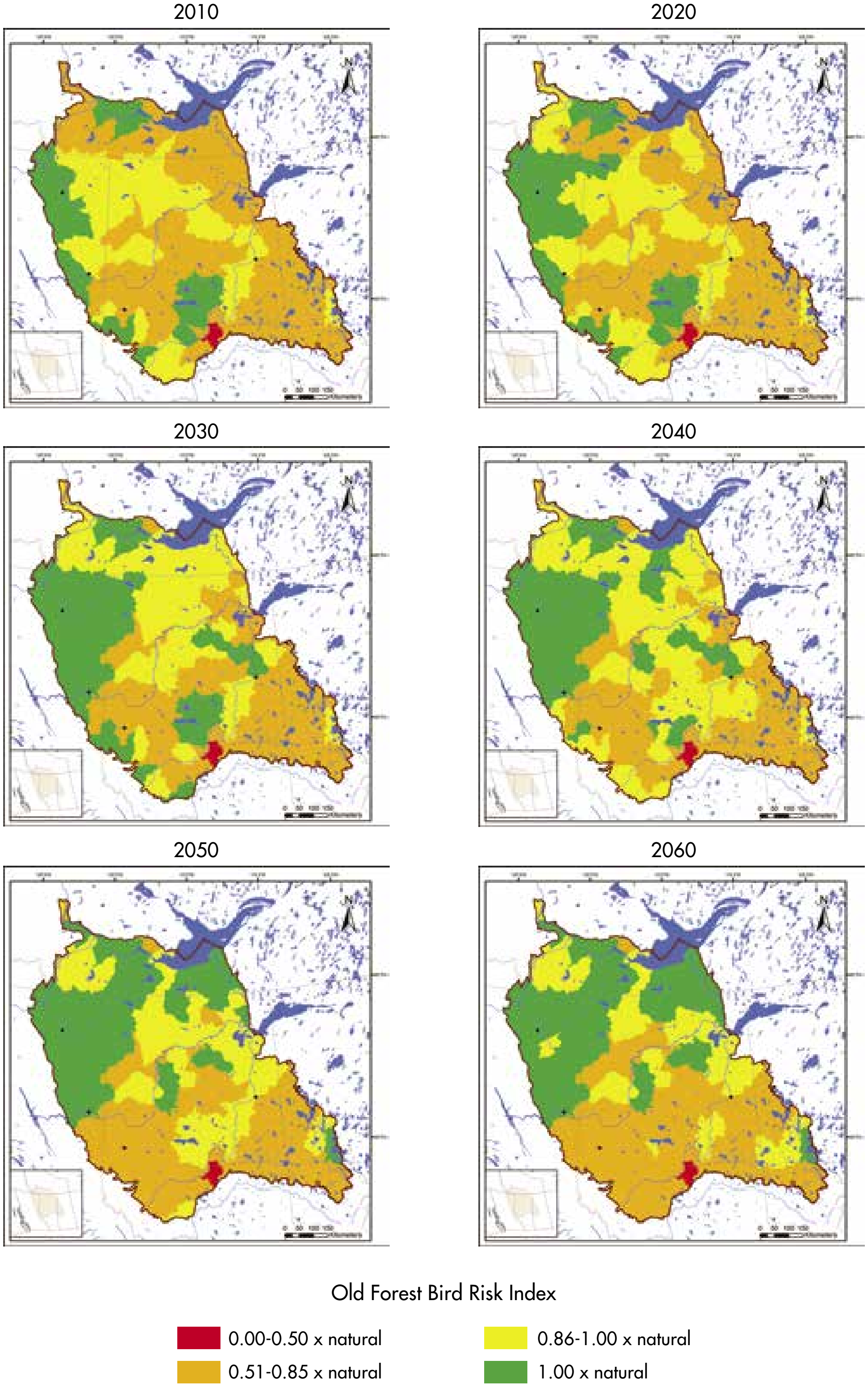
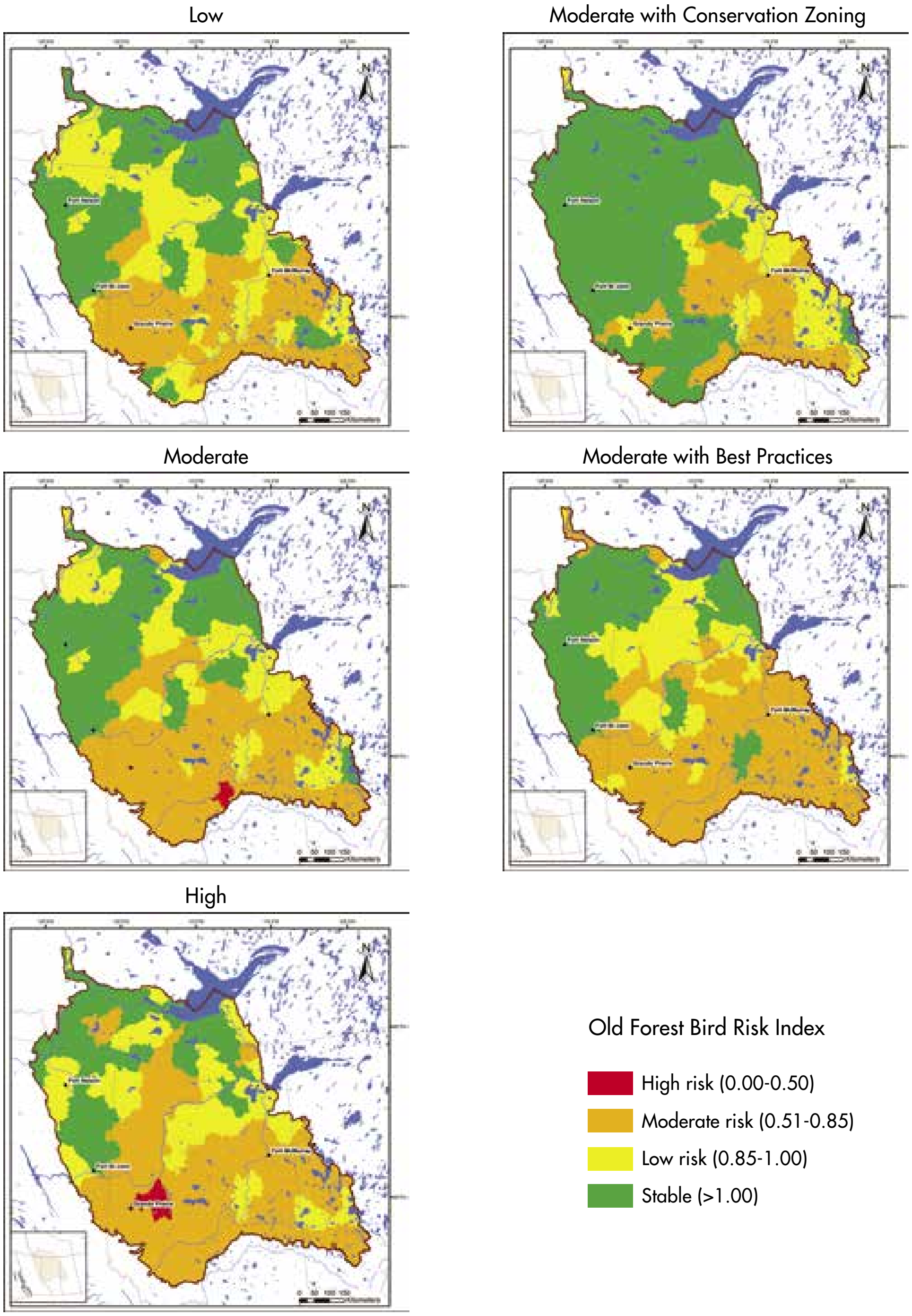


Figure 37. Old forest songbird risk index averaged across each tertiary watershed for 2010 to 2060 under the business as usual scenario with moderate development rate.



Low

Moderate with Conservation Zoning

Moderate

Moderate with Best Practices

High

Figure 38. Comparison of old forest songbird risk index averaged across each tertiary watershed for all land use scenarios at year 2060.

3.5 Implications for Ecosystem Services

3.5.1 Forest Carbon

Our analysis looked at two pools of forest carbon; namely, biotic or living carbon (i.e. living vegetation such as trees) and dead carbon made up of deadwood, plant litter, and soil (referred to collectively as dead organic matter). Total forest carbon declined below the estimated range of natural variation during the simulations (Figure 39). Although the decline is small relative to total regional forest carbon, it is large in absolute terms. The average annual loss of 12.4 million tonnes of carbon is equivalent to 6.2% of Canada's annual greenhouse gas emissions[9] and hundreds of millions of dollars in natural capital[10].

Dead organic matter (DOM) accounts for the majority (75%) of forest carbon in the region, and is currently at the lower bound of its range of natural variation due to the historical conversion of 6% of the study area to agriculture. DOM decline in the simulations was minor (Figure 40), in part because simulated agricultural conversion was low (1% of the study area). Also contributing to DOM's stability was an increase in the abundance of very young forest (i.e., within the first seral stage), which is high in DOM due to the influx and subsequent decomposition of dead vegetation following disturbance. The increase in very young stands during simulations due to timber harvest was sufficient to offset the small decline in DOM carbon caused by a decrease in average forest age.

