A FORK IN THE ROAD

FUTURE DEVELOPMENT IN ONTARIO'S FAR NORTH

WILDLIFE CONSERVATION SOCIETY CANADA

CANADIAN BOREAL INITIATIVE
INITIATIVE BORÉALE CANADIENNE

By Matt Carlson and Cheryl Chetkiewicz

A FORK IN THE ROAD:

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A report prepared by Matt Carlson[1] and Cheryl Chetkiewicz[2]

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ABOUT THE CANADIAN BOREAL INITIATIVE

The Canadian Boreal Initiative is a national convener for conservation in Canada's Boreal Forest. We work with conservation organizations, First Nations, industry and other interested parties – including members of the Boreal Leadership Council – to link science, policy and conservation solutions across Canada's Boreal Forest. For more information visit: www.borealcanada.ca

ABOUT WILDLIFE CONSERVATION SOCIETY CANADA

Wildlife Conservation Society Canada was established in May 2004 as a Canadian non-government organization with a mission to save wildlife and wildlands by improving our understanding of and seeking solutions to critical problems that threaten key species and large wild ecosystems throughout Canada. We implement and support comprehensive field studies, particularly in Ontario's Far North, gather information on wildlife and seek to address conservation challenges by working with First Nation communities, governments, regulatory agencies, conservation groups, and industry. For more information visit: www.wcscanada.org

ABOUT THE AUTHORS

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EXECUTIVE SUMMARY

Ontario's Far North contains some of the world's most intact sub-arctic terrestrial and aquatic ecosystems. It is a stronghold for a number of fish and wildlife species such as woodland caribou, wolverine, and lake sturgeon. The region is also the homeland of Ojibwe, Oji-Cree and Cree First Nations who have established long-standing traditional cultural values and a unique relationship with this land that they have used and occupied for thousands of years. The environment in the Far North provides important "services" to people such as climate regulation, food, cultural values, and clean and abundant water supplies. The Far North also includes a wealth of natural resources such as minerals, hydropower development potential, timber resources, and other resource development opportunities. In 2010, the Government of Ontario committed to working with First Nation communities to develop land-use plans that support conservation and development of the Far North. An important step in the planning process is assessing whether the cumulative effects of the full suite of potential future developments are compatible with the aspirations of First Nations and Ontario.

To support decision-making in this unique region, we applied a simulation model (ALCES) to explore changes in the composition of regional landscapes associated with potential future mining, hydroelectric development, and forestry activity as well as forest fires, and the implications for woodland caribou, wolverine, moose, and the intactness of watersheds.

To support decision-making in this unique region, we applied a simulation model (ALCES®) to explore changes in the composition of regional landscapes associated with potential future mining, hydroelectric development, and forestry activity as well as forest fires, and the implications for woodland caribou, wolverine, moose, and the intactness of watersheds. Our study focused on the James Bay Lowlands, which includes the large mineral reserves in the Ring of Fire, numerous kimberlite deposits, including the Victor Diamond mine, and major rivers with hydropower potential such as the Attawapiskat, Moose, and Albany. To encompass the full extent of the Pagwachuan Caribou Range, the study area extended south of the James Bay Lowland thereby also incorporating portions of five Sustainable Forest Licenses that are managed primarily for timber production.

The simulated development scenario resulted in a three-fold increase in anthropogenic footprint over 50 years, primarily due to road and transmission corridor expansion to support industrial developments. The spatial pattern of the simulated footprint differentiated between the dispersed road network associated with forestry in the south and the more isolated, but intensive, mining and hydroelectric developments in the north. The simulated forestry activity in the south had consequences for the Pagwachuan Caribou Range where the risk to herd survival approached the high category and range disturbance exceeded a threshold of 35% – a guideline in the national caribou recovery strategy. Simulated impacts to wolverine were also greatest in the south, where expansion of the road network caused habitat suitability to decline. Land use impacts to wildlife such as caribou and wolverine may be exacerbated by climate change. As an example, the moose population was simulated to increase two-fold when climate change was incorporated, which would likely cause the region's wolf population to grow with negative implications for caribou herd viability. Simulated mining and hydroelectric developments were sufficiently isolated at a regional scale to avoid large impacts to caribou and wolverine. A greater concern, however, may be the consequences of these developments to the integrity of aquatic ecosystems. The watershed impact score increased for a number of northern watersheds, demonstrating that risk to aquatic ecosystems is likely to increase in watersheds that contain important natural resource regions such as the Ring of Fire due to the presence of multiple mining and hydroelectric developments.

The outcomes of this pilot project offers important considerations when addressing cumulative effects in northern Ontario, including: the benefit to wildlife of limiting land use to isolated regions within an otherwise intact landscape; the need to improve understanding of the cumulative effects to aquatic ecosystems of multiple large-scale developments (e.g., mines, dams) within northern watersheds; and the potential for climate change to increase the sensitivity of wildlife to industrial land use. We hope these findings will inform land-use planning at both the community and regional scale and motivate additional analyses that are needed to comprehensively assess cumulative effects in Ontario's Far North.

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1. INTRODUCTION

1.1 Ontario's Far North: A Region of Vital Ecological and Cultural Importance

Ontario's Far North[3] is a 450,000 km^2 subarctic, boreal landscape of international importance due to its intactness and the immense ecological goods and services that it provides. Combined with eastern Manitoba, the region constitutes one of the largest blocks of forest in the world free from industrial development (World Resources Institute 2010). The lowland portion of the region includes the world's second largest peatland complex and North America's largest wetlands along James Bay and Hudson Bay. Three of Canada's largest rivers (Albany, Moose, Severn) flow through this region, which contains 5 of the 12 remaining undammed and unregulated watersheds in North America south of 55 degrees (Dynesius and Nillson 1994). The region's ecosystems are a stronghold for a large number of plants, fish, and wildlife, including those exhibiting population declines elsewhere in Ontario and nationally such as woodland caribou and wolverine, as well as the most southerly subpopulation of polar bears. The abundant and diverse aquatic habitats, particularly unfragmented river systems, support at least 20 species of freshwater fish, including lake sturgeon, a species of special concern under Ontario's *Endangered Species Act, 2007* (Golder Associates Ltd. 2011).

The area is of particular importance to the 24,000 people who have been settled in 34 communities in the region (Statistics Canada 2006). The population is largely indigenous, consisting of Ojibwe, Oji-Cree and Cree First Nations who have established long-standing traditional cultural values and a unique relationship with this land that they have used and occupied for at least five millennia (Berkes 2011).

Ontario's Far North ecosystems provide important social and cultural benefits to First Nations, including food, fiber, and water. Far North forests and especially peatland ecosystems contribute globally to climate regulation by storing approximately 40 billion tonnes of carbon (Far North Science Advisory Panel 2010). The hydrological and geochemical processes working in wetlands, peatlands, and forests provide habitat and clean drinking water for wildlife and people.

[3] Ontario's Far North is that part of the province north of the forestry allocation limit, at approximately 51 degrees and defined by Ontario's *Far North Act, 2010*.

These ecosystems also confer erosion control along coasts and river systems, protecting communities from storms and extreme weather. Taken together, these services have tremendous value to First Nations, Ontarians, and the world (Anielski and Wilson 2009).

1.2 The Far North's Future

Ontario's Far North contains an abundance of natural resources, including rich mineral deposits, hydropower potential, and timber. While these resources remain largely undeveloped, pressure to open the region to development is building. Development south of the Far North has generally caused ecosystem degradation, including loss of species (e.g., Schaefer 2003), degradation of aquatic ecosystems (e.g., Magurran 2009, Revenga et al. 2000), and changes in land cover. Exploitation of the Far North's natural resources could likewise impact regional ecological integrity, and the Royal Commission on the Northern Environment[4] stressed the vulnerability of First Nation communities in the region to the impacts of large-scale resource development such as forestry. In 2010, the Government of Ontario passed the *Far North Act*[5]. The objectives state that First Nations communities and Ontario's Ministry of Natural Resources (MNR) will work together to create community-based land-use plans that identify areas for future development and protection (at least 50% of the region), with the goal of securing sustainable development in the Far North and ensuring a role and benefit for First Nations.

Identifying land-use approaches that achieve the desired balance between resource use and ecological integrity requires consideration of ecosystem response to potential land-use trajectories (DeFries et al. 2004). Assessment of ecosystem response requires an understanding of the ecological effects, or response to a change to the environment, as well as the impact, or consequences of these changes (Wärnbäck and Hilding-Rydevik 2009). The need to proactively consider the consequences of land-use options was a key recommendation of the Far North Science Advisory Panel (2010)[6]. The Panel recommended that land-use planning follow the Conservation Matrix Model (Schmiegelow et al. 2006, Krawchuck et al. 2012 – see Appendix 2), whereby conservation planning is integrated with renewable and non-renewable resource use through adaptive management with attention to managing "islands" of development. Further, the Panel identified cumulative effects assessment as a necessary component of proactive land-use planning in the region.

4 In 1977, the Royal Commission on the Northern Environment was established by an Order-in-Council of the Ontario Cabinet to "inquire into any beneficial and adverse effects on the environment for the people of Ontario of any public or private enterprise north of the 50th parallel of north latitude relating to harvesting, supply and use of timber resources, mining, milling, smelting, oil and gas extraction, hydroelectric development, nuclear power development, water use, tourism and recreation, transportation, communications or pipelines." Their reports, atlas and recommendations issued in 1985 stressed the vulnerability of resident people and communities to impacts of large scale resource development, documented the physical and social environment of the region, and issued recommendations for development, particularly of forest resources.

5 http://www.e-laws.gov.on.ca/html/source/statutes/english/2010/elaws_src_s10018_e.htm

6 The Far North Science Panel was convened by the Ontario Government to obtain advice on broad-scale conservation for the Far North.

Cumulative effects are changes caused by an action in combination with other past, present, and future actions (Hegmann et al. 1999, Johnson 2011). Cumulative effects assessment requires consideration of the environmental and socio-economic consequences of current and potential future activities. Given the complexity of such an assessment, the Far North Science Advisory Panel (2010) recommended the creation of decision-support systems capable of integrating available information to assess the consequences of management options. Decision-support systems in the form of computer simulation models are well-suited for cumulative effects assessment due to their ability to integrate knowledge related to human land use and ecosystems, and track the consequences of diverse relationships operating over various spatial and temporal scales. Although contingencies and uncertainty preclude prediction of future outcomes, scenario analysis can demonstrate the benefits and liabilities of a range of management alternatives and support decision-making that is consistent with environmental and socio-economic objectives (Peterson et al. 2003).

Decision-support systems in the form of computer simulation models are well-suited for cumulative effects assessment due to their ability to integrate knowledge related to human land use and ecosystems, and track the consequences of diverse relationships operating over various spatial and temporal scales.

To contribute to the knowledge and tools available to inform land-use planning in the region, we applied a simulation model to explore the consequences of potential future land use in the James Bay Lowlands to caribou (*Rangifer tarandus*), moose (*Alces alces*), wolverine (*Gulo gulo*), and watershed intactness. By providing an integrated assessment of potential impacts of mining, forestry, and hydroelectric development, the analysis is a step towards comprehensive assessment of the consequences of land use to Ontario's Far North.

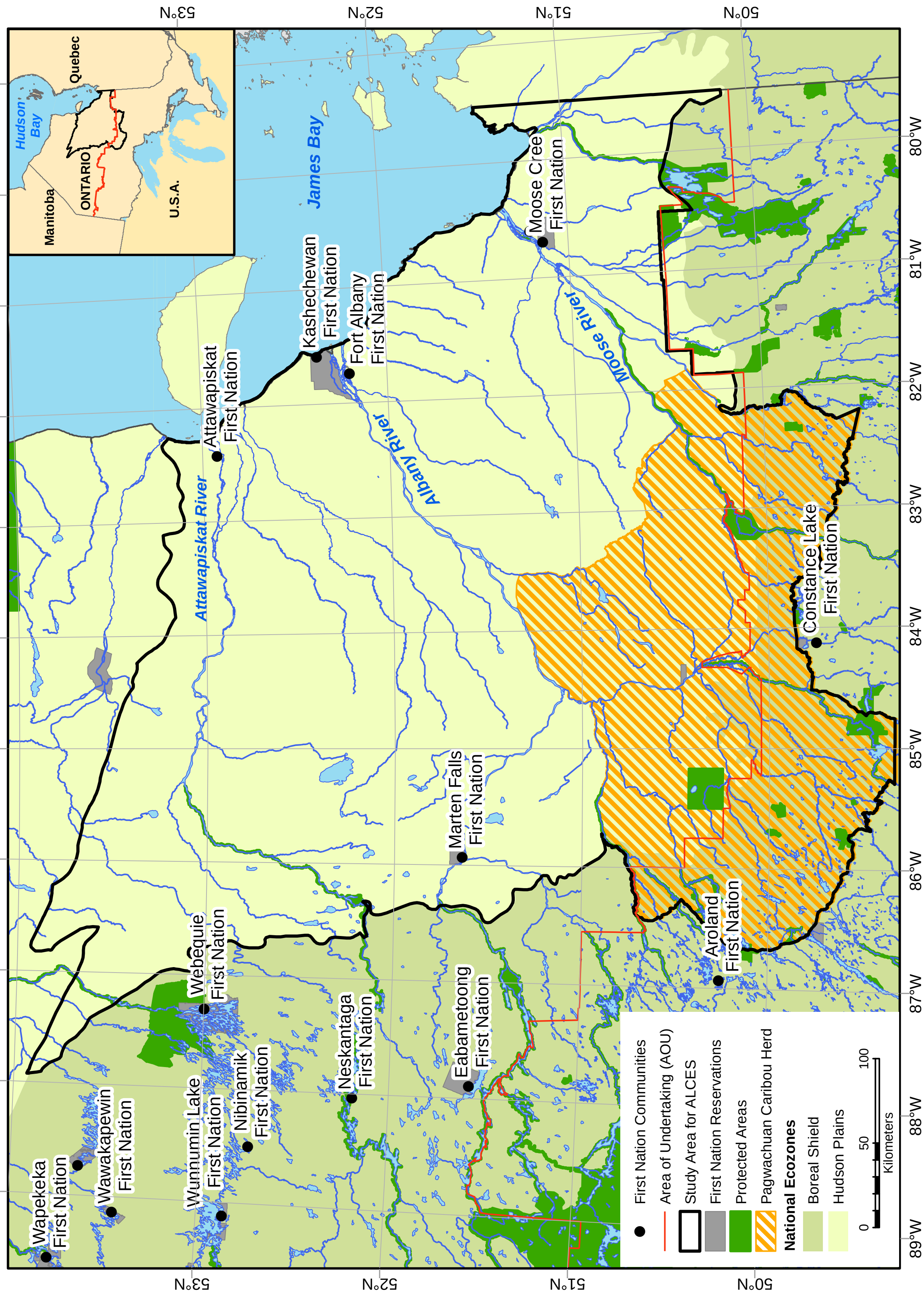
2. STUDY AREA

The pilot study area incorporates the entire James Bay Lowland ecoregion of the Hudson Plains ecozone in Ontario (Figure 1). The formerly submerged marine region (Abraham et al. 2011) is dominated by wetlands, flat terrain, and impervious soils creating a myriad of muskegs, bogs, and connecting water (Marshall and Jones 2011). The study area extends south of the James Bay Lowland ecoregion into a portion of the Lake Abitibi ecoregion, within the Boreal Shield ecozone, to include the full extent of the Pagwachuan caribou range (OMNR 2012) and permit range-level considerations of land-use impacts to caribou. The Lake Abitibi portion of the study area also extends into the area of undertaking (AOU) and includes portions of five sustainable forest licenses (SFLs). The study area covers 158,844 km^2.

The climate is cool in the James Bay Lowland with a mean annual temperature of -2°C, while the summers are short and the winters are cold. The mean summer temperature is 11.5°C and the mean winter temperature is -16°C. The ecoregion is an area of transition, lying between the coniferous and mixed forests of the clay belt to the south, and the tundra to the north. Rivers are shallow and slow-moving and tidal influences may occur 15-20 km upstream of the major rivers in the James Bay Lowland ecoregion (e.g., Attawapiskat, Albany, Moose, Kenogami). In the southern section and along rivers, the forests are composed of balsam fir (*Abies balsamea*), white spruce (*Picea glauca*) and black spruce (*Picea mariana*), trembling aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera)*. Most of the ecoregion is dominated by peatlands and wetlands, while the dominant vegetation consists of sedge, mosses, and lichens with or without stunted black spruce and tamarack (*Larix laricina*).

The study area contains valuable natural resources, including the Ring of Fire mineral deposits and large rivers with hydropower potential, making it likely that the largely intact region will experience increased development in the coming decades. Development in the study area is currently limited to the Victor Diamond Mine located west of Attawapiskat, four hydroelectric dams located along the Mattagami River, and timber harvest within SFLs in the south.

Figure 1. The ALCES pilot project study area in northern Ontario.



3. METHODS

The project applied A Landscape Cumulative Effects Simulator (ALCES) to assess the long-term (i.e., 50 year) effects of land use in the region. ALCES and its companion mapping tool (ALCES Mapper) provide strategic land-use planning guidance by examining inter-relationships among the full range of relevant land-use sectors and natural disturbances, and exploring consequences at large temporal and spatial scales. ALCES has been extensively applied to assess cumulative effects in western Canada (Browne and Carlson 2012, Carlson et al. 2011, Gunn et al. 2011, Schneider et al. 2010, Carlson et al. 2009, Jordann et al. 2009, Schneider et al. 2003) as well as other regions (e.g., Carlson et al. 2011). An overview of ALCES and ALCES Mapper is provided in Appendix 1.

Parameterization of ALCES required the integration of available information to: a) assess the existing composition of the regional landscape; b) define assumptions for natural disturbance; c) define development trajectories and associated anthropogenic footprints for the major land-use sectors; and, d) establish coefficients that relate indicator status to simulated landscape composition and resource production.

3.1 Landscape Composition

The current composition of the landscape was derived from a variety of land cover and anthropogenic footprint inventories.

3.1.1 Land Cover

The Earth Observation for Sustainable Development (EOSD) land cover inventory was used to estimate current land cover composition, with the exception of the 16,464 km^2 of productive forest located within the SFLs. Forest Resource Inventories (FRIs) were the preferred source of land cover information for productive forest because the inventories include age information, identify areas available for timber harvest, and are current (2007 to 2011, depending on the SFL[7]). The EOSD dataset has a resolution of 25 m, was current to the year 2000, and does not provide an estimate of age because classification was derived from Landsat images. Time since disturbance (i.e., age) was added to the land cover data using a map of forest stand age created by Chen et al. (2003) from the Canadian

[7] FRI data were current to 2007 for the Big Pic and Hearst SFLs, to 2010 for the Gordon Cosens SFL, and to 2011 for Kenogami and Nagagami SFLs. The inventories were not updated to 2010 using fire data because disturbance in the SFLs is dominated by timber harvest.

