Predicting the Cumulative Effects of Human Development on Biodiversity in Northeastern Alberta

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Executive Summary

A new method to assess cumulative effects on biodiversity

We used information from the Alberta Biodiversity Monitoring Institute (ABMI) on birds, plants, human footprint, and vegetation, plus information from Dr. Bayne on birds, to test a new method for determining cumulative effects on biodiversity in northeast Alberta, Canada. This new method uses as much of the existing information as possible, and incorporates empirical modeling and mapping techniques to highlight changes in wildlife and biota in response to current human footprint (i.e., present cumulative effects), and to predict future cumulative effects as development continues. We tested the new method for a small suite of biodiversity indicators. Cumulative effects assessment for other biotic indicators and for other environmental aspects (e.g., soil, hydrology and air), were beyond the scope of the present project.

We created models that described empirical relationships between current species relative abundance measures and current vegetation / human footprint. We then applied the models to spatial vegetation / human footprint in a Geographic Information System (GIS) to map cumulative effects that have already occurred in one regional and one subregional study area in northeast Alberta. We also simulated human footprint expected in the region 25 and 50 years into the future to predict future cumulative effects. Projections of human development into the future were uncertain because future social, economic and environmental constraints are unknown, and may have significant implications for resource development and the resulting habitat changes that will be created. As such, predictions of future cumulative effects must be interpreted with caution.

As a coarse filter assessment of cumulative effects on biodiversity, we described the changes to vegetation that have already occurred as a result of existing human footprint in the region, and predicted future changes to the vegetation based on the simulations. We applied existing cumulative effects models for caribou *(Rangifer tarandus)* to the vegetation and human footprint maps to highlight cumulative effects for a species of high management concern. We created models and maps for black-throated green warbler *(Dendroica virens))* to describe cumulative effects for a species that was expected to be negatively affected as old forest becomes less abundant in the region. We extended the modeling and mapping beyond the species level to describe cumulative effects for species groups (i.e., forest plants, old forest birds, native plus introduced weedy plants) that were expected to be heavily affected by industrial development. Finally, we showed how modeling and mapping could be extended to assess cumulative effects for biodiversity in general. These empirical models and predictive maps add scientific rigor and spatial context to cumulative effects assessment of biodiversity.

The maps we created for species, species groups and biodiversity predict the cumulative effects expected in each quarter-section throughout the study area under current and projected future conditions. These maps show the spatial variation in cumulative effects, and allow resource

managers to better understand the amount and geographic location of cumulative effects that have already occurred and that are predicted to occur in the future. Maps of cumulative effects can be summarized at any spatial scale by averaging information across the area of interest. The maps can also be used to identify locations where developments are expected to alter species abundance greatly and where management would be most effective at mitigating those effects. We think this new method is more informative than the methods presently used to assess cumulative effects on biodiversity because they are spatially-explicit and based on empirical models using existing, freely-available datasets.

Coarse filter assessment – disturbance of vegetation in the region

Under current conditions, 6% of the regional study area has been converted to human footprint, with this expected to grow to 11% in the next 50 years. Approximately 50% of the footprint was due to forest harvest, with seismic lines, well sites, and pipelines accounting for 10-15% each. Three vegetation types - grassland/herbaceous, deciduous and mixedwood forest - had disproportionate amounts of conversion to human footprint. Forest harvesting is focused on upland stands of trees, and as expected old forest was often converted to cutblocks. It was not clear what caused the disproportional conversion of grass/herbaceous vegetation to human footprint, but these habitats may have been targeted for development by energy companies to avoid forest resources. As a coarse filter measure of cumulative effects on biodiversity, however, disproportionate conversion of grassland/herbaceous, deciduous and mixedwood forest suggests that species relying on these habitats may be disproportionally affected by human development in the region. Vegetation recovery in disturbed areas was not accounted for in the present study, and many native and non-native biota are expected to recolonize and use disturbed areas as the vegetation recovers.

Based on the present dispersion of human footprint through the regional study area, edge effects were common and greater than 50% of the region was within 200 m of human footprint. Only 1% of the region was presently greater than 2 km from human footprint and thus isolated enough to be considered true wilderness. The magnitude of edge effects on biodiversity is poorly understood at present.

Cumulative effects assessment – species, species groups, and biodiversity

Cumulative effects on caribou and black-throated green warbler were higher than those for species groups or biodiversity in general. Caribou was of particular management concern in northeastern Alberta (Alberta Sustainable Resource Development 2011, Environment Canada 2012) and maps of current habitat suitability for caribou supported this conclusion. Based on Environment Canada's model for caribou habitat suitability, only 32% of regional study area was currently suitable for caribou use. With continued development, only 15% of the regional study area was expected to provide suitable habitat for caribou 50 years into the future. Maps of habitat suitability provide a strong management tool by highlighting locations that were presently suitable for caribou, and identifying areas where active reclamation of human footprint could be done to increase habitat suitability for caribou. The effectiveness of habitat reclamation for caribou, however, has not been tested and if reclamation is implemented monitoring will be required to determine whether caribou populations recover.

For black-throated green warbler, old-forest birds, weedy plants, forest plants and biodiversity in general we found much lower cumulative effects in the regional study area than that found for caribou; intactness was currently above 85% for all of these indicators. Cumulative effects for black-throated green warblers were projected to increase over time as development continued, and the species was predicted to decline to 72% intactness 50 years into the future. Cumulative effects for species groups and biodiversity in general were projected to increase less than for caribou and black-throated green warblers; for all of these groups intactness was projected to remain above 80% for the next 50 years. For all indicators cumulative effects were projected to vary spatially, with relatively high cumulative effects in quarter sections containing abundant human footprint and lower cumulative effects in quarter sections with low or absent human footprint.

Cumulative effects were lower for forest plants and overall biodiversity than for old forest birds and weedy plants. Forest plants and total biodiversity included many species that were habitat generalists, and thus not surprisingly were less affected by the habitat/vegetation changes that accompany industrial development. However, cumulative effects were present for all species groups, and were predicted to increase as development increased over time. To provide a balanced picture of cumulative effects on biodiversity, it will be important to include high profile species, specialist species groups and generalist species groups – these specialists are expected to respond most strongly at low levels of resource development whereas generalist species respond as the amount and extent of development increases.

Differences among spatial scales

For all species and species groups, cumulative effects were slightly lower at the scale of the regional study area than the subregional area because development was slightly higher in the subregion. However, in the long term, increased human development is expected throughout the whole region. It will be important to track cumulative effects at a variety of spatial scales to assess incremental cumulative effects over time.

Pilot of the new method

The new method we developed for assessing cumulative effects on biodiversity improves previous approaches by: i) integrating assessments within a region so that local project-scale evaluation and regional land-use planning and management use a common suite of information, ii) facilitating collaboration and cost sharing, with all developers working together to produce a single assessment for the region, iii) ensuring that consistent high-quality information is produced for all areas within the region, iv) using all the available species and landscape information for the region to produce a scientifically robust assessment of cumulative effects on biodiversity, v) avoiding duplication of effort since the assessment can be completed once as a unit rather than as a number of piecemeal and potentially overlapping assessments, vi) facilitating regular and rapid updating of cumulative effects as new developments occur, vii) ensuring that stakeholders can access cumulative effects information from a single location for all developments in the region, and viii) having assessments done by a neutral third party that focuses on doing a rigorous unbiased evaluation.

There would be value in piloting the new cumulative effects assessment method to evaluate how it can support the evolution of policy, understand the costs to doing an integrated regional cumulative effects assessment for biodiversity, and assess the benefits/weaknesses of the resulting information. A shift towards conducting cumulative effects assessment as a collaborative effort would be a significant change to the EIA process in Alberta.

All cumulative effects assessments are predictions and long-term monitoring is required to test whether these predicted effects are real. Monitoring is the true test of whether the modeling assumptions are met, and through monitoring it will be possible to adaptively improve assessment and management over time.

1.0 Introduction

Cumulative effects assessment is designed to "… predict the environmental, social, economic and cultural consequences of a proposed activity and to assess plans to mitigate any adverse impacts resulting from the proposed activity" (Alberta Environmental Protection and Enhancement Act 2010). It is an important part of land use planning, as it can be used to evaluate the incremental environmental effects resulting from new developments in a region and, where possible, avoid or mitigate those effects (Hegmann et al. 1999). However, recent criticisms have suggested that the current cumulative effects assessment framework is too piecemeal to be useful for regional land use planning, because cumulative effects assessments are conducted independently by a variety of proponents, each using different assessment methods that are not necessarily compatible (Duinker and Grieg 2006).

Resource extraction, including in-situ oil sands development, affects biodiversity and ecological resources in a region. Current environmental impact assessments focus on key indicator resources, or valued ecosystem components, in local areas that may or may not be indicative of biodiversity throughout the region. In addition, the indicators and how they are measured are not consistent across development projects, making it difficult to compare between and calculate the cumulative effects of all projects in the region (Hegmann et al. 1999, MacDonald 2000, CEMA 2013). Finally, evaluations for species and biodiversity are mainly qualitative with few quantitative assessments. These deficiencies are due to the complexity of environmental systems, and because there is no accepted standard way to do assessments. However, stakeholders and the general public expect the best available knowledge will be applied to environmental problems.

In this project we collaborated with the Alberta Biodiversity Monitoring Institute (ABMI) to develop and test methods to conduct cumulative effects assessment for biodiversity (hereafter called cumulative effects) in a study area in northeastern Alberta. As a credible source of Alberta-specific information on biodiversity and its relationship to human land use, the ABMI is well positioned to support an improved cumulative effects assessment process for biodiversity. The ABMI collects standardized data on many species (e.g., vascular plants, birds, mammals and other taxa) and human footprint (e.g., roads, well sites, seismic lines, cutblocks, pipelines and other human footprints) across Alberta. This provides a large dataset that can be used to quantitatively model relationships between human footprint and biodiversity. In the present project, information on birds from Dr. Erin Bayne's lab at the University of Alberta was used to supplement ABMI information. We used the data from the ABMI and Dr. Bayne to develop and test methods to assess cumulative effects of energy developments on biodiversity at two spatial scales. We focused our assessment on species and habitats for which existing data were available and described how these species were affected by human-caused changes to the environment.

This project employed a new method to assess regional cumulative effects on biodiversity. The new method focuses on using standardized biodiversity data collected across the region to create rigorous quantitative species / habitat association models. The models are then applied to existing landscapes and simulated future landscapes to predict current and future cumulative effects. Therefore, this approach addresses the criticism that cumulative effects assessments are ineffective for land use planning because they are incompatible across projects. Furthermore, project-specific costs for doing cumulative effects assessment may be reduced, as this new approach can be applied to all developments that occur within a region rather than repeated for each development. If embraced by resource managers, this new method could become "standard practice" for cumulative effects assessment of biodiversity.

1.1 Project Goals

The project had three goals:

1) ***Empirically model relationships between species abundance and the natural vegetation and human created habitats in the study area:*** Models were created for biodiversity in general, species groups (forest plants, old-forest birds, weedy native and introduced plants) and focal species (black-throated green warbler, caribou). The species included in each group are identified in subsequent chapters. Human footprints created by the energy industry (industrial facilities, well sites, seismic lines, pipelines, transmission lines, roads) and those created by other sectors (roads, railways, cutblocks, cultivation, urban, residential) and natural vegetation types (forests, shrub lands, grasslands and wetlands) were included as inputs in the models. Upland forests were further categorized into four types (pine, white spruce, deciduous, mixedwood) and each of these categorized into 20 year age classes because vegetation composition and structure changed over time.
2) ***Assess current cumulative effects in the study area:*** Cumulative effects were measured as changes in abundance or intactness for the species/species groups between pre-disturbance and present conditions. We calculated results at two spatial scales (total study area and subregional area) and highlighted how cumulative effects varied between scales.
3) ***Describe cumulative effects expected as developments occurred in the next 50 years:*** Based on predicted spatial development of human footprint in the regional study area during the next 50 years, we predicted future cumulative effects. This simulation was preliminary. To improve the simulation it will be necessary to incorporate additional information on location, amount and accessibility of natural resources (particularly energy resources), and stakeholder plans to access those resources.

1.2 Outside of Project Scope

The present project was a test of a new method to assess cumulative effects on biodiversity in a study region. Assessments for other aspects of cumulative effects (e.g., soil, hydrology and air, social, economic and cultural considerations) were beyond the scope of the project.

2.0 Study Area

An essential component of cumulative effects assessment is determining the location and spatial extent of the area to be assessed (Therivel and Ross 2007). The smallest scale used in assessments is typically the area where infrastructure development is proposed (Ziemer 1994). Based on six in-situ developments (i.e., Devon Jackfish I, Devon Jackfish II, MEG Energy Christina Lake, EnCana Cenovus Christina Lake, CNRL Kirby and Harvest/KNOC Black Gold), development areas range in size from 40 km^2 to 221 km^2.

Cumulative effects assessments, however, also need to describe the ecological changes in the region surrounding the development(s). It was much less obvious which spatial extent to use for these regional assessments. Watersheds may be appropriate to assess regional effects on aquatic systems. Alternatively, an area that encompasses self-sustaining meta-populations for key wildlife species can be used to ensure that intra-specific and inter-specific interactions are managed effectively. Finally, cultural or political boundaries can be used because these integrate most easily with management (Ziemer 1994; Hegmann et al. 1999; Wu 2010). Regardless of the justification, a nested series of study areas are generally most defensible for cumulative effects assessment because both local and regional effects are assessed (Ziemer 1994).

The spatial extent of regional study areas used for cumulative effects assessments has not been consistent among in-situ energy developments. Of the developments listed above, one used a forest management unit of 10,478 km^2, another used a 6 x 6 township square totaling 3,357 km^2, with the remainder using combinations of ecodistricts, caribou habitat boundaries and caribou and moose home ranges (1,521 km^2 to 2,827 km^2). In the present project we evaluated cumulative effects at two spatial scales (regional study area of 27,992 km^2, and subregional area of 5,093 km^2).

2.1 Regional Study Area

We chose the regional study area to include the ranges of the East Side Athabasca River caribou herd and the Cold Lake caribou herd within Alberta, bounded on the east edge by the Saskatchewan-Alberta border (Figure 2.1). Caribou are a high profile species in this part of Alberta, and by choosing a regional study area that encompassed two caribou ranges the resulting cumulative effects assessment was well positioned to facilitate regional planning and management for this species.

2.2 Subregional Study Area

The subregional study area was nested within the larger area, and included the portion of the Winefred Lake management unit within watershed 07CE, plus a small extension to ensure the habitat around the four in-situ leases (i.e., within 10 km of the leases) was included.

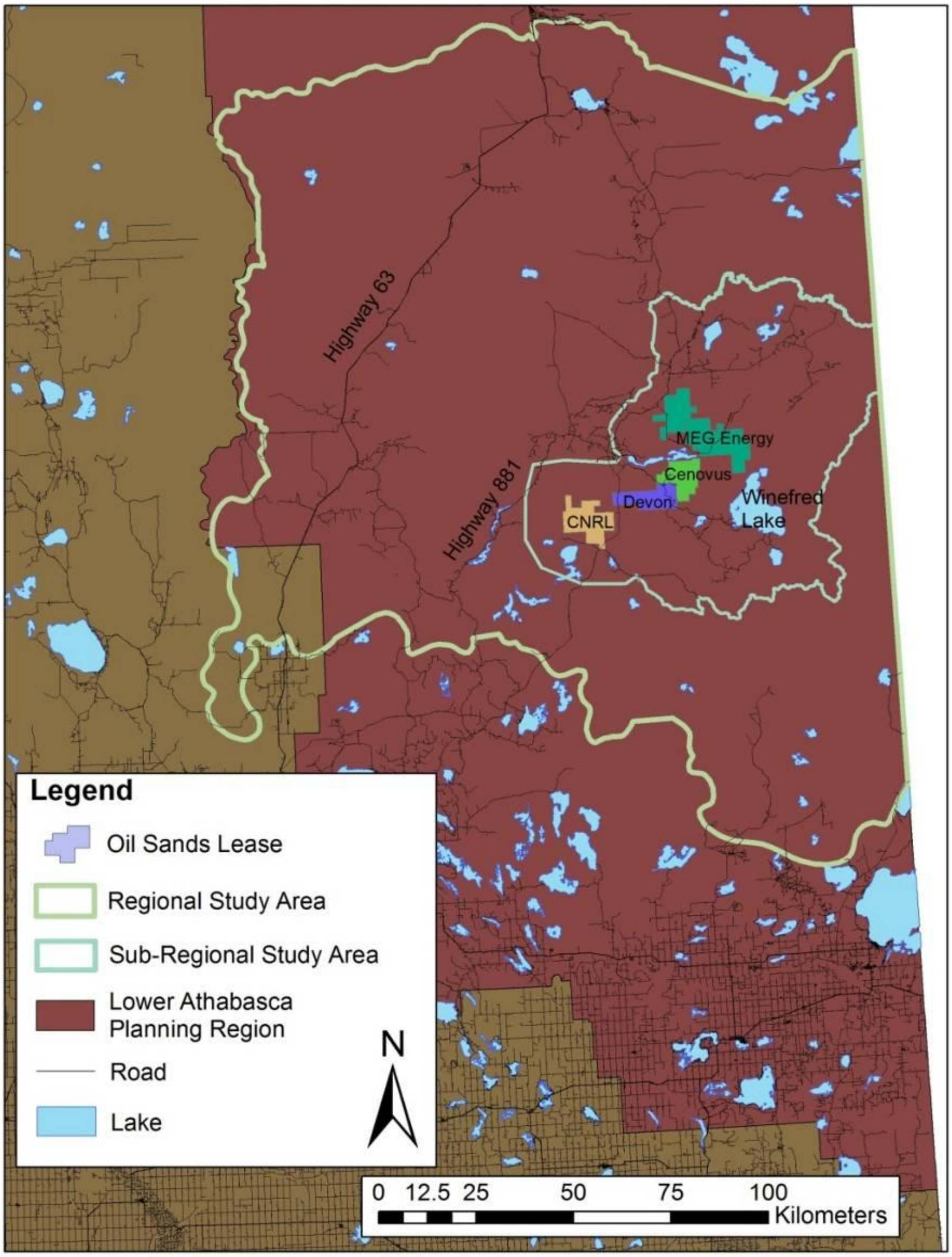

Figure 2.1. The regional and subregional study area and lease area boundaries where cumulative effects were assessed and predictions mapped.

3.0 Information Used in the Analyses

3.1 Species and Habitat Elements

Every ecosystem contains a wide variety of species and habitats, and all of these are important components of healthy functioning ecosystems. However, it was not possible to model cumulative effects for thousands of species and habitats. Rather, a representative subset was chosen as indicators. Careful thought is required when choosing indicators to ensure that the suite of species and habitats are broad and responsive enough to adequately capture cumulative effects that occur.

We reviewed five Environmental Impact Assessments (EIAs) from in-situ oil sands projects and identified the species and habitats that were included in their decision reports (Table 3.1). In addition, we reviewed the species and habitats that Government of Alberta, Fish and Wildlife identified as important to monitor when assessing ecological condition and biodiversity in the Athabasca Oil Sands region. A wide breadth of species and habitats were identified in each list, and the species and habitats varied greatly among lists.

In the present project, we chose examples that spanned the breadth of biodiversity reported in Table 3.1, and modeled those. We chose species and species groups that were expected to be affected by human development. In addition, we included an assessment of vegetation types (e.g., amount of old deciduous forest) as a coarse filter assessment of biodiversity, because vegetation can be managed explicitly during resource development. Similar methods could be used to assess cumulative effects for the other species identified in Table 3.1.

A) Coarse Filter (Landscape) Metrics: Landscape types were tracked as coarse filter assessments of ecological change in the regional and subregional study areas. Data sources are described in Chapter 4.

- For each vegetation type we assessed
    - % converted to human footprints
    - % of the remaining area that was core area (i.e., % that was >50, 200, and 2,000 m distant from human-disturbed areas)
- Forest types included:
    - Pine Forest
    - White Spruce Forest
    - Deciduous Forest
    - Mixedwood Forest
- Wetland vegetation types included:
    - Bog/Fen (wet areas with coniferous forest were included in this category)
    - Swamp/Marsh (shrub, grass, and wet areas with deciduous or mixedwood forest were included in this category)

Table 3.1. Species, vegetation and footprint indicators included in in-situ EIA's from the Christina Lake region of Alberta and/or suggested by Alberta Fish and Wildlife to monitor change in biodiversity. Ecological characteristics of the metrics are described.