In contrast to DOM, biotic carbon is currently high relative to the range of natural variation but declined throughout the simulation period (Figure 41). Forestry tends to reduce forest age, and therefore carbon storage, by shortening the disturbance

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[9] Canada's emissions in 2013 were 726 Mt CO2e or 198 Mt Carbon (https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=FBF8455E-1)

[10] The carbon tax in Alberta values carbon at $15 per tonne and set to increase to $20 per tonne in 2016. The average across more than 100 estimates of the social cost of carbon is $43 per tonne (Yohe et al. 2007).

cycle and preferentially harvesting older stands (Kurz et al. 1998, Didion et al. 2007). Most of the simulated decline in biotic carbon occurred on the portion of the landscape available for harvest (Figure 42), and the decline increased with the rate of timber harvest. The best practices scenario had a negligible effect because the suite of best practices did not influence forest age-class composition. Although not assessed in this study for biotic carbon, it is expected that expansion of the protected areas network would reduce biotic carbon loss by avoiding conversion of unmanaged forest to less carbon rich managed forest (Carlson et al. 2010).

Carbon within peatlands was not assessed due to limited information on the effects of land use to peatland carbon dynamics. As a result, the analysis excluded much of the region's ecosystem carbon given that the carbon density of peatlands substantially exceeds that of forests. Peatland carbon stores reflect thousands of years of biomass accumulation due to depressed decomposition rates, and disturbance by land uses such as oil sands mining cause substantial carbon loss (Lee and Cheng 2009). The effect of future land use on peatland carbon is a key uncertainty that deserves attention due to the globally significant amount of carbon contained with boreal peatlands.

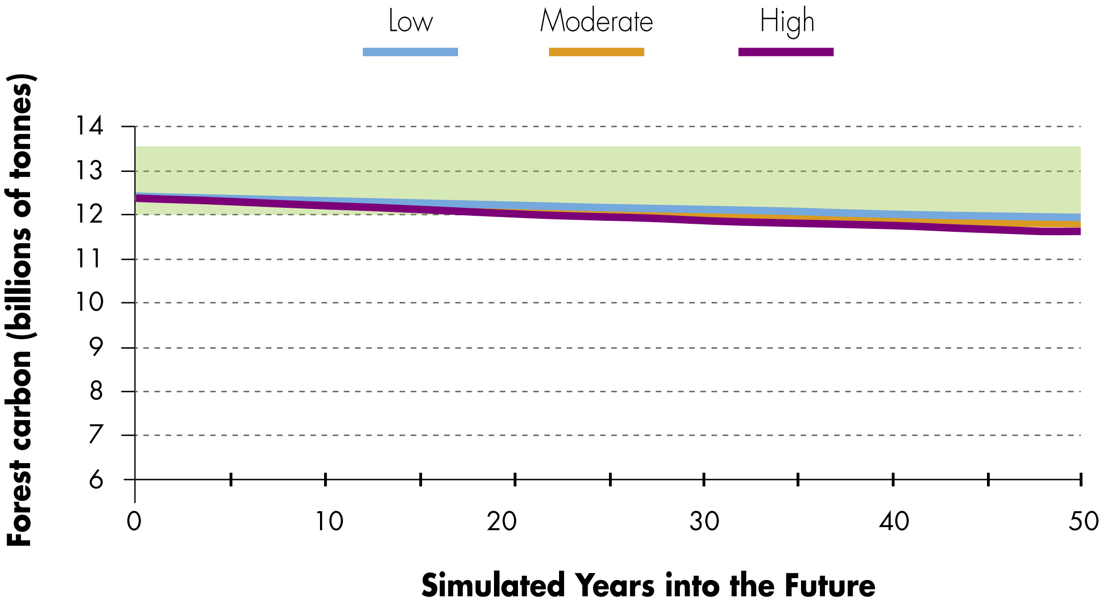


Figure 39. Trend over time of total forest carbon during simulations of low, moderate, and high development scenarios. The green band identifies the range of natural variation.

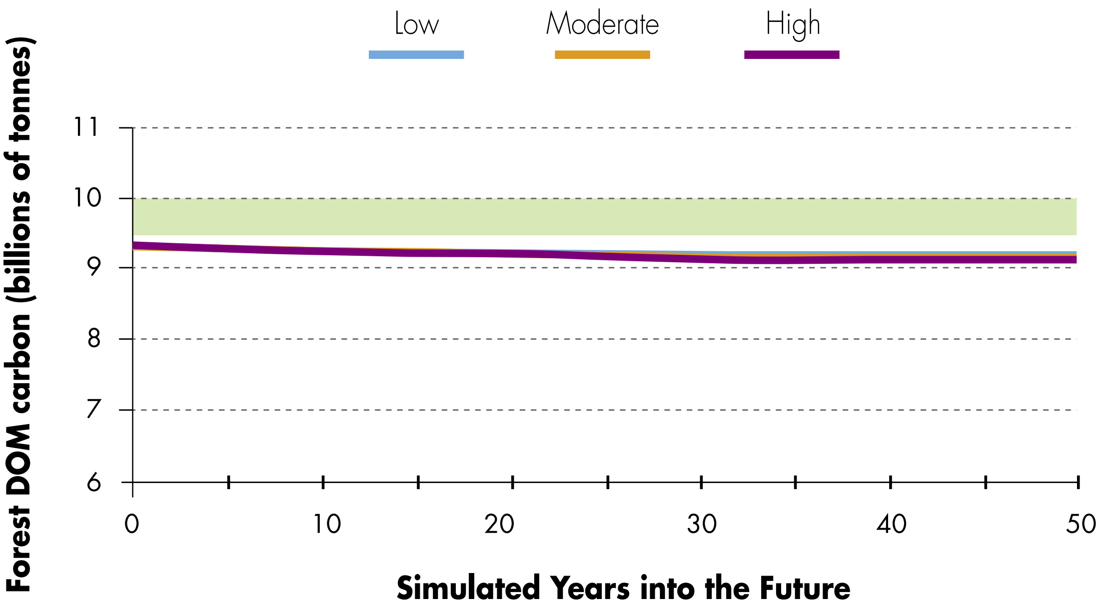


Figure 40. Trend over time of forest dead organic matter (DOM) carbon during simulations of land-use scenarios. The green band identifies the range of natural variation.

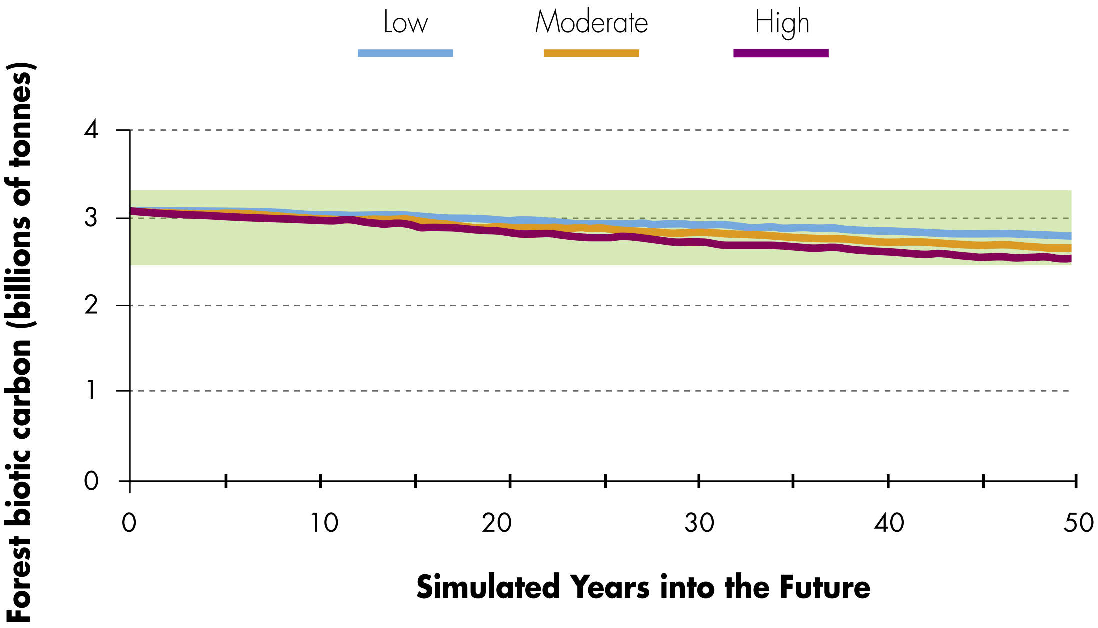


Figure 41. Trend over time of living forest biotic carbon during simulations of low, moderate, and high development scenarios. The green band identifies the range of natural variation.

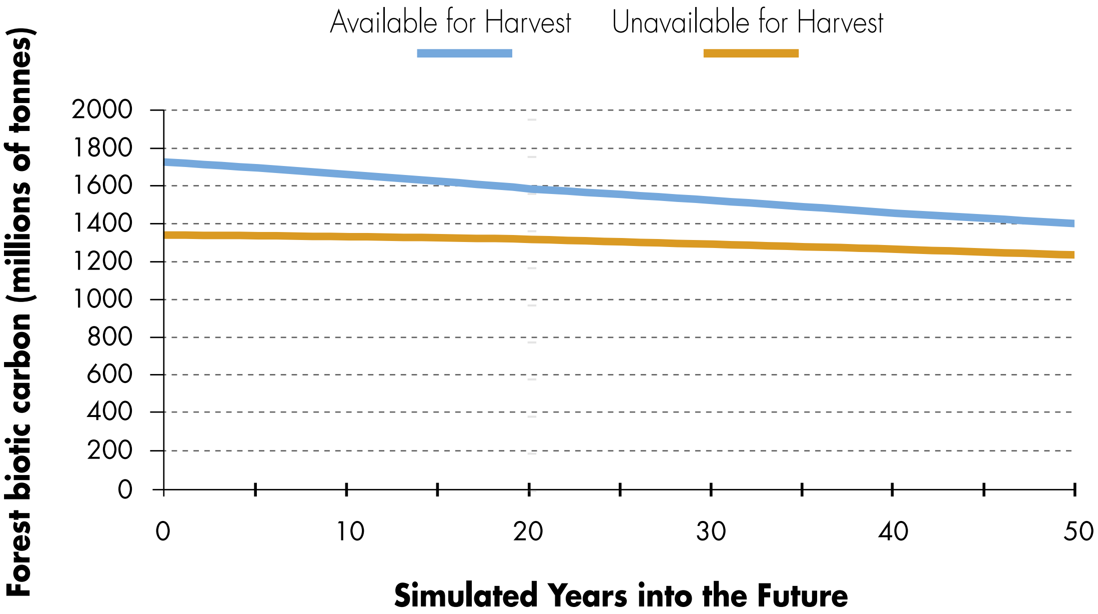


Figure 42. Trend over time in living forest biotic carbon in portions of the study area available and unavailable for timber harvest during simulation of moderate development scenario.