Forest Inventory, fire polygon data, and other remote sensing. The forest stand age map has a resolution of 1 km^2 and was current to 1998. The forest stand age map was updated to 2010 by increasing forest age by 12 years, with the exception of areas that burned between 1998 and 2010 according to provincial disturbance map data[8]. The age of burned areas equaled the number of years since the disturbance occurred.

The FRI and EOSD inventories were used to create a single land cover data set by adopting the reclassification rules described in Table 1. The land cover types were identified to promote consistency across the two inventories while also providing sufficient detail for wildlife indicator models. Separate land cover types were created for forest that was available for timber harvest to ensure that forestry activity was properly constrained spatially during the simulation. To integrate with the forestry assumptions (e.g., growth and yield), merchantable forest type was based on provincial forest types: mixed conifer upland (MCU); mixed conifer lowland (MCL), mixedwood (MIX), and intolerant hardwood. For non-merchantable forest, it was not possible to distinguish between lowland and upland conifer due to limitations of the EOSD inventory. Water bodies (i.e., lakes and rivers) were defined using the CanVec waterbody polygon dataset.

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3.1.2 Human Footprint

The abundance and location of footprint types was derived from a variety of footprint inventories through a data agreement between WCS Canada and OMNR (Table 2, Figure 2). Many of the footprint inventories were limited to line or point data and assumptions were made for footprint width. The widths of linear footprints were 40 m for major roads, 24 m for minor roads, 20 m for rail, and 40 m for transmission corridors based on assumptions used in previous ALCES analyses (e.g., ALCES Group 2011). Reported areas[9] were used to create reservoir polygons for the Smoky Falls, Harmon, and Kipling dams. Reservoir area was not available for the Highwood Rapids dam, but it was assumed to have a very small footprint (1 ha) given that the dam is run-of-river.

8 Provincial Satellite Derived Disturbance Mapping Data released in 2011.

9 http://www.moosecreeresourceprotection.org/existingdam.html

Table 1. Cover types used when parameterizing the ALCES simulation model, and associated FRI and EOSD cover types (see Appendix for cover type codes).

ALCES cover type	FRI cover type	EOSD cover type	Area (km²)
Merchantable deciduous forest	Forest belonging to provincial forest types BWT and POP and identified as available (i.e., for harvest)		1,448
Merchantable lowland coniferous forest	Forest belonging to provincial forest type MCL and identified as available		8,995
Merchantable upland coniferous forest	Forest belonging to provincial forest types MCU, PJK, and PWR and identified as available		4,209
Merchantable mixedwood forest	Forest belonging to provincial forest type MIX and identified as available		1,812
Non-merchantable deciduous forest	Forest belonging to provincial forest types BWT and POP and identified as unavailable	Deciduous Forest and Broadleaf Dense/Open/Sparse	603
Non-merchantable coniferous forest	Forest belonging to provincial forest types MCL, MCU, PJK, and PWR and identified as unavailable	Coniferous Forest/Dense/Open/Sparse	19,822
Non-merchantable mixedwood forest	Forest belonging to provincial forest type MIX and identified as unavailable	Mixedwood Forest/Dense/Open/Sparse	15,023
Treed peatland	Polytype TMS	Wetland, Wetland – Treed	60,012
Shrub peatland		Wetland – Shrub	35,340
Herbaceous peatland	Polytype OMS	Wetland – Herb	491
Shrubs	Polytype BSH	Shrubland, Shrub tall/low, prostrate dwarf shrub	883
Herbaceous/Barren	Polytype OMS, GRS, DAL, RCK	Herb, Tussock graminoid tundra, Wet sedge, Graminoid tundra (various types), Grassland, Bryoid, Barren/Non-vegetated, Snow/Ice, Rock/Rubble, Exposed land, Sparsely vegetated bedrock/till-colluvium, Bare soil	1,579
Water	Classified using the CanVec hydrology data set		8,340

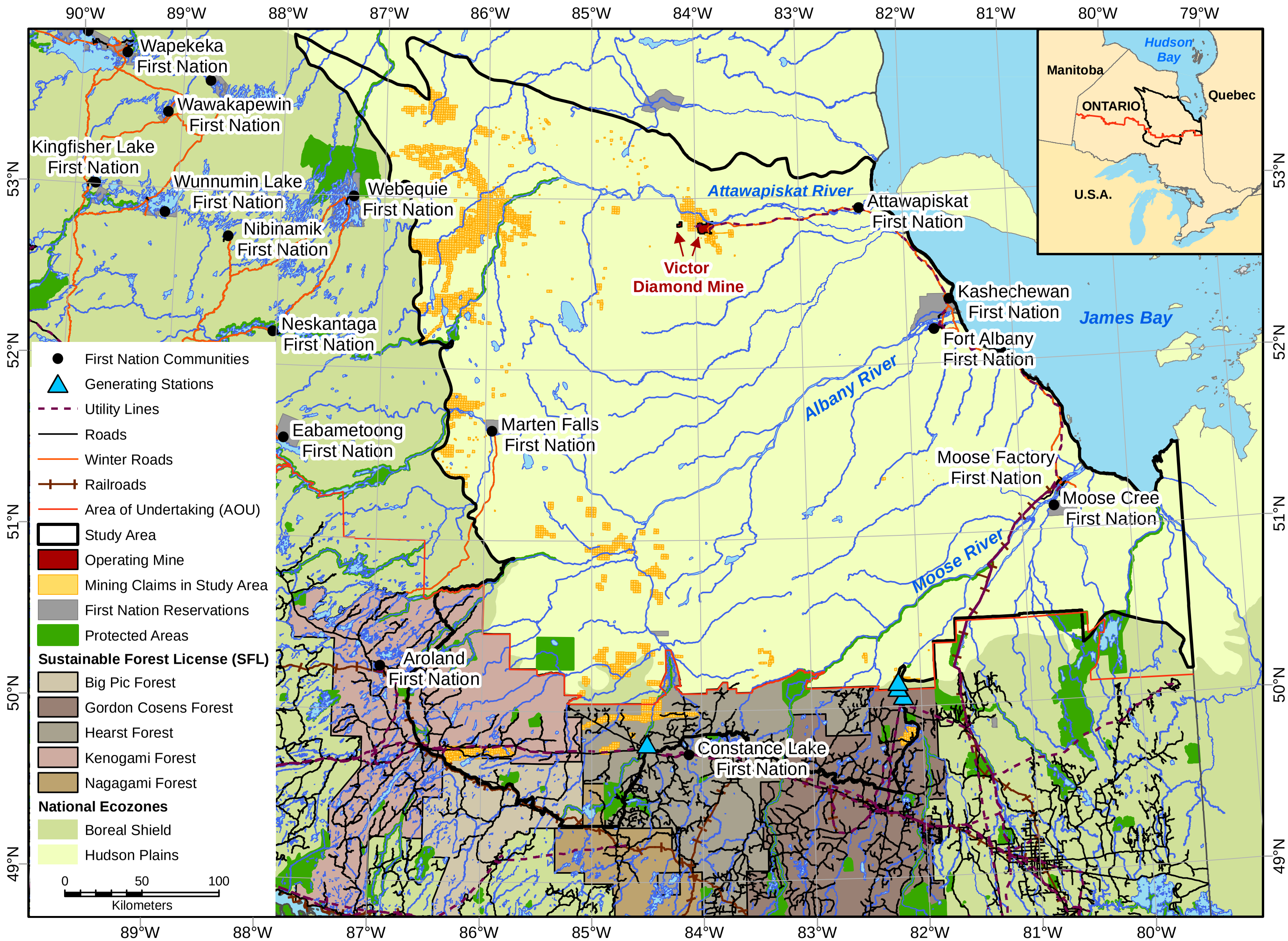
Table 2. Proposed footprint types and data sources for the scenario analysis.

Footprint type	Data source	Area (km²)
Major road	Ontario Road Network MNR class A	6.87
Minor road	Ontario Road Network MNR classes B, C, D	60.27
Rail	MNR Railroad dataset	6.18
Transmission corridor	MNR Utility Line dataset	23.59
Diamond mine	Ontario Ministry of Northern Development and Mines	15.32
Hydroelectric dams and reservoirs	MNR Waterpower Generation Station and Potential Hydrosite data sets[10]	5.43
Gravel pits	MNR Aggregate Site Authorized data set[11]	2.56
Settlements (i.e., First Nation reservations)	Digitized from aerial imagery	20.88

[10] The MNR generation station data was point data. The area of reservoirs was from http://www.moosecreeresourceprotection.org/existingdam.html. Reservoir area was not available for the Highwood Rapids dam. The dam is run of the river, and was therefore assumed to have a very small footprint (1 ha).

[11] The MNR aggregate data was point data. Area of aggregate sites was estimated from the polygonal CanVec aggregate dataset. OMNR aggregate sites that did not overlap with a CanVec aggregate site polygon were given the average age of aggregate site polygons in the study area.

Figure 2. Current land uses in the study area.



3.2 Ecological Processes

3.2.1 Succession

Simulation of timber harvest required that growth and yield curves be defined for merchantable forest types. Growth and yield curves were based on those used by Hearst Forest Management Inc. (2007a) in their strategic forest management model. Curves for the dominant forest unit belonging to each of the mixed conifer upland, mixed conifer lowland, mixedwood, and hardwood forest types in the SFL were used (Table 3). Distribution of available land belonging to each provincial forest type across forest units in the Hearst Forest is listed below (Hearst Forest Management Inc. 2007b). The forest unit whose growth and yield curve was used for each provincial forest type is identified in italics.

- Mixed conifer upland: *spruce pine* (75%); spruce fir (16%); and jack pine (9%)
- Mixed conifer lowland: *spruce 1* (59%); spruce site class 3 (31%); and lowland conifer (11%)
- Mixedwood: *mixedwood 2* (93%); and mixedwood 1 (7%).
- Intolerant hardwood: *poplar 1* (73%); and poplar 3 (27%)

Based on Hearst Forest Management Inc. (2007a), forest reaching the final age class remained in that age class until disturbed by harvest or fire.

3.2.2 Fire

Fire was simulated at rates assumed by Tembec (2008) for the Gordon Cosens Forest (Table 4). The natural fire rate assumed by Tembec (2008) is consistent with a fire return interval estimate of 263 years for a large landscape (Moose River Forest Management Unit (FMU)) located in the James Bay Lowland ecoregion, north of the allocation limit (Ter-Mikaelian et al. 2009)[14]. In contrast, pre-suppression fire rates assumed for the Hearst Forest (Hearst Forest Management Inc. 2007a), based on fire rates from the more southerly Lake Abitibi Model Forest, are substantially higher than Ter-Mikaelian et al. (2009) and were not used here. Fire suppression was applied to forests in the AOU. Suppression is assumed, by Tembec (2008), to extend the fire cycle to over seven thousand years for all forest types. As such, fire is assumed to be negligible in the managed portion of the landscape; i.e., timber harvest was the only disturbance type affecting merchantable forest within SFLs during the simulation. Suppression was not incorporated for areas north of the SFL's because fire rates north of the allocation limit do not appear to be affected by suppression (Ter-Mikaelian et al. 2009).

[14] One million ha of the 1.9 million ha Moose River FMU is non-forest, and assumed to be peatland (i.e., bog). The composition of the 0.9 million ha of forest is estimated to be 85% lowland black spruce, 14% upland mixed conifer, and 1% poplar-, white birch-, or jack pine-dominated forest. Applying fire return intervals from Table 4 to this landscape composition results in an average fire return interval of 248 years.

Table 3. Softwood (SW) and hardwood (HW) growth and yield curves for each forest type. Softwood includes pine, spruce, and fir volume. Hardwood includes poplar volume. Growth and yield curves are those associated with the pre-harvest forest[12].

Age class (years)	Conifer upland (m^3/ha)		Conifer lowland (m^3/ha)		Mixedwood (m^3/ha)		Intolerant hardwood (m^3/ha)	
	SW	HW	SW	HW	SW	HW	SW	HW
0-20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21-40	10.0	7.0	0.0	0.0	0.5	20.5	0.5	39.0
41-60	56.0	15.0	3.0	0.0	2.5	53.0	1.5	102.5
61-80	98.8	21.0	33.4	1.0	18.5	74.5	8.5	143.0
81-100	132.0	23.5	75.8	2.0	37.5	82.0	17.5	155.0
101-120	152.4	21.0	106.9	2.0	52.4	73.0	22.0	136.0
121-140	153.5	5.5	116.6	2.0	58.0	19.5	20.0	35.0
141-160	129.8	0.0	102.6	2.0	59.3	19.5	18.5	35.0
161-180	99.6	0.0	89.0	2.0	60.4	19.5	16.5	35.0
>180	74.4	0.0	78.5	2.0	58.7	19.5[13]	15.5	35.0[13]

Table 4. Fire return intervals, based on average rates across relevant forest units from Tembec (2008).

Cover type	Pre-suppression fire cycle in years (and associated annual burn rate)	Post-suppression fire cycle in years (and associated annual burn rate)
Upland conifer	128 (0.0078125)	7,192 (0.000139)
Lowland conifer, coniferous	203 (0.0049261)	7,192 (0.000139)
Mixedwood	134 (0.0074627)	7,192 (0.000139)
Hardwood	115 (0.0086957)	7,192 (0.000139)
Bog, shrub, herbaceous	300 (0.0033333)	7,192 (0.000139)

[12] Multiple sets of growth and yield curves (i.e., for a range of silvicultural intensities) were not used to avoid unnecessary complexity. The 50-year simulation period combined with the large area of pre-harvest forest remaining in the SFLs implies that most if not all of the simulated harvest will be first-rotation, such that variation in post-harvest growth and yield (i.e., with silvicultural treatment) would not affect simulation outcomes.

[13] The deciduous volume associated with older than 180 year mixedwood and hardwood forest types was increased from 0 to that of the 161-180 age-class to avoid old forest being excluded from harvest.

3.3 Land Use

3.3.1 Hydroelectric Sector

The hydroelectric scenario was informed by the Integrated Power System Plan (IPSP), the Ontario Power Authority's long-term (2005-2025 year) electricity plan, as well as Ontario's *Long Term Energy Plan* (Ministry of Energy 2010). The IPSP calls for increasing the province's hydroelectric generation capacity by 2,900 MW. The majority (2,500 MW) of the increase in capacity is planned for northeastern Ontario, with a smaller (300 MW) increase planned for the northwest (OPA 2007).

OPA (2007) identifies the location and approximate in-service dates for new hydroelectric generation sites that could collectively achieve the goal of increasing generation capacity by 2,900 MW. Included in the list are ten new hydroelectric projects in the study area with a total capacity of 1,585 MW (Table 5).

Table 5. Planned hydroelectric sites in the study area for the period of 2010 to 2025.
Source: OPA 2007: tables 27, 28, 31.

River	Site	Capacity (MW)	In-Service
Mattagami River	Grand Rapids	174	2016
Opasatika River	Opasatika Rapids	3	2017
Opasatika River	Breakneck Falls	4	2017
Opasatika River	Christopher Rapids	7	2017
Abitibi River	Sand Rapids	131	2019
Albany River	Hat Island	490	2020
Abitibi River	Blacksmith Rapids	140	2021
Abitibi River	Allen Rapids	131	2022
Albany River	Chard	370	2022
Moose River	Renison	135	2025

These planned hydroelectric projects were the basis for the first 15 years (i.e., 2011-2025) of the hydroelectric scenario (Figure 3). The assumed rate of hydroelectric development in northern Ontario from 2026-2061 approximated the rate projected for the region from 2005-2025 by the IPSP (average rate of increase of 140 MW/year[15]). Applied to the period of 2026-2061, this rate creates increased capacity of 4,900 MW. Of this, 1,250 MW are likely to come from the developments along the Nelson River in northeastern Manitoba, and an additional 800 MW may come from developments in north-western Ontario (Appendix 2 from OPA 2006). As such, a plausible projection for the increase in capacity from northeastern Ontario during the 2026-2061 period is 2850 MW. OPA (2005) identifies

15 The IPSP projects hydroelectric developments in northern Ontario will add 2800 MW of capacity between 2005 and 2025, resulting in an average rate of increase of 140 MW/year.

seven potential (as opposed to planned) hydroelectric sites within the study area with a collective capacity of 1762 MW (Table 6), which is within the 2,850 MW projection described previously. These sites were used to define the hydroelectric development trajectory during the 2026-2061 period (Figure 3). Simulated development initially focused on rivers that were partially developed during the 2010-2025 period (Albany River, Moose River), followed by a site on the Attawapiskat River.

Table 6. **Potential hydroelectric sites in the study area, to be developed between 2026 and 2061 in the scenario analysis. The constraints refer to policies including First Nation Agreements (A) (e.g., Northern Rivers Commitment[16] and Moose River Basin Commitment) and protected areas (P) that would need to be considered prior to development.**
Source: OPA 2005, Appendix 1.

River	Site	Potential (MW)	Connection Distance (km)	Constraint
Albany River	Buffaloskin	76	>25	A
Albany River	Wabimeig Creek	185	>25	A
Albany River	Stooping	285	>25	A
Albany River	Biglow	480	>25	A
Albany River	Blackbear Island	490	>25	A
Moose River	Grey Goose	140.4	5-25	P, A
Attawapiskat	Streatfield IV	105.76	>25	A

Reservoirs associated with dams having a capacity greater than 25 MW were simulated to be 274 ha, which is the average size of the three reservoirs that currently exist within the study area (Smoky Falls, Harmon, and Kipling). Reservoirs less than 25 MW were assumed to be run-of-river[17], and therefore associated with small reservoirs (1 ha). Transmission lines and roads were created to link all dams to the transmission network. Transmission capacity is the largest impediment to developing hydroelectric sites in northern Ontario (OPA 2006). The IPSP (OPA 2006) identifies new transmission corridors that will be needed to transport electricity from the proposed hydroelectric sites to market. These corridors were used to define the rate and location of transmission corridor growth for the first 15 years of the hydroelectric scenario (Figure 4). Transmission corridors were 40 m in width (Hearst Forest Management Inc. 2007a, Table 1). A 500 kV line already exists to transmit power from existing hydroelectric developments in the Moose River Basin to Sudbury. The planned hydroelectric developments in the basin will require construction of a second 500 kV line spanning 550 km between Sudbury and the Moose River Basin. The line is planned for 2016-2019. It was assumed that the simulated dam along the Attawapiskat would also tie in to this line. Development of up to

16 This commitment sets out that there will be no development greater than 25 MW in the basins of the Albany, Attawapiskat and Winisk Rivers; development less that 25 MW can proceed if it is proposed by the local indigenous community or communities and/or their partner(s). This commitment was made by a Minister of the Crown in response to community concerns about the potential for extensive flooding associated with hydroelectric development. In the interest of treating all the northern rivers in a consistent manner, the Severn River was added to this commitment at the time the Waterpower Site Release and Development Review policy was approved in 2004.