Element	Taxa	ABMI Data[1]	Other Data?	Alberta Status	Game/ Fur	Specialist/ Generalist[2]	Trophic Level	Migrant	Cenovus Christina Lake[3]	CNRL Kirby North	Devon Jackfish I	Harvest /KNOC Black Gold	MEG Christina Lake	Fish & Wildlife
Riparian vertebrates	Mammal/Bird/Amphibian ?	Y		N/A	N/A	N/A	N/A	N/A						X
Grassland vertebrates	Mammal/Bird/Amphibian ?	Y		N/A	N/A	N/A	N/A	N/A						X
Wolf	Mammal	Y	X	Secure	Y	G	Carnivore	N						X
Wolverine	Mammal	N		May be at risk	Y	G	Carnivore	N						X
Fisher	Mammal	Y(?)		Sensitive	Y	S	Carnivore	N	X	X	X	X	X	
Marten	Mammal	Y(?)		Secure	Y	S	Carnivore	N						X
Caribou	Mammal	N	X	At Risk	N	S	Herbivore	N	X	X	X	X	X	X
Snowshoe hare	Mammal	Y		Secure	N	G	Herbivore	N			X		X	
Red-backed vole	Mammal	N		Secure	N	G	Herbivore	N			X			
Canada lynx	Mammal	Y		Sensitive	Y	S	Carnivore	N	X	X	X	X	X	X
Black bear	Mammal	N		Secure	Y	G	Omnivore	N	X	X	X	X	X	X
Moose	Mammal	Y	X	Secure	Y	G	Herbivore	N	X	X	X	X	X	X
Deer	Mammal	Y	X	Secure	Y	G	Herbivore	N						X
Beaver	Mammal	N		Secure	Y	G	Herbivore	N	X	X			X	X
Muskrat	Mammal	N		Secure	Y	G	Herbivore	N					X	
River otter	Mammal	Y(?)		Secure	Y	G	Carnivore	N					X	
Mammalian integrity	Mammal	Y(?)		N/A	N/A	N/A	N/A	N/A						X
Boreal Owl	Bird	?	X	Secure	N	S	Carnivore	N			X		X	
Barred Owl	Bird	?	X	Sensitive	N	G	Carnivore	N	X	X				X
Great grey owl	Bird	N	X	Sensitive	N	S	Carnivore	N				X		
Pileated Woodpecker	Bird	Y(?)	X	Sensitive	N	G	Omnivore	N			X		X	
Ruffed grouse	Bird	Y(?)	X	Secure	Y	G	Omnivore	N			X		X	
Sharp-tailed grouse	Bird	N	X	Sensitive	Y	G	Herbivore	N						X
Black-throated green warbler	Bird	Y	X	Sensitive	N	G	Insectivore	Y	X	X				

Element	Taxa	ABMI Data[1]	Other Data?	Alberta Status	Game/ Fur	Specialist/ Generalist[2]	Trophic Level	Migrant	Cenovus Christina Lake[3]	CNRL Kirby North	Devon Jackfish I	Harvest /KNOC Black Gold	MEG Christina Lake	Fish & Wildlife
Cape May warbler	Bird	Y	X	Sensitive	N	G	Insectivore	Y						X
Palm warbler	Bird	Y	X	Secure	N	G	Insectivore	Y						X
White-throated sparrow	Bird	Y	X	Secure	N	G	Omnivore	Y						X
Yellow rail	Bird	N	X	Undetermined	N	S	Omnivore	Y	X					
Whooping crane	Bird	N	X	At Risk	N	S	Omnivore	Y						X
Ducks and geese	Bird	Y(?)	X	N/A	Y	N/A	Omnivore	Y					X	X
Mixedwood forest birds	Bird	Y(?)	X	N/A	N/A	N/A	Omnivore	N/A				X	X	
Old forest birds	Bird	Y	X	N/A	N/A	N/A	Omnivore	N/A						X
Tree cavity nesting birds	Bird	Y	X	N/A	N/A	N/A	Omnivore	N/A						X
Human associated birds	Bird	Y	X	N/A	N/A	N/A	Omnivore	N/A						X
Canadian toad	Amphibian	N		May be at risk	N	S	Omnivore	N	X	X		X	X	X
Northern long-eared bat	Bat	?		May be at risk	N	S	Insectivore	Y				X		X
Native fish	Fish	N	X	N/A	Y	N/A	N/A	N/A						X
Jack pine community	Plant	Y		N/A	N/A	N/A	Autotroph	N/A	X	X			X	
Riparian plants	Plant	Y		N/A	N/A	N/A	Autotroph	N/A	X	X			X	
Productive/economic forest	Plant	Y		N/A	N/A	N/A	Autotroph	N/A	X	X	X		X	
Old growth forest	Plant	Y		N/A	N/A	N/A	Autotroph	N/A	X	X	X	X	X	
Rare plants	Plant	N		N/A	N/A	N/A	Autotroph	N/A	X	X	X	X	X	
Traditional use plants	Plant	Y		N/A	N/A	N/A	Autotroph	N/A	X	X		X	X	
Ecosite	Plant	Y		N/A	N/A	N/A	N/A	N/A			X	X		

Element	Taxa	ABMI Data[1]	Other Data?	Alberta Status	Game/ Fur	Specialist/ Generalist[2]	Trophic Level	Migrant	Cenovus Christina Lake[3]	CNRL Kirby North	Devon Jackfish I	Harvest /KNOC Black Gold	MEG Christina Lake	Fish & Wildlife
Total species at risk	All	?		N/A	N/A	N/A	N/A	N/A						X
Patterned fens	Wetland	Y	X	N/A	N/A	N/A	N/A	N/A	X	X		X		
Peatlands	Wetland	Y	X	N/A	N/A	N/A	N/A	N/A	X	X	X	X	X	
Landcover	Plant/Human	Y		N/A	N/A	N/A	N/A	N/A						X
Human/Linear Features	Human	Y		N/A	N/A	N/A	N/A	N/A						X
LFH[4] depth	Plant	?		N/A	N/A	N/A	N/A	N/A						X
Density of large snags	Plant	?		N/A	N/A	N/A	N/A	N/A						X
Coarse woody material	Plant	?		N/A	N/A	N/A	N/A	N/A						X
Land Use Footprint (Cleared/Disturbed Area)	Human	Y		N/A	N/A	N/A	N/A	N/A						X
Corridor Density	Human	Y(?)		N/A	N/A	N/A	N/A	N/A						X
Riparian Footprint (Riparian Disturbance)	Human	Y(?)		N/A	N/A	N/A	N/A	N/A						X
Core Area	Human	Y(?)		N/A	N/A	N/A	N/A	N/A						X
Inactive Footprint	Human	N		N/A	N/A	N/A	N/A	N/A						X
Restored Footprint	Human	Y(?)		N/A	N/A	N/A	N/A	N/A						X
Total Footprint	Human	Y(?)		N/A	N/A	N/A	N/A	N/A						X

1. Y indicates "Yes" the species is found in the data, N indicates "No" the species is not found in the data, Y(?) indicates "Yes" the species is found in the data but that it may not occur at high enough frequencies to be useful for producing a species distribution model.
2. Indicates whether the species' ecological niche is narrowly (specialist) or broadly (generalist) defined.
3. X indicates the species was included in the environmental assessment.
4. The organic layer of soil.

B) Biodiversity: A metric that combined information from birds and plants was used to assess how biodiversity in general respond to human footprints in the region.

- Biodiversity was modeled based on ABMI's intactness index (see Chapter 6)

C) Species Groups: We modeled three species groups as examples of how change could be evaluated for multiple groups. The groups included:

- Forest Plants (species intactness averaged across the group – see Chapter 7)
- Old-Forest Birds (species intactness averaged across the group – see Chapter 8)
- Weedy Plants (species intactness averaged across the group –see Chapter 9)

D) Focal Species: Particular species often are highlighted in cumulative effects assessments because they are thought to be especially vulnerable. Detailed modeling that takes into account unique behaviours / characteristics of that particular species is required to accurately reflect how the species respond to changes in human footprint. Two example species were modeled in this project:

- Black-throated Green Warbler
    - Cumulative effects were modeled based on changes in relative abundance (see Chapter 10)
- Caribou
    - Cumulative effects were modeled based on changes in critical habitat (see Chapter 11)
    - Interaction between the large mammal predator / ungulate community was also evaluated (see Chapter 12)

Using information from the ABMI and from Dr. Bayne's lab, predictive models were developed for each of the chosen indicators. The models, plus underlying GIS maps of vegetation and human footprint, were then used to predict cumulative effects on the indicators throughout the study area. Cumulative effects that have already occurred (defined as change in the indicator between undisturbed and 2010 conditions) in the regional study area were evaluated. Source of vegetation information is described in Chapter 4. Each indicator was mapped to highlight spatial variation in the cumulative effects. Coarse filter indicators were mapped based on actual polygons. Species and biodiversity indicators were mapped at the quarter-section resolution (approx. 65 ha^2). Cumulative effects were summarized at 2 spatial scales – the regional and subregional study areas – to highlight differences between the spatial scales.

Predicted future cumulative effects (change in the indicators between present and simulated future conditions) were evaluated for 25 and 50 years into the future. These future predictions are preliminary (see Chapter 4).

3.2 Vegetation and Habitat Information

Abundance of species in a region often changes as the habitat in which they live is altered by resource development. By understanding how species abundance varies among vegetation types, and by knowing how the availability of vegetation types change, it is possible to predict how species abundance and distribution will change as development occurs. As a complicating factor, developments often occur in landscapes that already have some existing development. Thus, managers often wish to understand both the degree to which species have already been affected by development (i.e., current cumulative effects), and the degree to which new developments will further affect the species (i.e., future cumulative effects).

To predict cumulative effects in the regional study area, four maps were created: one showing vegetation in the region with human footprint backfilled to undisturbed conditions, a second showing vegetation and human footprint presently occurring in the region, a third showing projected future human footprint and vegetation in the region 25 years into the future, and a fourth showing projected future human footprint and vegetation in the region 50 years into the future. By having maps for the complete regional study area it was possible to predict cumulative effects for the regional and subregional study areas.

For each of the four time-periods, general vegetation and human footprint types (Table 4.1) were extracted from existing GIS layers (see below).

Table 3.2. General vegetation and human footprint features that were extracted from existing GIS layers and used as inputs to cumulative effects models.

Human-disturbed Features	**Natural Vegetation Types**
Linear Features	Forest
Road & Rail	Pine (by 20 year age classes)
Seismic lines	White Spruce (by 20 year age classes)
Pipelines / Transmission Lines	Deciduous (by 20 year age classes)
Forestry	Mixedwood (by 20 age year classes)
Cutblocks	Non-Forest
Agriculture	Shrubland
Cultivated Areas	Herbaceous
Urban & Industrial	Wetland
City/Town/Rural Residential	Bog/Fen (including lowland Black Spruce and Larch Forest)
Industrial Sites	Marsh/Swamp (including wet treed areas)
Well Sites	Other
	Open Water (Lakes, Rivers & Streams)
	Rock/Bare Soil

Backfilled vegetation map ("undisturbed" conditions)

We used the ABMI Wall-to-Wall Landcover Map Version 2.1 (Alberta Biodiversity Monitoring Institute 2012a) to map current land cover (i.e., vegetation and footprint) conditions in the regional study area. We used Government of Alberta layers to differentiate pine from white spruce in this layer. In addition, we added information on wetlands and forest age from Government of Alberta GIS layers. To describe the vegetation that would have been present in the regional study area if there was no footprint (i.e., in undisturbed conditions), we backfilled linear features, cutblocks, cultivated areas and urban areas on the map based on the types of vegetation surrounding the footprint (unpublished ABMI layer). The backfill vegetation map incorporated information about fires in the region, described ages of the natural vegetation for 2010 conditions, and projected ages of the backfilled polygons for 2010 conditions.

To facilitate mapping of relative abundance, intactness and habitat suitability of the indicators, we summarized vegetation and human footprint for each quarter-section in the regional study area.

Current vegetation and human footprint (2010)

To describe the vegetation currently present in the regional study area, we used the backfilled map (above), and overlaid the ABMI Wall-to-Wall Human Footprint map 2010 Version 1.2 (Alberta Biodiversity Monitoring Institute 2012b). All vegetation that was "under" the human footprint was clipped and removed.

To facilitate mapping species relative abundance, intactness and habitat suitability under present conditions, vegetation and human footprint in the current map were summarized for each quarter-section in the regional study area.

Projected future vegetation and human footprint conditions (+25 and +50 years)

To forecast a potential scenario of future cumulative effects, we developed a simulation model that represented activity of the energy and forestry sectors and how they may spatially affect land cover over time. The model was spatially-explicit using current information on land cover (including upland and wetland vegetation types and year of last stand disturbance), human footprint, and a preliminary layer for bitumen thickness. The simulation provided a proof-of-concept approach to predicting future landscape conditions, and requires refinement.

Starting with the spatial layout of human footprint in 2010, each industry's activities were simulated into the future under a defined growth rate (for energy) and a constant harvest rate for forestry. Energy growth rates were derived from ERCB annual reports. Forestry harvest rates were simulated based on what occurred in the regional study area during the past decade (ABMI unpublished information). The simulation model operated as a grid of cells with a 6 ha resolution. Each cell contained parameters imported from the vegetation information listed above, as well as area of each human footprint by the following categories:

- Hard (paved and gravel) linear surfaces
- Soft (vegetated) linear surfaces
- Industrial

- Forestry

The simulated energy development represented individual wells (classed into active and abandoned) placed on top of the 6 ha grid of cells. Wells were generated probabilistically based on the bitumen thickness, with higher bitumen thickness receiving more new wells, up to the expected growth rate for wells. Active wells depleted the energy reserves and were converted to abandoned well when the benefit-cost equation was less than 0.

Forestry activity was simulated by harvesting upland forest stands >80 years old, within the area of the 'mixed use activities' as outlined in the Lower Athabasca Regional Plan (Figure 4.1). All other vegetation types were avoided by harvest. Cells which met the harvestable criteria were harvested, up to a constant harvest rate of 4,971 ha per year.

Energy and forestry activities were calculated for 25 and 50 years into the future in the simulation, and the result was predicted spatially on the landscape. Other human footprint types, including hard linear surfaces (roads, rail, etc.), urban, agriculture and mines were assumed to remain static in the simulations. Forestry footprint included only areas that had been harvested during the last 40 years. Energy footprint was assumed to be a 2.62 ha area around each of the simulated well sites. Wells typically have an area of 1 ha, but because other related activities such as processing plants and supporting industrial facilities were not modelled in this preliminary work, the well pad area was increased by a multiplier of 2.62, as estimated from geospatial statistics from the backfilled data. Lastly, soft linear surfaces were modelled as a statistical relationship between the density of wells and the presence of pipelines and unpaved roads. The geo-spatial statistic for soft linear features was preliminary and requires further development.

To simulate future conditions, information from the ABMI backfilled layer (described above) was converted to the categories/format used in the simulation (Figure 4.2). By combining vegetation information, simulation assumptions on forestry and energy development, and the assignment of human footprint types to the grid of cells, we were able to generate simulated future of development for the region. Simulation information was summarized and mapped 25 and 50 years into the future (at both the 6 ha and quarter section scales). These maps were used to model cumulative effects on biodiversity at these points in time.

Although we have labeled the simulations as 25 and 50 years into the future, those dates are approximate. Economic and regulatory drivers will determine the actual pace of resource development in the region, and the landscape conditions described for 25 and 50 years may occur much earlier or later.

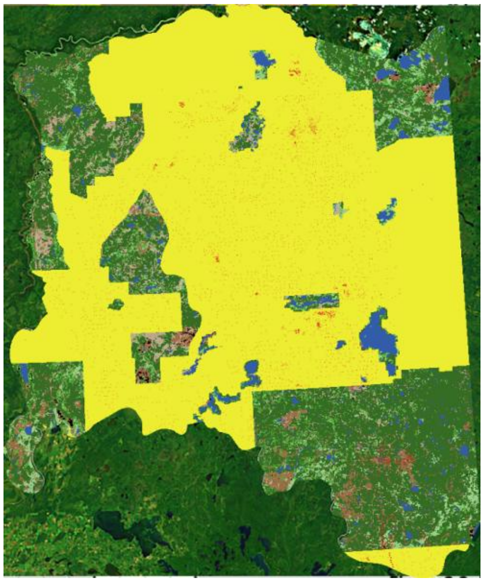

Figure 3.1. Location of the Lower Athabasca Regional Plan mixed use areas (coloured in yellow) that were used in the simulation modeling for forest harvest.

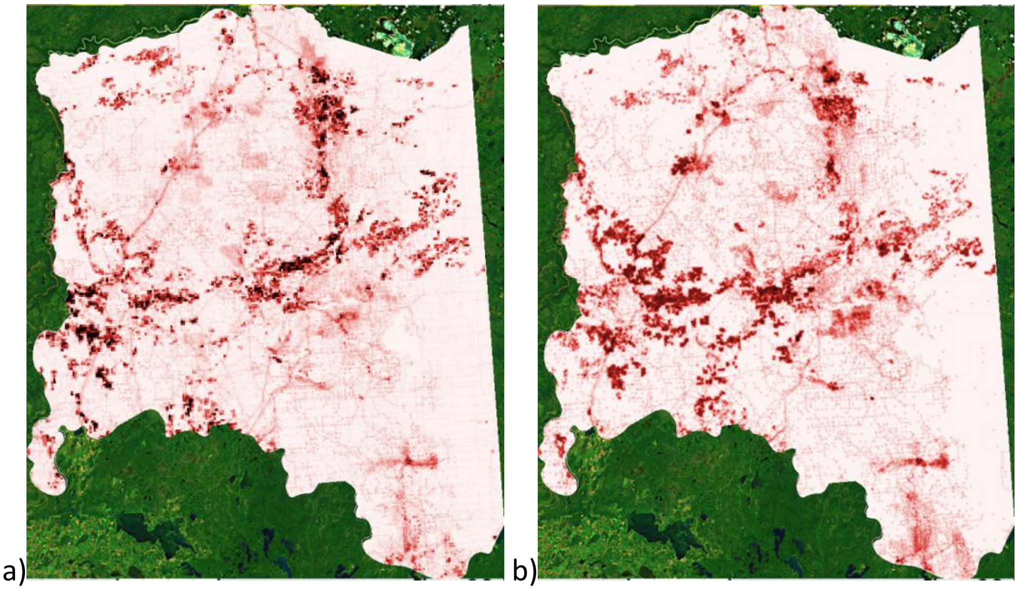

Figure 3.2. Total Human Footprint (THF) for: a) 2010 conditions [this information was used to facilitate fine resolution sampling for the simulation modeling], and b) the estimated 2010 THF using the simulation modelling assumptions [for comparison to a]. This conversion was necessary to facilitate simulations that used pixels rather than polygons. Linear gradient of shaded indicates 0% THF = white to 80% THF = dark red.

4.0 Modeling Limitations

Although robust statistical modeling techniques were used in the present study, a number of limitations were inherent in the approach and/or data used; these are discussed here.

There were errors in the vegetation and footprint layers

Uncertainty in the vegetation and human footprint information affected models for individual species and for species groups. The ABMI wall-to-wall vegetation map had a moderate rate of classification error for some vegetation types. This was the best vegetation information available for the complete region, but errors still affected modeling results. The ABMI human footprint layer was more accurate than the vegetation layer, but it also contained errors.

Vegetation recovery was not completely accounted for

All human footprints that occurred in the region were included in our analyses. Vegetation and biota recover over time in some disturbed areas (eg., trees and native vegetation regrow in cutblocks and along seismic lines and this results in native biota using these features), and this recovery was only partially captured in our analyses. We modeled differences in species relative abundance and intactness between cutblocks of different ages, but were not able to model recovery of seismic lines or well sites. Incorporating vegetation recovery will be important for future modeling.

Future simulations did not encompass all footprint types

Agriculture and urban development were not modeled as part of the future simulations. In addition, roads and railways were assumed to remain static. Finally, amount of seismic lines and pipelines were modeled as a function of the well sites that were predicted to be created in the future. These modeling limitations require research to determine how they can be included in future simulations. Also, accurate data for bitumen pay thickness, other energy reserves, and information on actual planned future developments will be required to improve accuracy of future simulations.

Backfilled and future conditions are examples

Backfilled and simulated future conditions used in the present study were just examples of many suites of conditions that were possible. The backfilled map was created by filling the human footprints with the same types of native vegetation as presently existed around these footprints. However, the amount and distribution of old forest in the region will have varied historically due to the dynamics of fires, pest outbreaks and other natural disturbances. As such, the diversity of seral stages that has been present historically was not captured by our models. Future simulations were also created using a single scenario, whereas a number of scenarios are possible. It will be necessary to estimate current and future cumulative effects under a variety of backfilled and simulated future scenarios to more fully understand the range of cumulative effects that may occur in the region. The cumulative effects presented in this project are just one outcome of a family of potential cumulative effects scenarios.

Only broad categories of vegetation and human footprint types were used in the modeling

Because we had a limited number of sites and many species to model, our models were based on broad vegetation and human footprint types. We did not have sufficient data to look at relationships between species occurrence and specific human footprint types. For instance, mines, processing facilities, well pads, compressor stations, refineries were all called "industrial footprint", and due to mapping limitations these industrial footprints were included in the same category as urban and residential footprints. In addition, forest types were evaluated as four broad categories in the modeling. Combining human footprint categories may have had large effects on the models for some individual species. For example, species associated with human residences were erroneously modeled as preferring industrial sites (because urban and industrial footprints were combined into the same category). More data will be required to model more detailed vegetation and human footprint categories.

Not all species were modeled

In this project, we modeled cumulative effects for only a small proportion of species living in the regional study area. Species-specific models were presented for only two species (caribou and black-throated green warbler) yet many species of birds, mammals, herptiles, fish, vascular plants, mosses, lichens, insects, bacteria, fungi, and algae live in the region. In addition, our species groups included only a small proportion of the species groups that could have been modeled. Finally, we only selected species with enough detections to create statistically robust models; this excluded more than half the species detected in field surveys within the region. For a robust assessment of cumulative effects on biodiversity, it will be necessary to model more species and species groups. Note, however that we assessed conversion of vegetation types as a practical coarse filter tool to assess cumulative effects for species that were not modeled directly.

Modeling involved confounded data

Even with the large sample size included in our data, it was not possible to create balanced sampling designs for some species. For example, the spatial pattern of human disturbance was sometimes confounded with spatial trends in occurrence/abundance of a species. We included spatial terms in the models to account for the confounding effect of location where possible.

Footprint modeling was at a local scale

Vegetation and footprint coefficients were calculated at the sampling scale appropriate for the species being modeled (1 ha scale for plants, 150 m radius circle scale for birds with additional effects of footprint at the quarter section scale included). Modeling, however, did not include effects at larger scales. At the scale of the regional study area, we were therefore reporting the additive effects of local footprint, not larger emergent effects of landscape isolation and connectivity.

There was uncertainty in the models and large uncertainty in pixels on the cumulative effects maps

There were two types of statistical error in the maps of intactness/cumulative effects. The first was uncertainty in the underlying statistical models, which was directly related to the amount of data used in the analyses. Secondly, there was a large amount of uncertainty for predictions about each quarter section because predictions were simply the regional average values given the vegetation and human footprint types present in that quarter section. We did not know the actual abundance, intactness or habitat suitability for a specific quarter section nor how it changed between reference and current conditions. The actual abundance, intactness and habitat suitability of each quarter section could be much higher or lower than the average value we depicted due to unique features of that quarter section. As such, when information was summarized for a small area, we assumed that the relationships derived from models for the larger region held for the small area. That assumption may not have been true for small areas with distinct vegetation types or with distinct footprint types.

Intactness measures predict effects of local change in footprint, not necessarily historic change in species abundance

Cumulative effects (intactness) was calculated by first modeling the relationship of each species to human footprint types, then predicting their abundances with current vegetation and human footprint compared to the abundance predicted when the human footprint was backfilled. Intactness was the ratio of current/backfilled conditions, or its inverse for species that increased in human footprints. Intactness was therefore simply a measure of how much the species was predicted to have been affected by local human footprint. This information can be thought of as “change in the habitat suitability for each species”. We had no information about how much species changed in the study area, or at a given location within the study area, due to other reasons. For example, species’ actual change may have been related to climate change, change in conditions on the wintering ground for species that migrate, changes in intra-specific interactions or other changes.

5.0 Vegetation / Habitat

5.1 Introduction

Many species live in the Oil Sands region but it was not possible to assess cumulative effects for all of them. Thus, vegetation and landscape metrics are often included in cumulative effects assessment as “coarse filter” evaluations for species that cannot be assessed individually (Franklin 1993). By understanding the degree to which the amount and pattern of native vegetation changes, managers can assess coarse environmental changes in the region (Lindenmayer et al. 2000). Coarse filter assessment of vegetation change usually is accomplished through remote sensing.

We evaluated the degree to which native vegetation was converted to human footprints. The following vegetation types were included in the analyses:

- Pine Forest
- White Spruce Forest
- Deciduous Forest
- Mixedwood Forest
- Shrubland
- Grassland/Herbaceous
- Bog/Fen (wet areas with coniferous forest were included in this category)
- Swamp/Marsh (shrub, grass, and wet areas with deciduous or mixedwood forest were included in this category)

Upland forest types were sub-divided into 20-year age categories.

Species abundance also can be affected indirectly by the human footprints that are created during development. Some species live within human created habitats, and these often use adjacent native vegetation types. These species may forage both within the human footprints and within the adjacent native vegetation (Brothers & Spingarn 1992). In addition, environmental conditions in the human footprints can affect conditions in adjacent vegetation (Chen et al. 1995). These “edge effects” may result in native species having relatively low abundance in native vegetation surrounding developed areas simply because that vegetation is adjacent to human footprint (Flaspoller et al. 2001). We measured core area, the inverse of edge effects, by creating spatial buffers of various sizes around human footprint and determining the proportion of the study area that was outside of these buffers.

5.2 Methods

Changes in amount and pattern of vegetation were summarized using GIS. Four spatial datasets were created for the regional study area: one describing the native vegetation expected with the human footprint backfilled, a second describing the native vegetation plus human footprint occurring in the study area for 2010 (labeled as present conditions), a third for footprint and vegetation simulated 25 years in the future, and the last for footprint and vegetation simulated 50 years into the future. Methods used to create these datasets were described in Section 4.1. Simulations of future conditions were preliminary, and need to be interpreted with caution.

Habitat conversion

We calculated the difference between the area of each natural vegetation type expected based on the backfilled map, and the area of each vegetation type remaining under current conditions in which some native vegetation has been converted to human footprint. Analyses were conducted at two spatial scales: the total regional study area and the subregional study area.