3.5.2 Water Quality

The average phosphorous runoff index value across the current landscape suggests that past conversion of land to agriculture and industrial footprint has elevated phosphorus runoff to water bodies by approximately 25% relative to natural conditions (Figure 43). The clearing of vegetation to create roads, well sites, pipelines and other footprints exposes soil to erosion, which in turn contributes not only sediment to the aquatic system but also phosphorus that is attached to soil particles. Eutrophication of boreal lakes is on the rise due to expanding land use, with various negative implications including algae blooms, oxygen depletion, and loss of coldwater fishes (Schindler and Lee 2010). The runoff index increased during the simulations, suggesting that water quality is likely to decline further as development expands northwards (Figures 44 and 45). The phosphorus run-off index began to stabilize in later decades of the simulation as footprint growth slowed, but runoff remained substantially above natural levels. By reducing the size and duration of industrial footprint, the best practices and low development scenarios slowed but did not stop the northward expansion of watersheds with high phosphorus runoff. Only the conservation zoning scenario succeeded at curtailing growth in phosphorous runoff by protecting numerous watersheds from future anthropogenic footprint (Figure 45).

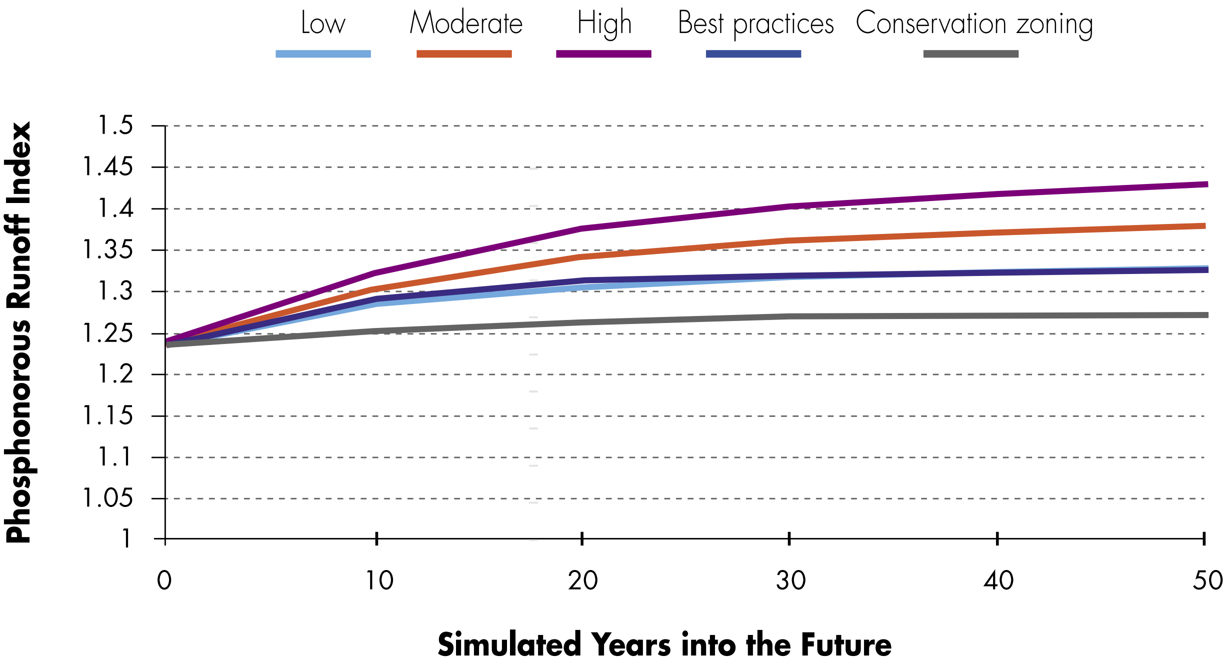


Figure 43. Trend over time of the phosphorus runoff index during simulations of all land-use scenarios. An index value of 1 indicates natural levels of phosphorus runoff, and higher values indicate progressively higher levels of phosphorus runoff (and therefore lower water quality).

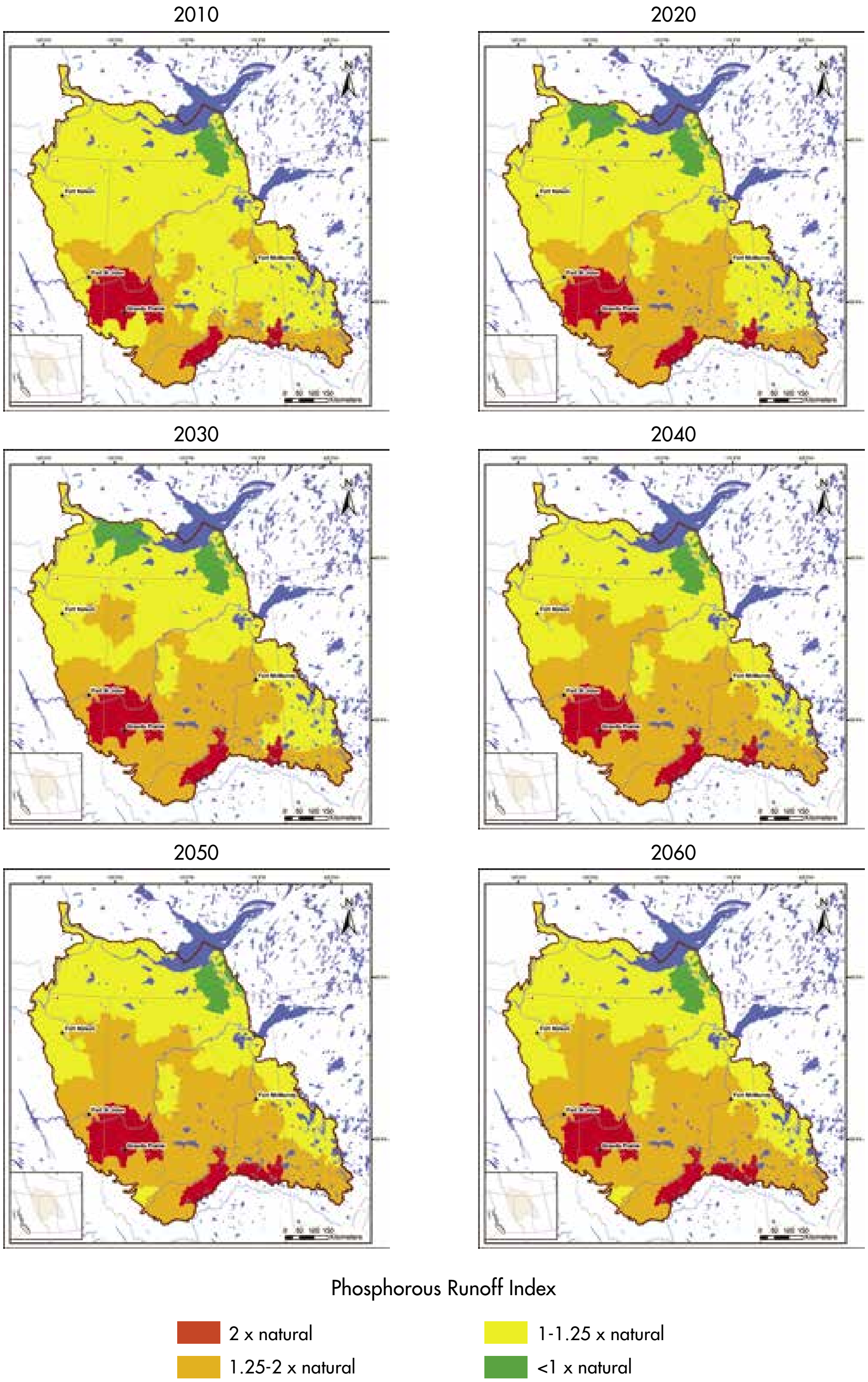
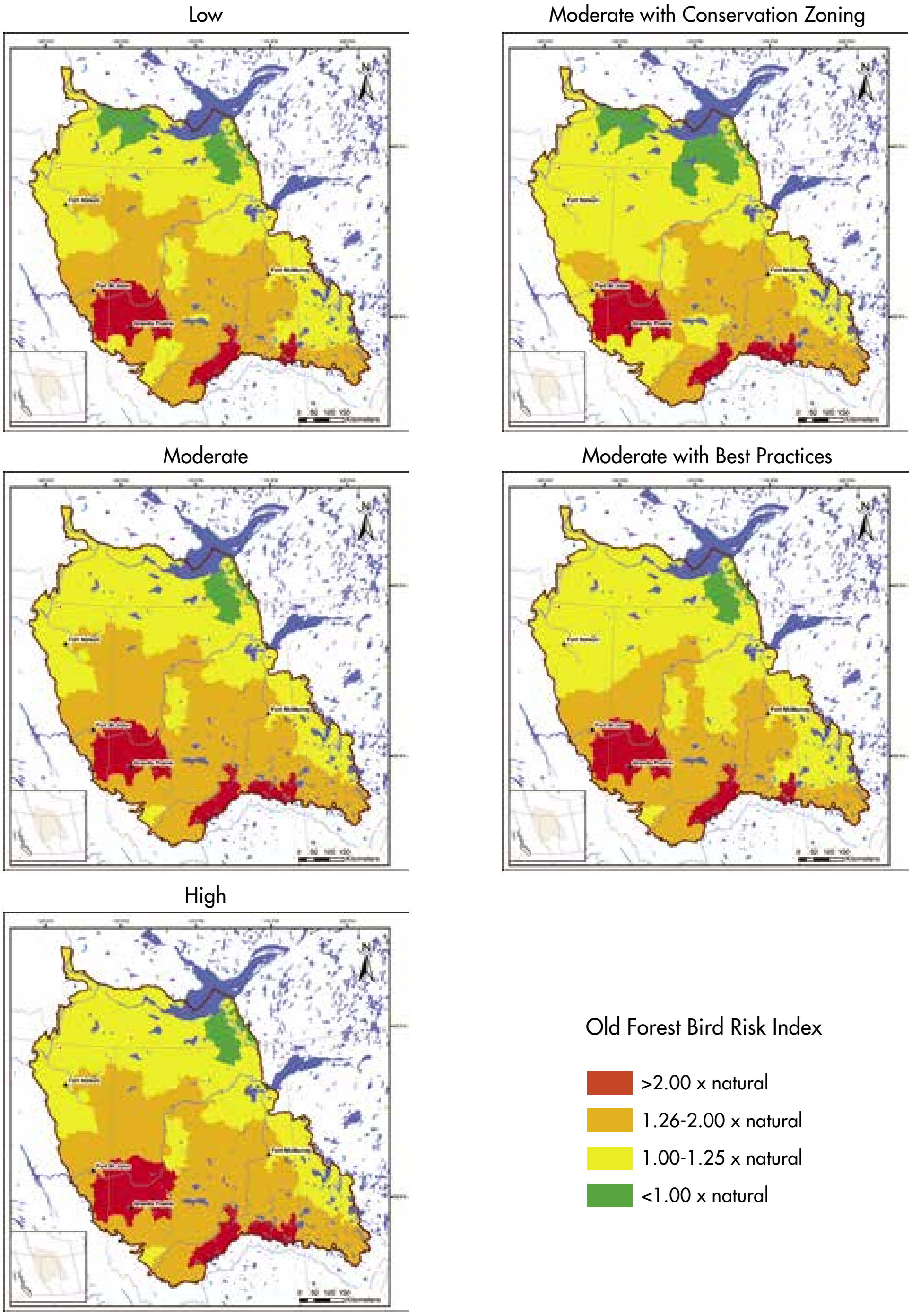