17 Small hydroelectric facilities, which are typically run-of-river, are generally classified as having a maximum capacity of 10 MW but can refer to projects with a capacity of between 20 and 25 MW in Canada (http://www.pembina.org/re/sources/hydro-power).

Figure 3. Current, planned, and potential hydroelectric sites used in scenario development.

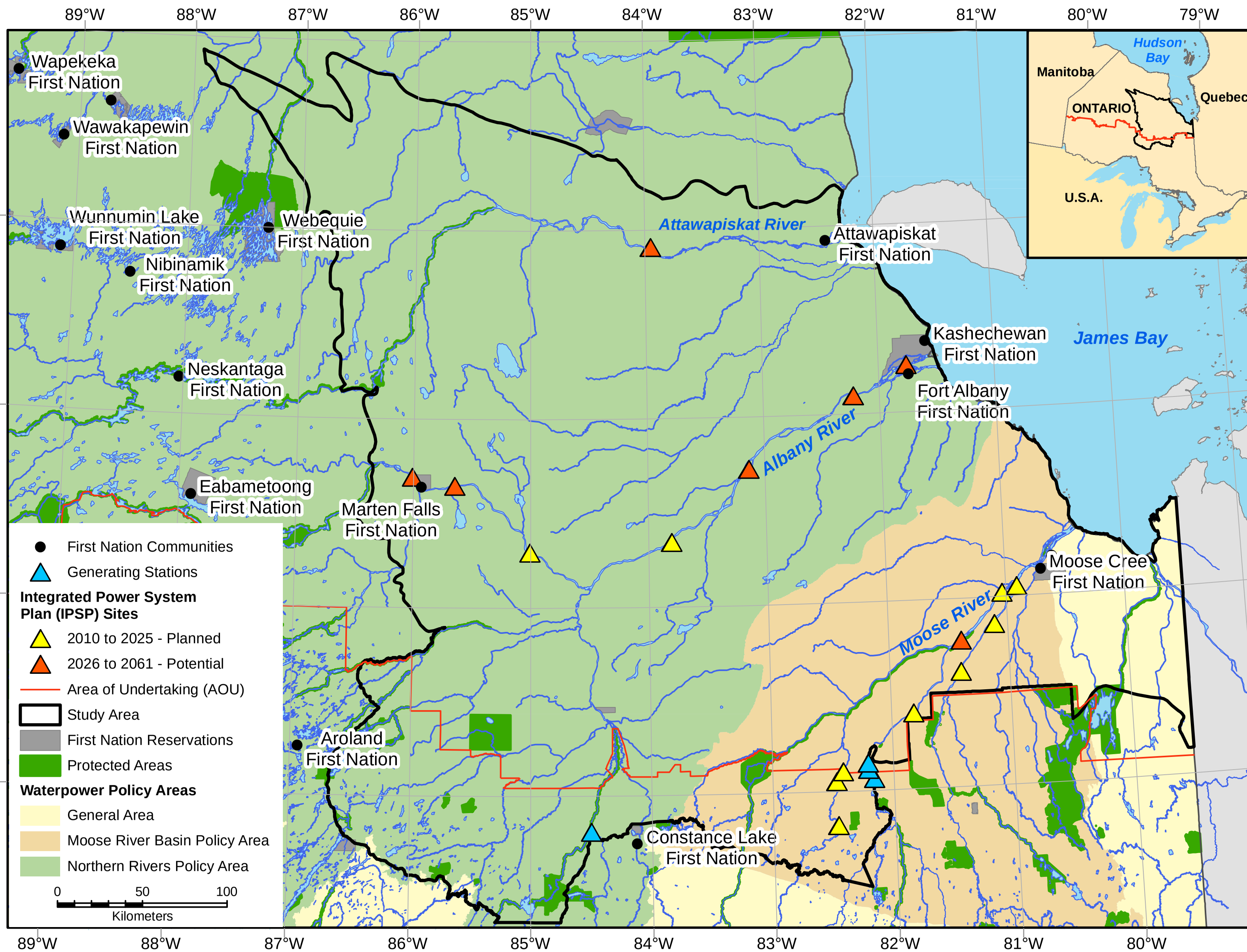
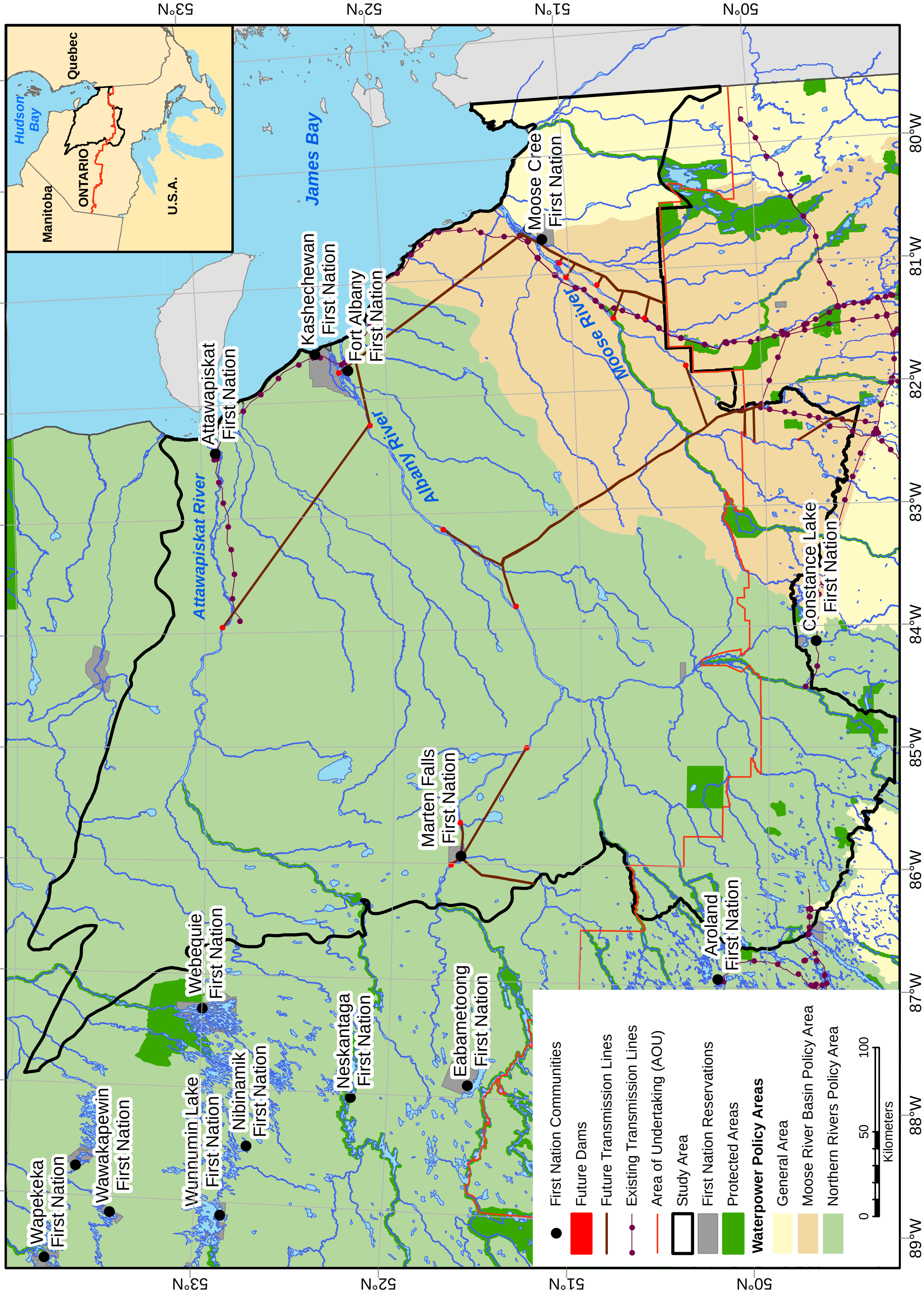


Figure 4. Future dams and transmission lines used in scenario development.



2,000 MW of hydropower potential in the Albany River Basin will require construction of a High Voltage Direct Current (HVDC) line either to Sudbury (650 km) or the Greater Toronto Area (1,075 km); it was assumed to link to Sudbury in the simulation. The line is planned for post-2020. The simulation included an additional line in the west to tie in three simulated dams located along the Albany River that are likely too distant to tie in to the Sudbury line; the line could continue southwest beyond the study area boundary to link with existing or proposed transmission lines, such as the NW transmission line for the proposed Little Jackfish River hydroelectric development[18].

3.3.2 Mining Sector

Mining activity in the study area includes: an active diamond mine (Victor Diamond Mine) and its recently announced expansion[19]; advanced exploration of kimberlite deposits[20]; and exploration of chromite, diamond, copper and nickel deposits in the Ring of Fire where two proposed mines are undergoing environmental assessment by the federal and provincial governments (Figure 5). The Victor Diamond Mine began commercial production in 2008 and is expected to have an active lifespan of 12 years with an average production rate of 2.5 million tonnes/year (Government of Canada 2005). The Victor Diamond Mine is located at one of 16 known kimberlite pipes in the region that contain diamonds[21]. In addition, De Beers Canada Incorporated is proposing the construction, operation and decommissioning of a second pit and additional ancillary components, approximately 6.5 km northwest of the existing Victor Diamond Mine with an expected production capacity of just over 9,000 tonnes per day and a mine life of roughly seven years. As a basecase assumption, we assumed that new mines will be brought online such that there will always be one diamond mine in operation with a lifespan equivalent to that of Victor (12 years). Ten potential mine sites were identified for the scenario, five in the Ring of Fire region and five in the vicinity of the Victor Mine (Dickason 2009). During the simulation, the ten potential mine sites were sequenced randomly to "develop" five kimberlite mines in our scenario. The location of the Ring of Fire mine sites were based on Dickson (2009), whereas the location of additional mine sites near Victor was based on commodity claims (according to the Ministry of Northern Development and Mines' (MNDM) Mineral Deposit Inventory (MDI) (2013)[22] and Mining Claims (2012)[23] databases) (Figure 6).

18 http://www.hydroone.com/Projects/Northwest/Pages/Default.aspx
19 http://news.gc.ca/web/article-eng.do?nid=747149
20 http://www.metalexventures.com/2012-01-20.pdf
21 http://www.metalexventures.com/html/attawapiskat.html
22 http://www.geologyontario.mndmf.gov.on.ca/mndmaccess/mndm_dir.asp?type=pub&id=mdi
23 http://www.mndm.gov.on.ca/en/mines-and-minerals/applications/claimaps

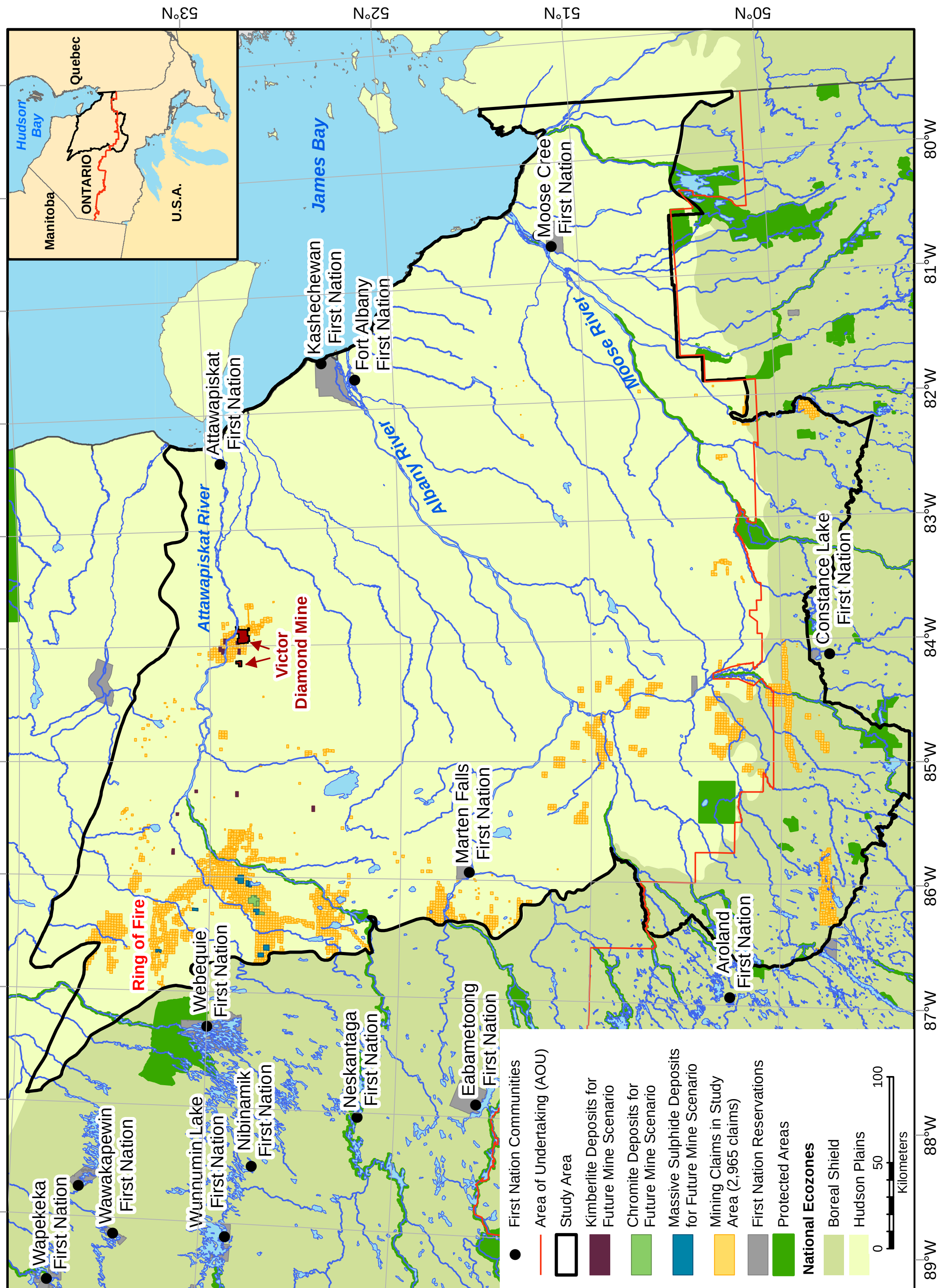
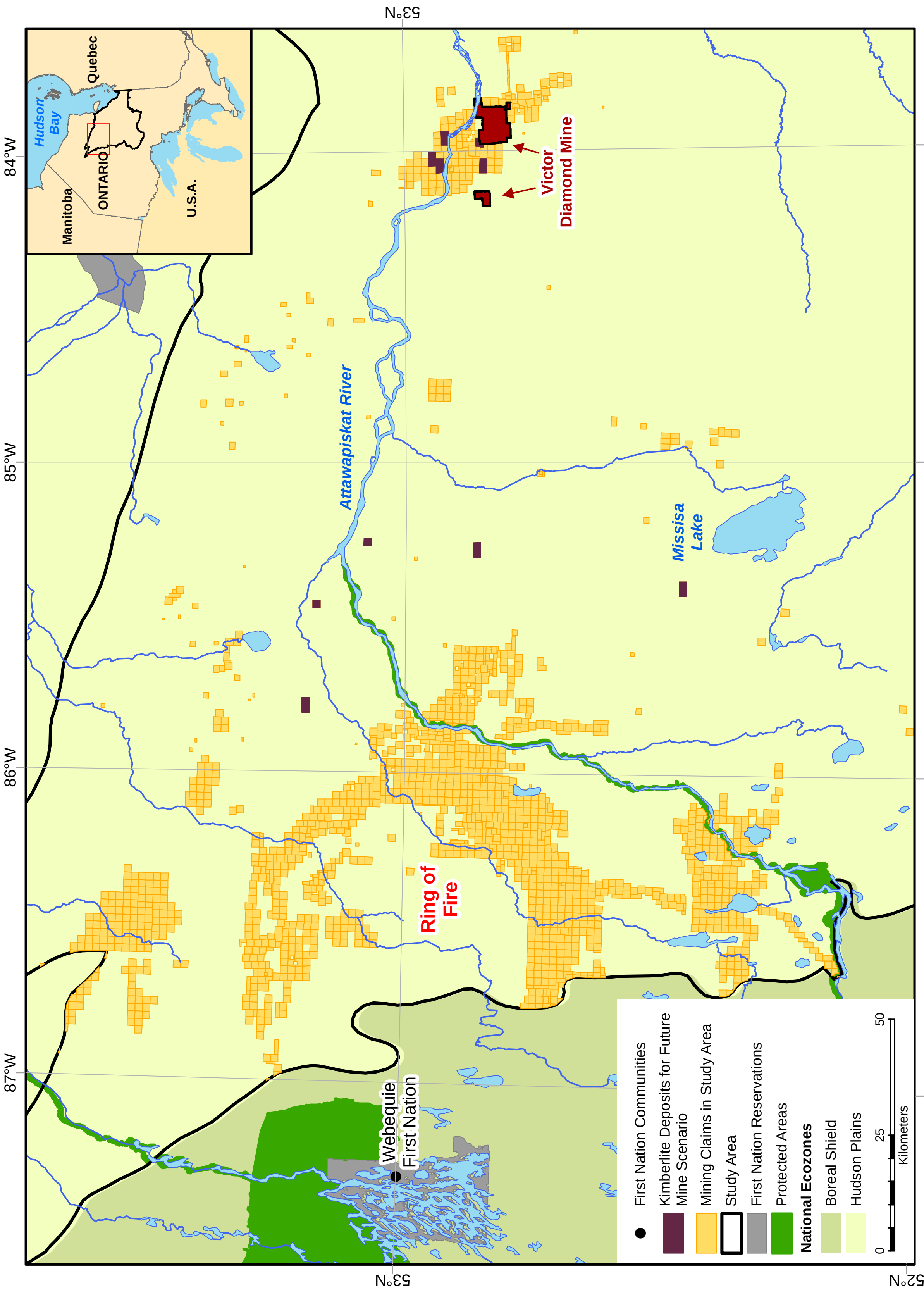


Figure 5. Active mines, mineral occurrences, and mining claims in the study area.

Figure 6. Kimberlite deposits used in the scenario.



The Ring of Fire is thought to contain one of the largest chromite deposits in the world, as well as significant deposits of nickel, copper, and platinum. The two largest chromite deposits discovered to date are Black Thor (69.5 Mt; Cliffs Natural Resources Inc. 2011) and Big Daddy (39 Mt; KWG Resources Inc. 2011). Production from Black Thor is expected to begin in 2015 and last approximately 30 years (Cliffs Natural Resources Inc. 2011). The mine and an onsite ore processing facility is expected to produce approximately 2 million tonnes of ore and concentrate per year[24]. We assumed that production at the Big Daddy mine will commence upon closure of the Black Thor mine, and that production will continue at 2 million tonnes per year, resulting in a lifespan of approximately 20 years. We assumed a third chromite deposit in the Ring of Fire will be developed upon closure of the Big Daddy mine (Figure 7).