Edge effects

We calculated the degree to which the native vegetation remaining under current conditions was adjacent to human footprints. We created buffers around the human footprints present in 2010, and summarized the area of each vegetation type in each of the buffers. Four buffer sizes were used:

- 0-50 m from the human footprint
- 51-200 m from the human footprint
- 201-2,000 m from the human footprint
- >2,000 m from the human footprint.

Distances of 50 and 200 m were chosen because they were typical edge-effect distances reported in studies about microclimate and biota, respectively. A buffer distance of 2,000 m was chosen to identify areas that would be classified as “wilderness”. All human footprint types were treated as equivalent in these analyses.

5.3 Results

Vegetation composition

Under backfilled conditions, bog/fen was the most common vegetation type and it occupied approximately 50% of the regional study area (Table 5.1). Bog/fen habitats were present throughout the entire region (Figure 5.1). Swamp/marsh occupied 18% of the study area, with most found in the eastern half of the region. White spruce forest was the next most common, occupying 11% of the region. Approximately one-third of the upland forest was less than 40 years old, one-third 40-100 years old, and one-third older than 100 years (Table 5.1). Upland forest occurred as a semi-circular band in the northwestern part of the study area, but also as many scattered pockets throughout other areas (Figure 5.1). None of the other vegetation types occupied more than 7% of the region.

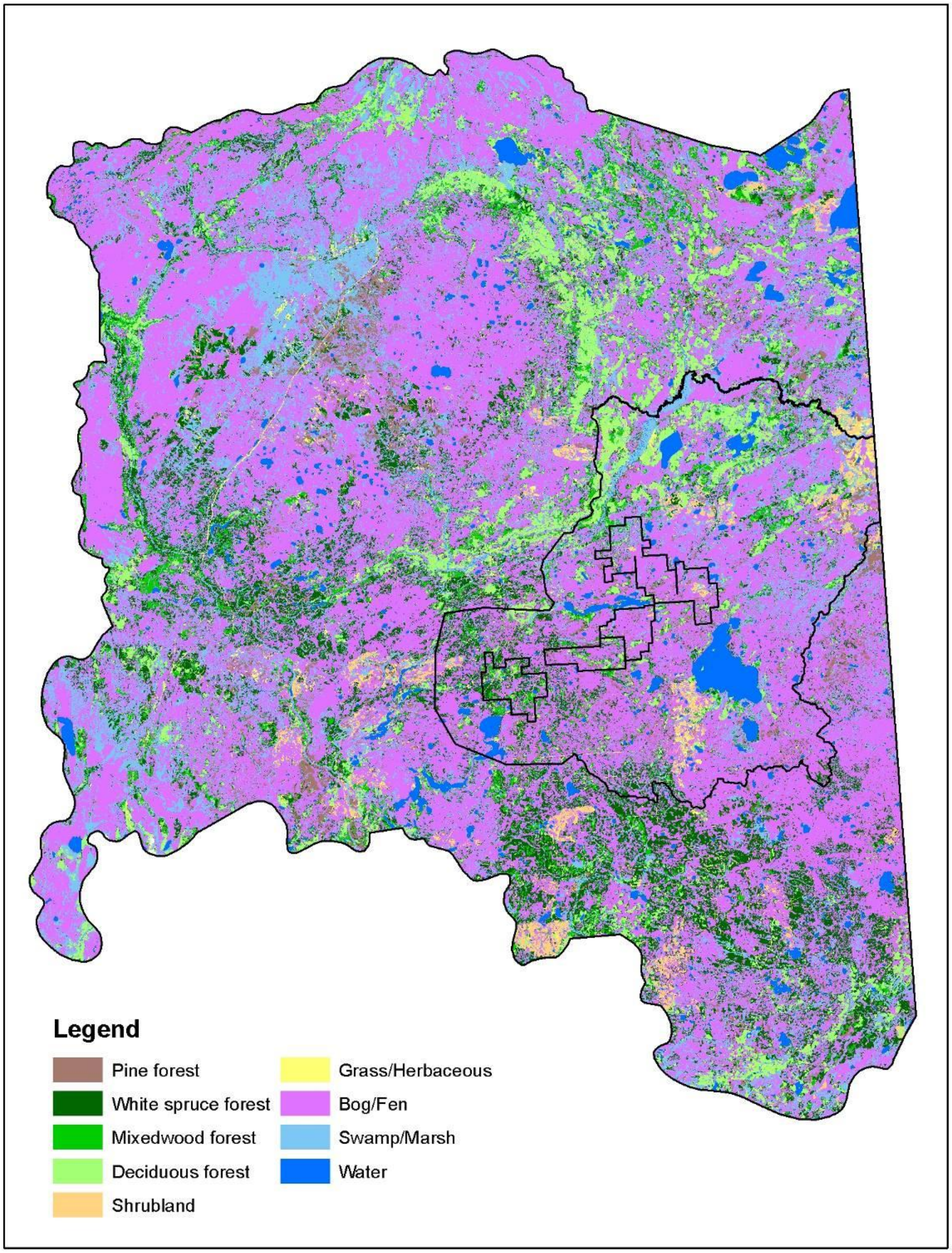

Figure 5.1. Map of the regional study area showing the native vegetation expected based on present (2010) conditions with human footprint backfilled (as described in Section 4.1). Boundaries for the subregional area and oil sands lease areas are outlined in black.

Table 5.1. Area (ha) occupied by each vegetation type under backfilled "undisturbed" conditions in the regional and subregional study areas.

Habitat Type/Age	Within Region (ha)	Within Subregion (ha)
Pine Forest		
0-19 yr	27,566	4,174
20-39 yr	14,964	2,836
40-59 yr	1,757	60
60-79 yr	22,404	5,961
80-99 yr	17,699	6,346
>100 yr	8,352	2,012
All Ages	92,742	21,389
White Spruce Forest		
0-19 yr	92,093	13,734
20-39 yr	18,302	2,791
40-59 yr	4,019	149
60-79 yr	37,895	6,592
80-99 yr	28,518	6,049
>100 yr	133,549	9,127
All Ages	314,377	38,442
Deciduous Forest		
0-19 yr	17,537	1,844
20-39 yr	10,971	1,293
40-59 yr	8,489	436
60-79 yr	54,633	7,027
80-99 yr	46,560	10,831
>100 yr	55,047	9,753
All Ages	193,237	31,185
Mixedwood Forest		
0-19 yr	16,937	2,925
20-39 yr	3,534	471
40-59 yr	1,977	124
60-79 yr	21,821	2,911
80-99 yr	18,645	4,024
>100 yr	44,573	6,806
All Ages	107,486	17,260
Shrub land	45,962	12,523
Grass/Herbaceous	38,966	7,594
Bog/Fen	1,415,594	245,775
Swamp/Marsh	489,354	69,693
Bare	43	0
Water	101,358	33,597
Total	**2,799,119**	**509,307**

The subregional area encompassed approximately 20% of the regional area, and had very similar vegetation composition (Figure 5.1, Table 5.1).

Habitat conversion

Under current conditions, human footprint covered 6.0% of the regional study area. Cutblocks were the most common human footprint (these accounted for approximately 50% of the footprint), with seismic lines, pipelines and well sites each accounting for 10-15% of the footprint (Table 5.2). Human footprint covered a similar percentage (6.3%) of the subregional area as found in the region, and the composition of this footprint was similar (Table 5.2).

Table 5.2. Area (ha) of the current human footprint in the regional and the subregional study areas.

	Within Region (ha)	Within Subregion (ha)
Urban/Industry	3,892	1,018
Mine	2,192	296
Well	16,100	3,777
Cultivation	1,203	234
Cutblock	94,153	15,666
Rail	460	152
Road	5,864	1,785
Pipeline	17,731	3,921
Transmission Line	1,708	301
Seismic Line	25,223	4,675
Total Footprint	**168,525**	**31,824**

Human footprint occurred throughout the regional study area (Figure 5.2). Well sites, seismic lines, and linear features (Figure 5.3B, C, and D, respectively) had higher densities in the center of the region than on the east and west edges. Note that widths of linear features were exaggerated on the maps so that the features were visible. Not surprisingly, cutblocks were most common in areas with upland forest (compare Figures 5.1 and 5.3A). There were very few agriculture, mine, and urban footprints in the region (Figure 5.3A). Percentage of each quarter section occupied by human footprint was mapped to accurately describe amount and dispersion of human footprint throughout the region (Figure 5.4). Forest harvest was the predominant human footprint in quarter sections that had >50% of their area disturbed.

Human footprint occurred disproportionally in deciduous forest, mixedwood forest and grass/herbaceous vegetation types with 15-20% of these habitat types converted to human footprint (Table 5.2). Most other habitats had less than 5% of their area converted to human footprint, although white spruce had an intermediate level of conversion (12%).

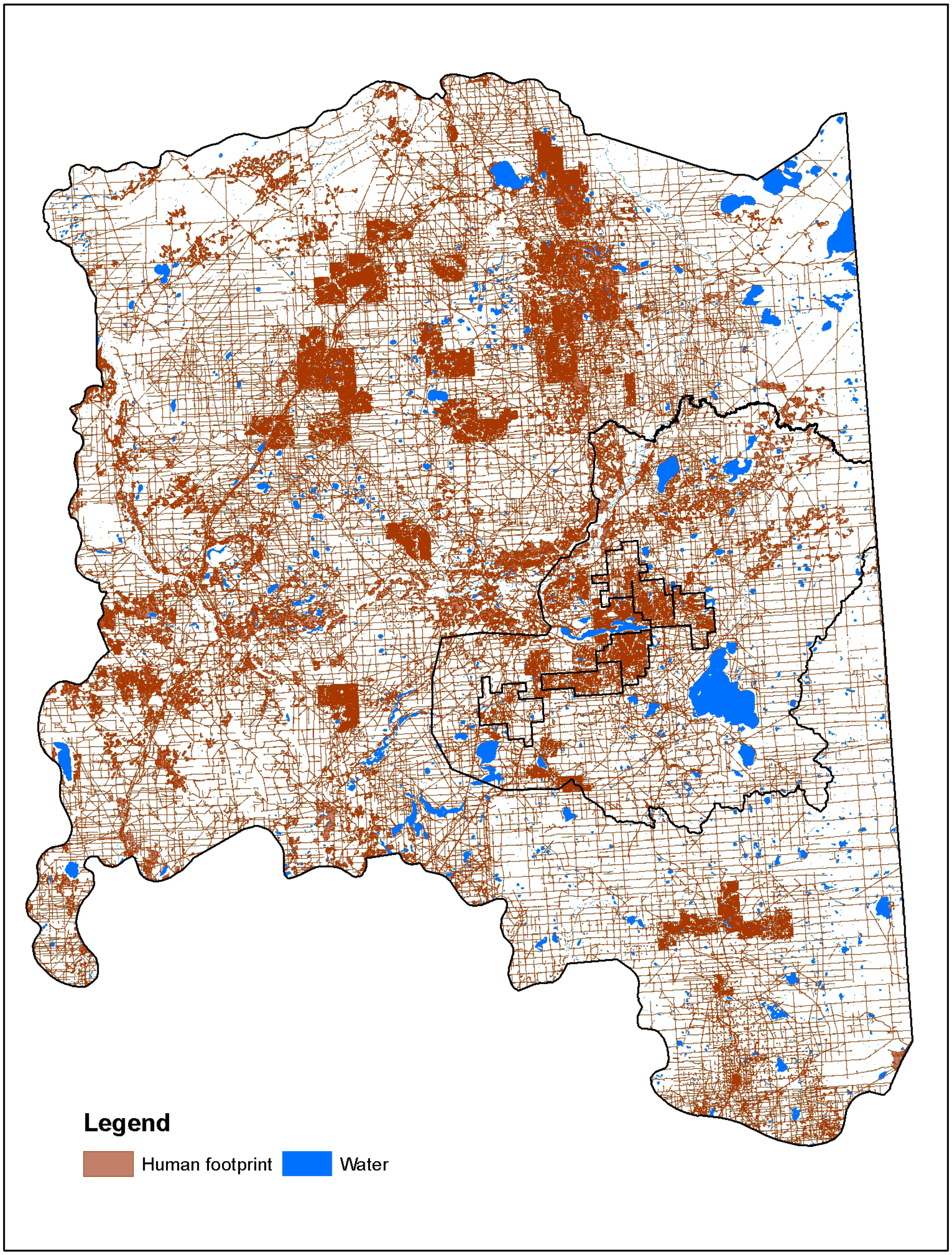

Figure 5.2. Map showing all human footprints (circa 2010) throughout the regional study area. Note that linear features were plotted with lines as thin as possible, but the width of these was still exaggerated resulting in “apparent patches” of development created by clusters of very dense seismic lines.

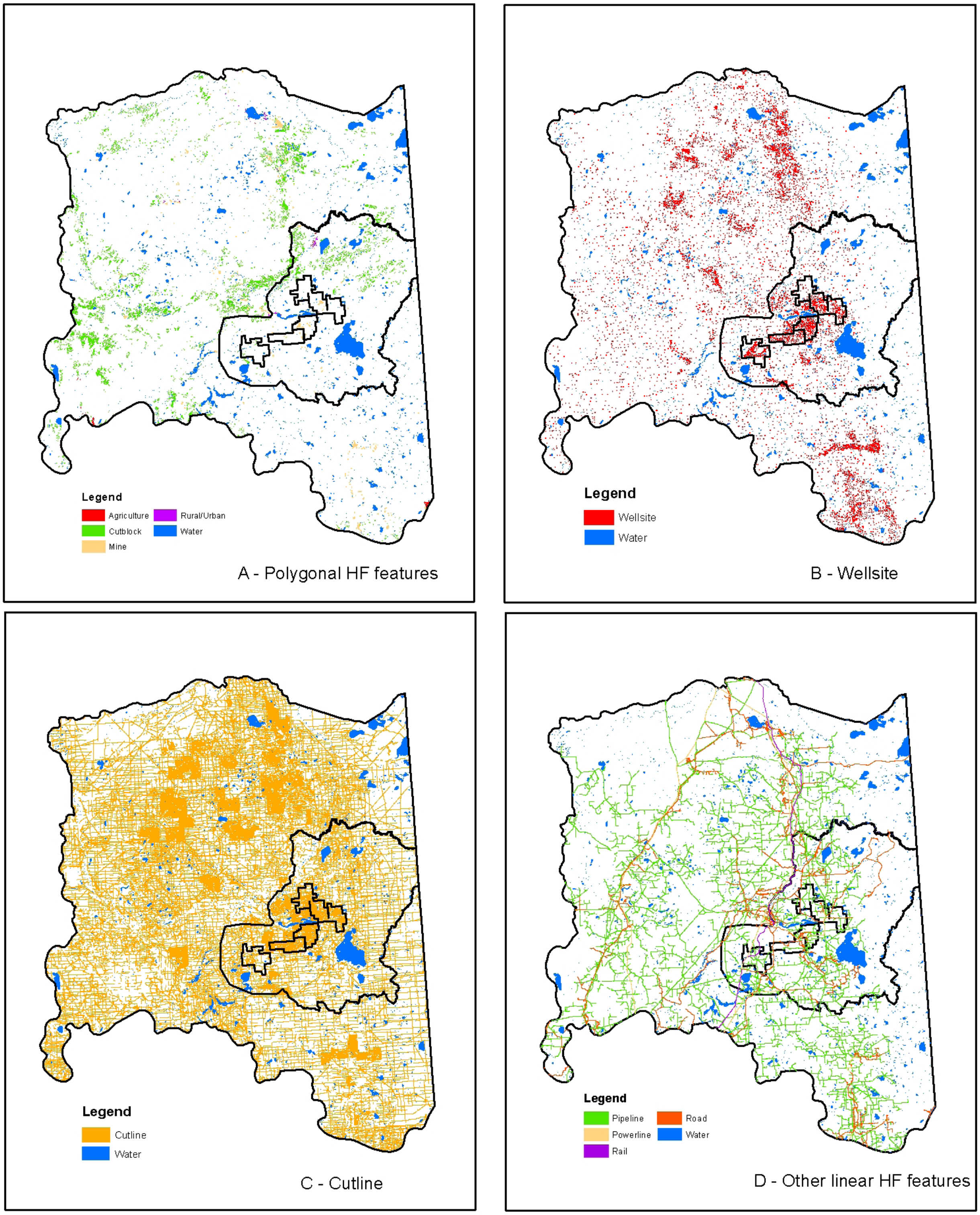

Figure 5.3. Map of the study area (circa 2010) showing: A) agriculture, cutblocks, rural residential, industry and mine sites, B) well sites, C) cutlines, and D) roads, railways, pipelines and transmission lines. Note that widths of linear features were exaggerated so they are visible.

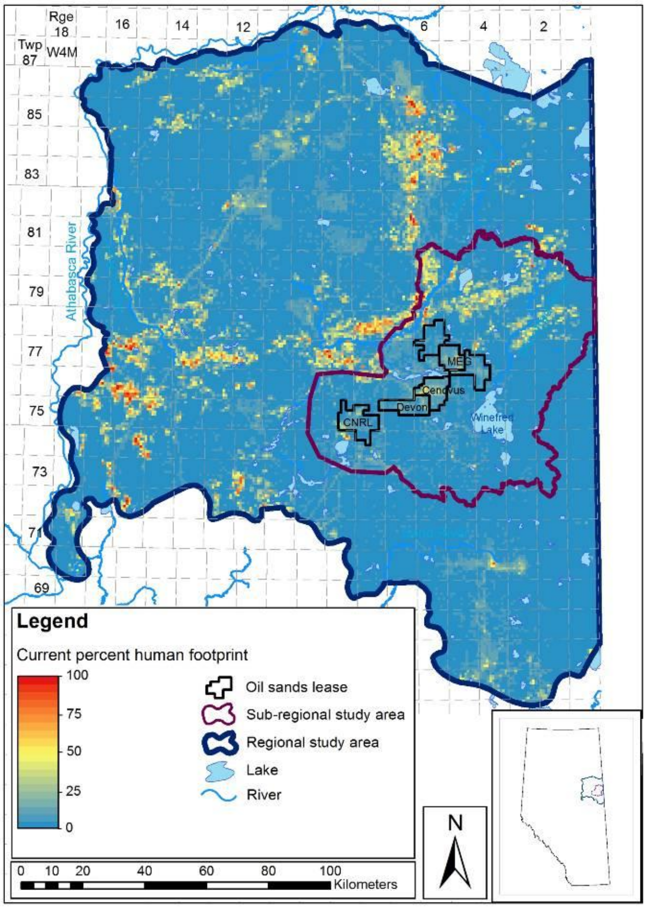

Figure 5.4. Map showing the proportion of each quarter section occupied by human footprint in 2010. Vegetation recovery in footprints has not been incorporated.

Core area

Human footprints were dispersed throughout the regional study area (Figures 5.2 & 5.4). As a result, even though there was only 6% of the native vegetation converted to footprint in 2010, many areas had little or no native vegetation greater than 50 m from human footprint (Figure 5.5B). Recall that all human footprints, including seismic lines, were buffered when calculating core area. Large portions of the study area were less than 200 m from human footprints (Figure 5.5C), and only 1% of the area was greater than 2 km from human footprint (Figure 5.5D).

For the most part, buffers on human footprint did not occur within a particular vegetation type more than expected at random (Table 5.3). The one exception was grass/herbaceous vegetation, which had approximately half of its remaining area less than 50 m from footprint, compared to the 20% that was expected at random.

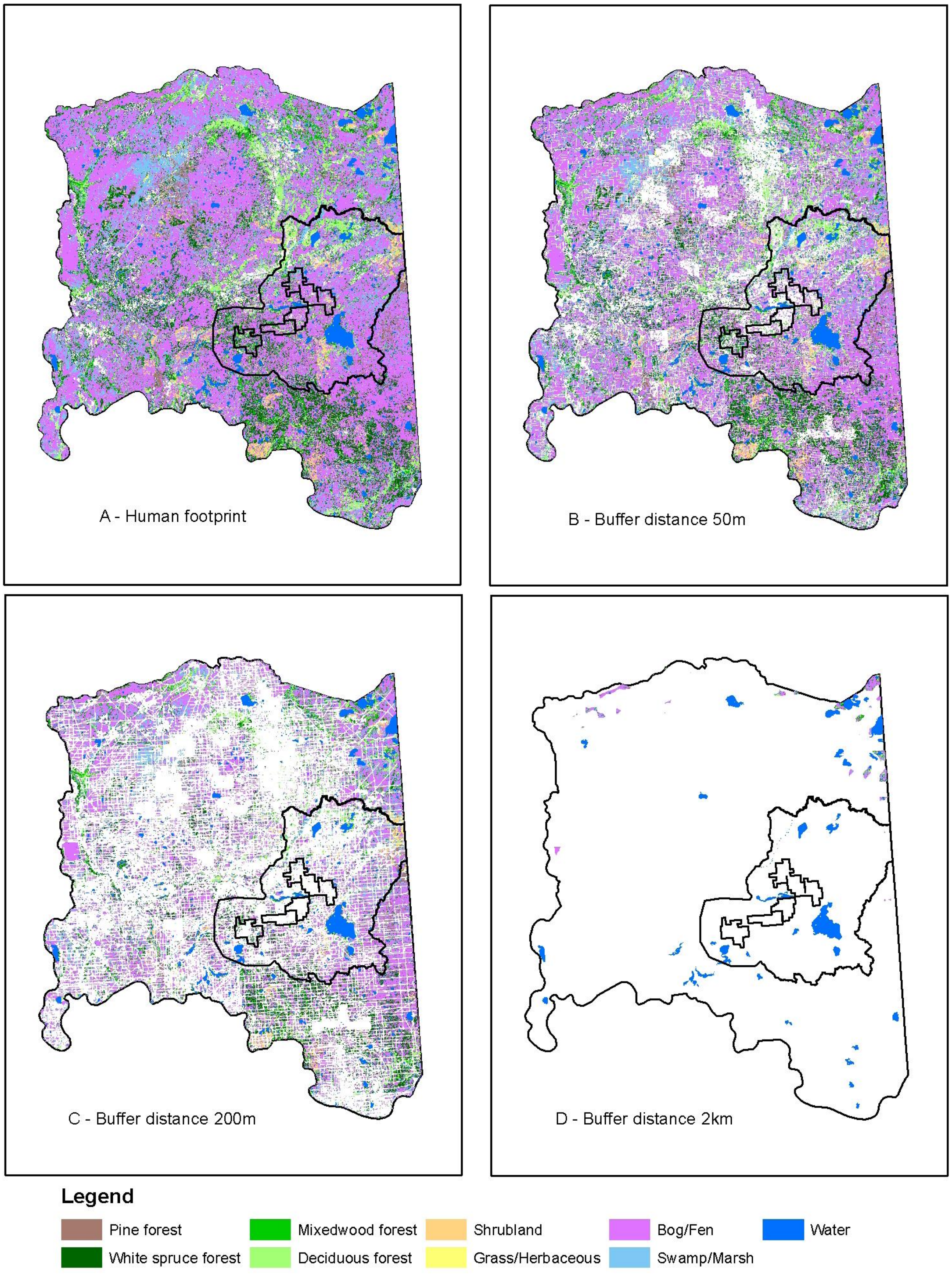

Figure 5.5. Map of the regional study area showing native vegetation that was: A) is outside the human footprint, B) >50 m from human footprint, C) >200 m from human footprint, and D) >2,000 m from human footprint. Due to the scale of the presentation, many of the narrow footprints (e.g., seismic lines) were not visible in panels A & B.

Table 5.3. Percent of each vegetation type categorized based on distance from human footprint. Categories include: directly converted by human footprint, 0-50 m, 51-200 m, 201-2,000 m, and >2,000 m from human footprint. Area of each vegetation type in the regional study area was provided in the second column (shaded in grey).