Figure 44. Simulated phosphorous runoff index averaged across each tertiary watershed for 2010 to 2060 under the business as usual scenario with moderate development rate.


Low

Moderate with Conservation Zoning

Moderate

Moderate with Best Practices

High

Figure 45. Comparison of phosphorous runoff index across all land use scenarios at year 2060.

3.5.3 Water Use

Land use in the region consumes large quantities of water, and the demand for water is expected to increase with time (Figure 46, Figure 47). It is estimated that resource production and settlements currently consume almost 400 million m^3 (400 billion L) of surface water and almost 60 million m^3 (60 billion L) of groundwater. While large in absolute terms, simulated surface water consumption represents a small fraction of the surface water available in the region. For comparison, the average volume of water exiting the region annually through the Mackenzie River between 2000 and 2009 was 227 billion m^3/year. Regional surface water use did not exceed 0.2% of this volume during the simulations. Although regional surface water use is small relative to availability, there is potential for a larger proportion of surface water to be consumed by land use at the sub-regional scale. Oil sands mining accounts for the vast majority of surface water use in the region (Figure 48) and is concentrated in a small portion of the study area. As discussed by Schindler et al. (2007), this level of water demand could surpass a critical proportion of winter low flow of the Athabasca River, especially if the Athabasca's flow is reduced as expected by climate warming. A water management framework established to maintain the health of the Athabasca River sets a maximum wintertime cumulative withdrawal of 15 m^3/s (AENV 2007), and was approached by the moderate development scenario (14 m^3/s) and exceeded by the high development scenario (17 m^3/s).

The dominant groundwater use during simulations was in situ bitumen and shale gas production, which exceeded all other uses combined (agriculture, settlements, and forestry). Given that in situ bitumen and shale gas production is focused in a subset of the study area, associated groundwater consumption may stress local groundwater supplies. However, knowledge of groundwater availability in the region is insufficient to assess the sustainability of simulated groundwater consumption.

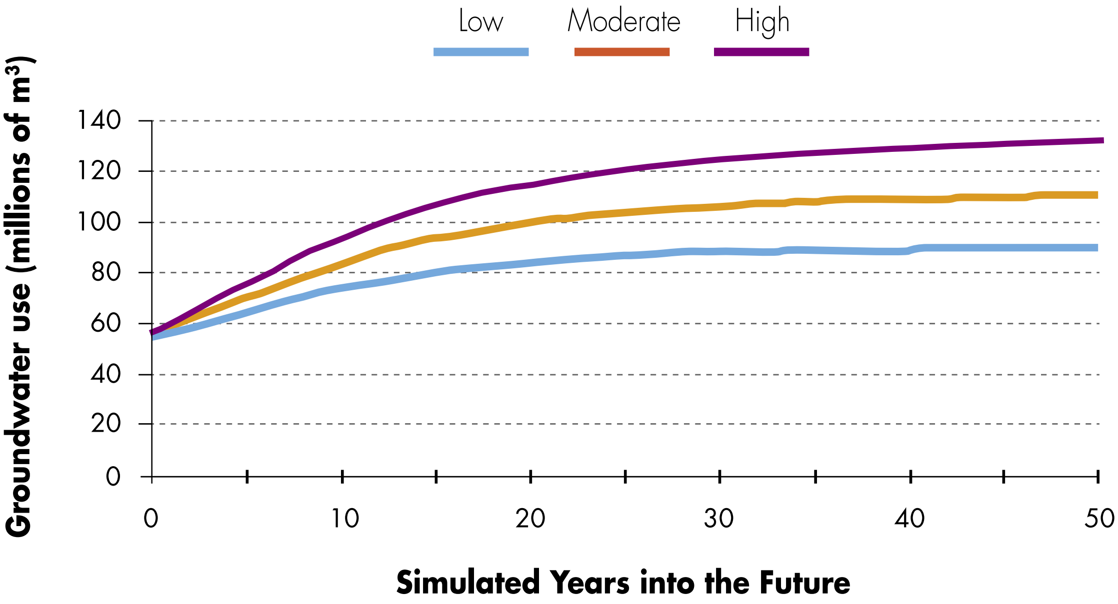


Figure 46. Groundwater use during simulations of low, moderate, and high development scenarios.

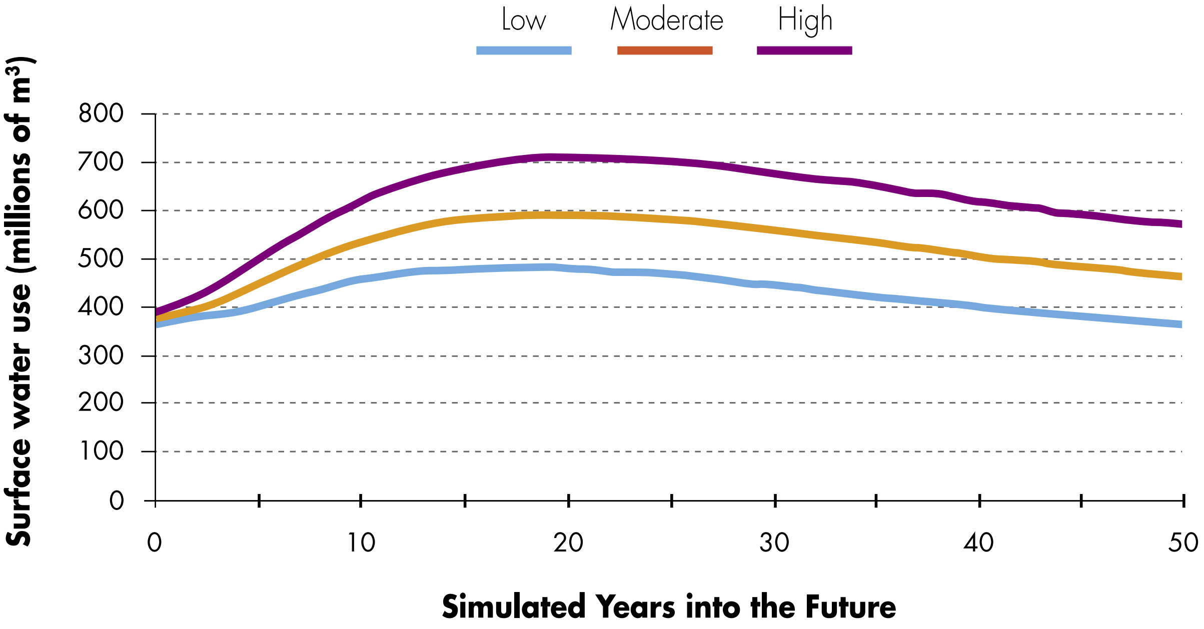


Figure 47. Surface water use during simulations of low, moderate, and high development scenarios.