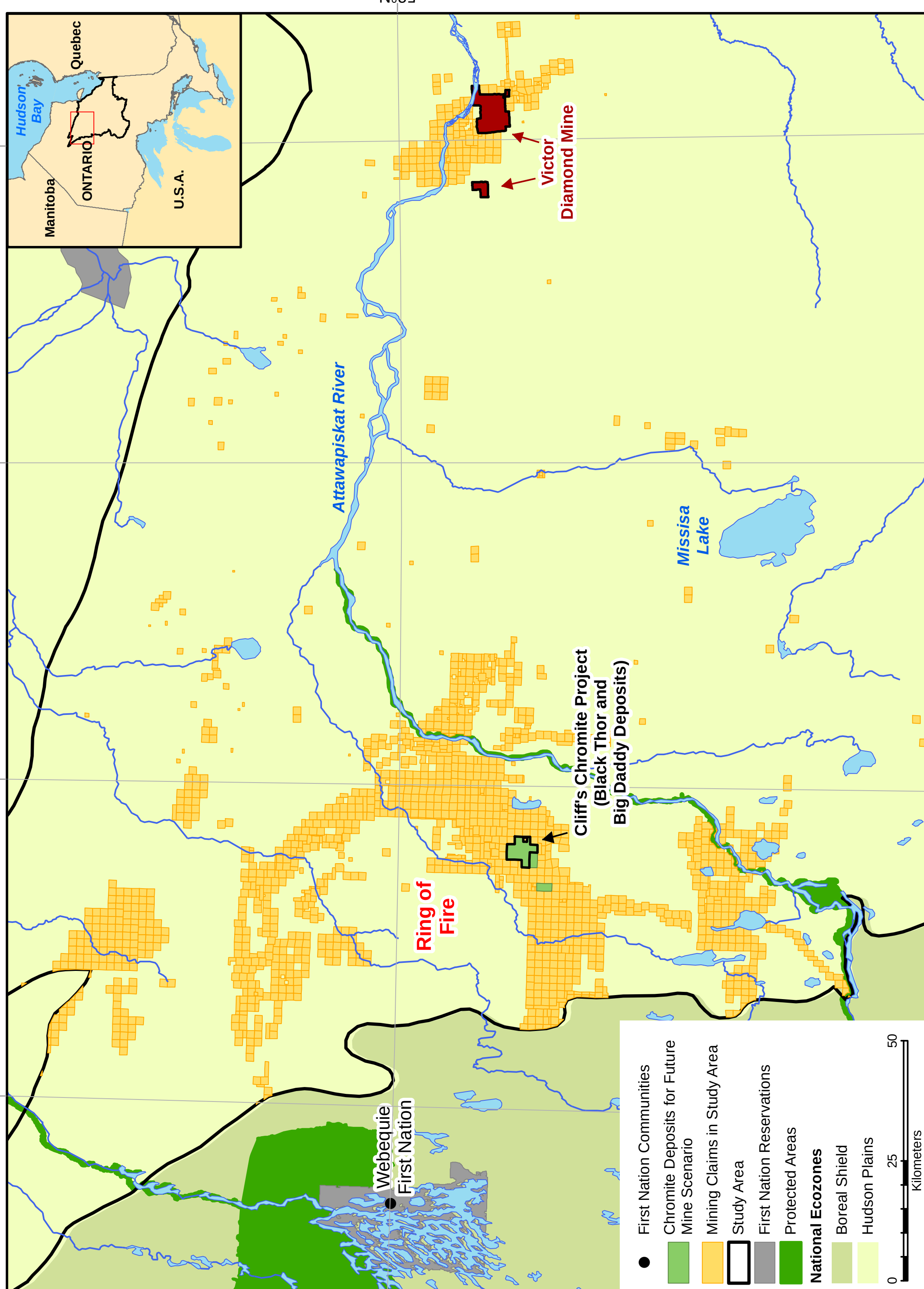
The assumption that mine development will proceed sequentially and that production will not exceed 2 million tonnes per year may be conservative, given that a railway line has been proposed to transport ore from the Ring of Fire to Nakina. However, information on start-up dates is only available for the Black Thor mine (2015; Cliffs Natural Resources Inc. 2011), and some think that the Big Daddy deposit may sit idle for decades if Black Thor is developed first (Tollinsky 2010). The viability of these projects depends primarily on providing all-weather access to deposits from processing facilities and national and international markets. The general consensus on mineral exploration and mine development in the Ring of Fire is that the creation of all-weather infrastructure, such as roads and transmission corridors, will open up previously inaccessible regions to more development beyond the two mines currently identified in our scenario. It is highly likely that the development of all-weather infrastructure will precipitate further mineral exploration and development in the region, increasing the risk of cumulative effects. Well-planned and managed infrastructure is considered a critical component of environmental planning (e.g., land use, environmental assessment) for the Far North (Far North Science Advisory Panel 2010[25]).

The scenario also included nickel/copper mining in the Ring of Fire. Based on discoveries at their Eagle's Nest deposits, Noront Resources plans to finish construction of a mine by 2015 (Knight Piesold 2011). The nickel/copper mining trajectory was based on the Eagle's Nest project description, which predicts production of 11 million tonnes over 11 years (Knight Piesold 2011). Numerous additional massive sulphide discoveries exist within the Ring of

[24] Cliffs Natural Resources Inc. (2011) expects that ore and concentrate production will be 3,600 to 7,200 tonnes per day. Using the average production rate from this range (5,400 tonne per day) and a 365-day year results in an annual production rate of 1,971,000 tonnes.

[25] The Far North Science Advisory Panel Report suggested that the most important issue is the cascading and incremental effects of roads. Once a road is built, to serve a single purpose or development project, it opens up the potential for further development, and creates pressure to build more road networks and power transmission lines.

Figure 7. Chromite deposits used in the scenario.



Fire, and it was assumed that one nickel/copper mine equal in size to Eagle's Nest was always in production during the simulation (Figure 8). This assumption may be conservative given the number of discoveries in the region and the intensity of ongoing exploration. For example, the CEO of one mining company that is active in the region expects 50 mines to be found in the region (Tollinsky 2010). Eight additional potential nickel/copper mines were located based on massive sulphide discoveries (Dickson 2009) and commodity claims (referenced with MDI and Mining Claims (2012) databases). The sequencing of the deposits for development, following Eagle's Nest, was random.

The size of a mine's footprint was based on the claim footprints and description of mine sites in project descriptions associated with environmental assessment documentation, cross-referenced with the MDI and mining claims datasets managed by MNDM. Transmission lines, roads, and a railway were created to link to mines, energy sources, and the provincial transportation network.

The size of a mine's footprint was based on the claim footprints and description of mine sites in project descriptions associated with environmental assessment documentation, cross-referenced with the MDI and mining claims datasets managed by MNDM. Transmission lines, roads, and a railway were created to link to mines, energy sources, and the provincial transportation network. A single transportation corridor linking the Ring of Fire to southern infrastructure was based on the proposed north-south transportation corridor to the Big Daddy mine[26]. The corridor was simulated as being 100 m wide, as per the environmental assessment, and was assumed to include both a road and transmission line. A railway parallel to the transportation corridor was also simulated. Potential future diamond mines in the eastern portion of the study area were assumed to be serviced by the existing transmission line and road linking the Victor Diamond Mine to Attawapiskat and then south along the winter roads used by First Nation communities along the James Bay coast. Roads and transmission lines linking potential future mines to infrastructure were based on shortest distance (i.e., straight line), such that the footprint estimate was conservative. The width of simulated roads, transmission lines, and railways were 24 m, 40 m, and 20 m, respectively, based on assumptions used in previous ALCES analyses (e.g., ALCES Group 2011).

3.3.3 Forestry Sector

The study area overlaps with portions of five SFLs: Kenogami Forest, Hearst Forest, Gordon Cosens Forest, Big Pic Forest, and Nagagami Forest (Figure 9). The simulated timber harvest rate was based on annual allowable cuts (AACs) of the SFLs. The AAC's were adjusted based on the proportion of each SFL's productive forest area occurring within the study area (Table 7).

[26] http://www.cliffsnaturalresources.com/EN/aboutus/GlobalOperations/chromite/Pages/StakeholderEngagement.aspx

Figure 8. Massive sulphide deposits (e.g., nickel/copper) used in the scenario.

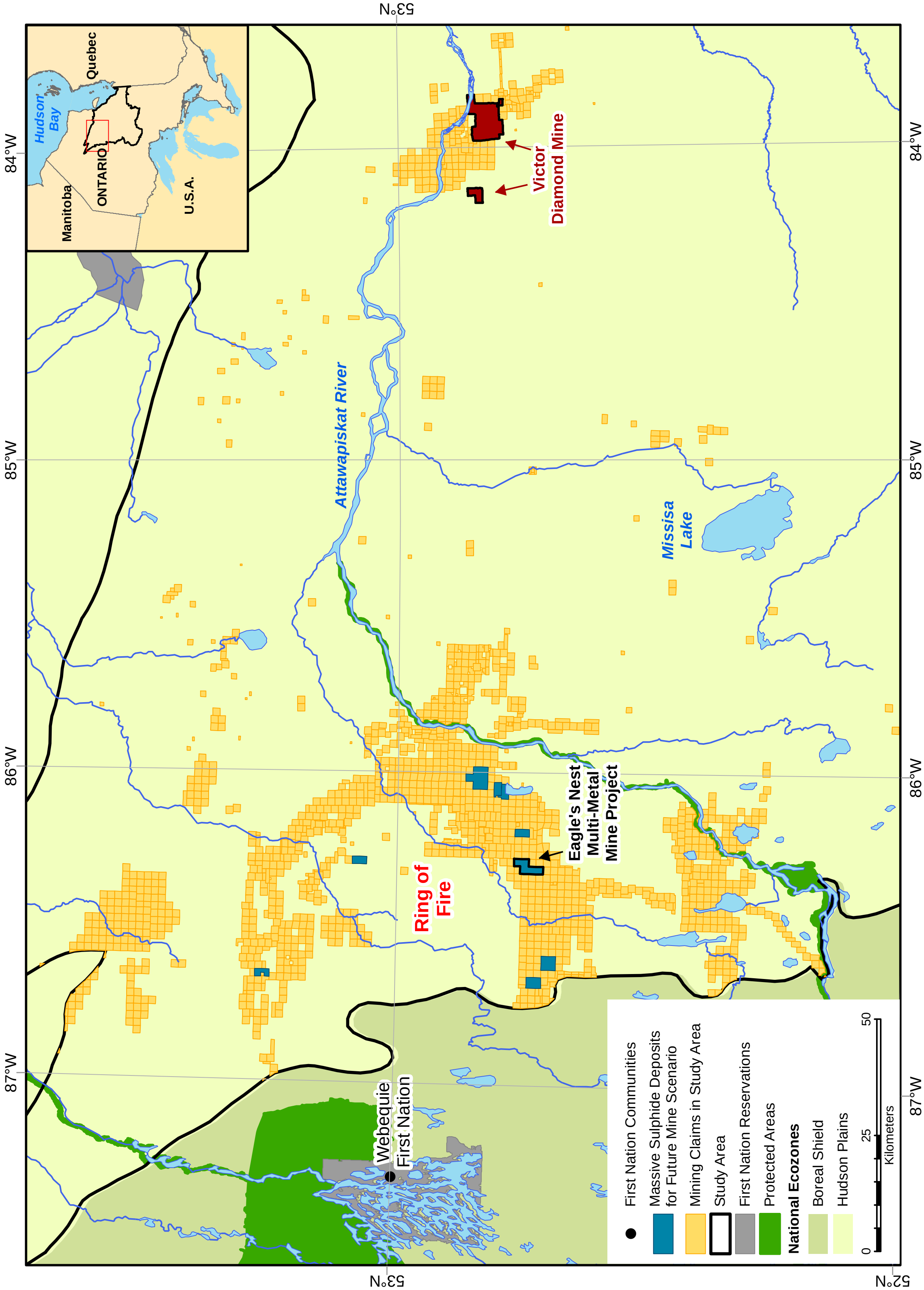


Figure 9. Forestry SFLs overlapping the study area.

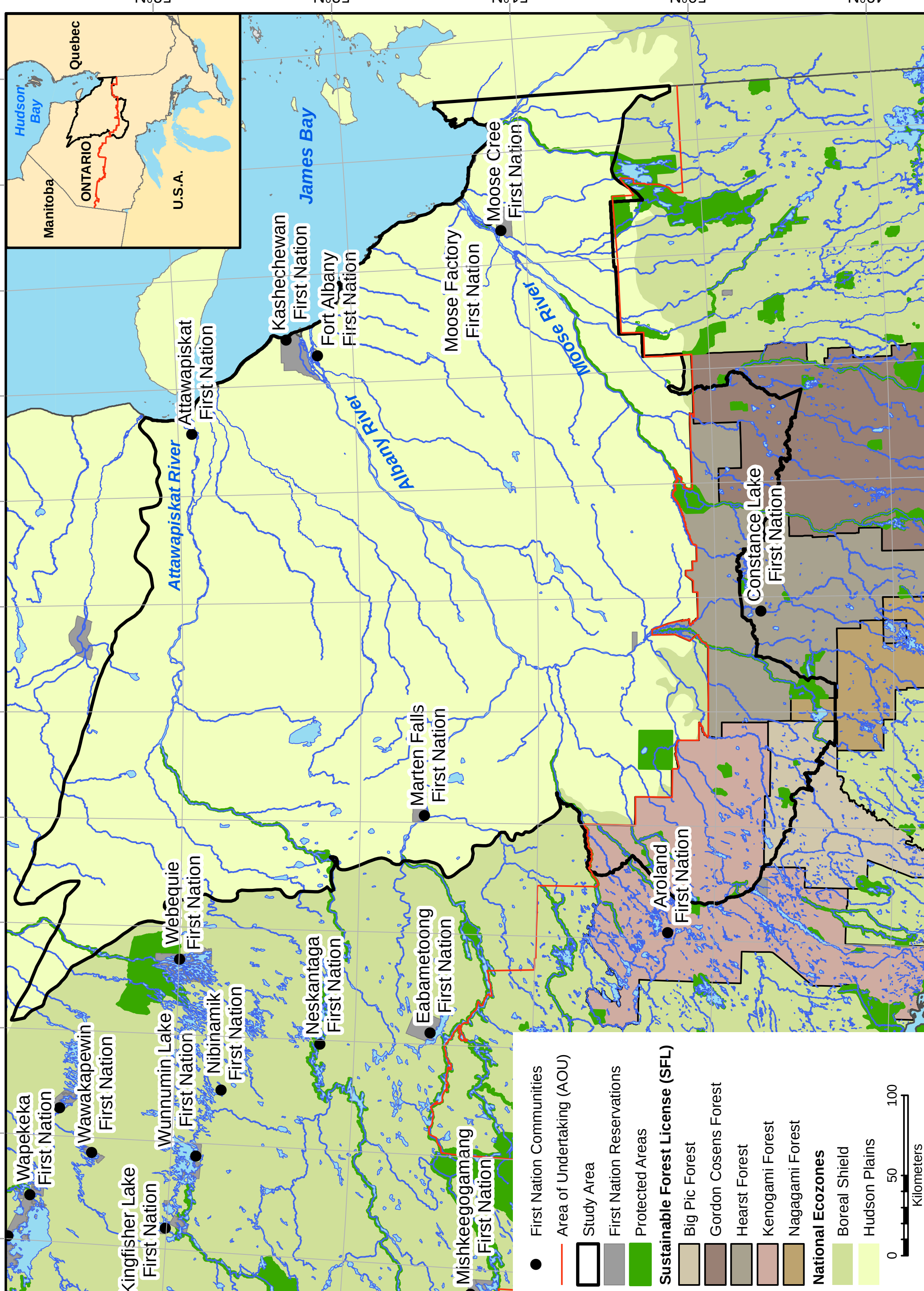


Table 7. Simulated harvest levels will be based on the AAC's of the SFL's within the study area, adjusted to account for the proportion of each SFL that is within the study area's boundary[27].

	AAC (m^3)	% of SFL within study area	Adjusted AAC (m^3)
Kenogami[28]	Softwood=1,010,781 Hardwood=259,366	Softwood=49% Hardwood=28%	Softwood=496,330 Hardwood=72,746
Hearst[29]	Softwood=588,000 Hardwood=232,000	Softwood=62% Hardwood=42%	Softwood=361,889 Hardwood=97,610
Gordon Cosens[30]	Softwood=1,230,000 Hardwood=428,332	Softwood=17% Hardwood=8%	Softwood=208,125 Hardwood=34,158
Big Pic[31]	Softwood=918,098 Hardwood=375,525	Softwood=33% Hardwood=28%	Softwood=305,976 Hardwood=105,194
Nagagami[32]	Softwood=240,000 Hardwood=192,350	Softwood=10% Hardwood=2%	Softwood=24,316 Hardwood=4,246
Total			Softwood=1,396,636 Hardwood=313,953

Table 8. Timber harvest assumptions, based on the Hearst FMP.

Forestry Parameter	Assumption
Minimum harvest age[34]	Conifer lowland = 100 Conifer upland = 80 Mixedwood = 80 Hardwood = 80
Harvest sequencing[35]	Harvest is distributed across available seral stages relative to the distribution of volume across available seral stages.
Merchantable structure retention[36]	1% across forest types
Riparian residuals[37]	Conifer lowland = 1% Conifer upland = 2% Mixedwood = 3% Hardwood = 3%

Table 9. Road development rates estimated from FMPs for SFLs in the study area.

	Road development (km/year)			AAC (m^3/year)	Road development rate (km/m^3)
	Primary	Branch	Total		
Hearst[38]	14.17	36.43	50.6	820,000	6.2e-05
Kenogami	11.14	21.1	32.24	1,270,147	2.0e-05
Gorden Cosens	19.4	60.3	79.7	1,658,332	4.7e-05
Weighted average					4.0 e-05

27 When calculating the percent of the softwood and hardwood forest landbase that occurs within each SFL, deciduous forest was assumed to contribute to hardwood landbase and coniferous forest was considered to contribute to softwood landbase. Mixedwood forest was assumed to contribute 50% to hardwood and 50% to softwood landbases.

28 Annual allowable cut is from Table FMP-13 of the Kenogami Forest 2011-2012 Contingency Plan (GreenForest Management Inc. 2010).

29 Annual allowable cut is from page 239 of the FMP (Hearst Forest Management Inc. 2007).

30 Annual allowable cut is from page 126 of the Gordon Cosens Forest 2010-2012 Contingency Plan (Tembec 2010).

31 Annual allowable cut is from Table FMP-13 from the Big Pic 2007-2017 FMP.

32 Annual allowable cut is from page 150 of the Nagagami 2011-2021 FMP (Jackfish River Management Ltd. 2011).

33 Ninety-two percent of planned harvest area for the Hearst Forest area are clearcuts larger than 520 ha, which approximates the size of a cell in the spatial mapping of the scenario analysis (500 ha). The size of these clearcuts range from 520 to > 20,000 ha (i.e., from 2 to > 40 cells). To represent this pattern, approximately 92% of clearcuts were greater than one cell in size. The maximum size of a clearcut was 40 cells. When attempting to create large clearcuts, Mapper was constrained by the existing spatial distribution of forest age.