Habitat Type	Area (ha)	Converted to Human Footprint (%)	0-50 m from Footprint (%)	51-200 m from Footprint (%)	201-2,000 m from Footprint (%)	>2,000 m from Footprint (%)
Pine Forest	92,742	6.4	22.6	30.8	39.5	0.7
White Spruce Forest	314,377	11.5	18.8	32.2	37.3	0.3
Deciduous Forest	193,237	19.2	19.2	31.6	29.4	0.6
Mixedwood Forest	107,486	14.0	18.6	31.9	34.5	0.9
Shrub land	45,962	2.1	18.4	33.9	45.4	0.2
Grass/Herbaceous	38,966	19.1	45.6	20.5	14.8	0.1
Bog/Fen	1,415,594	3.1	21.0	34.8	40.4	0.8
Swamp/Marsh	489,354	4.4	20.5	34.6	39.8	0.7
Bare	43	14.0	60.4	25.6	0.0	0.0
Water	101,358	0.0	1.9	15.5	73.6	9.1

5.4 Projections

Based on simulated forest harvest and development of energy facilities during the next 25 years, human footprint was predicted to grow from 6% of the regional study area at present, to 10% in 25 years, and 11% in 50 years. The dominant change was predicted to be human footprint spreading away from what was present in 2010 (compare Figure 5.4 with Figure 5.6a). In addition, the intensity of human footprint in many quarter sections was predicted to decrease as some of the cut-blocks became older than 40 years and were no longer considered as human footprint. A secondary pattern noted was the gradual accumulation of well sites and soft linear features throughout the region. Both of these changes were projected to continue during the following 25 years (compare Figure 5.6a with Figure 5.6b), but the absolute amount of human footprint was not predicted to increase greatly because cut-blocks and well sites older than 40 years were assumed by the model to have recovered to natural vegetation by this time. Note that these projections were preliminary and should be interpreted as a "proof of concept"; as better information and models are developed the results may change.

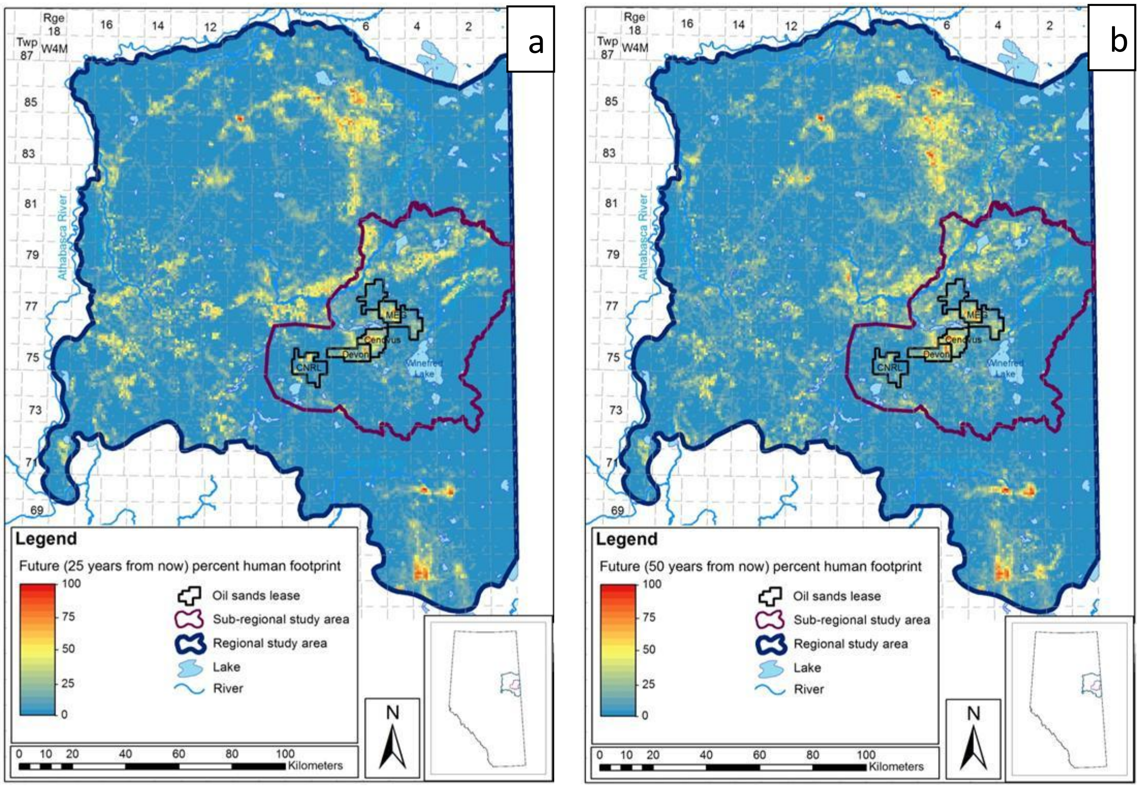

Figure 5.6. Maps showing proportion of each quarter section projected to be occupied by human footprint (a) 25 years, and (b) 50 years into the future. Cutblocks and well sites were assumed to recover to native vegetation 40 years after they were disturbed.

5.5 Discussion

Present conditions

Two main results emerged from the evaluation of coarse filter metrics. First, although conversion to human footprint only occurred for 6% in the region, three vegetation types (grassland/herbaceous, old deciduous and old mixedwood forest) had disproportionate amounts of their area converted to human footprint. For the forested blocks, this was not surprising because forest harvesting targets older upland forest. Landscapes with abundant cutblocks however, still have high biodiversity intactness because forest cutblocks - although large in size - have only moderate effects on species living in the area (Chapters 6-10). In cutblocks, soil disturbances are minimized during harvest and abundant natural vegetation and structure are often retained. In addition, trees and natural vegetation regenerates in the cutblock, and natural forest biota, including native forest birds, mammals and other small biota return to these areas as the forest regrows.

It is unclear what caused the disproportional conversion of grass/herbaceous vegetation to human footprint, but this vegetation type may have been attractive for industrial development because it did not require forest clearing to develop it. The high rate of disturbance for this vegetation type, however, suggests that management actions may be required to retain it on the landscape.

The second major result was that edge effects were very prominent throughout the regional study area. Even with only 6% of the native vegetation converted to human footprint, more than half of the region was within 200 m of footprint. As such, biota that thrive in human-disturbed edge habitats (i.e., “weedy” and “human associated” species) were expected to be common throughout the region. In addition, “weedy” and “human associated” biota were expected to invade much of the remaining native vegetation and interact with native biota living there. The consequences of these interactions, however, will differ among species. Some native species are able to live close to human footprint, and intactness for some birds and vascular plants remained high in landscapes that had high densities seismic lines and other small/disturbance (Chapters 6-10). At the other extreme, selected by caribou declined near human footprints (Chapters 11, 12), and the broad dispersion of human footprints in the regional study area is expected to negatively affect this species. Differences among species highlight the need to assess cumulative effects for multiple species, so that the complete range of consequences are evaluated. Only 1% of the regional study area was greater than 2 km from human footprint and thus isolated enough to be considered true wilderness. Management for wilderness areas, under present and currently predicted future conditions, may only be feasible outside the study region.

Predicted future conditions

Projected future conditions were a preliminary depiction because i) location and amount of energy resources in the region were only coarsely described, ii) the simulation model was preliminary, and iii) growth of hard linear features, agriculture, mines and urban development were not modeled. Human footprint was predicted to increase from presently occupying 6% of the regional study area to occupying 11% in 50 years. Recall that the actual rate of resource development is uncertain, and the 50-year results may occur earlier (e.g., by 30 years into the future), or later (eg., 90 years into the future). The pattern and amount of footprint growth was directly determined by the simulation algorithm, and if a different algorithm had been used the results would have been different.

6.0 Biodiversity

6.1 Introduction

We represent biodiversity in this study by using 192 vascular plant species and 90 songbird species with enough data to analyse (present at ≥30 sites within the datasets used; Appendix 16.1 and 16.2).

Results included current and reference abundance of each species. Reference abundance was defined as the predicted abundance of a species with no footprint (i.e., all footprint was back-filled with the vegetation expected prior to disturbance). Current and reference abundances were combined into intactness of the species, using the ABMI intactness measure: current/reference*100% if current < reference (i.e., a species that decreased with footprint) or reference/current*100% if current > reference (i.e., a species that increased in footprint) (Nielsen et al. 2007)[1] . For example, a species that had current abundance at half the reference value or twice the reference value both have an intactness of 50%. Intactness for groups of species, and for the entire taxonomic groups of birds and plants, were the average intactness for all species in the group. Overall (biodiversity) intactness was calculated as the average values for all birds and plants. The broader roll-ups of intactness for many species may be most useful for cumulative effects assessments, but individual species results may be used in specific cases and were important for checking that the components of broad intactness made sense.

6.2 Methods - Abundance by Habitat Type and Surrounding Footprint

The analysis estimated the index of relative abundance (i.e., intactness) of each species in the following habitat types:

- upland pine, 20-year age classes
- upland white spruce, 20-year age classes
- deciduous, 20-year age classes
- mixedwood, 20-year age classes
- lowland conifer, 20-year age classes
- open types (grass, shrubs, wetlands),
- human footprint types, including forestry cutblocks by pine/conifer/deciduous and 20-year age classes, agriculture, urban/industrial[2], soft linear features and hard linear features.

Estimates of relative abundances were for the actual area sampled for each group: 1 ha for plants, 150 m radius circle for birds. The analysis also included additional parameters to describe effects of footprint types in a quarter-section (~64 ha) area around the sampling point.

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[1] For details of the intactness calculation, see: http://www.abmi.ca/ FileDownloadServlet?filename= 20029_ABMI_2011-07- 07_Species_Habitat_Intactness_Manual.pdf&dir=REPORTS_UPLOAD

[2] Current footprint information did not reliably distinguish urban/residential footprint from industrial sites.

ABMI was the only source of information used to model habitat associations and footprint effects for the vascular plants, but for songbirds additional information from Dr. Erin Bayne (University of Alberta) and North American Breeding Bird Survey (BBS) were used. The analyses therefore differed between the two taxa.

Plants

The ABMI data are too sparse to allow direct estimates for each 20-year age class for all forest types. The analysis was therefore done using broader groupings of age classes, followed by interpolation to the 20-year classes. Two complementary analyses were used:

1) General linear models (GLM) were fit as a logit-link binomial GLM for each species, the data being 0-4 occurrences of the species within 4 quadrats at the 1 ha site. Six models were used with different options for grouping the vegetation types. Latitude, longitude and latitude*longitude were used as covariates, to account for spatial trends in species' abundances. To get coefficients for each vegetation type, predictions were made for a hypothetical site with 100% of the vegetation type, with results from the 6 models combined using AIC-weighted model averaging.

2) Dominant-type estimates were direct estimates of the species abundances in sites that had >75% of a vegetation type. This simple mean often was more precise than the parameter from the complex GLM model, but it could not factor out the contribution made by the area (up to 25% of the site) composed of other vegetation types and spatial trends. There were no sites with >75% hard or soft linear features, or grass. For these types, were combined with urban/industrial footprint, recent cutblocks, and shrubs, respectively, and the resulting categories used to calculate the simple mean.

To obtain a single estimate for each habitat type, the GLM and simple dominant-type mean estimates were combined by multiplying the probability distributions of the estimates. The procedure was bootstrapped 100 times, with the site as the unit of resampling, to estimate uncertainty in the coefficients.

These analyses produced estimates combining three or more age classes within a forest type, and some models combined different forest types. To obtain estimates for each 20-year class within a forest type, we applied the estimates for broader vegetation groups to each of the 20-year classes they contained, producing nine points (i.e., nine 20-year age classes) for each forest type. We then fit a smoothing spline to the 9 points, and used this to estimate the values for each 20-year class (see Figure 6.2). The spline was moderately flexible, allowing maxima or minima at intermediate age classes, but smoothing out any erratic extreme values and jumps that otherwise occurred when changing from one broader group to the next. Because we had very little direct data for the youngest forest age classes, we also averaged in the estimates for grass and shrub with the value for the youngest forest age class prior to smoothing.

We had little data from cutblocks >20 years old, so we assumed that conditions in cutblocks converge on natural (post-fire) age trajectories at 60 years post disturbance. To smooth the transition from the recent cutblock values to the values for older cutblocks that were converging on natural stands, we averaged the raw estimates for the older cutblocks with the estimate for the 60-80 natural age class within the forest type. The value for 20-40 year old cutblocks was taken as 2/3 of the estimate for recent cutblocks plus 1/3 the estimate for 60-80 year natural stands, while the value for 40-60 year cutblocks was taken as 1/3 the estimate for recent cutblocks plus 2/3 the estimate for the 60-80 year natural stands. This ensured the expected smooth convergence of cutblocks and natural stands at 60 years.

These vegetation type coefficients were applied at the 1 ha plot scale. To assess the additional effects of footprint in the surrounding quarter-section area (451 m radius circle centered on the site), the relative abundance of the species was predicted for each site using the vegetation coefficients derived above. The residual difference between this prediction and the actual observed value was then calculated. These residuals were modeled as a function of the human footprint (HF) in the surrounding quarter-section area, using 6 GLM models in the AIC framework: Model 1) THF [total human footprint], Model 2) THF + THF^2 [a quadratic relationship with THF], Model 3) Successional HF + Alienating HF, 4) Successional HF + Alienating HF + Successional HF^2 + Alienating HF^2, 5) Nonlinear HF + Linear HF, 6) Nonlinear HF + Nonlinear HF^2 + Linear HF. Successional footprint (including forestry and soft linear features) retained native vegetation. Alienating footprint (including industrial developments, agriculture, roads, etc.) removed or replaced native vegetation and disturbed the soil. The AIC-weighted average predictions from these models represented the amount that the occurrence of a species was expected to differ from the prediction based on vegetation type due to the human footprint in the surrounding quarter-section.

Birds

Point count data from ABMI, BBS and Dr. Erin Bayne were used to model relative abundance of 88 bird species in the different habitat types. All Point counts from the Boreal and Lower Foothills natural regions in Alberta north of 53.5° latitude were included in these analyses. Point counts of different duration and radius were standardized using the offset approach (Sólymos et al. 2013) which also controlled for nuisance variables (i.e. time of day, time of year, habitat) affecting availability of birds for sampling and detectability.

For the bird analyse, relative abundance was estimated in the following habitat types:

- Forests: Deciduous, Mixed wood, Upland white spruce, Pine, Lowland conifer;
- Open types: grass, shrub, wetlands;
- Human footprint types: Cultivation, Urban-Industrial.

Habitat was treated as a categorical variable based on the dominant habitat types. This is a reasonable simplification because the dominant habitat comprised > 50% of the area within 150 m radius buffers around point count locations in 95% of the cases. Habitat age was used as a continuous variable in 20-year increments based on the area-weighted age of the forest habitats within the 150 m radius buffer. Forest harvest was included as a categorical variable to describe differences between natural and human created forest in each age class. Linear features comprised small portions of the 150 m buffers; therefore, these were not used as dominant habitat types. A categorical variable was used to indicate when the point was surveyed on roads (BBS surveys are roadside surveys, otherwise a 4% cut-off based on area within 150 m buffers was used to indicate the point count was influenced by roads). The proportion of soft linear features (including seismic lines, road verges, unimproved roads, pipelines) within the survey buffer was used as a continuous variable. Linear feature effects were modeled as additive effects to the dominant habitat types.

Spatial trends in relative abundance were accounted for by using latitude, longitude, mean annual precipitation (MAP), and potential evapotranspiration (PET). Climate variables (MAP, PET) were derived bioclimatic variables calculated at a 4 km resolution using monthly climate normals of temperature and precipitation averaged over 1961–1990. These monthly climate normals came from instrument-measured climate data that were interpolated by PRISM (Daly et al. 2002) and WorldClim (Hijmans et al. 2005). The western North American portion of these data were described by Wang et al. (2011).

The amount of linear, nonlinear, alienating, successional and total human disturbance was calculated in 451 m radius buffers around each point count location. This corresponded to the average area of a quarter section (64 ha) that was the unit for prediction. Proportion of human footprint was used as a continuous covariate in modeling, using the same footprint models as listed for plants.

Model parameters for relative abundance of 90 bird species were estimated using generalized linear models (GLM) with Poisson error and log link. Uncertainty in variable selection and parameter estimates was quantified using the coefficients from 200 bootstrap iterations.

Prediction was done for each quarter section in the study region for each species using the bootstrapped model estimates. Mean relative abundance for each quarter section was the area-weighted average of the relative abundances in the habitat types of that quarter section. Current relative abundance was calculated based on actual values. For reference abundance, the value for quarter section level human footprint was set to zero, and average age of forests in the quarter section was used as age for cutblocks.

6.3 Methods - Mapping and Summarizing Predicted Abundances

Current abundance of each species was predicted for each quarter-section in the region. The estimates of relative abundance in each habitat type were first applied to the habitats in the quarter-section. The models of the modifying effects of surrounding footprint were then applied based on the footprint in the quarter-section.

Reference abundances were used as part of the intactness calculation, and to show the effect that current footprint was predicted to have had on species. Reference abundances were the model predictions with no footprint. This required “backfilling” areas that currently have footprint, replacing them with the habitat type that was expected to have occurred prior to the footprint using rules about what habitat types different footprint can occur in (e.g., forestry). The relative abundances by habitat type were applied to the backfilled quarter-sections to estimate reference conditions.

Intactness values for groups of species or the entire taxon (plants, birds) in a quarter-section were calculated as the weighted average of the intactness values for each species. Weighting was based on the species reference abundance in that quarter-section compared to its maximum reference abundance across the whole region. This means that lowland species, for example, were more important than upland species in the average intactness for a quarter-section dominated by lowlands. Weighting by relative abundance ensured that the roll-up values for quarter-sections in a region can simply be averaged to give intactness for the region.

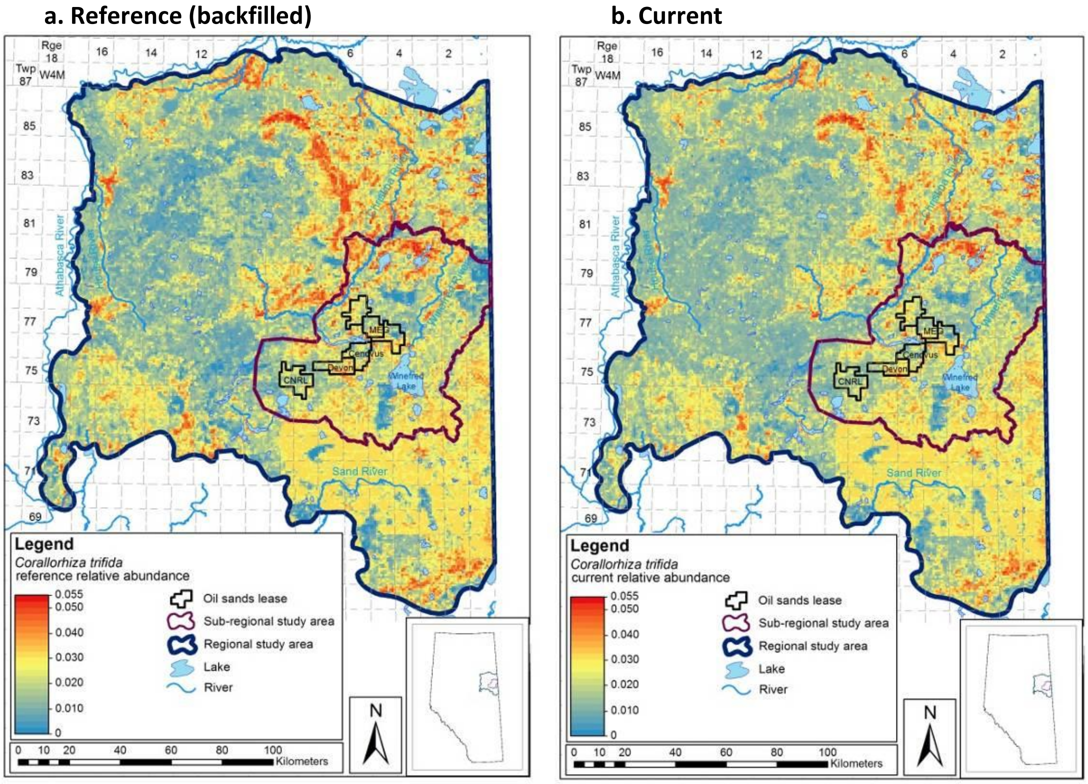
Overall biodiversity intactness for each quarter-section was the simple average of intactness values for plants and birds. Confidence intervals on intactness values were generated using the bootstrapped models. Confidence intervals were most practical to present for roll-up intactness values for regions, rather than trying to show the uncertainty for each quarter-section on a map.

6.4 Results

An example describing variation in relative abundance yellow coralroot (*Corallorhiza trifida*) throughout the study area was shown in Figure 6.1.

The roll-up intactness across all species highlights the distribution of different footprint types, weighted by how much they affect species (Figure 6.2). Biodiversity intactness declined from 100% with no footprint to about 30-40% with 100% successional footprint (forestry, soft linear features), and to about 15-20% with 100% alienating footprint (agriculture, urban, industrial, roads). Intactness did not go to 0 at 100% footprint, because some species live in human disturbances. At intermediate footprint levels, intactness dropped nearly linearly with footprint area when footprint occurred in large clusters (typical of agriculture), but dropped somewhat more quickly if the footprint was more scattered across many quarter-sections (typical of energy developments).

The map for plants and birds was very similar, with plants having slightly lower minimum values and birds having more intermediate values in moderately disturbed quarter-sections. The latter difference probably reflected the 1 ha scale at which plants were analyzed, which tended to be entirely within or outside of footprint, compared to the larger scale of birds, which tended to include footprint and non-footprint areas.

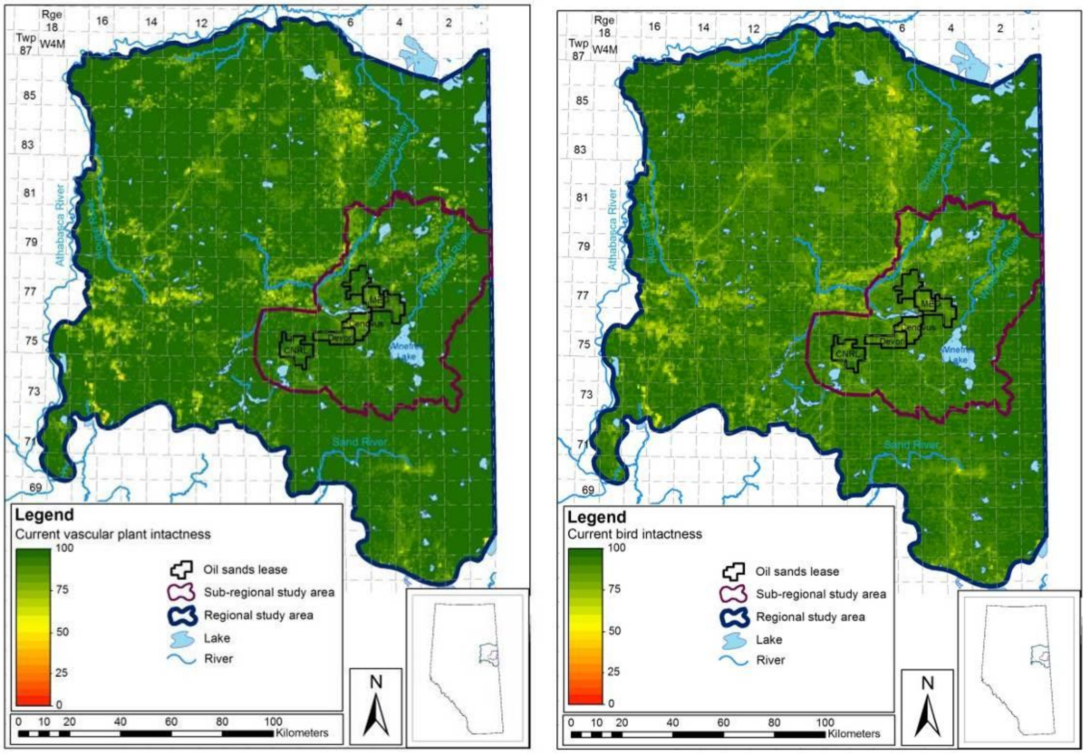

a. Reference (backfilled)

b. Current

Figure 6.1. Predicted relative abundances of yellow coralroot in the study region: a) reference (footprint removed and "backfilled"), and b) current conditions. Patterns were mainly generated by the distribution of habitat types. Some small effects of footprint were visible when comparing the reference and current conditions.