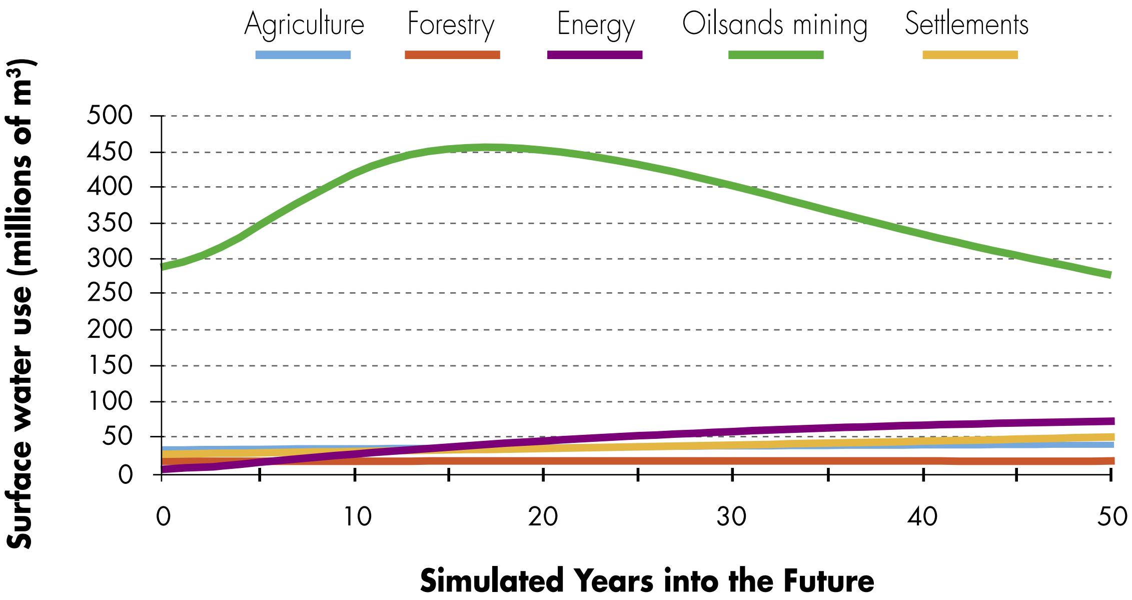


Figure 48. Surface water use by sector during simulation of the moderate development land-use scenario.

3.5.4 Air emissions

Current natural resource production in the region is estimated to contribute approximately 50 megatonnes (Mt) of carbon dioxide equivalent (CO_2e) to the atmosphere, which accounts for 7% of Canada-wide emissions in 2009 (690 Mt CO_2e). Greenhouse gas emissions were simulated to more than triple over 50 years in the moderate scenario, reaching 169 Mt CO_2e by the end of the simulation (Figure 49). The vast majority of simulated emissions were associated with the production of hydrocarbons (Figure 50), especially bitumen which accounted for 90% of emissions during the moderate simulation. When considered relative to Canada's greenhouse gas target, it is apparent that simulated rates of natural resource production in the region would be a strong impediment to Canada's international obligations to curb emissions. Under the Copenhagen Accord, Canada committed to reduce emissions to 607 Mt by 2020, or 17% below 2005 levels[11]. In the moderate scenario, GHG emissions from natural resource production was simulated to increase to 135 Mt by 2020, accounting for 22% of the total emissions target for the country.

By reducing the intensity of GHG emissions associated with energy production by 50% over the next 40 years, the best practices scenario stabilized emissions towards the end of the simulation but still exceeded current emissions two-fold. Gradual achievement of the emission intensity target, which can be expected due to technological and cost impediments, implied that GHG emissions increased during the early decades of the best practices simulation. As such, even under the optimistic scenario of reducing GHG emission intensity by 50% over 40 years, hydrocarbon

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[11] https://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=FBF8455E-1#fnb1

production in the study area is likely to be an impediment to Canada's commitments for reducing GHG emissions. Under the best practices scenario, emissions are simulated to be 94 Mt CO_2e by 2020, which is 16% of Canada's emission target for that year.

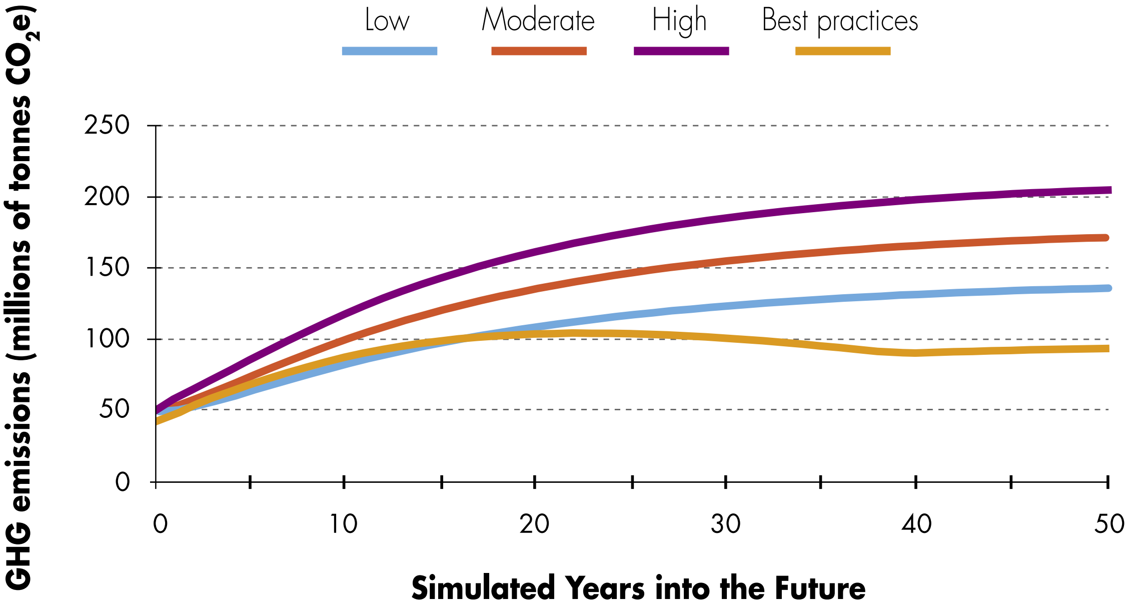

Figure 49. Industrial greenhouse gas (GHG) emissions during simulations of low, moderate, and high development rate, and moderate development rate with best practices.

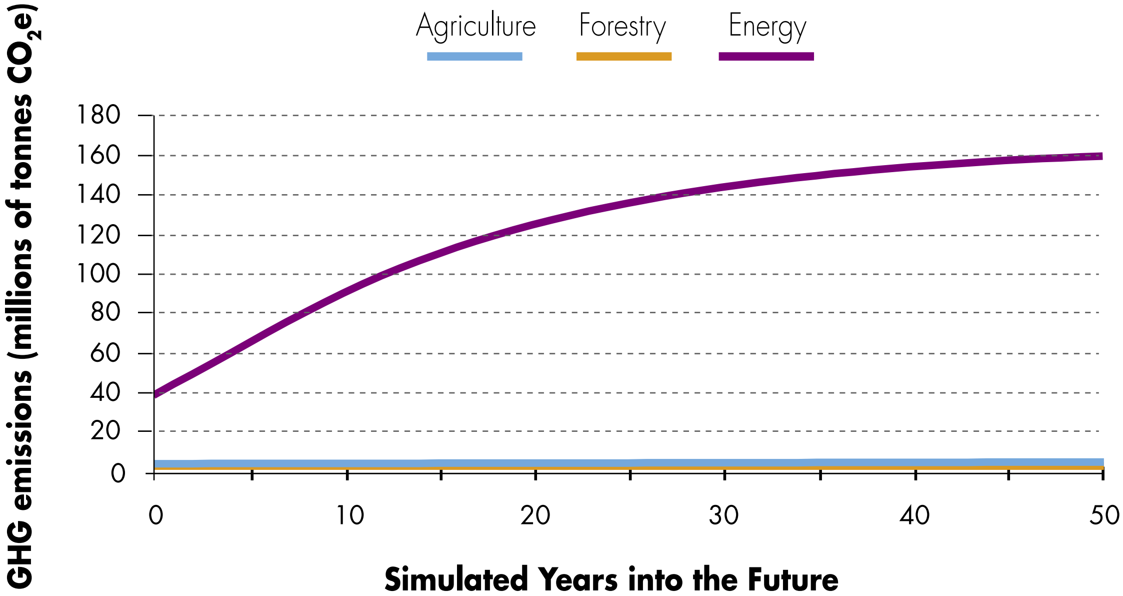

Figure 50. Industrial GHG emissions by sector during simulation of the moderate development rate scenario.