As per Hearst Forest Management Inc. (2007a), the scenario analysis incorporated the combined spruce, pine, and fir harvest (referred to here as softwood) and the poplar harvest (referred to here as hardwood). Species contributing only minor volumes to the AAC, including cedar, larch, and birch were not assessed; demand for these species was assumed to be met through incidental harvest.

Simulated timber harvest strategies (Table 8), including the cut block size distribution[33], reflected the forest management plan for the Hearst Forest, the largest SFL in the study area.

A network of primary, branch, and operational roads are needed to access forest for harvest and transport timber to mills. Primary and branch roads were simulated at a rate of 0.00004 km per m^3 of timber harvest, based on road construction forecasts from the Hearst, Kenogami, and Gorden Cosens FMPs) (Table 9). Primary and branch forestry roads were 24 m wide and permanent over the term of the simulation. Although branch roads are not considered permanent in FMPs, they are also not necessarily reclaimed. The Hearst FMP states that future use management of branch roads is unplanned to maintain flexibility for future operations or use by other parties; if no future access is required then a road typically becomes the responsibility of MNR. FMPs in the region do not identify plans to decommission branch roads, and a FMP for the Kenogami Forest (Ministry of Natural Resources and Neenah Paper Company of Canada 2005) states that there are no primary or secondary roads scheduled for abandonment or decommissioning during the planning period (2005-2025). Further, Hearst Forest Management Inc. (2007b; page 35) states that no roads or road networks have been identified as candidates for abandonment. Operational roads, such as those constructed within cut blocks, are more transitory. Operational roads were assumed to reclaim with cut blocks, which may be optimistic given that Ontario wood supply analyses commonly assume that 2.5-3% of harvest area is lost to operational roads and landings that do not reclaim (Arborvitae Environmental Services Ltd. 2004).

34 Minimum harvest ages for Hearst SFL are higher than for other SFL's in the region because the majority of wood harvested from the Hearst SFL is for saw and veneer mills, which require larger roundwood materials. To better represent typical minimum harvest ages in the region, the average minimum harvest age from the Hearst and Gordon Cosens Forest Management Plans (FMP) was used, rounded to the nearest 20-year increment (minimum harvest age in ALCES is defined in 20-year increments). No maximum harvest age (or minimum volume) limit was set because it is expected that old degraded low-volume stands will be harvested (Hearst Forest Management Inc. 2007a; page 30).

35 The Hearst FMP (Hearst Forest Management Inc. 2007b) does not state that forest in older seral stages is prioritized for harvest. Therefore, ALCES was instructed to distribute harvest across available seral stages relative to the distribution of volume across available seral stages.

36 A proportion of volume is left unharvested in each harvested stand to emulate interior structure left following a fire. The retention level was set at the level defined in by Hearst Forest Management Inc. (2007a; page 31) for the primary species in each forest type.

37 The percent of each forest type set aside for riparian residuals is based on assumption used by Hearst Forest Management Inc. (2007a; page 291) in their Strategic Forest Management Model.

38 The Hearst FMP forecasts that 141.7 km of primary roads and 364.3 km of branch roads will be constructed over 10 years (Hearst Forest Management Inc. 2007b; page 473).

3.4 Ecological Indicators

In addition to forest age and anthropogenic footprint, four indicators were incorporated to track impacts on wildlife: caribou, wolverine, moose, and watershed impact. Although the list of potential indicators was constrained by information availability, the selected indicators permitted an assessment of some of the key impacts of land use to wildlife in the region. Mining, hydroelectric development, and forestry have the potential to impact wildlife through a variety of mechanisms, including changes to forest age, increased anthropogenic footprint and associated human access, and various impacts to aquatic systems such as fragmentation of aquatic habitat, altered flow regimes, and contaminants (Browne 2007). Caribou response was assessed due to the species' sensitivity to forest disturbance and government commitments to species recovery and assessing cumulative effects on ranges[39]. Similarly, wolverine was included due to the species sensitivity to human access that is associated with anthropogenic footprints as well as provincial direction to address cumulative effects in Ontario's recovery strategy for wolverine (Ontario Wolverine Recovery Team 2011)[40]. Moose are also negatively affected by human access but, unlike caribou, the species is positively associated with recently disturbed forest. The lack of data for freshwater fish in the pilot study area precluded the development of species-specific fish habitat models (Jenni McDermid, pers. comm.). As a preliminary assessment, a watershed impact score was adopted that was developed as part of an assessment of freshwater fish in the same region (Browne 2007). In addition to being related to simulated stressors, it is hoped that the indicators will be useful for conveying land-use consequences to decision-makers and stakeholders due to their relevance to legislation (e.g., species at risk, environmental assessment) and First Nations (e.g., moose, water resources).

3.4.1 Caribou

Caribou response to the simulated landscape transformations was assessed by applying risk categories developed for the federal caribou recovery strategy (Environment Canada 2012). The risk categories are based on a relationship between caribou population parameters and disturbance estimated from a meta-analysis of boreal caribou population data from across Canada (Environment Canada 2011). Risk categories are assigned to levels of disturbance, where disturbance refers to anthropogenic footprint (including cutblocks[41]) buffered by 500 m and areas burned within the past 40 years. When applying the relationship to maps of future landscape composition, percent disturbance was calculated within each cell (5 km^2) and

39 http://www.mnr.gov.on.ca/en/Business/Species/2ColumnSubPage/249504.html

40 http://www.mnr.gov.on.ca/en/Business/Species/2ColumnSubPage/STDPROD_092934.html

41 According to page 76 of Gordon Cosens management plan, the majority (> 90%) of harvest area exceeds the size of a cell (5 km^2). Forestry was therefore simulated to harvest all merchantable forest within a cell. This approach, combined with the 500 m buffer around cutblocks, implies that cells in the management forest containing forest younger than 40 years will be interpreted as 100% disturbed.

averaged over the caribou range to estimate percent disturbance at the range scale[42]. Caribou ranges in the study area include the Pagwachuan and a portion of the Far North range. Far North caribou ranges were not publicly available at the time of this analysis, so this report considers caribou north of the Pagwachuan herd as part of the "Far North Herd" (OMNR 2009, p. 9).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Caribou response to disturbance was modelled for both the Pagwachuan range and the Far North range.

Table 10. Risk categories (Environment Canada 2011; Appendix E) applied to assess caribou response to simulated landscape composition.

Probability of Sustained Stable or Positive Growth	Likelihood of Desired Outcome	Disturbance* Interval	Level of Risk
≥ 90%	Very Likely	≤ 10%	Very Low
<90 to ≥ 60%	Likely	> 10 to 35%	Low
< 60 to ≥ 40%	As Likely as Not	> 35 to 45%	Moderate
< 40 to ≥ 10%	Unlikely	> 45 to 75%	High
< 10%	Very Unlikely	> 75%	Very High

*Disturbance refers to fires younger than 40 years and anthropogenic disturbances buffered by 500 m.

3.4.2 Wolverine

Wolverines were present in the study area until the 1950s, at which point the range of this species retracted to the northwest of the province (Dawson 2001). Since the 1970s, however, the range has been recovering (Ontario Wolverine Recovery Team in press), and OMNR and WCS have recorded the presence of this species in the study area in recent surveys (Ray 2012). The response of wolverine habitat to changes in landscape composition was assessed using a habitat suitability index (HSI) model. A HSI is a knowledge-based (as opposed to empirical) model that can incorporate information from a variety of sources. The wolverine HSI was based on a literature review (e.g., Ontario's Wolverine Recovery Team 2011, Bowman et al. 2010, Dawson et al. 2010, Jokinen 2004) and expert opinion (Justina Ray, pers. comm.). The HSI model combined information related to habitat availability and quality to calculate an index that ranged from 0 to 1. Steps required to calculate the index are summarized below.

[42] Disturbance buffers were assumed to be non-overlapping within the scale of a single cell (i.e., 5 km^2). This may exaggerate disturbance if footprint distribution is highly aggregated within a single cell. However, it may also under represent disturbance buffers because footprint buffers did not extend from one cell to another.

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Wolverine have been recovering in Ontario and have recently been sighted in the study area.

3.4.2.1 Habitat availability

For each cover type (including footprints), habitat availability is assessed as the product of its proportional abundance and its habitat value. Habitat value is a parameter that expresses the utility of a cover type to the species, where 0 indicates no utility and 1 indicates capacity to support the species' maximum density. All natural land cover types were assigned a value of 1, given that wolverines are habitat generalists in fire-driven landscapes (Justina Ray, pers. comm.). Research in northwestern Ontario found wolverine avoid deciduous forest relative to coniferous forest, but it is thought that the avoidance was due to another underlying biotic or abiotic variable (Bowman et al. 2010). Footprints were assigned a value of 0 because wolverine prefer intact habitat.

To account for avoidance and mortality, the habitat value of land cover in proximity of anthropogenic footprints was reduced by applying buffers to footprint and down-weighting the value of habitat within the buffer by a proportional use coefficient (i.e., the proportion of habitat within the buffer that is used). Buffer widths and use were based on an HSI model constructed for wolverine in Alberta (Jokinen 2004), which includes buffer relationships for four footprint types.

- All weather roads (applied here to major and minor roads): habitat suitability was reduced by an average of 65% within 1,000 m of the footprint.
- Good weather roads (applied here to winter roads): habitat suitability was reduced by an average of 50% within 600 m of the footprint.
- Vegetated linear disturbances (applied here to transmission lines and railroad): habitat suitability was reduced by an average of 35% within 400 m of the footprint.
- Polygonal footprints (applied here to all other footprint types, except reservoirs): habitat suitability was reduced by 70% within 700 m of the footprint.

3.4.2.2 Habitat quality

Habitat quality is a value ranging from 0 to 1 that incorporates the effect of one or more landscape attributes on habitat such as road density, forest age, and human population density. For each relevant landscape attribute, a response surface ranging from 0 to 1 dictates the relationship between habitat quality and the status of the attribute.

Road density is consistently identified in empirical research as being negatively associated with wolverine habitat, and was included as a habitat quality attribute in the wolverine HSI. Research in lowland boreal forests of central Canada and northwestern USA found mortality risk to increase within home ranges where road density exceeded 0.44 km/km^2 (Justina Ray, pers. comm., Rowland et al. 2003). The relationship between road density and wolverine is probably not a well-defined threshold, but rather a gradual impact (i.e., habitat quality declines with higher road density). The influence of road density on habitat quality was represented by a linear relationship where habitat quality equals 1 (i.e., 100%) when road density equals 0, dropping to 0.5 (50%) when road density equals 0.44 km/km^2, and 0 when road density equals 0.88 km/km^2. The relationship is consistent with the finding that wolverine are unlikely to occupy home ranges with road densities greater than 0.44 km/km^2. The relationship also helps to incorporate the finding from the boreal lowlands study (Dawson et al. 2010) that denning sites are likely to be 7 km from roads (i.e., there is a negative impact of roads over and above the 1 km buffer). The availability of denning sites is therefore negatively related with road density. When assessing habitat quality, road density was calculated at the tertiary watershed scale. Rowland et al. (2003) suggest that the watershed scale is appropriate when planning wolverine conservation.

Road density is consistently identified in empirical research as being negatively associated with wolverine habitat.

Other potential habitat quality attributes such as forest age or human density were not included in the HSI. Forest age does not seem to be an important determinant of wolverine habitat, given that cuts and burns were not selected for or against relative to other cover types in northwestern Ontario (Bowman et al. 2010). Human density in the study area is unlikely to reach levels that are detrimental to wolverine (beyond the negative relationship already captured by the road density relationship). Rowland et al. (2003) propose a human density threshold of 3.9/km^2 for northwestern USA, which is substantially higher than the current population density in the study area (< 0.2 people/km^2).

3.4.2.3 Habitat suitability

For each tertiary watershed, habitat suitability was calculated as the sum of the products of each cover type's habitat availability and the watershed's habitat quality (based on road density).

3.4.3 Moose

The response of moose habitat to simulated landscape transformations was assessed by applying the following bioclimatic regression model developed from Ontario moose density data (Rempel 2011):

$$\mathbf{Pden = exp(0.647 + YF(0.105) - YF^2(0.158) + MC(0.104) - MC^2(0.241) - AWT(0.154) - AWT^2(0.006) - TCP(0.001) + TCP^2(0.000002) - AST(0.141) + AST^2(0.004)) - 1}$$

where Pden is the predicted moose density (per km^2), YF is the proportion of young (< 20-years) forest[43], MC is proportion mature (> 60-years) conifer forest[44], AWT is average winter temperature (°C) from December-February, TCP is total precipitation (mm) from October-March, and AST is average summer temperature (°C) from June-August. The model explained 32% of the variance in moose density in the 2000-2006 Ontario moose dataset, and performed fairly well at predicting moose density for the 1990-1999 moose dataset that was not used during model fitting. Unexplained variance was thought to be due to variance in hunting pressure and weather (Rempel 2011).

Current climate variable values were available at a resolution of 450 ha (Rob Rempel, pers. comm.). Climate was simulated to change over the next 50 years according to outcomes from the Canadian Coupled Global Circulation Model (CGCM2) for the A2 climate scenario (as reported by Rempel 2011). Climate changes were: 4 degree increase in AWT; 2.83 degree increase in AST; and 1.12 mm decrease in TCP. These changes were based on CGCM2 simulated change between the periods 1971-2000 and 2041-2070 for MNR's Cervid Ecological Zone A, the most northern zone assessed by Rempel (2011) and a zone that overlaps with the southern portion of the study area (Appendix 3). The changes in climate variables were assumed to occur linearly across the 50-year simulation period.

To incorporate the effect of hunting, predicted moose density in proximity to roads was reduced by 58% based on research from northwestern Ontario (Rempel et al. 1997). Rempel et al. (1997) found that landscapes disturbed by timber harvest and fire were similar in their habitat quality (habitat suitability index values of 0.85 for modified clearcut and 0.80 for wildfire burn), but that the harvest landscape supported 58% lower moose density (5.6 vs. 13.2 moose/25 km^2). The difference in density was attributed to hunting; hunter access was severely restricted in the wildfire burn landscape due to low road density (0.3 m/ha vs. 8.1 m/ha) and heavy blow down after the burn. In our simulation, the 58% reduction

43 Includes all forest types; i.e., coniferous, deciduous, mixed, merchantable mixed conifer upland and lowland, merchantable intolerant hardwood, and merchantable mixedwood.

44 Includes all coniferous forest types; i.e., coniferous forest, merchantable mixed conifer upland forest, and merchantable mixed conifer lowland forest.

in population density was applied to habitat within 1 km of roads and other linear footprints, such as transmission lines. The 1 km buffer is consistent with research from Alaska that estimated a road-effect zone of > 1,000 m for female moose and 500-1,000 m for male moose (Shanley and Pyare 2011). Shanley and Pyare (2011) found that moose were impacted by even low levels of human access along roads (0.25 km of vehicle travel/ km^2/day). The 1 km buffer is also supported by research in southeastern New Brunswick that found 92% of moose were killed within 1 km of a road (Boer 1990). However, the 1 km buffer will under-represent the effect of human access on the moose population if hunting pressure is sufficiently high to cause mortality sinks. Moose can travel large distances, such that moose densities within several km of roads and other linear footprints could be affected by hunting pressure.

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Hunter access may be a major determinant for how moose fare.

3.4.4 Watershed Intactness

As part of an assessment of freshwater fish in Ontario's boreal region, Browne (2007) developed a watershed cumulative impact score. The impact score, applied at the tertiary watershed scale, incorporates seven stressors to northern fish communities, including number of acid mine drainage sites, number of dams, human population density, land transformation, road density, number of pulp and paper mills, and number of tourism outposts[45]. When applying the index for this study, human population density was not incorporated due to the study area's low population (< $0.2/km^2$). Pulp and paper mills were similarly excluded because none are present in the study area, and tourism outposts were excluded because these features were not tracked during the simulation. Instead of assessing the index based on the number of acid mine drainage sites, impact was assessed based on the number of mines. Although some mines, most notably diamond, will not be potential acid mine drainage sites, they may be associated with other aquatic impacts such as the draining of water from large expanses of peatland and the potential mobilization of mercury stored in the peat (Far North Science Advisory Panel 2010).

[45] Tourism outposts were not included when calculating the impact score for this study because tourism outposts were not tracked during the simulation.

Table 11. Scoring system when applying impact scores to tertiary watersheds (Browne 2007). Cumulative impact score was calculated as the sum score across threats.

Mines		Hydroelectric sites		Road density		Recent cut (interpreted as within 20 years)		Settlement	
#	Score	#	Score	km/km^2	Score	%	Score	%	Score
0	0	0	0	0	0	0-0.9	0	0	0
1	2	1	3	1	1	1-5.9	1	0.1-2	2
2	4	2	5	2	2	6-10.9	2	2.1-5	4
3	6	3	7	…	…	11-15.9	3	5.1-10	6
4	8	>3	10	9	9	16-19.9	4	10.1-15	8
5	10			Etc.	Etc.	>20	5	>15	10

4. RESULTS

Simulated development resulted in a three-fold increase in anthropogenic footprint, primarily due to road and transmission corridor expansion (Figure 10). Footprint expansion was greatest in the southern portion of the study area where a dispersed road network was needed to access timber. Footprint growth did occur in the north, but was more spatially constrained (e.g., corridors to access mines in the Ring of Fire and dams along major rivers). Impacts to forest age were also greatest to the south where the average age of the forest declined in response to timber harvest (Figure 11). Average forest age increased outside of the SFLs, suggesting that the simulated fire rate may be less than the natural disturbance regime responsible for shaping the current age-class composition. Underrepresentation of the true natural disturbance rate could in part be due to insect outbreaks and autogenic disturbances (e.g., gap dynamics) not included in our simulation. Alternatively, the estimate of the current age-class composition could underrepresent the abundance of older forest in the region. This possibility is supported by forest inventory data from 1978 for 5,250 km^2 of the Moose River FMU, which is immediately north of the AOU in the eastern portion of the study area. According to the inventory data, almost 70% of the forest was older than 120 years (Ter-Mikaelian et al. 2009). In comparison, 31% of non-merchantable forest was assigned an age greater than 120 years by the forest age data set (i.e., Chen et al. 2003) used in this study. However, the discrepancy in the abundance of older forest between the data sets could be a reflection of the stochastic nature of fire in the region, which creates a variable forest age structure through time and space.

Simulated development resulted in a three-fold increase in anthropogenic footprint, primarily due to road and transmission corridor expansion. Footprint expansion was greatest in the southern portion of the study area where a dispersed road network was needed to access timber.

Figure 10. Response of anthropogenic footprint to the simulated land-use scenario.