Average intactness for all plants was 95.3% for the study region, and 94.9% for the subregion (Table 6.1). Confidence intervals on those values were all very small, <±1%, because of the large number of species contributing to the average. Average values were lower for birds (90.6 and 90.0) across the region and subregion, respectively, which was due to greater sensitivity of birds to linear and industrial features, particularly to low levels of these footprint types.

We calculated the contribution the subregion made to lowering the regional intactness. These values showed how much higher the regional intactness would have been if the entire subregion had no footprint of any type. The absolute contribution of the subregion to the regional loss of intactness was small, 1.4%. That is, the regional intactness would have been 1.4% higher if there was no footprint in the subregion. The small change reflects the relatively small area compared to the region, modest amount of current footprint in the subregion, and the fact that some species included in the average intactness were not very sensitive to footprint. Expressed as a percentage of the regional reduction of intactness (7% = 100-93.0%), the subregion contributed 29.7% of the reduction in regional intactness (1.4%/7% = 29.7%).



a. Plants

b. Birds

Figure 6.2. Intactness in the study region for a) all plant species, and b) all bird species used in this study.

The plant and bird results were averaged to give overall intactness (Figure 6.3).

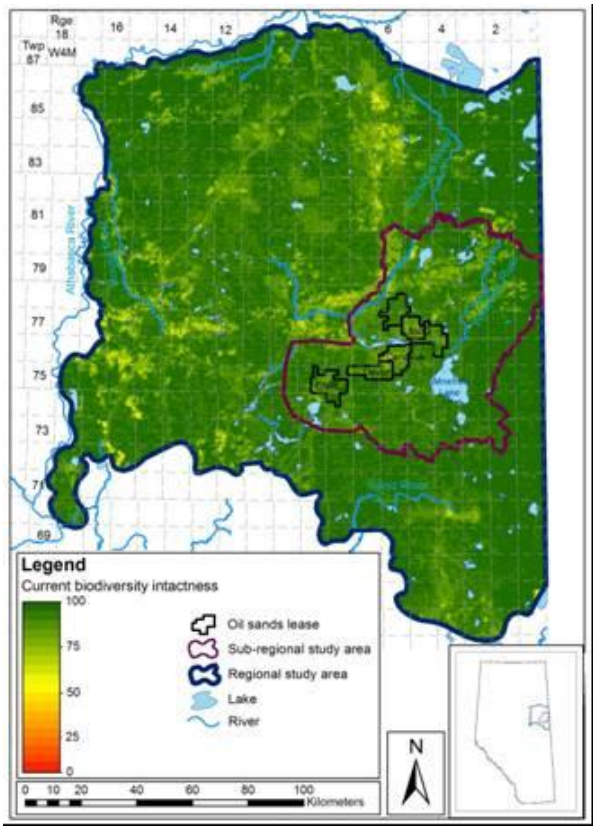


Figure 6.3. Overall biodiversity intactness, based on averaging intactness for the plants and birds used in this study.

Table 6.1. Current intactness based on plants and birds for study region and subregion, and the contributions of the subregion to reducing regional intactness.

	Intactness			Contribution to Reducing Intactness	
Area	**Plant**	**Bird**	**Combined**	**Absolute**	**% of Total Reduction**
Region	95.3	90.6	93.0		
Subregion	94.9	90.0	92.5	1.4	29.7

6.5 Projections

The projected scenario for all plants and all birds showed a continued drop in intactness from the current year for the next 25 years, then a lesser decline in the following 25 years (Figure 6.4). The reduced rate of decline after 25 years was mainly due to forestry approaching an equilibrium, in which old cutblocks were projected to recover at about the same rate that new blocks were created. Some energy developments were also abandoned, as new ones were created. Intactness declined a bit faster at 50 years in the subregion, where energy developments were projected to be more common than forestry.

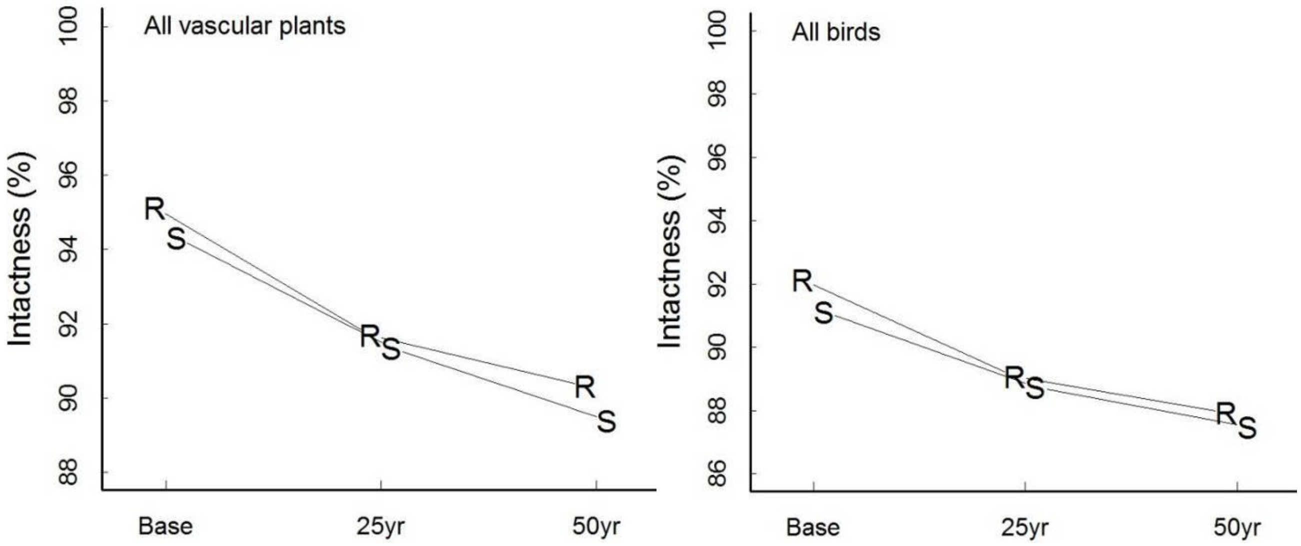


Figure 6.4. Current (base) and projected intactness for all vascular plants (left) and all birds (right), in the study region (R) and subregion (S).

A main effect on intactness in the projected scenarios was a “diffusion” of footprint. In current conditions, footprint was concentrated in relatively few quarter-sections, showing up as distinct yellow areas on the current intactness map (Figures 6.5a, 6.6a, 6.7a). After 25 years, more quarter-sections had footprint effects, but there were no additional areas with intense effects (except a few patches in the south of the region) (Figures 6.5b, 6.6b, 6.7b). This process continued to year 50, where quarters-sections with moderate reductions in intactness were widespread, but there were few additional areas with intensive impacts (Figures 6.5c, 6.6c, 6.7c). This pattern was due to forestry footprint reaching an equilibrium between new and recovering cutblocks, while seismic lines and pipelines became more ubiquitous on the landscape. The modeling approach emphasized this diffusion of footprint, because it relied on statistical distributions of footprint, in the absence of specific spatial development plans. Projections tied to polygons would have had less diffusion. The diffusion of footprint over time was visible in histograms of the intactness of each quarter-section in the study region (Figure 6.8). Over time in the projections, there were fewer quarter-sections with >95% intactness, but the number of quarter-sections with <80% intactness did not increase much. Most of the change in the modelled footprint was attributable to an increase in quarter-sections with a moderate intactness of 80-95%.

Individual species showed a wider predicted range of changes in the projections than the average, but not a markedly wider range. The vascular plant species that was predicted to decline the most based on future simulations, American milkvetch (*Astragalus americanus)*, only declined a further 10% in the next 50 years. The largest increaser, alfalfa (*Medicago* sativa), only increased 54% over that time. These fairly mild changes exhibited by even the most extreme species reflect the relatively low rates of footprint creation assumed in the projections, and the “close to the equilibrium” state between footprint creation and recovery.

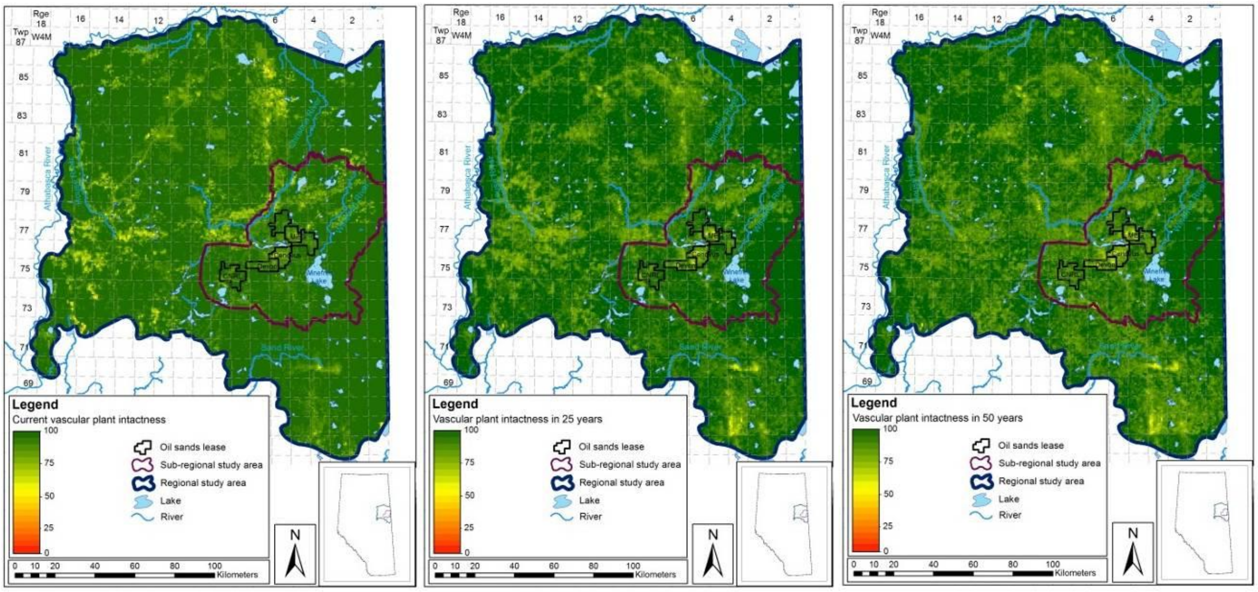

a. Current b. 25 years c. 50 years

Figure 6.5. Intactness of vascular plants in a) Current landbase, b) Landbase projected 25 years into the future, and c) Landbase projected 50 years into the future.

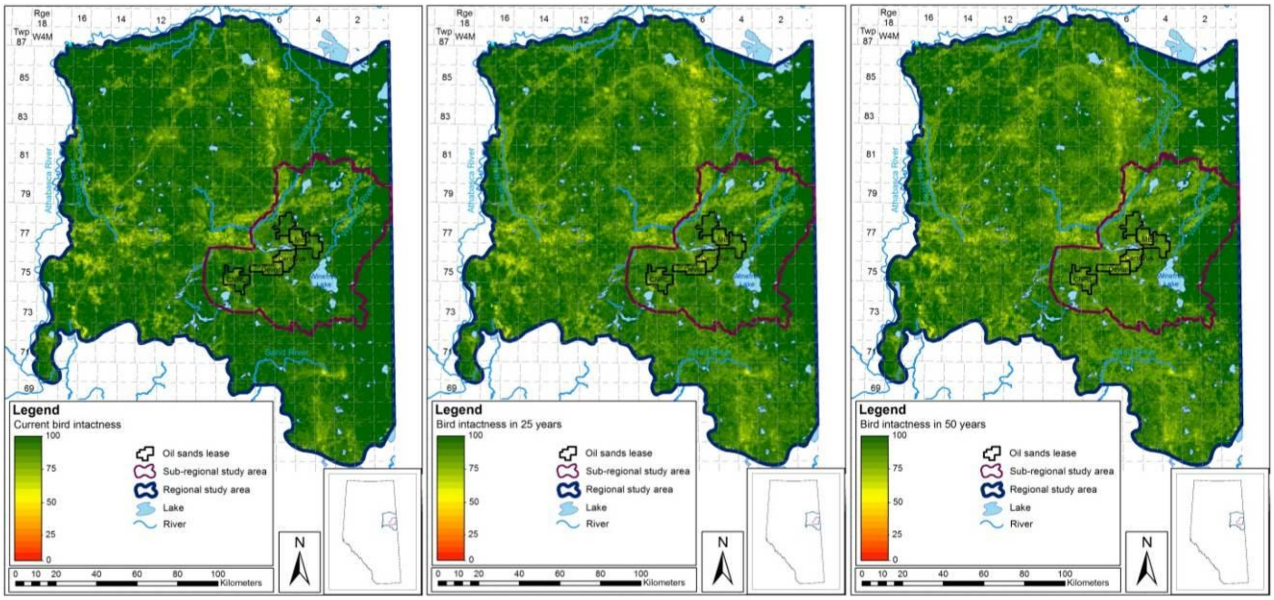


Figure 6.6. Intactness of all birds in a) Current landbase, b) Landbase projected 25 years into the future, and c) Landbase projected 50 years into the future.

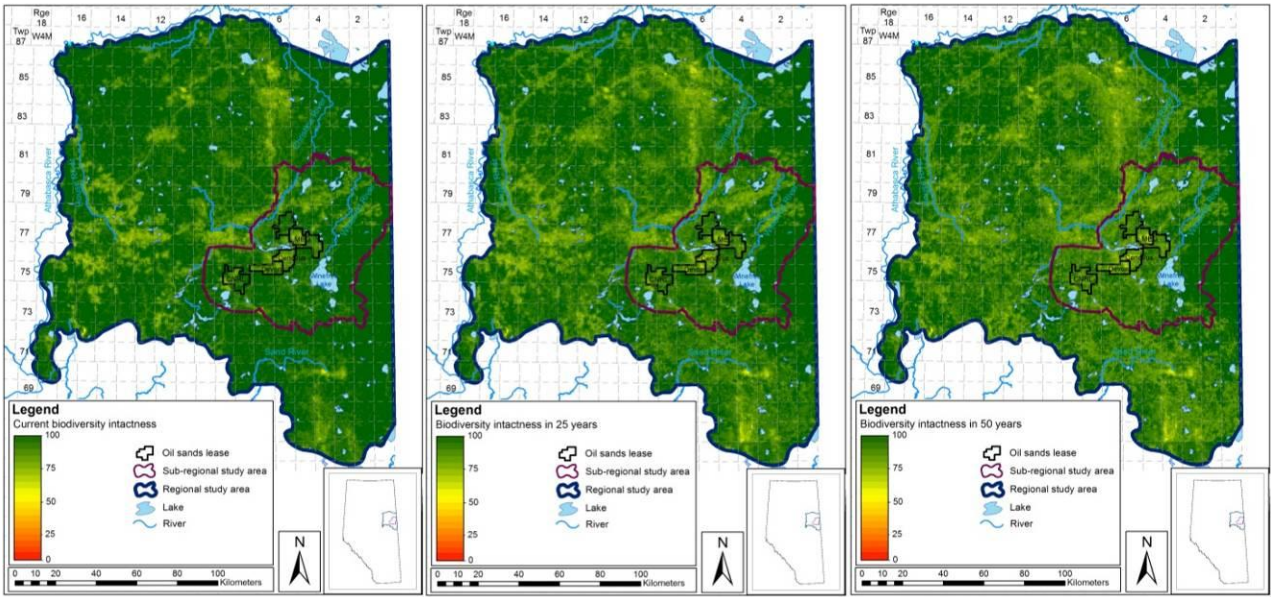
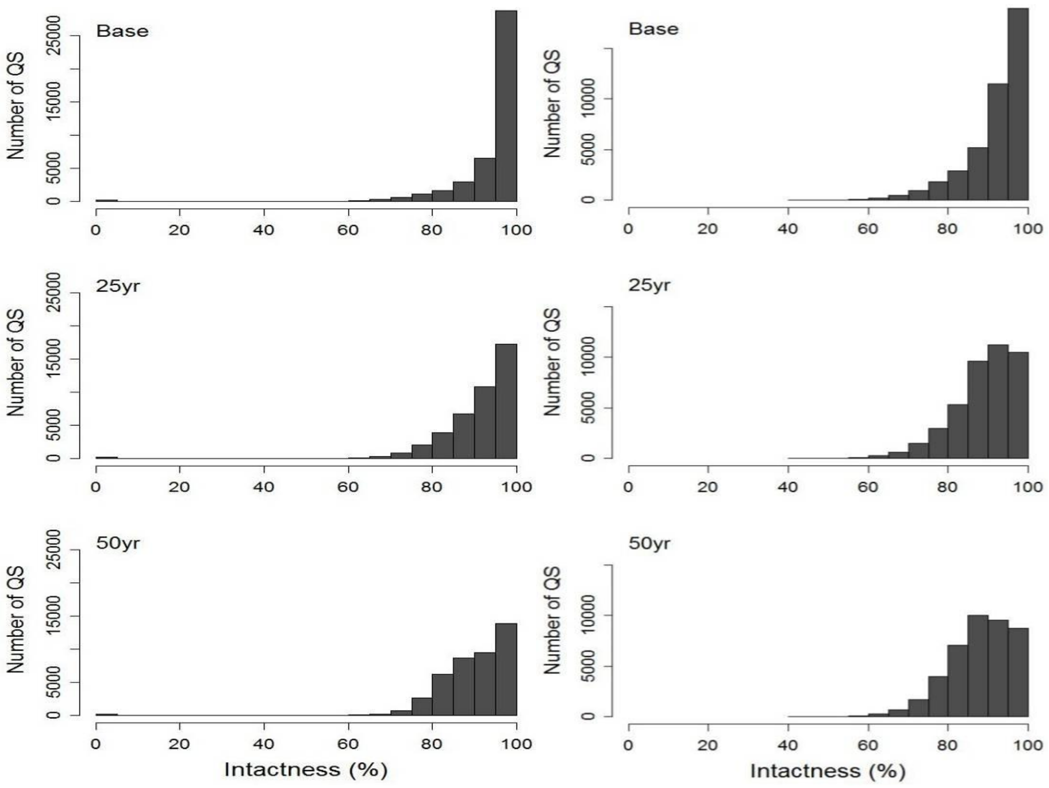


Figure 6.7. Combined (plant+bird) intactness in a) Current landbase, b) Landbase projected 25 years into the future, and c) Landbase projected 50 years into the future.



a. All vascular plants **b. All birds**

Figure 6.8. Intactness for all vascular plants (left) and all birds (right) by quarter section (QS) in the study region, for current conditions and 25 year and 50 year projections.

6.6 Discussion

Across large taxa like birds and plants, intactness was not very affected by the type of vegetation that was converted to human footprint, because there were species occupying every habitat type. Biodiversity intactness across broad groups of species was therefore a fairly simple function of footprint in the area. Individual species were much more affected than the broad intactness, particularly when footprint was widely distributed and/or concentrated in certain vegetation types. For a thorough assessment of biodiversity, it is thus important to also assess finer groups of similar species, and the most sensitive individual species. Examples are given in the following chapters.

7.0 Forest Plants

7.1 Introduction

Species models were produced for 190 plant species and used to produce overall plant intactness (Chapter 6). Results for forest-associated plants, were summarized here as an example of how species groups can be assessed for cumulative effects.

Forest species included in the analyses were: *Abies balsamea, Actaea rubra, Alnus viridis, Aralia nudicaulis, Arnica cordifolia, Betula papyrifera, Circaea alpina, Cornus canadensis, Diphasiastrum complanatum, Equisetum scirpoides, Galium triflorum, Geocaulon lividum, Goodyera repens, Gymnocarpium dryopteris, Halenia deflexa, Lathyrus venosus, Leymus innovatus, Linnaea borealis, Lonicera dioica, Maianthemum canadense, Mitella nuda, Moehringia lateriflora, Orthilia secunda, Picea glauca, Pinus banksiana, Pinus contorta, Populus balsamifera, Populus tremuloides, Prunus virginiana, Pyrola asarifolia, Pyrola chlorantha, Ribes glandulosum, Ribes hudsonianum, Ribes oxyacanthoides, Ribes triste, Rubus pubescens, Salix scouleriana, Schizachne purpurascens, Shepherdia canadensis, Stellaria longifolia, Symphoricarpos albus, Trientalis borealis, Vaccinium caespitosum, Vaccinium myrtilloides, Viburnum edule, Viola canadensis,* and *Viola renifolia*. Scientific names were used for plants because many species do not have a standard common name.

7.2 Methods

Analytical methods to extract coefficients for vegetation types and additional effects of surrounding footprint were summarized in Chapter 6. Intactness of the group was calculated and mapped as the weighted average of the intactness of forest plant species.

7.3 Results

The intactness map for forest species (Figure 7.1) was very similar to the overall map for all plant species (Figure 6.2a), because the large group of forest species dominated the overall intactness result in upland areas, where most footprint occurred.

Regional and subregional intactness of forest plants was similar to the overall plant intactness (Figure 7.2). The overall plant intactness was lower than the intactness for forest-species mainly because it was lowered by weedy species (Chapter 9).

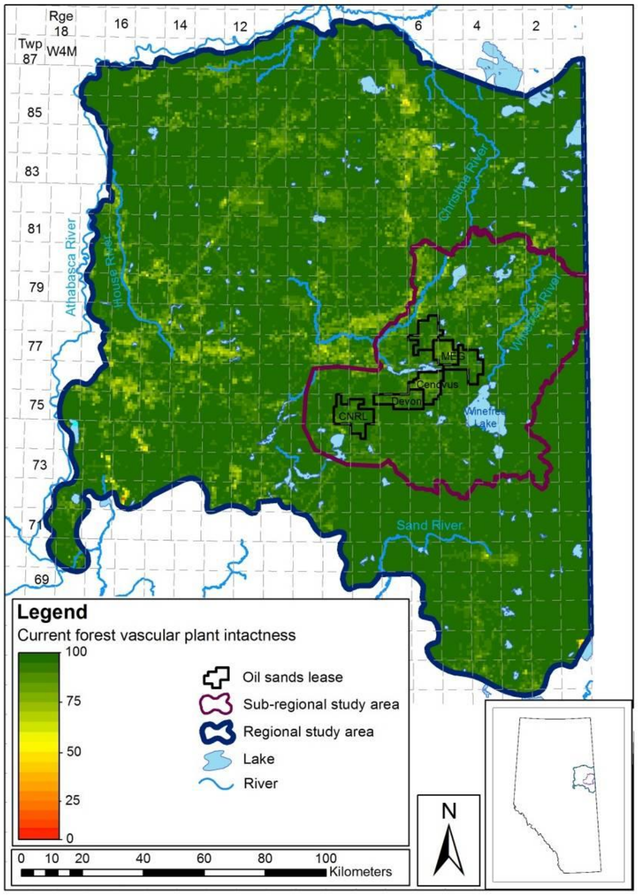


Figure 7.1. Intactness map for forest-associated plant species.