Estimated sulphur dioxide emissions from resource production in the 2010 simulation base year for the study area accounts for 10% of Canada's total emission of 1370 kilotonnes in 2010[12]. As with GHG's, sulphur oxide emissions from natural resource sectors increased during simulations (Figure 51), primarily in response to growing bitumen production. During the moderate simulation, sulphur oxide emissions increased more than 3-fold, and 87% of emissions were associated with bitumen production. By the end of the moderate scenario, simulated sulphur oxide emissions from resource production in the study area account for 16% of Canada's sulphur oxide cap of 3.2 million tonnes under the 1991 Canada-United States Air Quality Agreement[13]. Nitrogen oxide emissions almost doubled during the moderate development simulation (Figure 52), with the majority of emissions attributable to the energy sector. Gas production is an important contributor to nitrogen oxide emissions, accounting for approximately the same amount of emissions as bitumen production. Future gas production is focused in the shale gas deposits of northeastern British Columbia, and the magnitude of simulated nitrogen oxide emissions lends support to the view that non-point source emissions in northeastern British Columbia are of concern (Krzyzanowski 2009).

The simulated increase in sulphur (~3x) and nitrogen (~2x) emissions from the region, much of which emanate from northeastern Alberta, may increase the risk of acidification of neighboring ecosystems. Research suggests that the potential for lake acidification in northeastern Alberta is limited (Curtis et al. 2010) but possible in areas with acid-sensitive soils (Whitfield et al. 2010). Perhaps at greater risk is northwestern Saskatchewan where there exists an abundance of lake catchments that have soils with limited capacity to buffer against acidification. Regional deposition models suggest that the critical load for acid deposition may already be exceeded along the Alberta border in proximity to Alberta's oil sand developments (Aherne 2008). Additional emissions could threaten numerous lakes in the region (Jeffries et al. 2010). Total sulphur and nitrogen deposition is estimated at approximately 150-300 molc ha-1yr-1 in northwestern Saskatchewan along the Alberta border where the oil sands are located (Aherne 2008). This deposition rate is in proximity to the critical load for soils (approximately 200-400 molc ha-1yr-1; Carou et al. 2008), and a doubling or tripling of emissions could increase risk of lake acidification in the region. To properly assess the risk of acidification, further research is needed to model increased acid deposition that can be expected under future emission scenarios.

By reducing emission intensity of bitumen production by 50% over 40 years, the best practices scenario reduced sulphur oxide emissions relative to the business as usual scenario. The 50% reduction in emission intensity was insufficient to eliminate growth in emissions, however, due to the large expected increase in bitumen production. Even under the best practices scenario, sulphur oxide emissions increased rapidly before stabilizing at approximately twice the current level of emissions in the region.

[12] http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=402A9845-1

[13] http://www.ec.gc.ca/air/default.asp?lang=En&n=F5CBD0BB-1

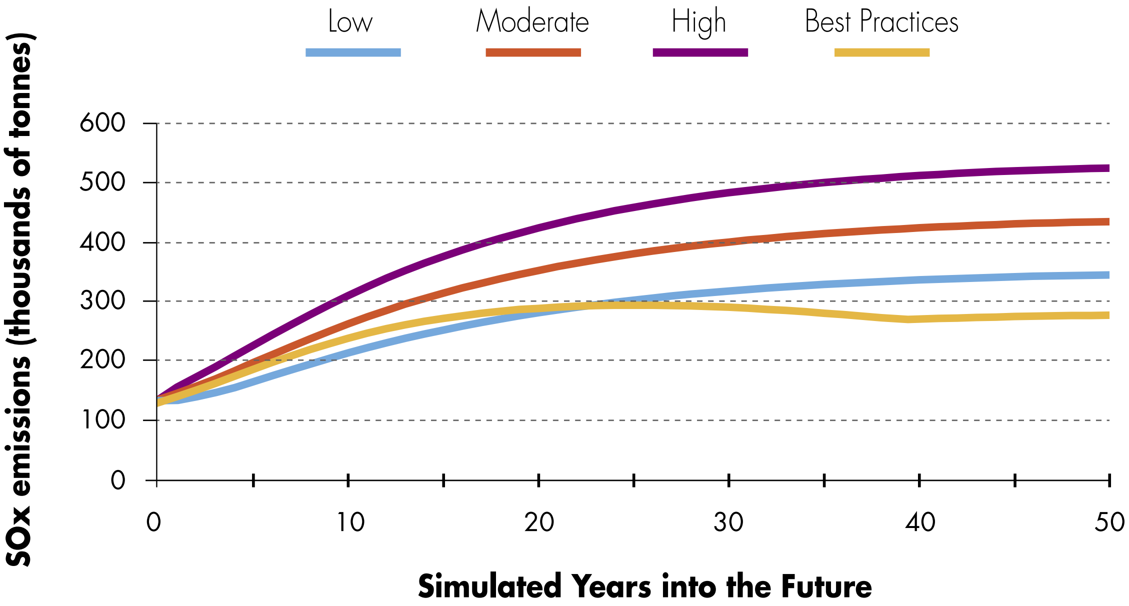

Figure 51. Industrial sulphur oxide (SOx) emissions during simulations of low, moderate, and high development rate, and moderate development rate with best practices.

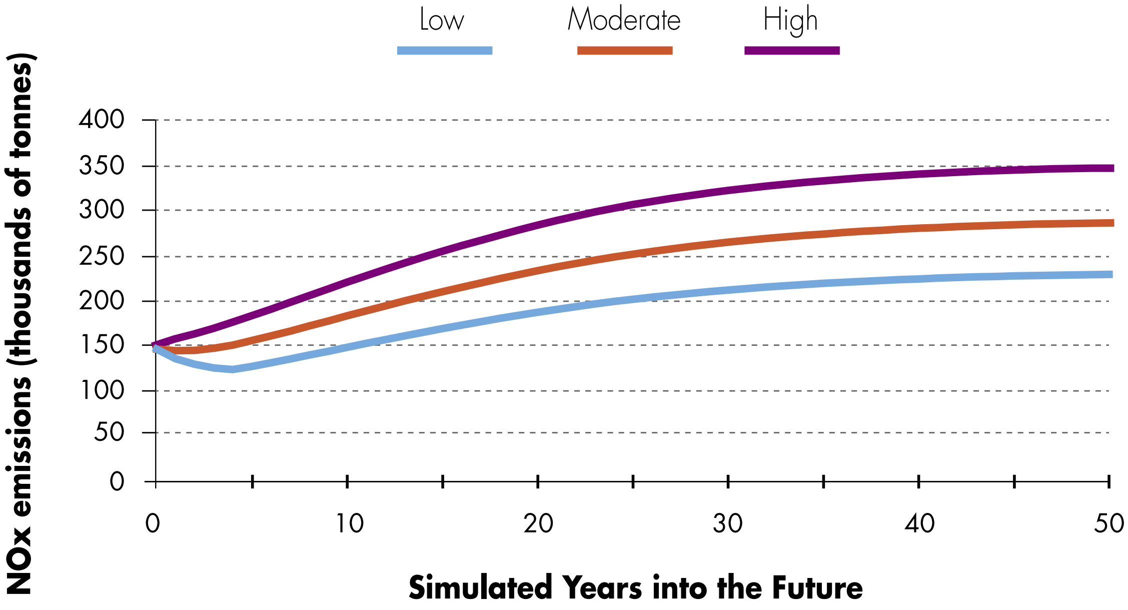

Figure 52. Industrial nitrogen oxide (NOx) emissions during simulations of low, moderate, and high development rate.


HITACHI

CONCLUSIONS

4.1 What is the Future Under Business as Usual?

The outcomes of the moderate development rate simulation suggest that natural resource development in Canada's western boreal region has the potential to generate rapid economic growth at the cost of substantial ecological integrity. GDP and employment more than doubled over the next 50 years, largely in response to accelerated extraction of bitumen and, of secondary importance, shale gas. Direct environmental impacts of the upward trend in bitumen production included rising emissions and water use. Greenhouse gas emissions more than tripled during the simulation which, if realized, would be a strong impediment to Canada's international obligations to curb emissions. By 2020, simulated GHG emissions from the region accounted for 22% of Canada's total emissions target under the Copenhagen Accord. Also of concern due to potential lake acidification risk were a tripling of sulphur oxide and doubling of nitrogen oxide emissions, although further research is needed to model acid deposition under simulated emission scenarios.

Wildlife that are sensitive to forest disturbance and loss were adversely affected by the expanding development, especially caribou. By the end of the simulation, the majority of watersheds exhibited a high risk of caribou extirpation and it is likely that caribou will be lost from most of the region over the next 50 years if no action is taken to conserve habitat. This conclusion, while dire, is consistent with previous studies including a national assessment of boreal caribou critical habitat which identified all herds in the region outside of the Northwest Territories as not self-sustaining.

Many fish populations in the region are already in decline, and simulation outcomes indicate that degradation of fisheries is likely to continue as development intensity increases in northern watersheds. The spread of linear access corridors, as well as a growing human population, were simulated to increase angling pressure and cause a concomitant decline in the integrity of the fish community.

Another impact to aquatic ecosystems was increased phosphorous runoff. The clearing of vegetation to create anthropogenic footprint exposes soil to erosion, which in turn contributes sediment and associated phosphorous to the aquatic system. Phosphorous runoff followed the northwards expansion in development during the simulations, indicating associated impacts such as eutrophication may become more prevalent.

In the southern portion of the study area, an additional change in landscape composition was declining forest age due to the prevalence of timber harvest. A consequence was that biotic carbon storage declined below natural levels due to the lower carbon content of younger forest. The increased abundance of younger forest contributed to the simulated decline in caribou viability, and also elevated risk levels for songbirds and fisher in southern watersheds. In contrast, moose responded positively to the shift towards younger forest, although the population growth effect was partially offset by increased hunter access.