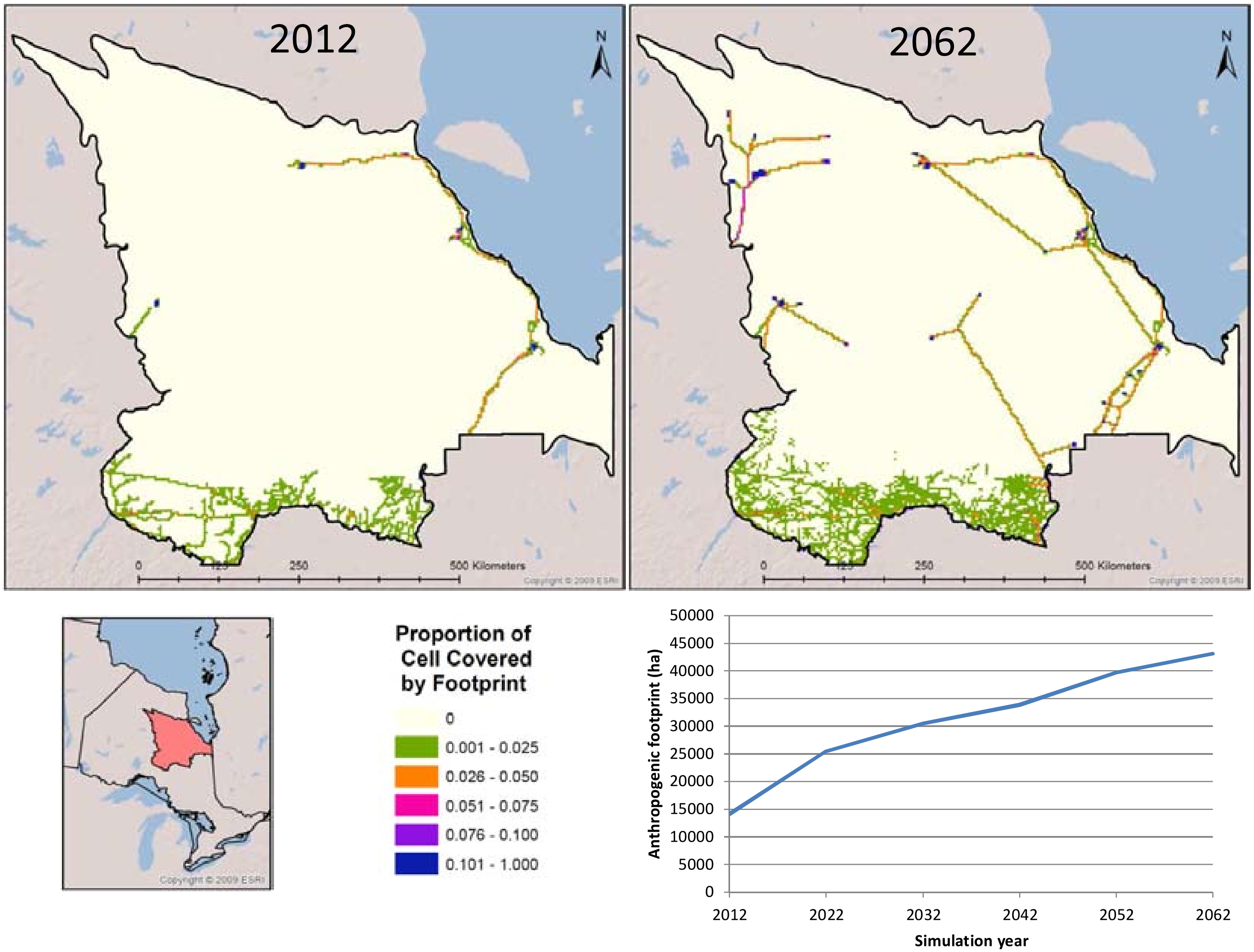
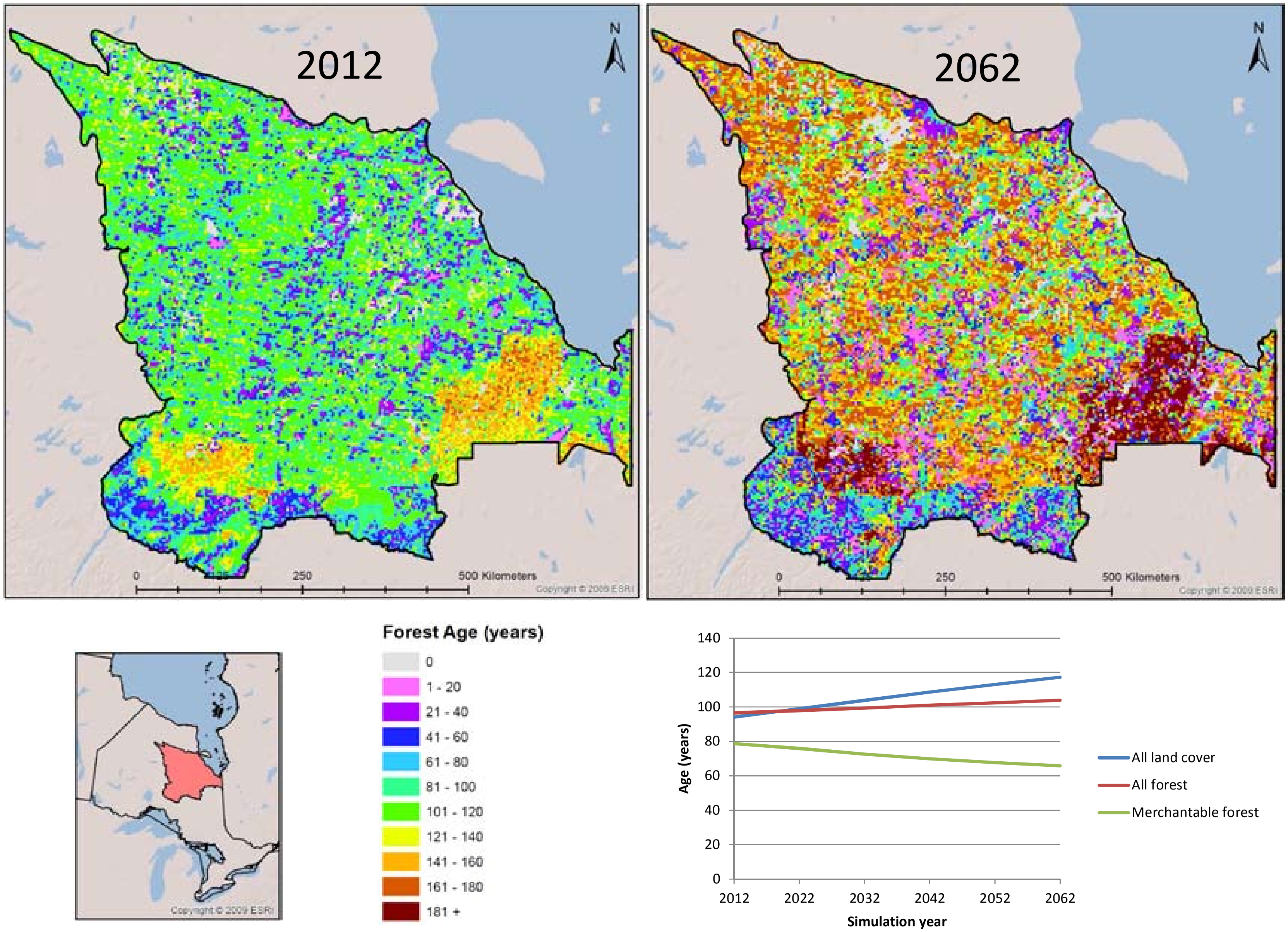


Figure 11. Response of forest age to the simulated land-use scenario.



Risk to herd viability approached the high category and range disturbance exceeded the threshold set forth in the national boreal caribou recovery strategy.

The more rapid changes to landscape composition in the southern portion of the study area translated to larger simulated impacts to terrestrial wildlife. Increased prevalence of footprint and young forest caused disturbance within the Pagwachuan caribou range to double from 22 to 44% (Figure 12). As a result, risk to population viability approached the high category and range disturbance exceeded the threshold (35%) set forth in the national boreal caribou recovery strategy (Environment Canada 2012). Elsewhere in the study area, disturbance to caribou habitat (considered here as one population) occurred in proximity to the network of corridors accessing new mines and dams, and in areas that were burned by the simulated fire regime. Risk to caribou viability increased as a result, but did not exceed the 35% disturbance threshold where scientific assessments have indicated an increased risk to caribou populations (Environment Canada 2011). Simulated impacts to wolverine were also greatest to the south, where expansion of the road network caused habitat suitability within many watersheds to decline (Figure 13). Elsewhere in the study area, expanding anthropogenic footprint caused a loss of wolverine habitat suitability in most watersheds, but the decline seldom exceeded 10%.

Figure 12. Simulated response of caribou range disturbance to the simulated land-use scenario. Caribou disturbance is expressed in terms of risk categories defined in the national boreal caribou recovery strategy.

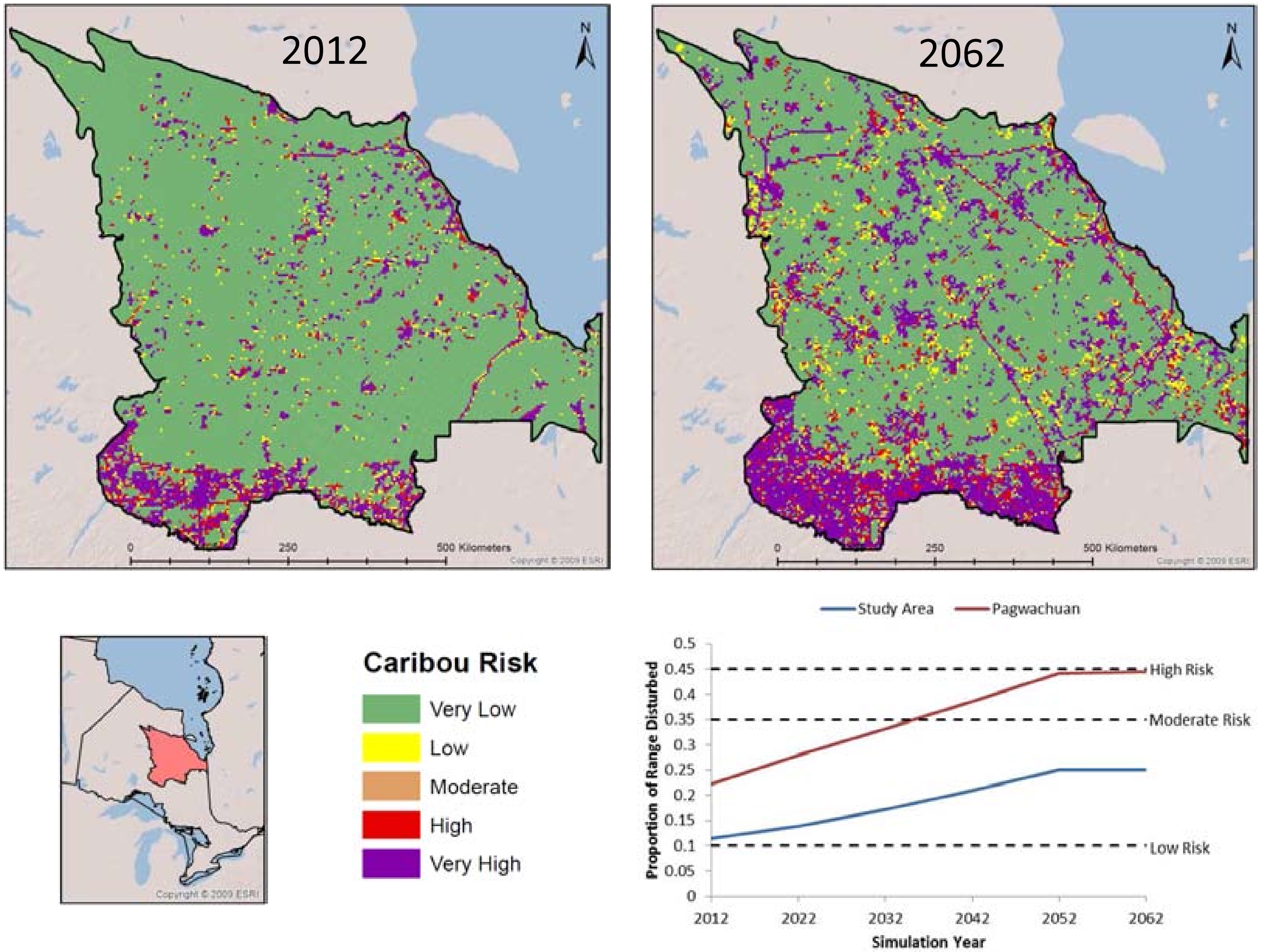
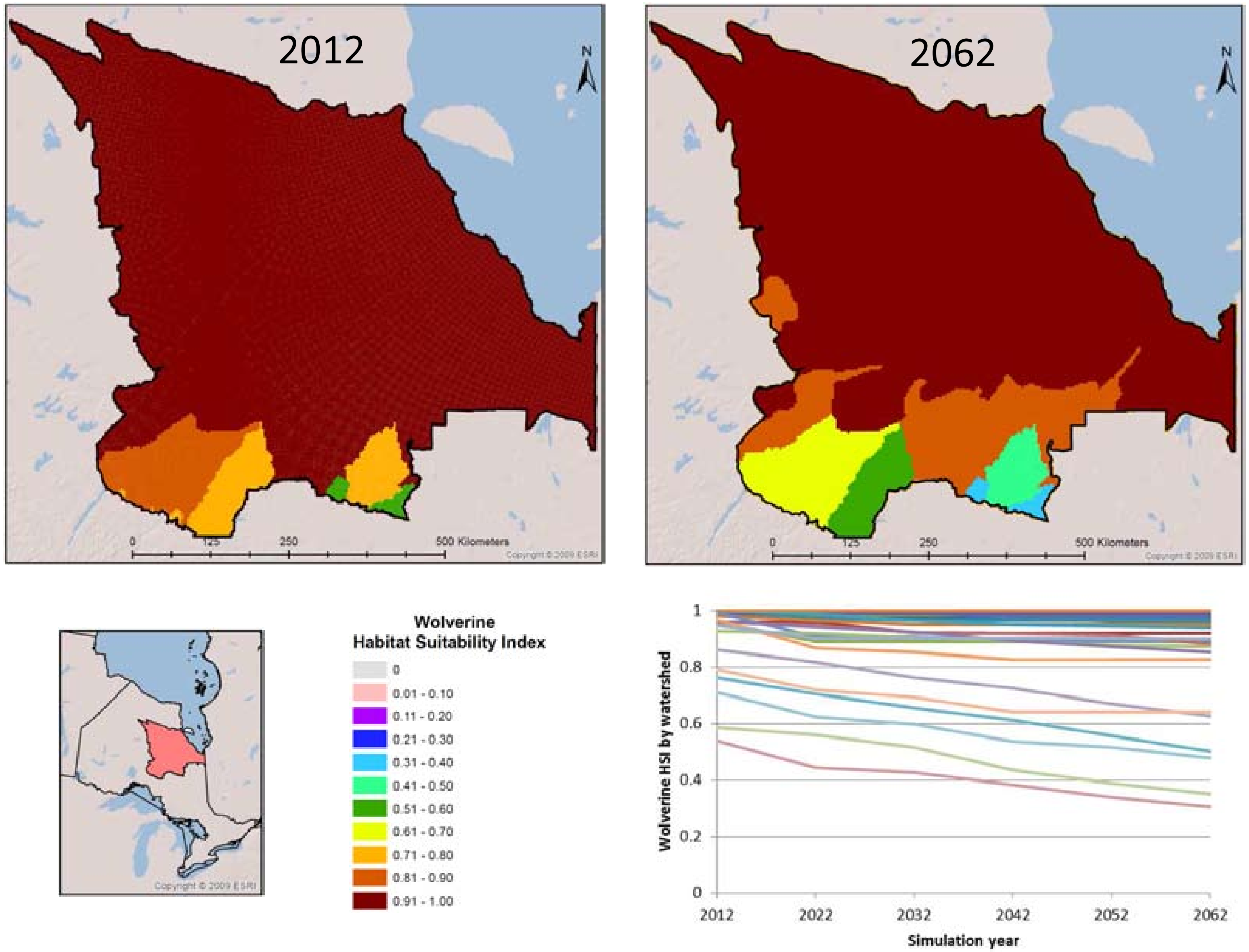


Figure 13. Simulated response of wolverine habitat suitability to the simulated land-use scenario. Habitat suitability was assessed at the tertiary watershed scale; the graph presents trajectories in habitat suitability for 30 watersheds that overlap with the study area. A habitat suitability index of 1 is representative of natural habitat



The moose population was insensitive to the simulated expansion of anthropogenic footprint (Figure 14), but increased dramatically when climate change was incorporated (Figure 15). The expected warming of winters caused the moose population to more than double and expand across the study area. Increased hunting pressure associated with simulated road expansion was insufficient to dampen moose population growth, with the exception of portions of the SFLs where road density was high.

The expected warming of winters caused the moose population to more than double and expand across the study area..... The development of mines and dams increased aquatic impacts for a number of northern watersheds.

The current distribution of aquatic impacts is similar to that of terrestrial impacts; northern watersheds are intact whereas southern watersheds exhibit some degradation of ecological integrity largely due to the impacts of roads and timber harvest (Figure 16). As the simulation proceeded, however, the development of mines and dams increased aquatic impacts for a number of northern watersheds. Two watersheds, in particular, received high watershed impact scores by the end of the simulation: the Lower Attawapiskat watershed received an impact score of 13 due to the presence of 11 mines; and, the Albany - Mouth watershed received an impact score of 10 due to the development of four dams.

Figure 14. Response of moose density to the simulated land-use scenario when climate change impacts are excluded.