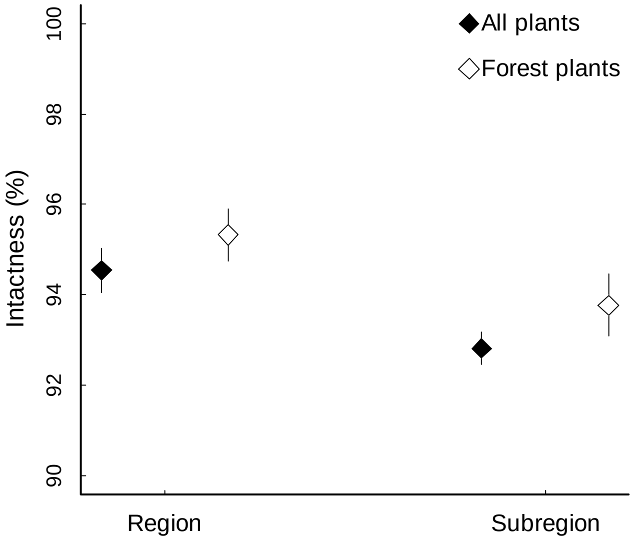


Figure 7.2. Intactness for forest-associated species (◊) compared to all plant species (◆) (with 90% confidence intervals), for the regional and subregional study areas.

Responsibility

It is impractical to use results from every individual species in management decisions; there are simply too many species and each responds differently. However, the results can be used to highlight the most important species in a subregion from a regional perspective. One measure is “responsibility” (Dun et al. 1999), which refers to the percentage of the population found in the area of interest. In this case, the subregional responsibility for a species would be the percentage of the regional population found in the area. Using predicted relative abundances under reference conditions (no footprint) as our population measure for each quarter section, we listed the 10 forest-associated plant species with the highest responsibility in the subregion (Table 7.1). Because the subregion is a substantial part of the region, and was fairly typical of the broad region, responsibility was only slightly higher than proportional to area for any species (which would be a value of 100 in the responsibility standardized by area in Table 7.1).

Chokecherry (*Prunus virginiana*) was the highest responsibility species for the subregion. Responsibility would be more meaningful for smaller, more distinct areas, such as individual lease areas.

Table 7.1. Percent of regional populations and relative responsibility for the 10 highest-responsibility forest plant species in the subregion.

	Regional responsibility	
Species	**%**	**Standardized by area**
Prunus virginiana	20.44	109.76
Arnica cordifolia	19.97	107.26
Salix scouleriana	19.93	107.04
Pinus contorta	19.70	105.78
Pinus banksiana	19.69	105.72
Ribes glandulosum	19.34	103.83
Schizachne purpurascens	19.23	103.27
Alnus viridis	19.22	103.22
Maianthemum canadense	19.07	102.38
Gymnocarpium dryopteris	19.05	102.31

Contribution to regional change

A second way of assessing individual species is to look at the contribution of current footprints in the subregion to regional change in the species. The 10 forest species where footprint in the subregion was predicted to have caused the greatest losses to regional populations were provided in Table 7.2. For example, footprint in the subregion was predicted to have lowered the regional population of chokecherry (*Prunus virginiana*) by 1.43%. Most of these losses were approximately proportional to the 18.6% of the regional area represented by the subregion. However, the (small) regional decline of skunk current (*Ribes glandulosum*) has was disproportionately caused by footprint in the subregion.

Table 7.2. The 10 forest plant species for which the current footprint in the subregion had the greatest effect on regional populations of the species.

	Regional change		
Species	**%**	**Subregional component**	**Percent due to subregion**
Prunus virginiana	-7.71	-1.43	18.50
Goodyera repens	-6.07	-1.09	18.02
Pinus banksiana	-4.16	-0.76	18.19
Geocaulon lividum	-3.79	-0.74	19.47
Orthilia secunda	-3.73	-0.72	19.39
Salix scouleriana	-3.32	-0.56	16.85
Vaccinium caespitosum	-1.99	-0.47	23.77
Schizachne purpurascens	-1.93	-0.47	24.28
Ribes glandulosum	-0.79	-0.39	48.65
Vaccinium myrtilloides	-1.19	-0.32	27.12

7.4 Projections

The intactness of forest plants in the future projections was very similar to the intactness of all plants, because forest plants were a large component of the vascular plant species pool. Intactness of forest plants showed a similar reduction in the rate of decline over time (Figure 7.3), and the same “diffusion” of intactness lost across the landscape (Figure 7.4) as for vascular plants as a group.

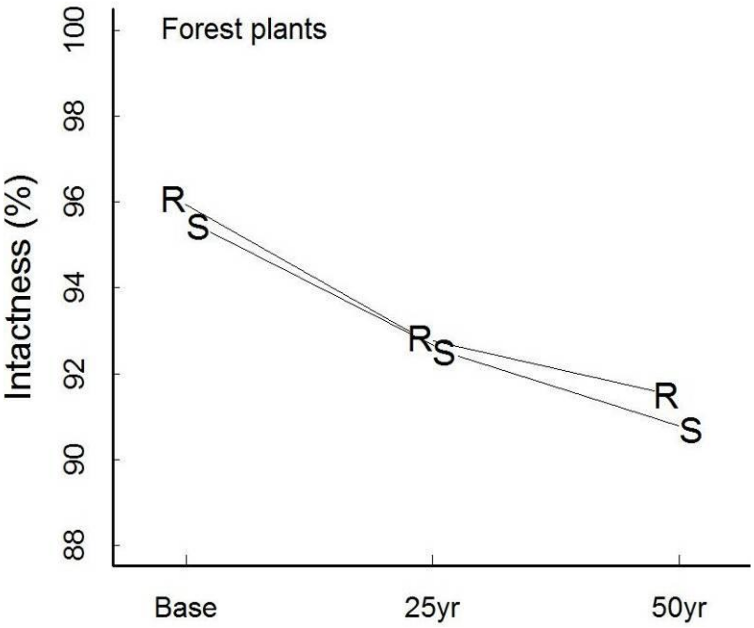
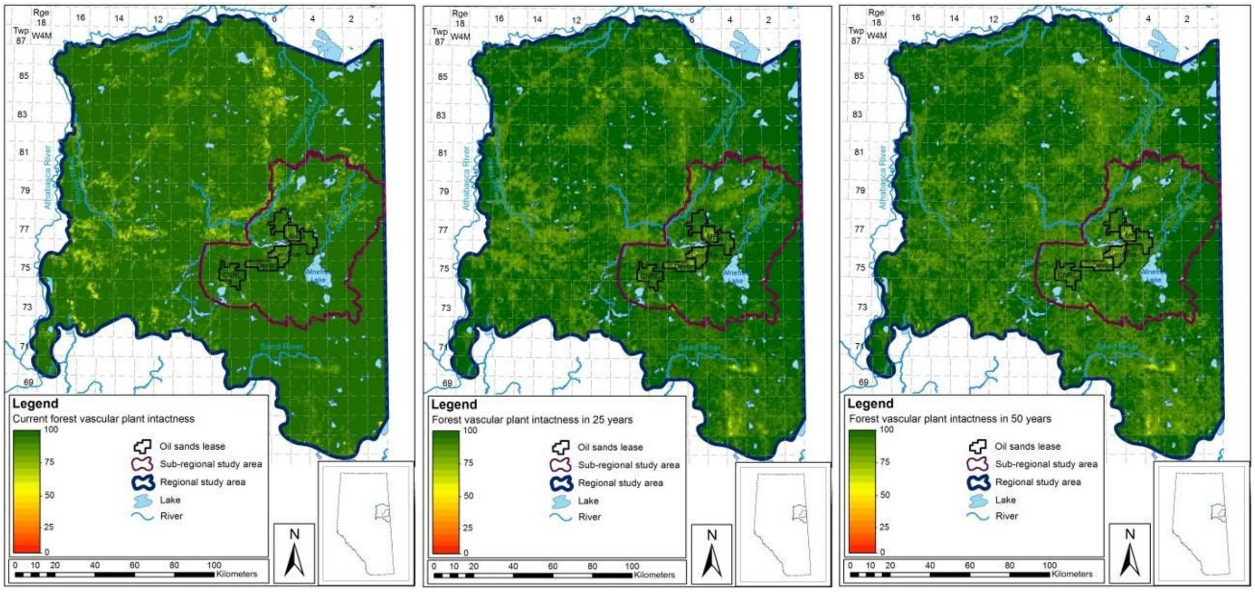


Figure 7.3. Current (base) and projected intactness for forest plants, in the study region (R) and subregion (S).



a. Current b. 25 years c. 50 years

Figure 7.4. Intactness of forest plants in a) Current landbase conditions, b) Landbase projected 25 years into the future, and c) Landbase projected 50 years into the future.

7.5 Discussion

Forest-associated plants were a broad group, and show similar intactness patterns to plants overall. Smaller groups (examples were evaluated in Chapters 8 and 9) were expected to show stronger patterns, because they respond more consistently to human footprint and/or live in vegetation types that are affected by human development. Ultimately, cumulative effects assessments for biodiversity needs to assess a breadth of species so that the range of potential changes are understood. The concepts of responsibility and an area’s contribution to regional changes in species’ populations can be useful tools for reducing the number of species to consider. These ideas were illustrated for forest plant species, but they can be extended to other taxa.

8.0 Old Forest Birds

8.1 Introduction

Species models were produced for 90 bird species and these models were used to produce the bird component of biodiversity intactness estimates (Chapter 6). Results are summarized here for 28 old forest birds (Baltimore (Northern) Oriole, Bay-breasted Warbler, Black-throated Green Warbler, Blue-headed (Solitary) Vireo, Boreal Chickadee, Brown Creeper, Cape May Warbler, Evening Grosbeak, Golden-crowned Kinglet, Least Flycatcher, Magnolia Warbler, Northern Waterthrush, Philadelphia Vireo, Pine Siskin, Purple Finch, Red Crossbill, Red-breasted Nuthatch, Rose-breasted Grosbeak, Ruby-crowned Kinglet, Swainson's Thrush, Warbling Vireo, Western Tanager, Western Wood Pewee, White-breasted Nuthatch, White-winged Crossbill, Winter Wren, Yellow-rumped Warbler).

8.2 Methods

Analytical methods to extract coefficients for vegetation types and additional effects of surrounding footprint were summarized in Chapter 6. Intactness of the group was calculated and mapped as the weighted average of the intactness of old forest bird species.

8.3 Results

The current (2010) quarter section level intactness map for old forest birds (Figure 8.1) was very similar to the intactness map for forest plants (Chapter 7). Regional and subregional intactness values for old forest birds (Table 8.1) were similar to the overall bird intactness. However, old forest bird intactness values were a few percent lower than for all bird species, due to more consistent responses to forestry footprint and to linear features in the region and subregion.

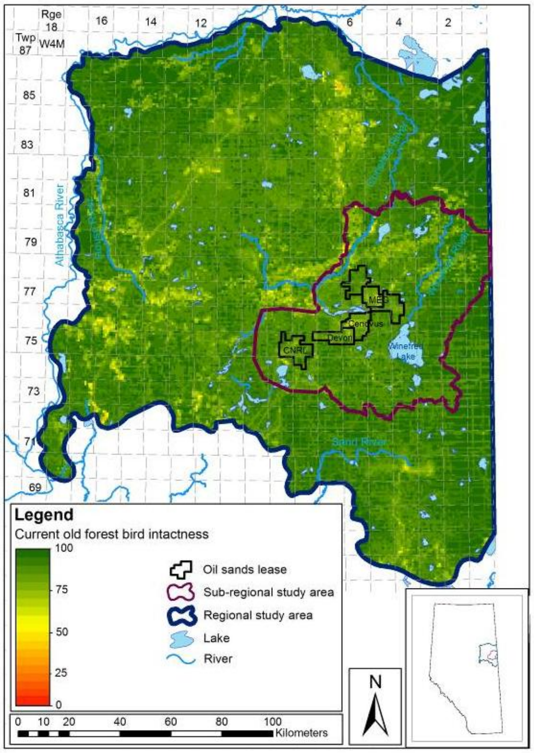


Figure 8.1 Map of current quarter section level intactness for old forest birds in the study region (*n* = 28 species).

Table 8.1 Intactness values for all bird species and old forest birds in different regions.

	All birds	Old forest birds
Regional Study Area	90.6	87.3
Subregional Study Area	90.0	86.5

Responsibility

Responsibility for each old forest bird species in the subregion was calculated as the percentage of the regional population under reference conditions falling within the limits of the subregion. Relative responsibility was expressed as the percent population standardized by area, with values higher than 100% indicating disproportionately more responsibility concentrated in the subregion (Table 8.2). For example, the subregion makes up 18.4% of the total area of the region. However, 20.7% of the regional population of Pine Siskins (*Carduelis pinus*) was predicted to occur within the subregion under reference conditions, indicating the subregion had a larger standardized responsibility (112%) for Pine Siskin than attributable solely to the size of the subregion. Other old forest bird species had close to 100% or lower standardized responsibility, indicating that the subregion would only support similar or smaller populations than the regional average.

Table 8.2 Percent of regional populations and relative responsibility for the 10 highest-responsibility old forest bird species in the subregion.

	Regional responsibility	
Species	**%**	**Standardized by area**
Pine Siskin	20.71	112.87
White-breasted Nuthatch	18.78	102.35
Brown Creeper	18.13	98.81
Black-throated Green Warbler	17.99	98.04
Boreal Chickadee	17.96	97.88
Rose-breasted Grosbeak	17.95	97.83
Philadelphia Vireo	17.92	97.66
Ruby-crowned Kinglet	17.81	97.06
Blue-headed (Solitary) Vireo	17.59	95.86
Red Crossbill	17.57	95.76

Contribution to regional change

We calculated how much the subregional change contributed to the regional change by comparing percent changes between the region and subregion. The difference from reference condition in the region was expressed as percentage relative to the reference population in the region. The difference in the subregion quantified how much the footprint in the subregion changed the population compared to the reference condition. The subregion based percent difference was expressed as the contribution of the footprint in the subregion to the regional change in the population. Table 8.3 lists the highest ranking species based on percent subregion level differences. The contribution to regional difference was considered high when it exceeded the contribution expected solely based on the percent area of the subregion relative to the area of the entire region. For example, the subregion comprises 18.4% of the region, yet the contribution to regional difference for the Boreal Chickadee was -2.1%, which represents almost 20.3% of the total regional change (absolute change = -10.4). Thus, the contribution of the subregion to the regional difference in Boreal Chickadee was higher than expected based on the area of the subregion. This indicates that the concentration of development in the subregion lead to disproportionate loss of suitable habitats for Boreal Chickadee, as well as other old-forest species. Contribution to regional difference was lower than percent area for some species (e.g. White-winged Crossbill in Table 8.3), because the type and amount of footprint the in the subregion had less impact on suitable habitats for the species than expected based on the average development in the region.

Table 8.3 The 10 old forest bird species for which the current footprint in the subregion had the greatest effect on regional populations of the species.

	Regional change		
Species	**%**	**Subregional component**	**Percent due to subregion**
Boreal Chickadee	-10.41	-2.11	20.30
Pine Siskin	-8.74	-1.85	21.16
Ruby-crowned Kinglet	-9.34	-1.77	19.00
Least Flycatcher	-8.31	-1.54	18.51
Western Tanager	-3.50	-0.67	19.03
Western Wood Pewee	-3.87	-0.64	16.50
Philadelphia Vireo	-2.07	-0.39	18.75
White-winged Crossbill	-3.82	-0.37	9.75
White-breasted Nuthatch	-1.86	-0.36	19.52
Golden-crowned Kinglet	-1.60	-0.35	21.72

8.3 Projections

Projected intactness for old forest bird species was similar to the results for all birds. The change in intactness in the first 25 years was greater than in the following 25 years (Figure 8.2). These changes were consistent with decreasing percentage of old growth upland forest (from 9.8% to 6.5% over 50 years) in the study area with increasing footprint (from 6.4% to 10.5% over 50 years).

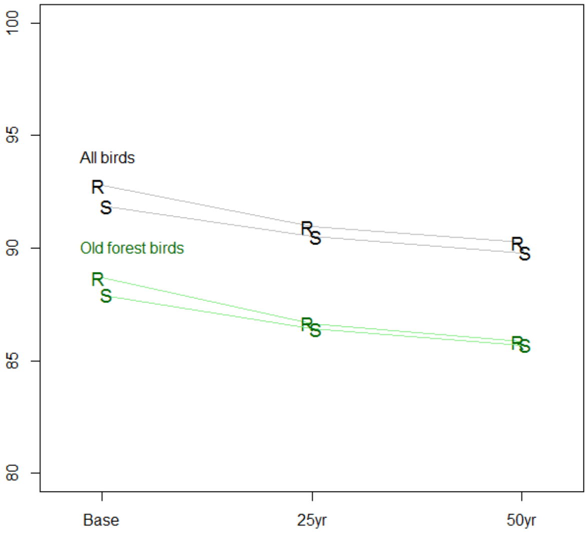
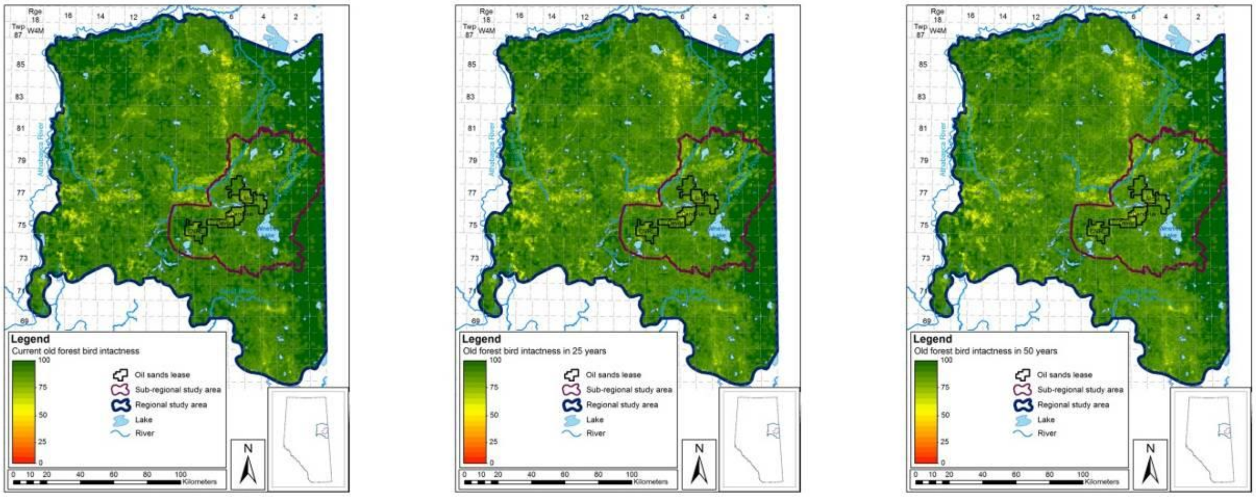


Figure 8.2. Current and projected intactness for old forest birds, in the study region (R) and subregion (S).

The maps of intactness for old forest bird species showed a widespread but small decrease in intactness over the entire study area during the next 50 years (Figure 8.3). Quarter sections with higher than 85% intactness became less frequent and those with less than 85% intactness became more frequent over the 50 years of projected land cover changes (Figure 8.4).


a. Current

b. 25 years

c. 50 years

Figure 8.3. Intactness of old forest birds in a) Current landbase, b) Landbase projected for 25 years into the future, and c) Landbase projected for 50 years into the future.

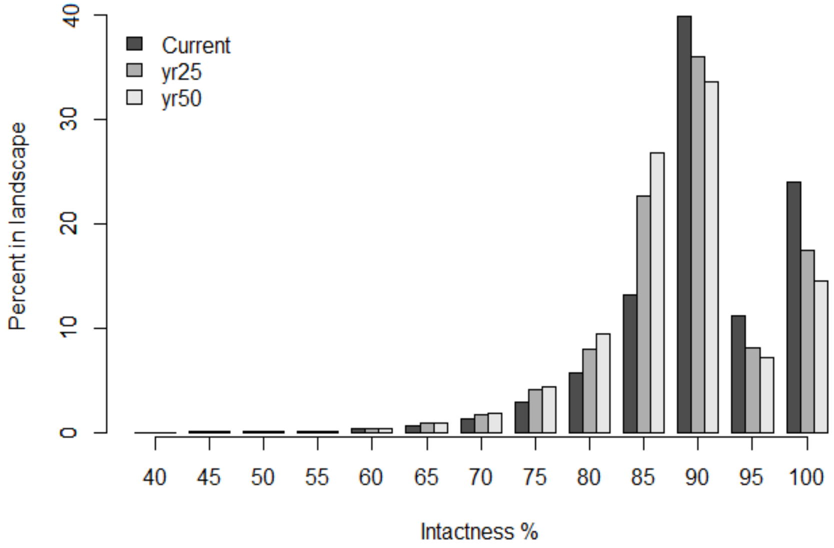


Figure 8.4. Distribution of quarter section level biodiversity intactness values for old forest bird species (values represented in the map in Figure 8.4).

8.4 Discussion

Old forest birds made up of 31% of the 90 bird species used to calculate intactness. As a result, old forest bird intactness in the region and subregion were very similar to the overall bird intactness. Spatial distribution of intactness (quarter section maps) were also very similar. This confirmed that overall bird intactness was dominated by old forest species responding similarly to the amount and type of human footprint in the region.

Relative responsibility for individual species in the subregional study area tended to be high only for few species because responsibility was a function of the undisturbed habitat types present in the region, and not a function of the actual development that happened to date in the subregion. Contribution to regional change varied among species, indicating that species responded to footprint in different ways.

Projections showed a widespread decline in old forest bird intactness over the study area. That was consistent with projected declines in old growth upland forest habitats and increase of footprint, which was expected to be distributed fairly evenly over the region.

9.0 Weedy Plants

9.1 Introduction

Weedy species examined during this project included 9 native and 11 non-native invasive species: *Agrostis scabra, Bromus inermis, Cirsium arvense, Corylus cornuta, Crepis tectorum, Equisetum hyemale, Galeopsis tetrahit, Hieracium umbellatum, Hordeum jubatum, Melilotus alba, Phleum pratense, Plantago major, Potentilla norvegica, Rosa acicularis, Solidago canadensis, Taraxacum officinale, Trifolium hybridum, Trifolium pratense, Trifolium repens,* and *Urtica dioic*. Scientific names were used for plants because many species do not have a standard common name.

9.2 Methods

Analytical methods to extract coefficients for vegetation types and additional effects of surrounding footprint were summarized in Chapter 6. Intactness of the group was calculated and mapped as the weighted average of all weedy plant species, as explained in Chapter 6.

9.3 Results

The intactness map for weedy species (Figure 9.1) showed a more pronounced deviation from 100% intactness than the map of average intactness of all plant species (Figure 6.2a). This occurred because many of the weedy species were rare under the reference conditions with no footprint, so any increase in footprint caused a rapid drop in intactness. Roads had a very noticeable effect on intactness of weedy plants, because these species thrive along road margins and roads represent major dispersal corridors (Mortensen et al. 2009). Note that a decline in intactness for of weedy plants means they increased in abundance relative to reference conditions.