Predictably, simulation outcomes were sensitive to the rate of development, with an accentuated trade-off between economic growth and environmental decline at the higher development rate. Across all simulated rates, however, the intensity and extent of anthropogenic footprint increased, thereby elevating risk to wildlife, thus a slower rate of natural resource extraction will not be sufficient to conserve wildlife over the long term.

4.2 Can Advancements in Industry Best Practices Change the Future?

The application of best practices mitigated some of the undesirable impacts of development in the region. Efforts to minimize the size of industrial footprint and accelerate its reclamation slowed the rate of habitat alteration and loss. Indicators such as caribou, recreational fish, fisher, and phosphorous runoff exhibited a similar response to best practices as they did to a reduction in development rate. The application of best practices generally slowed the decline in ecosystem indicator performance found in the moderate business as usual scenario, but was insufficient to shift the trend to an improvement in habitat over time. The combination of a low rate of resource development and application of best practices was not explored but would result in even greater improvements in the outcomes for wildlife and the environment while still maintaining significant economic growth. Emissions displayed the greatest sensitivity to best practices, but still increased two-fold under the aggressive best practice assumption of a 50% reduction in emission intensity. For sensitive species such as caribou, the lower disturbance intensities achieved under both the low development rate scenario and the moderate with best practices scenario were still insufficient to significantly reduce risk levels.

All of the footprint best practices proposed in this study are likely achievable. They involve actions to speed up reforestation through planting and minimizing soil disturbance as well as implementing more coordinated project planning such that minor road creation, use, and decommissioning is coordinated among projects. While not sufficient to achieve major risk reductions implementing the footprint best practices would improve habitat and mitigate some impacts on wildlife.

Achieving a 50% reduction in carbon emission intensity of the bitumen sector is a bigger challenge. An important component of meeting the challenge would be carbon capture and storage, a strategy thought to have the potential to reduce GHG emissions from the industry by about two-thirds (Bergerson and Keith 2010). The Alberta government’s climate change action plan assumes that carbon capture and storage will account for the majority of its targeted 50% reduction in emissions intensity, and the Government of Alberta has created a billion dollar fund to motivate demonstration projects (Government of Alberta 2008, Alberta Carbon

Capture and Storage Development Council 2009). Large-scale implementation of carbon capture and storage demands billions of dollars of investment, an investment which will only be possible if stricter regulations are implemented, the price of carbon substantially increases[14], and/or very large public subsidies are directed at the technology (Sawyer et al. 2008, Huot 2011).

4.3 Path Forward for Conservation Zoning

Protected areas currently cover 9% of the study area[15], much of which is accounted for by Wood Buffalo National Park. The study area's level of protected area coverage is slightly less than the national total of 10%[16] and, more importantly, below what is thought necessary to maintain ecological integrity. Forty percent of the study area is currently zoned for a maximum habitat disturbance of 65% under the federal Boreal caribou recovery strategy although 17 of the 19 caribou ranges in the study area already exceed this conservation zoning threshold. If enforced, requirements to protect critical habitat for caribou would result in the partial protection of a large portion of the region with significant benefits for the ecological integrity of the landscape. Ecological integrity requires: 1) representation of all native ecosystem types, 2) maintaining populations of all native species in natural patterns of abundance and distribution, 3) maintaining ecological processes, and 4) maintaining resilience to environmental change (Noss and Cooperrider 1994). Based on reviews of conservation planning initiatives, estimates of the level of habitat protection required to achieve ecological integrity objectives include: 25% to 75% (Noss and Cooperrider 1994); a median level of protection above 50% (Schmiegelow et al. 2006); and about three times higher than what is typically reflected by policy (Svancara et al. 2005).

The conservation zoning scenario that protected 20% of natural resource potential based solely on least cost of avoided disturbance had ecological shortcomings. For example, most woodland caribou herds in Alberta and British Columbian overlap with bitumen deposits or shale gas deposits. Conservation of these herds will likely require that some bitumen and shale resources in the region be excluded from development, despite their high economic value. These and other policy objectives will demand a conservation area design that is more refined than can be achieved solely based on least cost of avoided disturbance. In reality, achieving ecological objectives is likely to require the conservation of some areas with a high resource value. For example, achieving ecological objectives may require the protection of focal species habitat (e.g., caribou ranges), rare features, or underrepresented ecosystem types. It may also be advantageous to distribute conservation areas across a north-south gradient to capture variation in ecosystem productivity and to facilitate northward species migrations in response to climate change.

[14] The carbon price in Alberta is capped at $15 per tonne of CO2 and set to increase to $20 per tonne in 2016, whereas carbon capture and storage is estimated to cost in the range of from around $50 to over $200 per tonne (Bergerson and Keith 2010, Huot 2011). As such, the current price of carbon is insufficient on its own to motivate industry to invest in carbon capture and storage.

[15] Interim protected areas (i.e., not yet enacted by legislation) were not included in the simulations. These include conservation zones identified in the Dehcho Land Use Plan (Dehcho Land Use Planning Committee 2006) and areas identified through Alberta's Land Use Framework (Alberta Land Use Secretariat 2008).

[16] http://www.ec.gc.ca/indicateurs-indicators/default.asp?lang=en&n=478A1D3D-1

The conservation zoning scenarios illustrated that increased protection is likely to reduce risk to wildlife. Indeed, of the land-use strategies assessed, conservation zoning demonstrated the greatest potential for balancing economic and ecological objectives due to its ability to protect sensitive species from development while still allowing substantial resource development to occur in the region. The effectiveness of proposed conservation areas should not be assessed solely based on quantity (i.e., total area of land protected), but also based on quality in terms of capacity to avoid future disturbance in areas of high ecological value. Portions of the study area are unlikely to see significant habitat loss due to resource development. That makes these areas relatively easy to zone for conservation but also makes that zoning meaningless if it is not preventing habitat alteration or loss that would have otherwise occurred. Prioritizing the protection of certain portions of the study area to achieve objectives such as ecological representation or the conservation of focal species habitat will tend to require the protection of some landscapes that contain natural resources of high economic value. By applying land-use simulation to inform the location of proposed conservation areas, we were able to focus conservation on portions of the landscape where development is expected to occur while at the same time considering implications to regional economic growth.

As a next step in using cumulative effects scenario analysis to inform conservation planning, design factors such as focal species habitat, ecosystem representation, and sub-regional economic performance could be integrated into the scenario analysis approach used for this project to identify conservation area options that are consistent with desired economic and ecological outcomes. An example of how design principles can be combined with scenario analysis to explore protection options is presented in Appendix 1.

4.4 Balancing Wildlife Conservation with Economic Development

Economic growth is desirable, but so too are abundant wildlife, clean water, and intact wilderness. The western boreal region is vast but finite, and the fixed availability of resources imposes a trade-off between economic growth and ecological integrity. However, the scale of development in the region is already such that it is hampered by practical constraints such as workforce availability and movement of resources to market. Rapid increase of resource production in the short or even medium term may be unrealistic, and impediments that are being encountered in the rush to develop the region's resources provide an opportunity to step back and collectively consider where the region's future should lead. In the absence of a coherent land use strategy, continued expansion of development on a project by project and industry by industry basis across the region will diminish options for balancing economic and environmental objectives.

Promising examples of land-use planning do exist, such as the Dehcho land use plan, the Alberta Land Use Framework, and the Canadian Boreal Forest Agreement. By and large, public engagement in land use planning has been limited, despite public ownership of the natural resources and the environmental and economic importance of the region. Our hope is that this scenario analysis will motivate and inform public discourse around the desired future for the western boreal region and how that vision can be realized. The transformation of Canada's western boreal region has begun, but the end-point of that transformation is yet to be determined. The time to decide the future of the Canada's western boreal region is now.

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APPENDIX 1

The conservation zoning scenario used in the simulations can be modified by adding conservation design criteria. As a simple example, we added a design criterion of equal habitat protection across sub-regions. Five watershed-based sub-regions were used as coarse units of ecological representation (Figure A1). The five sub-regions divide the study area into similarly sized portions across latitudinal and longitudinal gradients. The region's most economically valuable resource, bitumen, occurs almost exclusively within one of the sub-regions (Lower Athabasca/Peace).