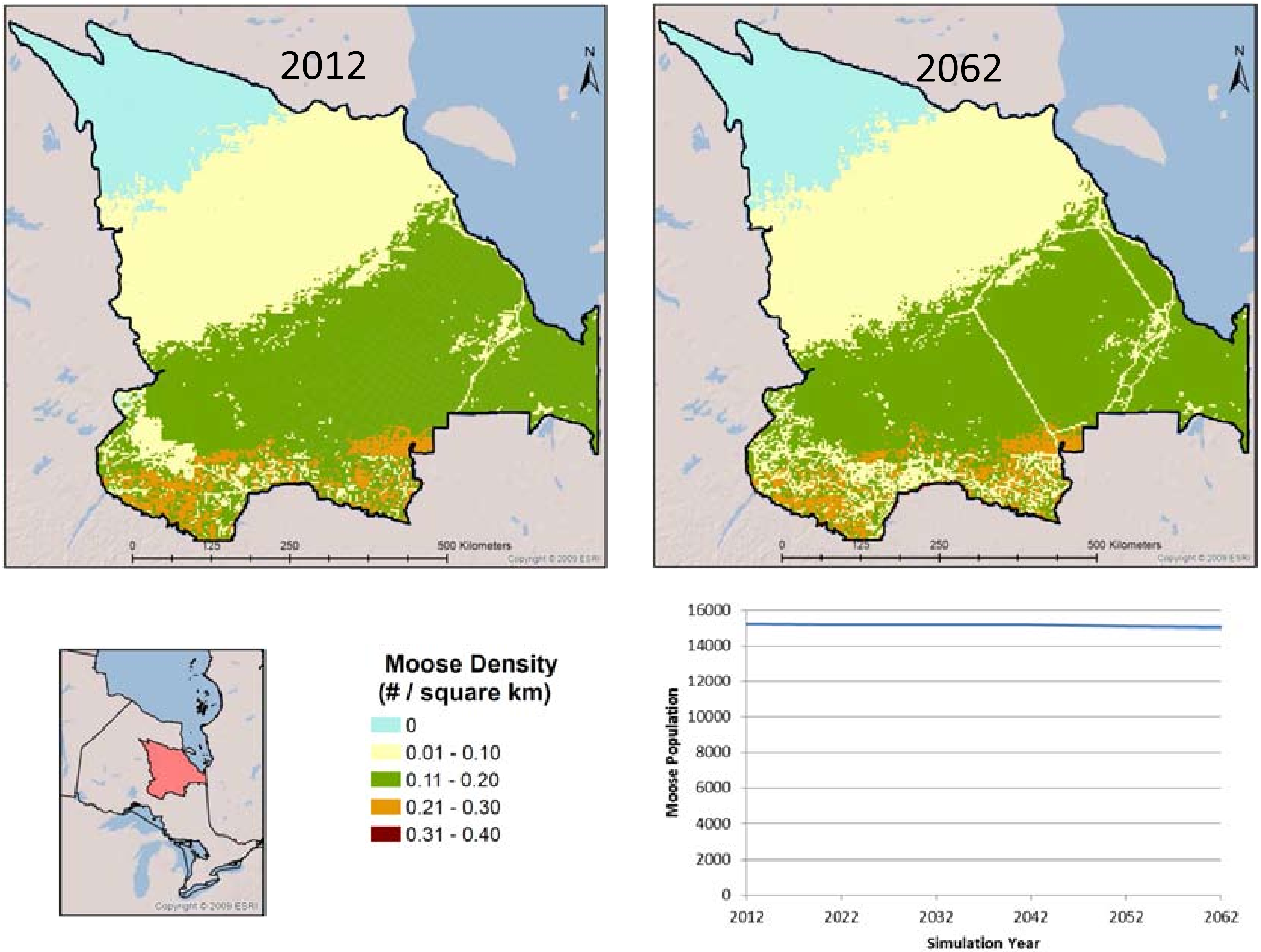


Figure 15. Response of moose density to the simulated land-use scenario and climate change.

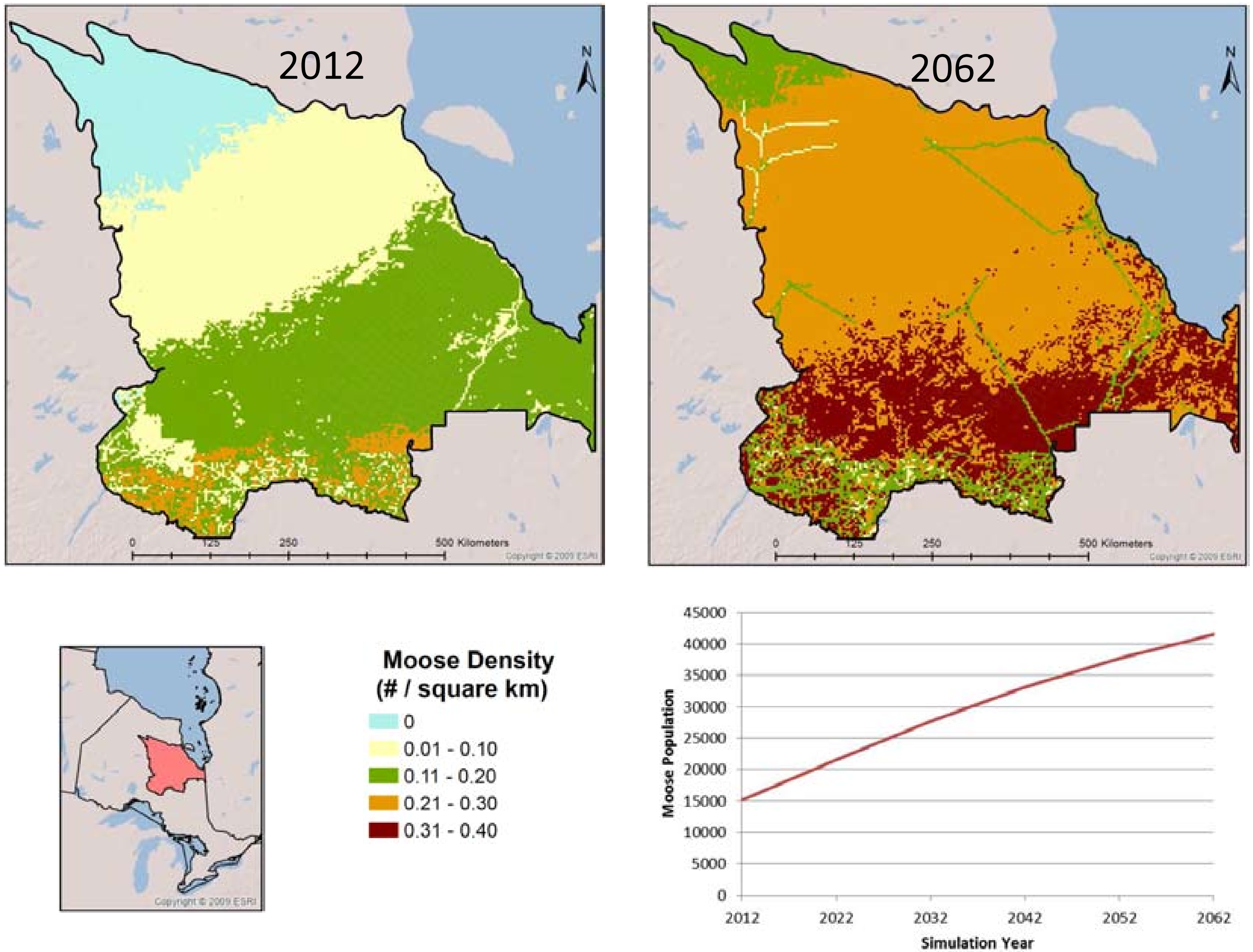
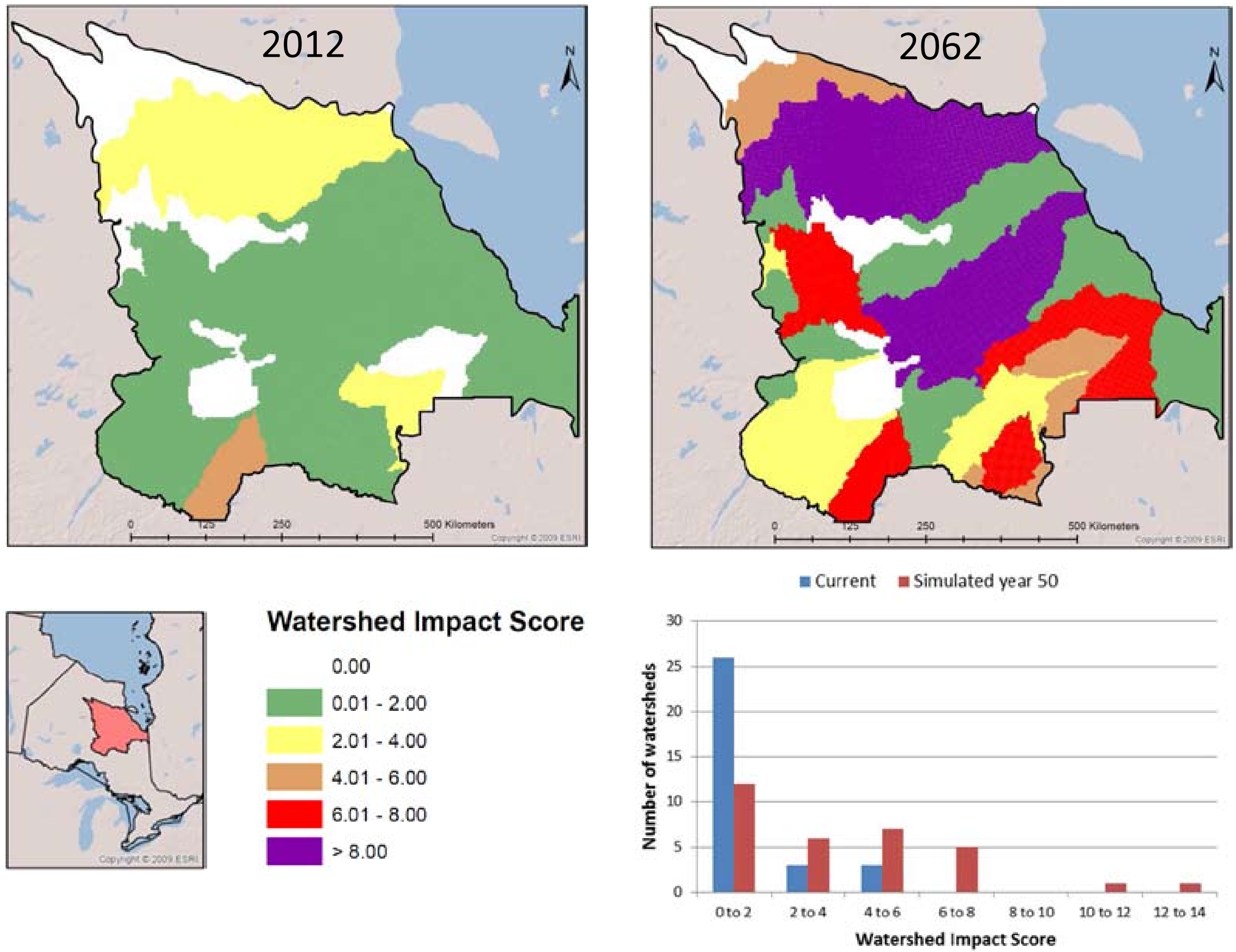


Figure 16. Distribution of watershed impact score across tertiary watersheds at the start and end of the 50-year simulation. A higher watershed score indicates greater risk to aquatic ecosystem integrity.



5. DISCUSSION

The primary purpose of the pilot project was to integrate information required for assessments of cumulative effects of anticipated industrial land use on wildlife. Our study demonstrated potential impacts on wildlife species and aquatic ecosystems from the multiple types of industrial development anticipated for Ontario's Far North. The outcomes of the analysis also suggest priorities for expanding the scope of scenarios and indicators to achieve more comprehensive assessments of cumulative effects in the region.

Our study demonstrated potential impacts on wildlife species and aquatic ecosystems from the multiple types of industrial development anticipated for Ontario's Far North. The outcomes of the analysis also suggest priorities for expanding the scope of scenarios and indicators to achieve more comprehensive assessments of cumulative effects in the region.

5.1 Impacts of land use to wildlife in Ontario's Far North

The level of disturbance created by industrial development simulated in our study was sufficient to increase risk to caribou and wolverine. Simulated forestry activity caused substantially greater road density within the SFLs than elsewhere in the study area, as well as an increase in recently disturbed forest. Disturbance of the Pagwachuan range surpassed the threshold identified to guide recovery planning, suggesting that the long-term viability of the population may require the expansion of protected areas in forest management planning.

Simulation results also included increased risk to wolverine within watersheds in the SFLs. As a coarse assessment of risk, risk categories were applied that were informed by the International Union for the Conservation of Nature (IUCN) classification of species at risk according to population change[46]. High risk was equated to the IUCN endangered category (> 50% decline in population), moderate risk was equated to the IUCN vulnerable category (> 30% decline in population), and low risk was equated to < 30% decline in population. According to these criteria, the area of watersheds posing a moderate or high risk to wolverine viability increased from 1,121 km^2 to 18,698 km^2 during the simulation.

The simulation's assessment of increased risk to caribou and wolverine is well supported by studies that have evaluated the historical or current relationship between land use and these species in northern Ontario. Woodland caribou range in Ontario has steadily receded northwards during the last century (Schaefer 2003), tracking the

[46] http://www.iucnredlist.org/static/categories_criteria_3_1

expansion of forestry activity (Vors et al. 2007). Land use has caused differentiation of mammal communities north and south of the province's allocation limit, with wolverine and caribou exhibiting greater abundance north of the limit and moose, deer, and wolves displaying greater abundance south of the limit (Bowman et al. 2010).

The assessment of risk to caribou may be conservative. The critical disturbance threshold of 35% in the recently-released Recovery Strategy (Environment Canada 2012), while based on a meta-analysis of caribou data from across Canada, is a management decision that still accepts a 40% risk to caribou and does not account for the variability associated with individual populations (see Environment Canada 2011). For example, herd-specific research conducted in the James Bay Region of Northern Quebec found that the critical disturbance threshold varied across herds, with one exhibiting a lower disturbance threshold of 30.6% before population declines were evident (Rudolph et al. 2012). Research in northern Ontario, including caribou ranges that encompass a significant proportion of non-treed habitat, is required to confirm the suitability of the 35% critical disturbance threshold.

Land-use impacts on species and watersheds may be exacerbated by climate change. In general, northern ecosystems are expected to experience more severe climate change than southern regions, with a number of consequences including shifts in the distribution of plants and wildlife as well as changes in natural disturbance rates and other ecological processes such as hydrology (Far North Science Advisory Panel Report 2010). The Hudson Plains ecozone is expected to experience severe impacts of climate change with amplified warming expected based on feedback effects from loss of sea ice (Abraham et al. 2011). While climate change has been identified as being important for addressing caribou (e.g., Fiesta-Blanchet et al. 2011) and wolverine (e.g., Brodie and Post 2009, Ontario Wolverine Recovery Team 2011) distribution and viability, we lacked suitable models for addressing climate change explicitly in our analyses for caribou and wolverine. We predict that increased fire ignition and spread in response to reduced fuel moisture under a warming climate scenario would have important consequences for caribou in Ontario's Far North. Climate change consistent with a 3 x CO_2 scenario has been projected to increase burn rates in the region by a factor of 2.1 by the end of this century in this region (Flannigan et al. 2005). A higher fire rate would increase the area of disturbed forest, which in turn would be detrimental to caribou. Further, the anticipated moose population expansion in response to warmer winters could facilitate

A higher fire rate would increase the area of disturbed forest, which in turn would be detrimental to caribou. Further, the anticipated moose population expansion in response to warmer winters could facilitate an increase in wolf density, with negative implications for caribou due to their susceptibility to predation.

an increase in wolf density, with negative implications for caribou due to their susceptibility to predation (Bowman et al. 2010). This should have implications for current cervid management and zoning in Ontario's Far North (Appendix 3). While the increased moose density projected in our study may be moderated by density-dependent mortality factors, other studies support the finding that moose populations are likely to expand into the Far North (Varrin et al. 2007, Rempel 2011). Climate change also has important implications for ungulate health because of the predicted expansion of deer (*Odocoileus* spp.) and meningeal worm (*Paralaphostrongylus tenius*) into northern ecosystems and changes to moose tick (*Dermacentor albipictus*) dynamics. (Varrin et al. 2007). Conserving wide-ranging species in the face of climate change will be aided by maintenance of intact landscapes, due to their roles in maintaining resiliency in the face of climate change and land use as well as facilitating range shifts (e.g., Hansen et al. 2010). Future scenario analyses could further explore the consequences of climate change by incorporating dynamics such as increased natural disturbance rate, altered predator-prey dynamics caused by shifts in species range (e.g., implications of moose population expansion to predation of caribou by wolves, implications of warming summers and disease dynamics on moose), and reduced habitat suitability for cold water species such as lake trout (*Salvelinus namaycush*) and brook trout (*Salvelinus fontinalis*) (Gunn and Snucins 2010).

In contrast to their simulated decline in the southern portion of the study area, wolverine and caribou appeared relatively resilient under our conservative scenario of expanding land use north of the allocation limit. Habitat was adversely affected in proximity to anthropogenic footprints, but the low density of these prevented widespread risk. The limited spatial extent of simulated wildlife impacts in the north suggests that economic growth in the region can be compatible with persistence of sensitive wildlife populations. However, this result must be interpreted with caution because our analysis may underestimate the extent and intensity of land use north of the AOU for two reasons.

- The prevailing pattern globally is that the creation of infrastructure such as roads and transmission corridors not only facilitates planned projects but, more generally, serves to open up previously inaccessible regions and tends to stimulate further development and roads (Far North Science Advisory Panel 2010, p. xiii). Specifically, the Far North Science Advisory Panel reviewed the implications of roads and transmission corridors in Ontario's Far

North and recommended that "transportation and transmission corridors needed to be planned in a coordinated fashion, recognizing community needs and protecting significant ecological features."

- The anticipated intensity of use for industrial all-weather roads may be relatively high compared to existing winter roads. The infrastructure corridor linking the Ring of Fire to the south will likely receive more than 100 large trucks per day[47]. Experience elsewhere (Forman and Alexander 1998, National Research Council 2005, Foreman et al. 2003, Beckmann et al. 2010) suggests that heavily used roads through otherwise intact landscapes cause impacts that are disproportionate to their physical footprint not only by acting as mortality sinks, but also by fragmenting movement and gene flow within populations. In the James Bay Region of northern Quebec, roads were found to be the most important factor affecting caribou occurrence and caribou aversion to roads was observed at distances exceeding 1 km (Rudolph et al. 2012). The high impact of infrastructure corridors in the region may be further exacerbated by their location in upland habitat such as eskers, which have been shown elsewhere to be disproportionately important for wildlife (e.g., Johnson et al. 2005, McLoughlin et al. 2010).

Potential impacts are such that infrastructure corridors demand careful consideration in terms of their location, level of use, and potential mitigation strategies, such as access management planning, and enforcement. Examples of mitigation strategies include prohibiting lateral road development from the corridor to limit cumulative effects, and minimizing traffic during periods critical to wildlife such as spring dispersal and calving (Rudolph et al. 2012). Achieving the simulated result of northern economic development and continued ecological integrity will require a proactive and regional planning approach to manage risks to species sensitive to industrial development. The Far North Science Advisory Panel reviewed the state of proposed and current development in the Far North and made three relevant recommendations. Our work supports these recommendations.

- The creation of a coordinated government-wide strategy for the management of interim and ongoing development.
- Acknowledge the development and infrastructure issues in the Ring of Fire by designating it as a Priority Management Area with an interim sub-regional planning process.