Regional and subregional intactness for weedy plants was considerably lower than the average for all plants, because of the dramatic increase from very low reference levels in response to human footprint by weedy plants (Figure 9.2). Confidence intervals were wide because there were fewer species contributing to the average and they were still rare in most boreal ABMI sites, so their models were less precise. Weedy species increased rapidly with even small amounts of footprint, whereas forest species responded more linearly to the amount of footprint (mainly in upland habitats).

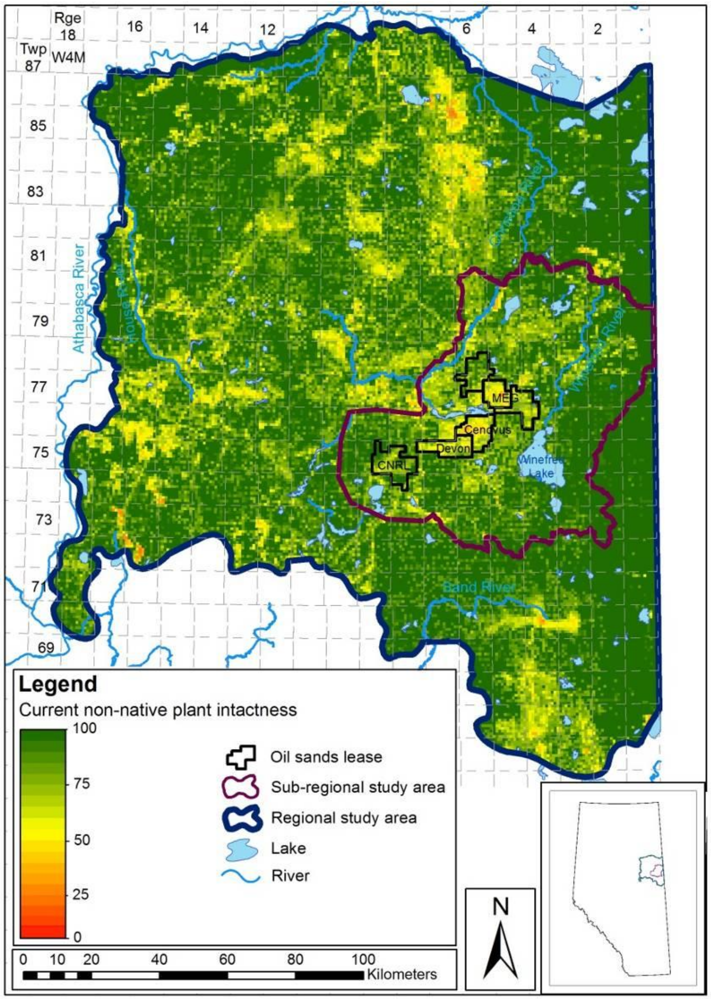


Figure 9.1. Intactness map for weedy plant species.

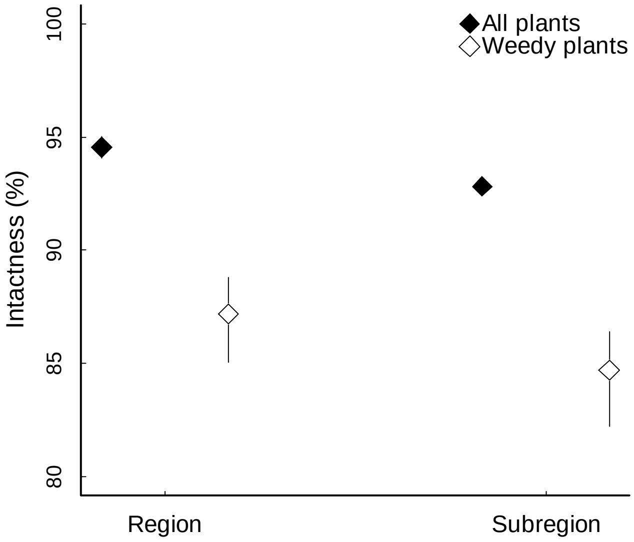


Figure 9.2. Intactness for weedy species (◊) compared to all plant species (◆) (with 90% confidence intervals), for the regional and subregional study areas.

9.4 Projections

Future projections for intactness of weedy plants were similar to the results for all plants and forest plants, showing a greater drop in the first 25 years than in the following 25 years (Figure 9.3). The intactness measure was more sensitive to increases of rare species, so overall intactness for weedy plants was lower than for forest plants. In the case of weedy plants, the reduced rate of intactness loss after 25 years was partly because common weedy species quickly became established in any quarter section with footprint, with the result that there was less incremental effect of additional footprint.

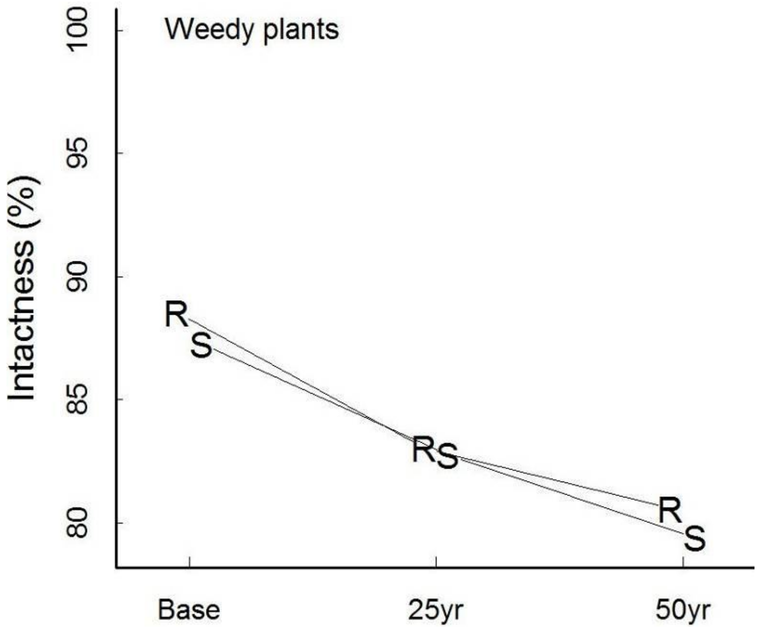
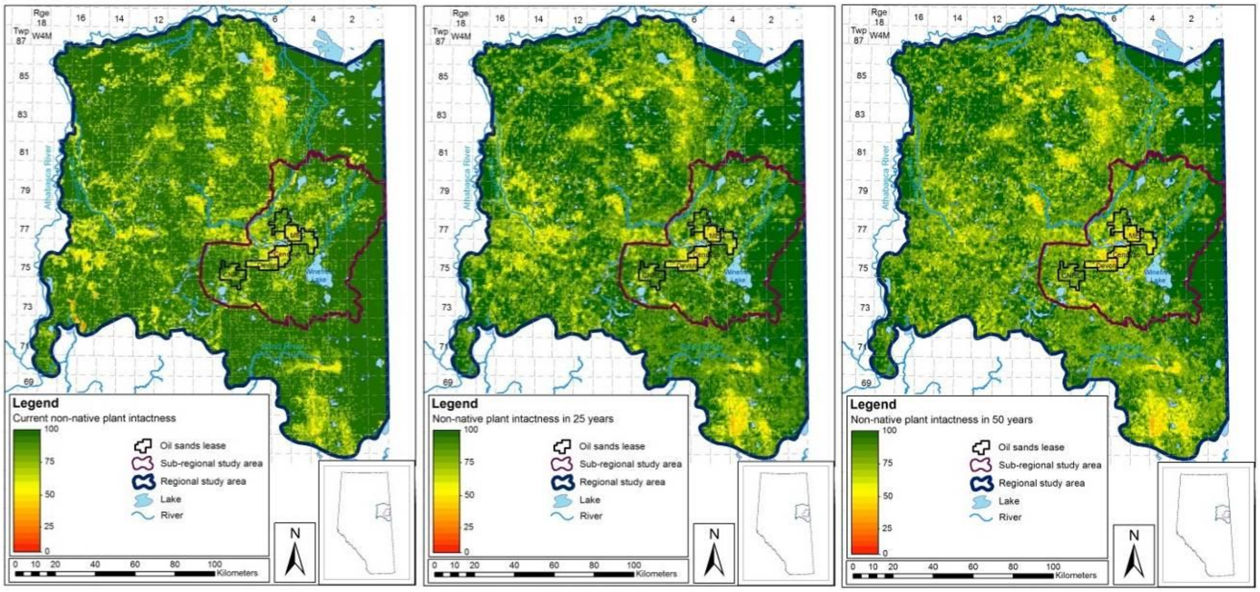


Figure 9.3. Current (base) and projected intactness for weedy plants, in the study region (R) and subregion (S).

The maps of intactness for weedy species projected over time showed the spread of weedy species as they entered quarter sections when footprint was first added (Figure 9.4). Consequently, much of the change on the maps was the result of quarter sections with intactness near 100% dropping in intactness to the 65-85% range, rather than quarter sections with mid-range intactness dropping even lower.



a. Current b. 25 years c. 50 years

Figure 9.4. Intactness of weedy plants in a) Current landbase, b) Landbase projected for 25 years into the future, and c) Landbase projected for 50 years into the future.

9.5 Discussion

Weedy species showed a larger drop in intactness than other species, because they rapidly increased from nearly zero in reference conditions to low abundances as footprint was added. This group was particularly indicative of the distribution of footprint, because even light footprint in a quarter section made them more ubiquitous than the same level of footprint concentrated in fewer quarter sections. This was apparent in the future predictions, where the statistical nature of the projections meant that low levels of footprint appeared in many quarter sections, creating widespread moderate declines in intactness of weedy plants. The future projection, however, are preliminary and as such the patterns we found should be interpreted with caution.

Our maps and roll-ups were for the predicted distribution of weeds based on vegetation types and footprint levels. We do not have any information on direct site-level management of the species, including the effects of seeding non-native species or any programs to control weedy species.

10.0 Black-throated Green Warbler

10.1 Introduction

This chapter describes results for the black-throated green warbler. Similar modeling was done for all 90 bird species presented in this report.

10.2 Methods

Analytical methods to extract coefficients for vegetation types and additional effects of surrounding footprint were summarized in Chapter 6.

10.3 Results

Habitat – age relationships

Relative abundance of the black-throated green warbler was highest in mixed and deciduous stands, lower in upland conifer (white spruce) and pine stands, and virtually zero in lowland and non-forested habitats, including cultivated and urban-industrial landscapes (Figure 10.1). This species showed preference towards old growth forests with a monotonous age relationship. Young age classes created by forestry did not differ statistically from naturally created young stands in terms of the relative abundance of black-throated green warblers that they harboured.

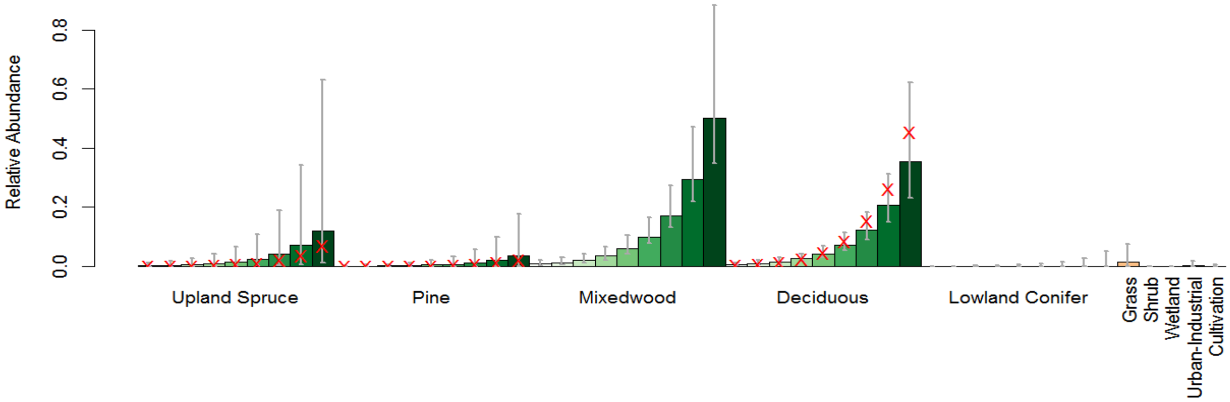


Figure 10.1 Habitat suitability as measured by relative abundance in different habitat types for the black-throated green warbler. Bars for forest habitat classes represent 20 year age classes. Whiskers represent 90% confidence intervals. Red x marks the additive in cutblocks (i.e., the higher relative abundance in cutblocks) relative to the top of the bars for similar aged natural forest stands.

The effects of linear features on black-throated green warbler relative abundance were assessed as a modifying factor based on the actual dominant habitat surrounding the hard linear feature, or the dominant habitat in which soft linear features were embedded. The relative abundance of black-throated green warbler decreased on average by two thirds when a road intersected the 150 m radius point count. This finding was consistent with observations that the species was more common in forest-interior than near road edges in northern forests (Ortega and Capen 2002, Morse and Poole 2005). The proportion of soft linear features did not have a detectable influence on relative abundance of black-throated green warblers (Figure 10.2).

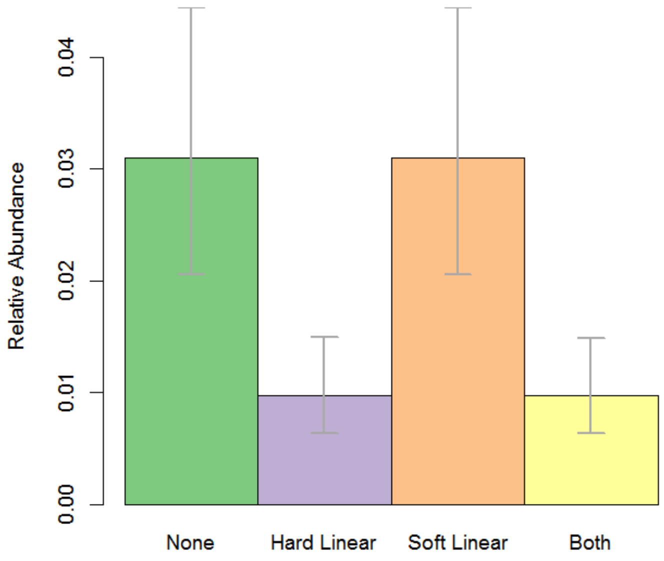


Figure 10.2 Effects of linear features on point level (150 m radius buffer) relative abundance of black-throated green warbler. Whiskers represent 90% confidence intervals. 'None' means no linear features in buffer. Effect of hard linear feature was estimated with no soft linear features present, effect of soft linear feature effect were estimated for an average proportion of soft linear features in the landscape with no hard linear feature present. 'Both' was estimated when hard linear feature and an amount of soft linear features were present. Soft linear features had no modifying effect on local relative abundance, thus mean and confidence interval for 'None' and 'Soft Linear', and 'Hard Linear' and 'Both' are of the same height, respectively.

Quarter section scale human footprint relationships

Relative abundance of the black-throated green warbler was not significantly affected by the proportion of human footprint types at the quarter section (64 ha) scale. Ninety-four % of the bootstrap iterations did not support the existence of a quarter section scale footprint effect (Figure 10.3)

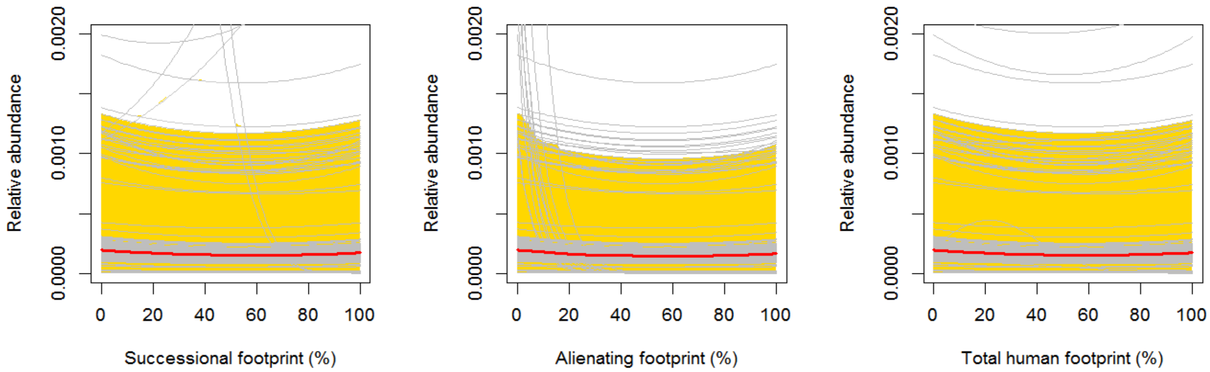


Figure 10.3 Effect of quarter section (64 ha) scale human disturbance on mean expected density of black-throated green warbler relative abundance. The yellow region represents the 90% confidence intervals around the mean response curve, which is shown in red. Grey lines represent response curves based on individual bootstrap iterations.

Regional responsibility

Average relative abundance under current and reference conditions was calculated for each quarter section within the regional study area (Figure 10.4). Regional responsibility for black-throated green warbler in the subregion was calculated as the percentage of the regional population under reference condition that occurred within the subregion standardized by area. Values higher than 100% indicated disproportionately more responsibility concentrated in the subregion. Subregional responsibility was 18.0% which was very close to the percent area of the subregion (18.4%), therefore the standardized responsibility was 98.0%. The fact that the standardized responsibility was close to 100% means that undisturbed area in the subregion supported similar population densities as would a similarly-sized area in the larger region.

Contributions to regional change

A map of quarter section level intactness for the black-throated green warbler is shown in Figure 10.4. On average, predicted current levels of relative abundance were lower than relative abundance under reference conditions. This was due to the low (almost 0) expected densities for black-throated green warbler in urban-industrial habitats, as well as negative effects of hard linear features and the fact that forestry converts old stands to young stands (Figures 10.1 and 10.2). Intactness for black-throated green warbler reflected negative changes in relative abundance for the species (Figure 10.4).

The predicted mean density in the regional study area was only 1.96% less under current footprint levels than under reference conditions. This decrease was roughly proportional to the small percentage of alienating footprint (human created wetlands, cultivation, urban-industrial areas, roads) and forestry footprint that created young stands in the region (Table 5.1). The subregion level contribution to the regional change was a 0.2% decrease under present footprint levels in the subregion. This change was 11.6% of the total regional change in relative abundance, thus the subregional contribution to the regional change was lower than expected based on the percent area of the subregion (18.4%). This indicated that most of the footprint affecting regional intactness for the black-throated green warbler were found outside of the subregion.

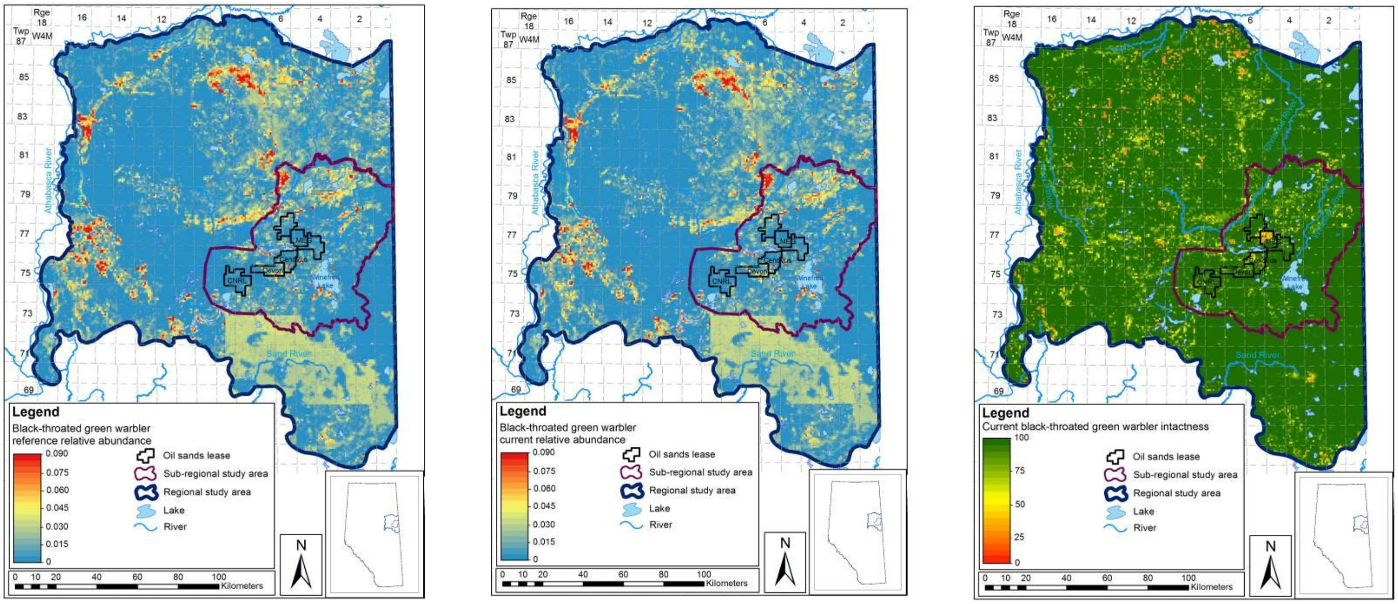
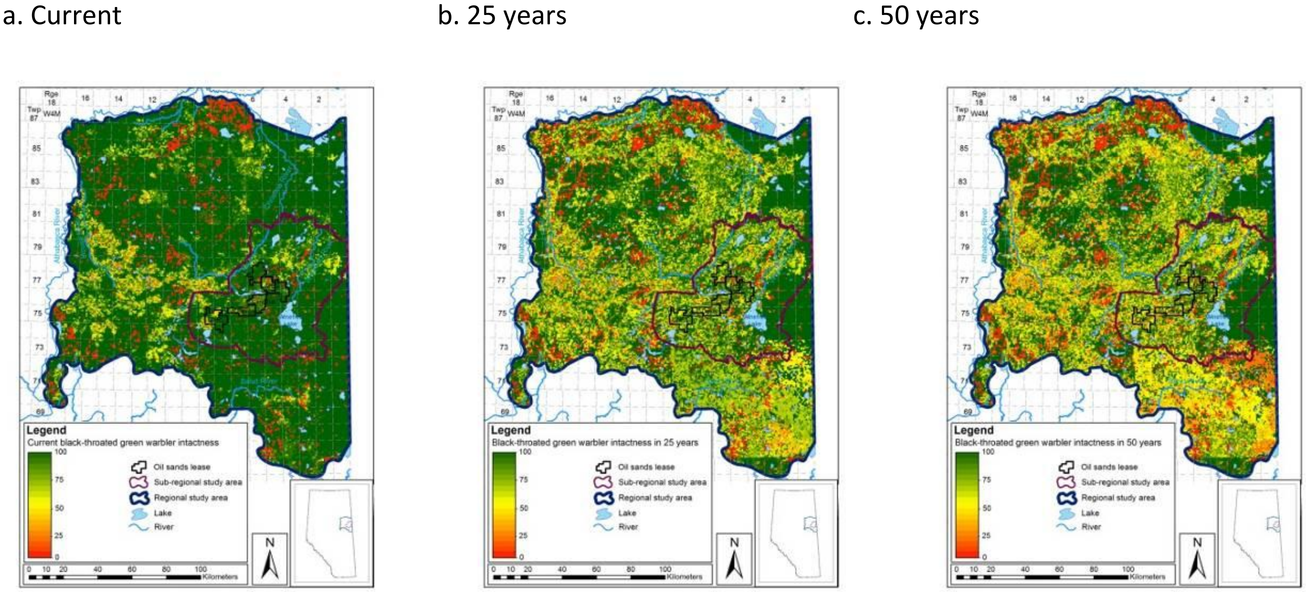


Figure 10.4 Predictive maps of black-throated green warbler relative abundances at quarter section (64 ha) scale in the regional study area; left: reference relative abundance, middle: current relative abundance, right: species intactness. Intactness values close to 100% indicated intact conditions (abundances were similar to expected reference values), while values close to 0 indicated deviations from reference condition.