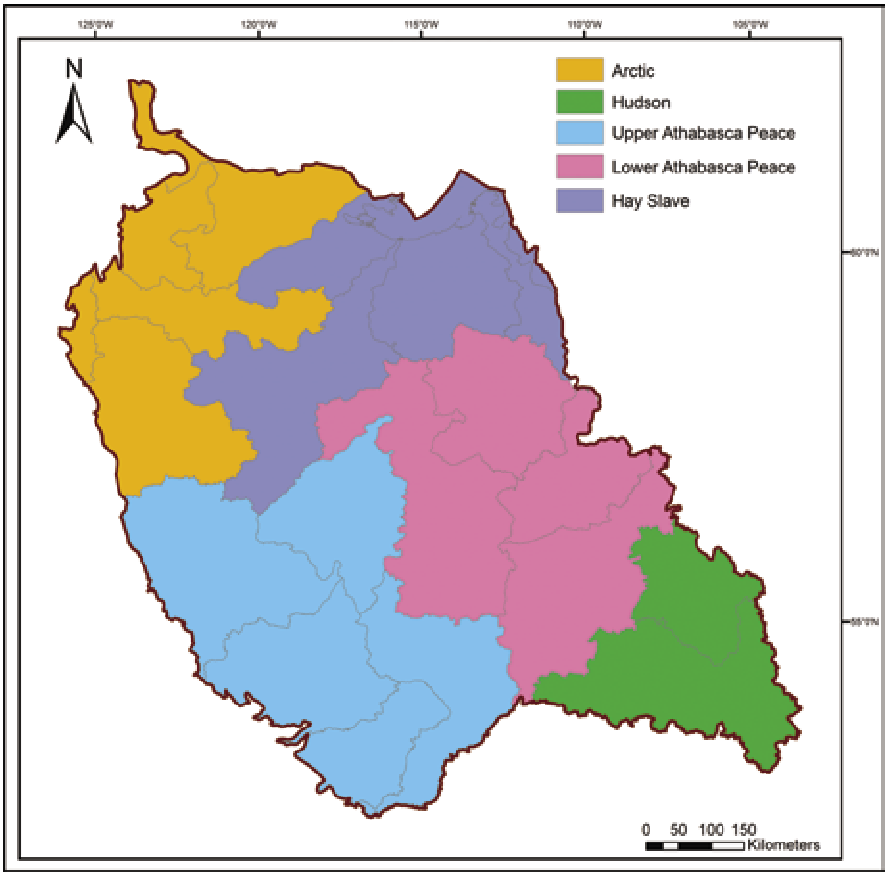

Figure A1. Sub-regions used to balance the proportion of the landscape designated for conservation evenly across the study area. Watersheds were iteratively zoned for conservation based on the two conditions that 1) no more than 20% of the simulated economic resource potential be foregone, and 2) that the proportion of the each sub-region zoned for conservation be approximately equal.

APPENDIX 1

To force equitable conservation across sub-regions, the selection criteria for watershed protection was modified by adding the requirement that the protection level (i.e., %) be approximately[17] equal across sub-regions. The modified selection process still prioritized watersheds offering the least cost of avoided disturbance, but not at the expense of sub-regional representation. The resulting set of watersheds selected for conservation is shown in Figure A2.

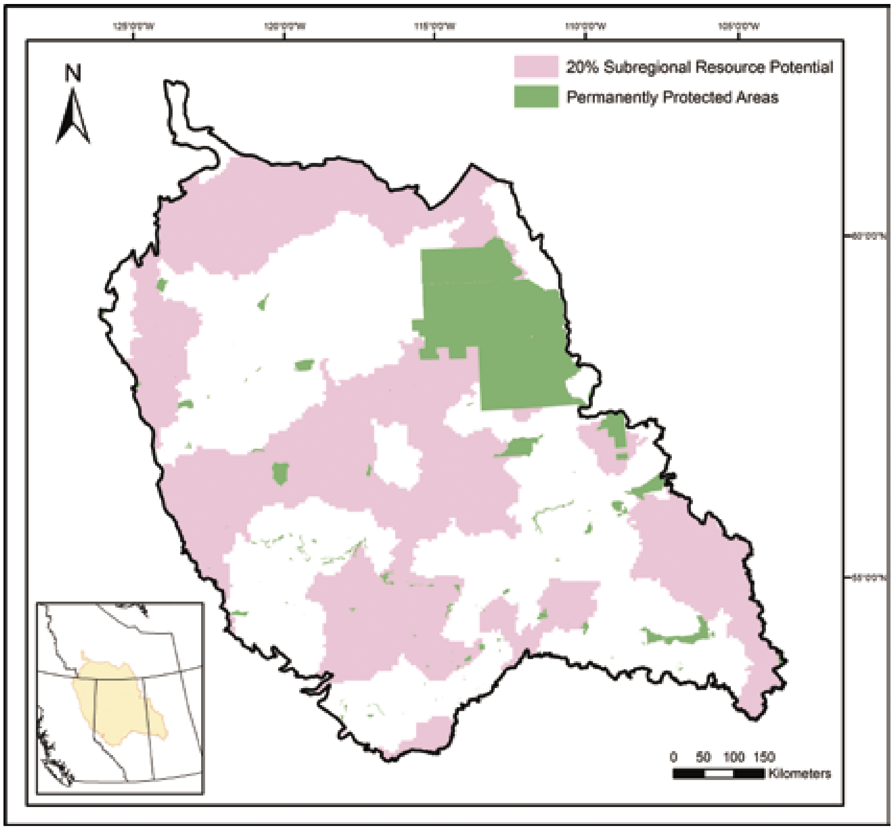

Figure A2. Watersheds designated for conservation (area in pink) under a balanced sub-regional approach to distributing habitat protection. Conservation areas cover 43% of the study area in addition to existing protected areas. Hypothetical scenario for exploring ways of thinking about economic versus wildlife conservation trade-offs, not a proposed conservation plan.

Adding the design criterion of equal protection across sub-regions reduced the risk to wildlife in the Lower Athabasca/Peace sub-region, resulting in more balanced ecological performance (Figure A3). However, forcing the protection of watersheds within that sub-region required the protection of landscapes with high economic value relative to elsewhere in the study area.

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[17] The conservation level could only be approximately equal across watersheds due to the large and variable size of the selection units (i.e., watersheds).

The land use simulation approach developed in this study allows for the strategic level exploration of the outcome of applying a variety of criteria to conservation zoning for the region. Insights from these high level scenarios can then feed into specific land use plan design and implementation.

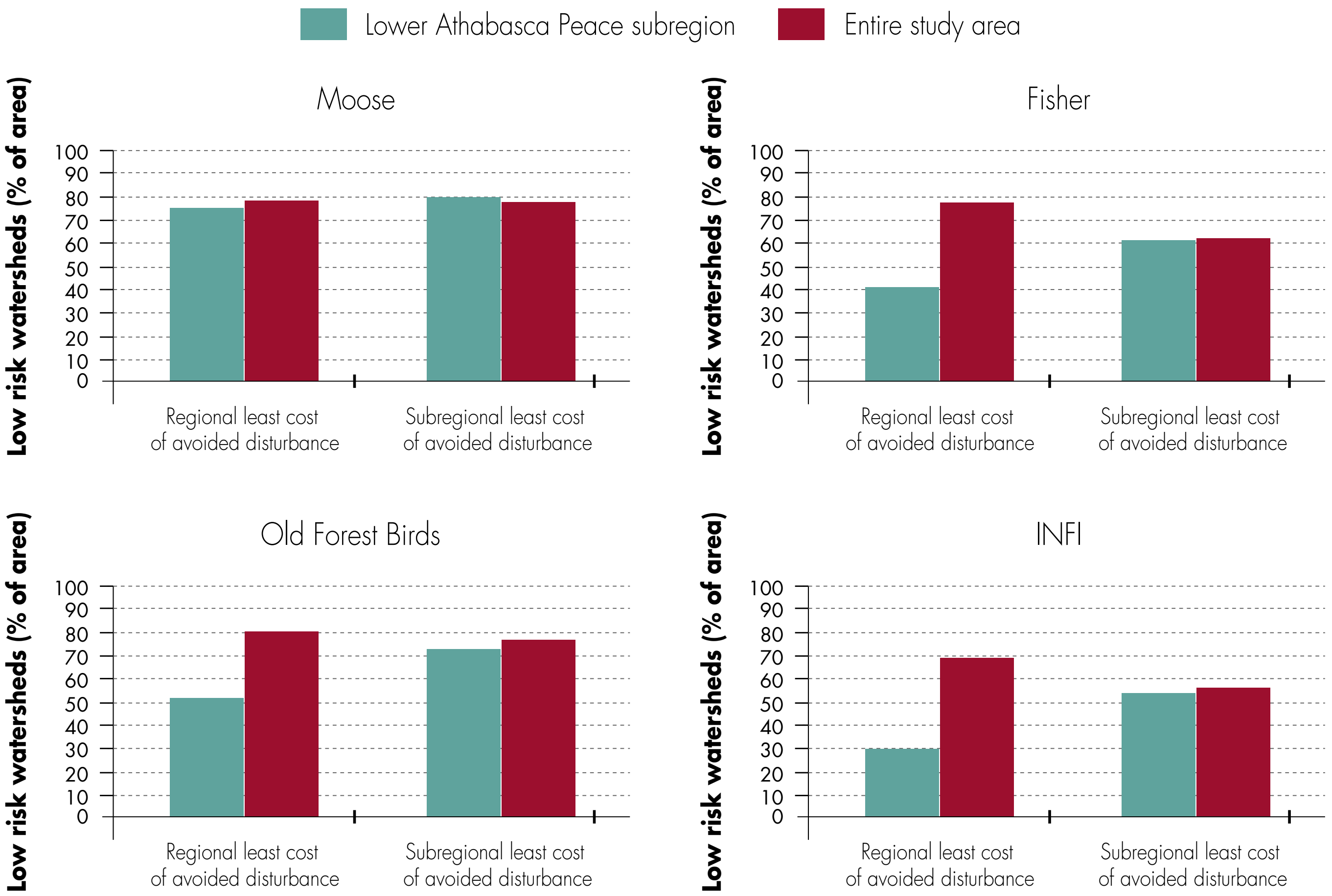

Figure A3. Proportion of watersheds with habitat characteristics that pose a low risk to moose, fisher, old forest songbirds, and fish at simulation year 50 under two scenarios that protected 20% of the study area's simulated natural resource economic potential: 1) selection of watersheds for protection based solely on their cost of avoided disturbance (blue) and 2) selection of watersheds for protection based on cost of avoided disturbance but also balanced protection across sub-regions (red). Outcomes are provided for the Lower Athabasca Peace sub-region and for the entire study area. The requirement for balanced protection across sub-regions improved conservation outcomes in the Lower Athabasca Peace sub-region, which otherwise received low protection due to the high abundance of valuable bitumen.

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