[47] Cliffs Chromite Project estimates traffic frequency of 50-100 trucks a day for most of the mines projected 30 year lifespan (Cliffs 2011). Given that multiple mines are likely to be developed concurrently, traffic exceeding 100 trucks per day is likely.

- Immediately establish the Far North Land Use Strategy as mandated in Ontario's *Far North Act*.

Unfortunately, none of these recommendations have been taken up by Ontario to date.

The relatively low simulated impact of isolated mining and hydroelectric developments to terrestrial wildlife belies potential impacts to the aquatic environment. Negative consequences of mines to aquatic ecosystems are numerous and include release of effluent, leaching of contaminant from tailings (e.g., acid mine drainage, selenium), physical destruction of habitat, and increased access to lakes and rivers (Browne 2007). Dams are also associated with a suite of potentially far-reaching impacts (summarized in Browne 2007), including the release of mercury from decomposing organic matter in reservoirs, fragmentation of aquatic habitat for species at risk such as lake sturgeon (*Acipenser fulvescens*) (McDermid et al. 2011), and alteration of downstream flow regime. Impacts from even a single mine site or dam can be widespread, due to the high connectivity of the aquatic system and because the low productivity of northern aquatic ecosystems makes them susceptible to stressors such as angling and the introduction of invasive species. As demonstrated by the simulated rise in impact scores for many watersheds in the northern portion of the study area, risks to the integrity of aquatic ecosystems are likely to increase with the future development of mines and dams. Aggregation of development during the simulation resulted in some watersheds experiencing a substantial increase in impact score. Most of the Ring of Fire deposits as well as the kimberlite deposits in the vicinity of the Victor mine all occur within a single watershed (Attawapiskat). As a result, ten of the simulated mines as well as the existing Victor mine were located in the same watershed, resulting in a high watershed impact score. Similarly, the distribution of dams was spatially aggregated, with a single watershed receiving as many as four dams during the simulation. Although negative effects can be mitigated to a degree through project design and ongoing management, impacts cannot be eliminated. The cumulative effect of numerous mines and/or dams occurring within a single watershed will increase risks to aquatic ecosystems and the people that rely on them. It is therefore prudent to establish limits to mine and dam intensities in order to avoid unacceptable impacts to First Nation communities and ecosystem services. Detailed consideration of the cumulative impacts of multiple mines and dams to attributes such as water quality and fish populations is needed prior to the expansion of mining and hydroelectric development in Ontario's Far North.

Impacts from even a single mine site or dam can be widespread, due to the high connectivity of the aquatic system and because the low productivity of northern aquatic ecosystems makes them susceptible to stressors such as angling and the introduction of invasive species.

Ontario's Far North Science Advisory Panel recognized the importance of addressing cumulative effects on aquatic ecosystems and made a number of recommendations about land use planning that are relevant to our results including:

- Maintain the existing moratorium on large-scale (> 25 MW) hydroelectric development, including interbasin divisions and watersheds.
- Use watersheds or other natural boundaries as the basis for establishing protected areas that may be affected by upstream development.

Outcomes of the analysis demonstrate the benefit of exploring the consequences of potential land use scenarios over large spatial and temporal scales. For example, the study area's overlap with SFLs south of the allocation limit and potential mineral and hydroelectric developments in Ontario's Far North provides insight into the relative consequences of temporary, but widespread (e.g., forestry) versus more permanent, but isolated (e.g., mining, hydroelectric development) land use.

5.2 Priorities for future scenario analyses

Outcomes of the analysis demonstrate the benefit of exploring the consequences of potential land use scenarios over large spatial and temporal scales. For example, the study area's overlap with SFLs south of the allocation limit and potential mineral and hydroelectric developments in Ontario's Far North provides insight into the relative consequences of temporary, but widespread (e.g., forestry) versus more permanent, but isolated (e.g., mining, hydroelectric development) land use. The spatial extent of disturbance was sufficient to cause substantial risk to caribou and wolverine in the SFL's, but not north of the AOU where land use was limited to mines and hydroelectric development. In contrast, however, the accumulation of multiple mines and dams in northern watersheds may create risks to aquatic ecosystems that are disproportionate to their small spatial extent due to the intensity and permanence of the disturbance. These differences emphasize that policies for managing land use must account for differences in the types of developments expected in the Far North as opposed to the AOU.

The scenario analysis reported here is a step towards a decision-support system to inform land-use planning in Ontario's Far North. A diversity of information was integrated during the study, including land cover and footprint inventories, potential land-use trajectories, and relationships between landscape composition and ecological impacts. Further work is required, however, to expand the scope of the assessment. Some impacts were not addressed, including climate change and land uses such as gravel pits (which are likely to impact relatively rare upland habitat) and the expansion of settlements and work camps associated with exploration and mines. Future scenario analyses could incorporate these impacts, and also assess the potential consequences of scenarios that increase the rate and/

or spatial dispersion of development. Natural disturbance regimes require more detailed consideration, especially given the implications of climate change. Aspects of natural disturbance that could be incorporated include spatial variation in fire rate across the study area (e.g., Shield vs. Lowland), increasing fire rates, and outbreaks of insects such as the spruce budworm, jack pine budworm, and forest tent caterpillar (Far North Science Advisory Panel Report 2010, pg. 51, Abraham et al. 2011).

In this pilot project, we focused on species of provincial and First Nation interest that have suitable habitat models applicable to the study area. As discussed previously, a more detailed set of aquatic indicators is required to better understand cumulative effects of development and climate change on aquatic species (e.g., lake trout (*Salvenlinus namaycush*), lake sturgeon). A priority for expanding the scope of the scenario analysis is to develop a fish community integrity index that relates land use to fish community impacts, building upon concepts applied in watersheds in the boreal forest of Alberta (Sullivan 2006). The assessment of terrestrial impacts could also be expanded, for example to assess consequences to species associated with various forest types and ages. Songbirds provide a suitable focal taxa in this regard. A scenario analysis for boreal Ontario concluded that conserving songbird species with diverse habitat characteristics required maintenance of a range of forest patterns, such as can be achieved through forest management that emulates natural disturbance (Rempel et al. 2007). Another potential source of habitat relationships is the Boreal Avian Modelling Project (BAM), a collaborative effort to create the best possible bird-habitat models from available data. The BAM dataset, which spans boreal North America, includes point-count locations within the study area and similar ecosystems, and predictive models of bird density by habitat type are available (www.borealbirds.ca).

Another important suite of indicators to be added are socio-economic attributes including economic performance associated with resource development (e.g., jobs, royalties), but also social impacts such as impacts on traditional lifestyles and health.

Another important suite of indicators to be added are socio-economic attributes including economic performance associated with resource development (e.g., jobs, royalties), but also social impacts such as impacts on traditional lifestyles and health. First Nation communities may struggle to maintain social cohesion in the face of rapid expansion of resource development, and the decision-support system must address this issue to help inform communities and governments as they seek to conserve values and rights while engaging in novel industrial developments.

6. CONCLUSION

Many of these outcomes support recommendations made by Ontario's Far North Science Advisory Panel and provide insights for considering the conservation matrix model approach to conservation and planning in an intact region like Ontario's Far North.

The outcomes of this pilot project offers important considerations when addressing cumulative effects in northern Ontario, including: the benefit to wildlife of limiting land use to isolated nodes within an otherwise intact landscape; the need to improve understanding of the cumulative effects to aquatic ecosystems of multiple large-scale developments (e.g., mines, dams) within northern watersheds; and the potential for climate change to increase the sensitivity of wildlife to land use. Many of these outcomes support recommendations made by Ontario's Far North Science Advisory Panel and provide insights for considering the Conservation Matrix Model approach to conservation and planning in an intact region like Ontario's Far North. We hope that these findings will inform land-use planning at both the community and regional scale in the region and support the need for a comprehensive assessment of cumulative effects in Ontario's Far North.

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APPENDIX 1. OVERVIEW OF ALCES®

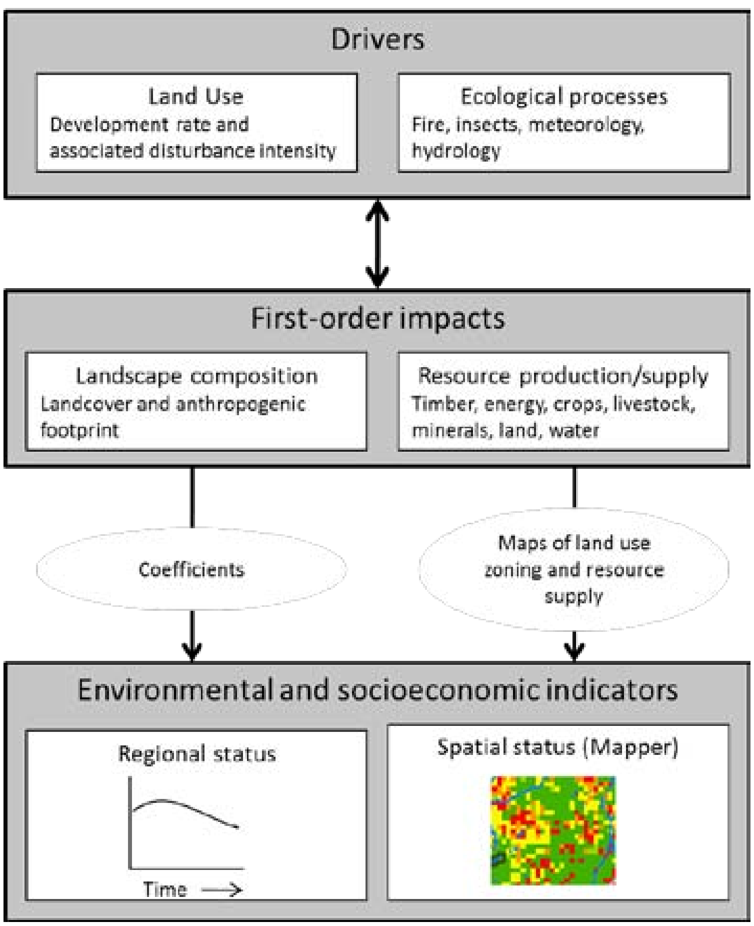
The ALCES land-use simulation model and its companion mapping tool (ALCES Mapper) provide strategic land-use planning guidance by examining inter-relationships among the full range of relevant land-use sectors and natural disturbances, and exploring their environmental and socioeconomic consequences at large temporal and spatial scales. The model was first developed by Dr. Brad Stelfox in the mid 1990's in Alberta, and has gradually expanded in scope to meet the needs of various regional planning initiatives in North America and beyond. The following description provides an overview of ALCES structure and function (Figure 17). More details can be found on the ALCES Group website (www.alces.ca), including reports and publications describing projects where ALCES has been applied.

To achieve a synoptic view of regional cumulative effects, a wide-range of land uses and ecological processes are incorporated into the model as drivers. The various land uses and ecological processes can be turned on or off depending on the needs of the scenario analysis. For each land use operating in a region, the user defines development rates, the portion of the landscape available for development, and management practices such as the intensity and lifespan of associated footprints. The influence of natural disturbances (e.g., fire) and plant succession on landscape composition are also tracked. Hydrological processes can also be addressed with surface and groundwater modules, and climate change effects can be incorporated by defining temporal changes in natural disturbances rates, successional trajectories, land cover, meteorology and hydrology.

The first-order effects tracked by ALCES are landscape composition and resource production/supply. Using an annual time-step, the model modifies the area and length of up to 20 land cover and 15 anthropogenic footprint types in response to natural disturbances, succession, landscape conversion, reclamation of footprints, and creation of new footprints associated with simulated land-use trajectories. ALCES also tracks resource production and supply using approaches that are typical of sector-specific models such as timber supply. Landscape composition and resource production attributes are translated into indicator variables using coefficients. A wide range of indicators are typically tracked so that trade-offs between diverse ecological and socioeconomic objectives can be assessed. Examples of indicators that can be tracked by ALCES include wildlife habitat and populations, water quality and quantity, biotic carbon storage, air emissions, employment, and gross domestic product.

Maps illustrating the plausible future condition of landscapes and indicators are created using ALCES Mapper, a companion tool to ALCES that exists as an ArcGIS application. Mapper allows users to specify the general location (i.e., where specified land-use footprints can or cannot occur) and pattern (e.g., dispersed versus contagious) of future development. This feature provides flexibility to map transformations of landscapes through time according to different spatial rules, and is useful for visualizing the implications of different zoning or resource utilization strategies. Maps of future landscape condition can then be analyzed to evaluate the spatial response of indicators such as wildlife habitat to potential future landscapes associated with land-use scenarios.

Figure 17. Overview of the ALCES land use simulation tool.



APPENDIX 2. THE CONSERVATION MATRIX MODEL

(WITH DR. HILARY COOKE, WCS CANADA)

The **Conservation Matrix Model** is a novel approach to conservation planning developed for Canada's boreal region by the BEACONs (Boreal Ecosystem Analysis for Conservation Networks) research team at University of Alberta (Edmonton, Canada) and Université Laval (Montreal, Canada) (Schmiegelow et al. 2006). The model was developed specifically for the large, relatively intact landscapes of Canada's boreal region and the natural disturbance regimes that drive change over space and time (Krawchuck et al. 2012). The premise of the model is to integrate systematic conservation planning with opportunities for sustainable resource use and adaptive resource management and thus facilitate integrated conservation planning over large regions.

The conservation-matrix concept includes four landscape elements (Figure 18), which together achieve the goal of adaptive resource management while ensuring maintenance of ecological flows across the landscape, such as movements of organisms, water, and nutrients, under the uncertainty of natural disturbance regimes.

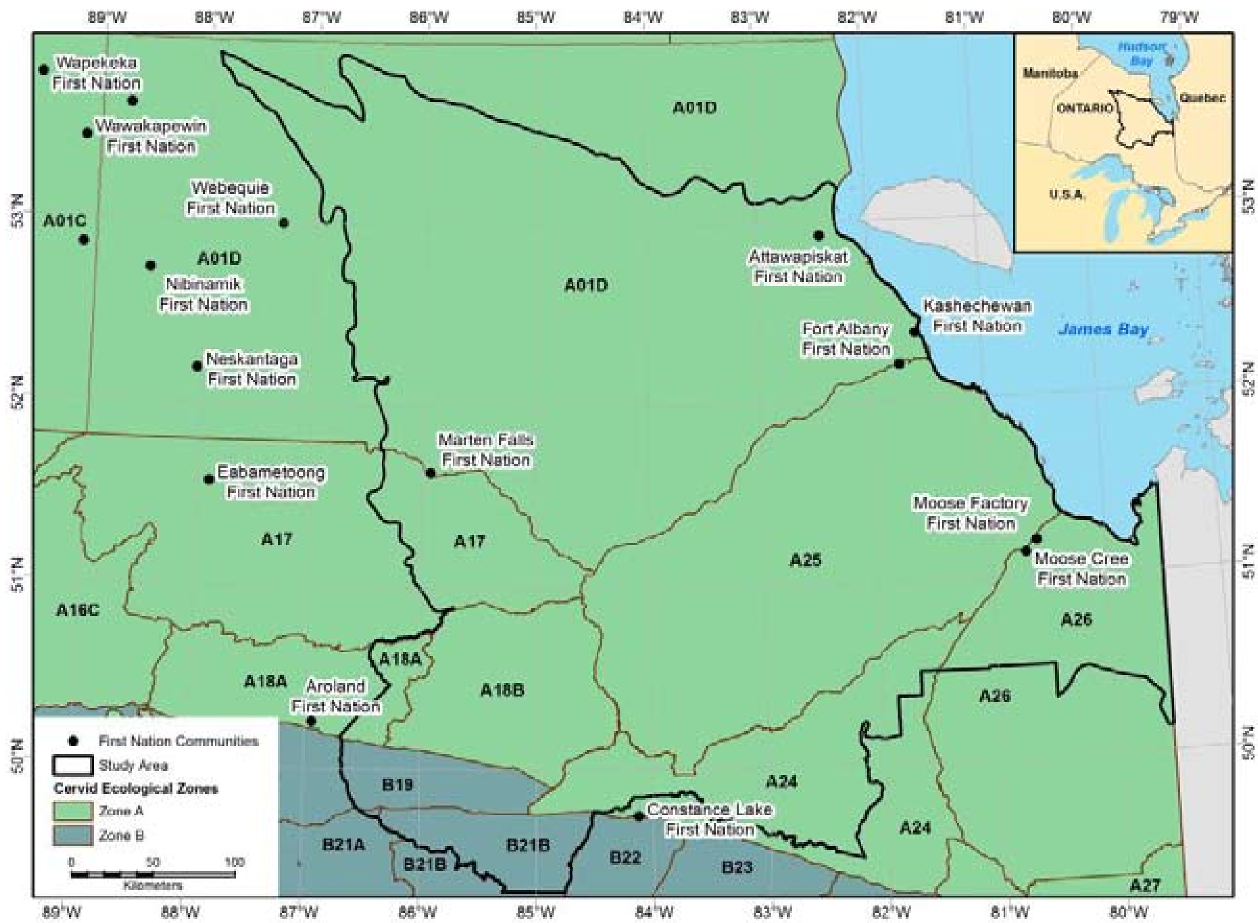
Active Management Areas are islands of relatively intense human development, e.g. human settlements, forestry, mining, agriculture, and the associated infrastructure. Active Management Areas are embedded in a **Conservation Matrix** 'sea'. The emphasis is on deciding limits to development and carefully managing for less-intense human activities within the Conservation Matrix. Thus, activities within the Matrix, such as recreation or hunting, are to be carefully planned and managed in an integrated fashion so as not to erode other values, such as ecosystem and landscape connectivity.

Figure 18. The Conservation matrix model (credit BEACONs).

Ecological Benchmark Areas (BA) are the foundation of the Conservation Matrix Model. These are relatively intact areas (i.e. with little or no human footprint) representative of natural environmental variation and sufficiently large to support natural ecosystem dynamics (specifically fire), ecologically functional wildlife populations, and maintain terrestrial and hydrologic connectivity (Schmiegelow et al. 2006, Krawchuk et al. 2012). Leroux et al. (2007) argue that, 'considering natural disturbance in reserve design may be especially important for the world's remaining intact areas, which still experience active natural disturbance regimes. Thus, BA design is intended to encompass the full natural variability of ecosystem structure and process, including fire and hydrologic regimes, and conserve biodiversity at all levels. A single BA will not be able to encompass all values of a planning region and thus a network of BAs is identified and which functions as a network of core protected areas for a region. A key component of the Conservation Matrix Model is incorporating opportunities for adaptive resource management into planning for intact landscapes. BAs are also intended to serve as reference or control sites for understanding the natural dynamics of ecosystems and their response to human activities, within an adaptive resource management framework.

The final element identified in the landscape are **Additional Reserves**. These site-specific protected areas are identified to capture values that may not be well represented within benchmark areas, such as areas of cultural significance, rare species occurrences, ecosystems of conservation concern, etc.

APPENDIX 3. OMNR'S CERVID MANAGEMENT ZONES[48]



[48] http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@fw/documents/document/263997.pdf

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