10.4 Projections

Maps used for current intactness and projected intactness calculations were different, therefore future intactness values were calculated based on a backfilled map used for the projections (Figure 4.2.b) to make the comparison across time steps meaningful. Intactness for black-throated green warbler changed from 93% to 78% in the first 25 years of change, and decreased further to 72% during the next 25 years (Figure 10.5). The change in intactness was due to an increase in forestry and corresponding decrease in old growth upland forest, and to a lesser extent a slight increase in urban-industrial features in the projections. Due to the statistical nature of the projections, changes in landscape composition and corresponding decrease in intactness was distributed throughout the region, but that may have been an artifact of the analysis. The number of quarter sections with higher than 90% intactness values decreased by half in the first 25 years of the projections. These quarter sections were mostly characterized by extremely low (less than 60%) intactness values and that explained the huge initial drop in species intactness (Figure 10.6).



a. Current b. 25 years c. 50 years

Figure 10.5. Projected change in intactness for black-throated green warbler in a) Current landbase, b) Landbase projected for 25 years into the future, and c) Landbase projected for 50 years into the future.

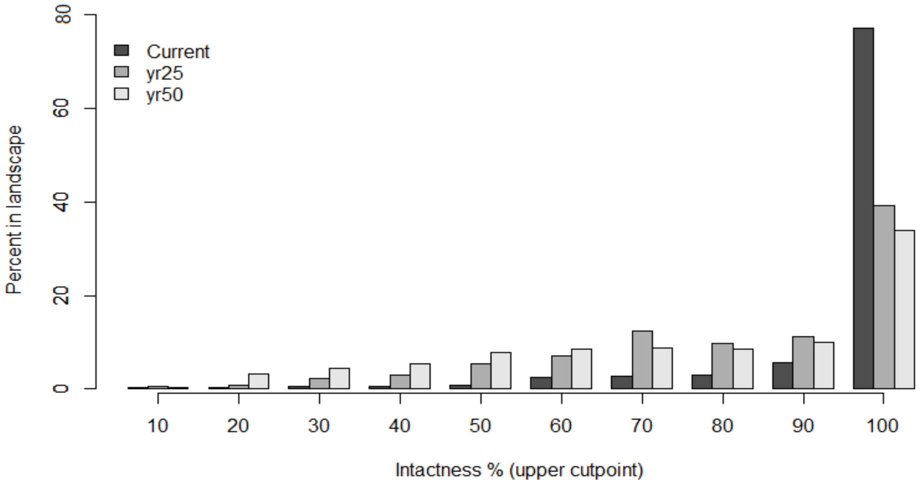


Figure 10.6. Distribution of quarter section level intactness values for black-throated green warbler (values represented in the map in Figure 10.5).

10.5 Discussion

Cumulative effects of human development on the black-throated green warbler were assessed based on a dose-response relationship framework (Nielsen et al. 2007), after controlling for habitat, age and spatial location. Effect of human footprint was assessed at both the point count (7 ha) and quarter section (64 ha) scale. Point level effects indicated low density of black-throated green warbler in habitats with harvest, cultivation or urban-industrial development and hard linear features (improved roads). Thus conversion of old forest led to declines of local populations. Both forest harvest and fires had negative effects on black-throated green warblers by creating low value young stands. The sharp decline in black-throated green warbler density adjacent to hard linear features indicated a numerical edge effect which decreased the amount of forest interior habitat available to the species.

Our framework for incorporating point and quarter section level footprint effects was suitable for expressing cumulative effects of multiple footprint types on black-throated green warbler relative abundance. Quarter section scale predictive mapping of relative abundance under current footprint levels and reference conditions enabled the calculation of relative responsibilities and contributions to regional and subregional intactness. The small scale (64 ha) of our predictive modeling approach enables quantification of these metrics in lease areas nested in a region. Beyond calculating intactness, the modeling framework also enabled us to apply the results of spatially explicit forecasted landscape conditions 25 and 50 years into the future.

11.0 Caribou

11.1 Introduction

Caribou were often identified as a priority species for measuring cumulative effects of industrial development in northeast Alberta (Table 3.1). We identified two existing models for predicting cumulative effects of industrial development on caribou: (1) the Government of Canada recovery strategy critical habitat criteria for caribou (Environment Canada 2012), and; (2) the Sorenson et al. (2008) caribou cumulative effects model. Both models were based on measuring the amount of burned forest and human footprint in a given area, with recently burned forest and footprint considered poor-quality habitat for sustaining caribou populations.

The Government of Canada defined critical caribou habitat as anywhere that had not been disturbed by fire in the last 40 years and anywhere greater than 500 m from human footprint. If greater than 35% of a landscape was disturbed (i.e., ≤65% is critical habitat), the landscape was considered unsuitable for supporting a self-sustaining caribou population (Environment Canada 2012). The Government of Canada defined human footprint as any human-caused disturbance to the natural landscape that was visible on Landsat imagery at a scale of 1:50 000 with a minimum mapping unit (MMU) of 2 ha (Environment Canada 2011). The Sorenson et al. (2008) model was based on an empirical relationship between caribou population growth rate (λ) and the percentage of human footprint buffered by 250 m (identified using 5 m spatial resolution imagery) and the percentage of area burned in the last 50 years within caribou ranges.

We applied the Environment Canada (2012) and Sorenson et al. (2008) models to our regional study area to predict cumulative effects of industrial development on caribou. We measured the proportion of disturbed habitat, following each of the models' criteria, within our regional and subregional study areas and caribou ranges. Furthermore, we applied the models to future scenarios of land use development in the regional study area to illustrate how predictions of future development may be used to predict cumulative effects of industrial development on caribou populations.

Our results predicted how current and future levels of industrial development influence caribou populations compared to the viability of caribou populations in a scenario where fire was the only disturbance (i.e., no human footprint). We highlighted how results of our approach can be interpreted, and the strength of our approach for conducting cumulative effects assessments on focal species in Alberta.

11.2 Methods

We used the ABMI Alberta Wall-to-Wall Human Footprint circa 2010 Version 1.2 (ABMI 2012b) to identify human footprint within the study areas. For the Environment Canada (2012) model, we buffered all human footprints by 500 m and calculated the proportion of that buffered footprint within each quarter section of the regional study area. It was unclear whether seismic lines would be used in the Environment Canada (2012) criteria for mapping human footprint. Specifically, they indicated that seismic lines less than 10 m wide were typically only partially visible in Landsat imagery and that on average there was a 62% underestimation of linear features (Environment Canada 2011) using Landsat. We therefore also measured the amount of 500 m buffered footprint, not including linear features less than 10 m wide, within each quarter section. This provided a more conservative estimate of human footprint in the regional study area. For the Sorenson et al. (2008) model we buffered the ABMI human footprint by 250 m and calculated the proportion of 250 m buffered footprint within each quarter section. Sorenson et al. (2008) identified human footprint in caribou ranges using 5 m spatial resolution imagery, suggesting they were likely able to identify most seismic lines.

We obtained historical (1931 – 2011) spatial wildfire data from the Government of Alberta (http://www.srd.alberta.ca/Wildfire/WildfireStatus/ HistoricalWildfireInformation/ SpatialWildfireData.aspx). For the Environment Canada (2012) model, we calculated the proportion of area burned between 1972 and 2011 within each quarter section of the study area. Burned areas and buffered footprint may overlap in space. We therefore did not count burned areas that occurred within the 500 m of buffered footprint to avoid double-counting disturbance within a given quarter section. For the Sorenson et al. (2008) model we calculated the proportion of area burned between 1961 and 2011 within each quarter section. Sorenson et al. (2008) indicated that they did not consider fire and footprint as spatially exclusive in their model. Therefore, we did not exclude from the analysis the amount of burned areas within 250 m of footprint.

We calculated the proportion of disturbed habitat within each quarter section as the sum of the proportion of the quarter section within 500 m of footprint and the proportion of the quarter section burned in the last 40 years. Therefore, the proportion of critical habitat for caribou as defined by the Environment Canada (2012) was one minus the proportion of disturbed habitat. We calculated caribou λ for each quarter section of the study area using the Sorenson et al. (2008) equation:

$$\lambda = 1.192 - \%HF*0.00315 - \%BU*0.00292$$

where %HF was the percent of the quarter section area within 250 m of buffered footprint and %BU was the percent of the quarter section area burned in the last 50 years. A λ of 1 indicated a caribou population with a stable growth rate whereas values >1 indicated a growing population and values <1 indicated a declining population. We estimated critical habitat area and λ within the regional and subregional study areas and caribou ranges by adding the proportion of disturbed habitat and λ within all quarter sections in the area and dividing by the number of quarter sections in that area.

For both the Environment Canada (2012) and Sorenson et al. (2008) cumulative effects models we calculated reference models that described the landscape without any footprint (i.e., the proportion of buffered footprint for both models = 0) but with current fire disturbance.

Therefore, only the proportion of area burned in the last 40 and 50 years, respectively, was considered as disturbed area in these models.

Finally, we predicted cumulative effects on caribou 25 and 50 years into the future based on a simulated future land-use scenario (see Chapter 4). In these simulations the spatial resolution of future human footprint was less than the spatial resolution of current human footprint. Specifically, future human footprint was simulated as a percentage of area within each 6 ha unit rather than as an actual polygon that could be accurately buffered. Therefore, in the future simulation for the Sorenson et al. (2008) cumulative effects model, we considered all 6 ha units with any human footprint in them as fully disturbed by buffered human footprint. Our rationale was that a 6 ha area is approximately 250 m by 250 m and if any footprint was located within it, the 250 m buffer would include the majority of the 6 ha unit. We then calculated the percentage of 6 ha units with human footprint within each quarter section (approximately 11 units per quarter section) to determine the %HF. In the future simulations for the Environment Canada (2012) cumulative effects model, we considered each 6 ha unit with human footprint in it plus all 6 ha units immediately adjacent to it as disturbed by human footprint. Our rationale was that a 500 m buffer would include the entire 6 ha unit that the human footprint occurred in, and would also likely include a large portion of all neighbouring 6 ha areas. However, we did not include soft linear footprint in this model, as the Environment Canada (2012) method for identifying footprint in caribou range was unlikely to detect seismic lines. We calculated the percentage of 6 ha units with human footprint (except soft linear) and adjacent to units with human footprint within each quarter section to calculate the proportion of human footprint.

11.3 Results

Reference conditions

If the study area had no human footprint (i.e., all current footprint was "backfilled"), we predicted that 30% and 33% of habitat would have been disturbed by fire within the regional and subregional study areas, respectively (Figure 11.1, Table 11.1). Fire disturbance was highly variable among caribou ranges, with the highest proportion of burned habitat in the East-side Athabasca River (ESAR) / Wiau caribou range (64%) and the lowest proportion in the ESAR Wandering range (3%).

Under reference (backfilled) conditions, caribou populations were predicted to be increasing in the regional ($\lambda = 1.11$) and subregional ($\lambda = 1.11$) study areas (Figure 11.2, Table 11.1). Caribou populations were also predicted to be increasing within all of the caribou ranges ($\lambda = 1.08$ to 1.18), with the exception of ESAR Wiau herd, which was stable ($\lambda = 1.00$).

Current conditions

Currently, 68% and 75% of habitat was within 500 m of footprint (not including seismic lines) or burned within the regional and subregional study areas, respectively (Figure 11.1, Table 11.1). Therefore, only 32% and 25% of these areas were considered critical habitat for caribou (Environment Canada 2012). Within caribou ranges, the ESAR Bohn herd had the lowest proportion of disturbed habitat (34%) and the ESAR Wiau herd had the highest (87%). Notably, all caribou herds, with the exception of ESAR Bohn, were below the 65% critical habitat threshold identified by Environment Canada as necessary for a self-sustaining caribou population (Environment Canada 2012).

Caribou population growth rates were 0.92 and 0.95 in the regional and subregional study areas, respectively, under current conditions (Figure 11.2, Table 11.1); therefore caribou populations were declining. Caribou populations were also declining within all caribou ranges, with the exception of the ESAR Bohn (λ = 1.03) and ESAR Christina (λ = 1.01) ranges.

Future conditions

Based on our future footprint simulation models, in 25 years, 82% and 85% of habitat was projected to be within 500 m of footprint (not including seismic lines) or burned within the regional and subregional study areas, respectively (Figure 11.1, Table 11.1). This increased by only 3% in the following 25 years (85% and 88% of the study areas, respectively). In 25 years the lowest level of disturbance was in the ESAR Bohn herd (56%) and the highest was in ESAR Wiau (97%). Disturbance increased a further 1% to 6% in most ranges during the following 25 years, with the exception of ESAR Agnes, which was the only herd where disturbance declined (79% to 77%).

Future footprint simulations predict that in 25 years caribou population growth rates (λ) declined to 0.85 in the regional and subregional study areas (Figure 11.2, Table 11.2). In 50 years, λ was predicted to stabilize at 0.85 in the regional and subregional study areas. Similarly, in 25 years λ was predicted to decline in all caribou ranges and then to stabilize (or recover slightly) in 50 years. The ESAR Bohn range was the only herd where λ was not predicted to drop below 1.0.

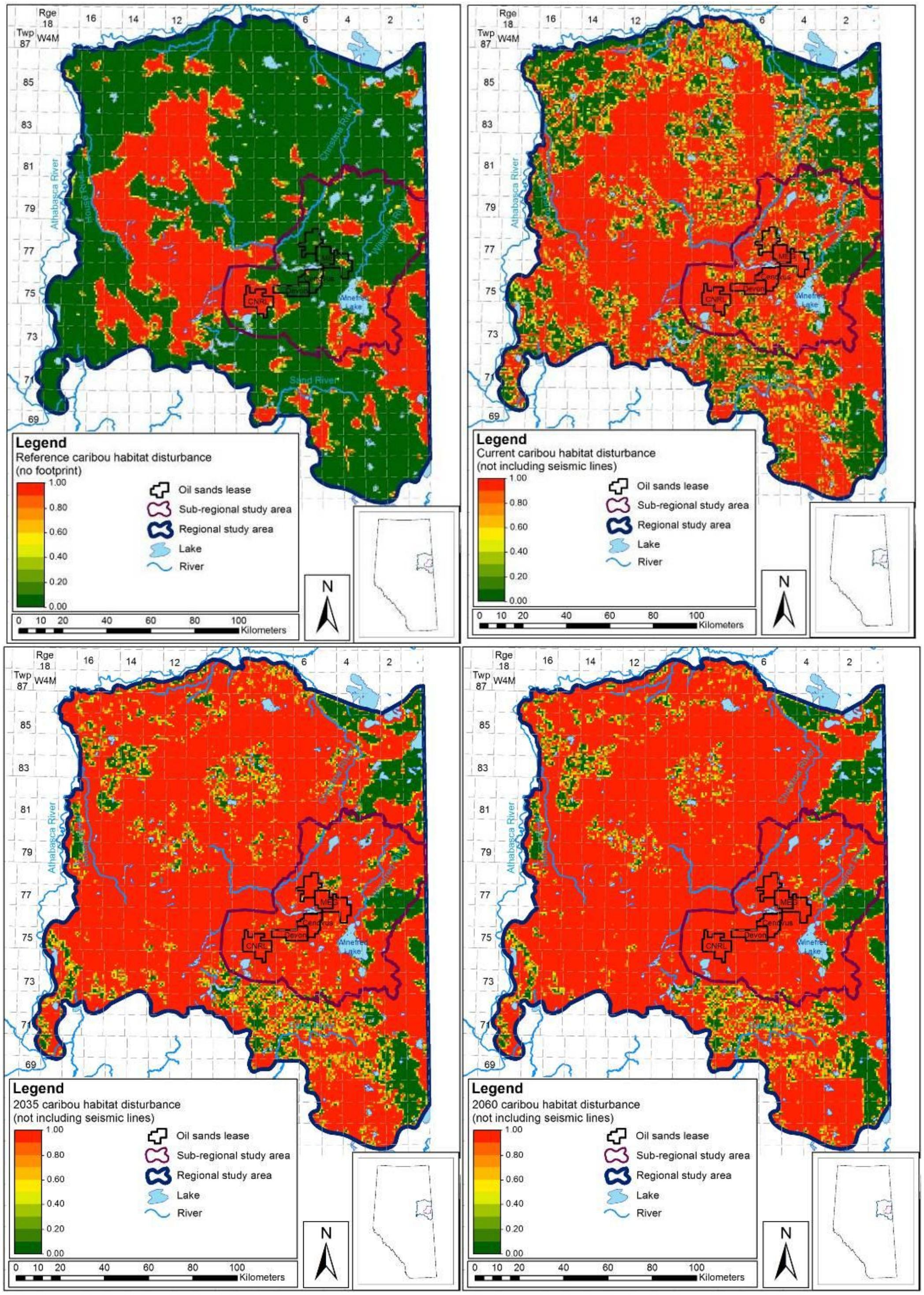


Figure 11.1. Proportion of predicted disturbed caribou habitat according to the Environment Canada (2012) critical habitat criteria for caribou within the regional study area in northeast Alberta, Canada, under reference conditions (top left), current footprint (top right), and simulated future footprint 25 (bottom left) and 50 (bottom right) years into the future. Proportion of disturbed habitat is indicated for each quarter section.

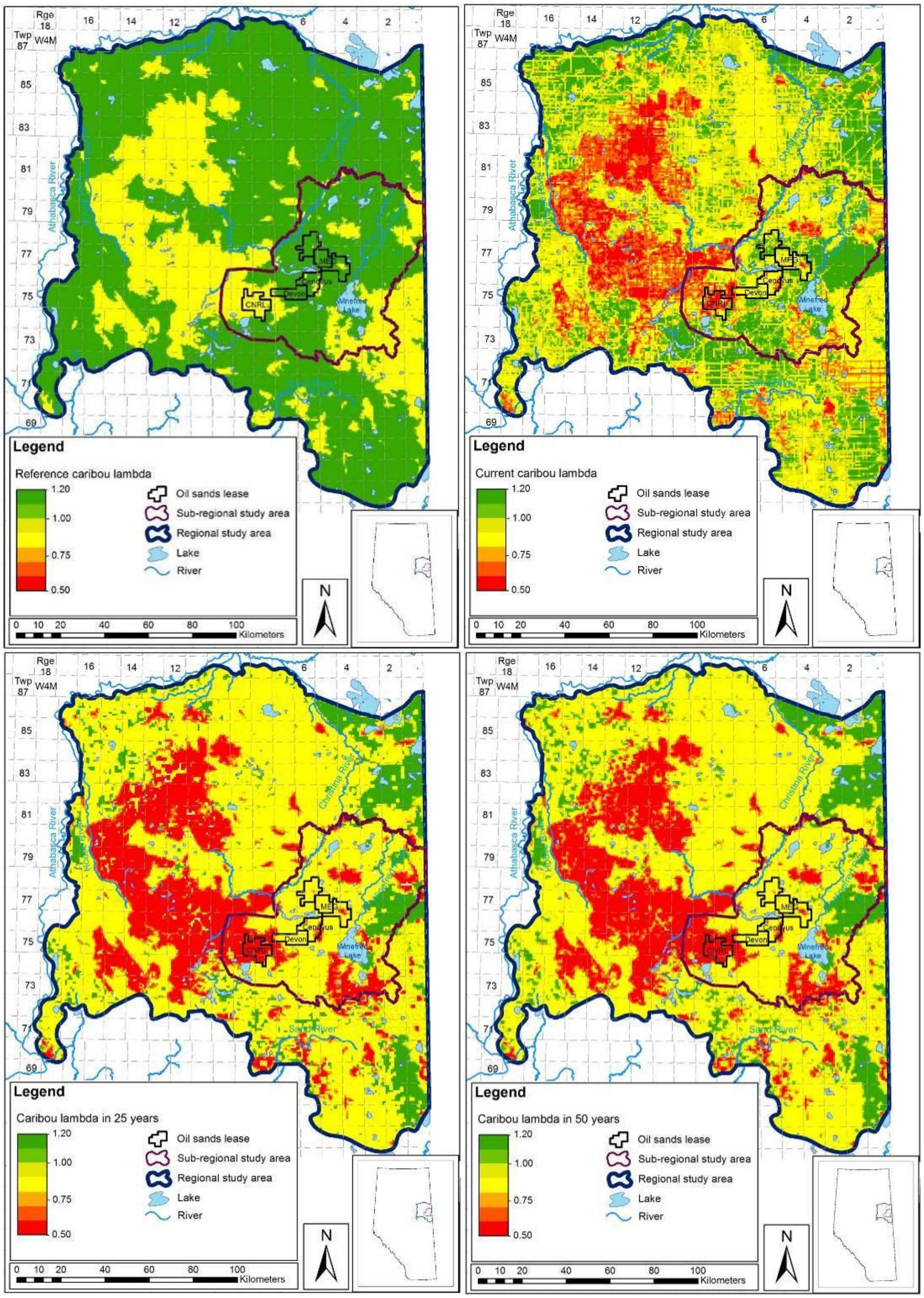


Figure 11.2. Predicted caribou population growth rate, calculated using the Sorenson et al. (2008) cumulative effects model, within the regional study area in northeast Alberta, Canada under reference conditions (top left), current footprint (top right), and simulated future footprint 25 (bottom left) and 50 (bottom right) years into the future. Growth rate was indicated for each quarter section, with values greater than 1.0 indicating population growth and values less than 1.0 indicating population decline.

Table 11.1. Proportion of disturbed caribou habitat according to the Environment Canada (2012) critical habitat criteria for caribou, under reference conditions, current and simulated future (25 and 50 years from 2010) footprint conditions in the regional and subregional study areas and caribou ranges in northeast Alberta, Canada.

Area	Reference	Current	Plus 25 years	Plus 50 years
Study Area				
Regional	0.30	0.68	0.82	0.85
Subregional	0.33	0.75	0.85	0.88
Caribou Range				
Cold Lake	0.32	0.71	0.77	0.81
ESAR Agnes	0.04	0.57	0.79	0.77
ESAR Algar	0.21	0.53	0.84	0.85
ESAR Bohn	0.08	0.34	0.56	0.62
ESAR Christina	0.16	0.59	0.73	0.76
ESAR Egg Pony	0.40	0.79	0.90	0.94
ESAR Wandering	0.03	0.59	0.79	0.81
ESAR Wiau	0.64	0.87	0.97	0.99

Table 11.2. Caribou population growth rate according to the Sorenson et al. (2008) model, under reference conditions, current and simulated future (25 and 50 years from 2010) conditions in the regional and subregional study areas and caribou ranges in northeast Alberta, Canada. Values >1 indicate population growth, those <1 indicate population decline.

Area	Reference	Current	Plus 25 years	Plus 50 years
Study Areas				
Regional	1.11	0.92	0.85	0.85
Subregional	1.11	0.95	0.85	0.85
Caribou Ranges				
Cold Lake	1.10	0.95	0.86	0.87
ESAR Agnes	1.18	0.96	0.91	0.92
ESAR Algar	1.13	0.95	0.86	0.86
ESAR Bohn	1.18	1.03	1.00	1.00
ESAR Christina	1.15	1.01	0.91	0.92
ESAR Egg Pony	1.08	0.83	0.77	0.77
ESAR Wandering	1.18	0.95	0.89	0.91
ESAR Wiau	1.00	0.80	0.70	0.70

11.4 Discussion

Effects of human footprint on caribou

Current (i.e., 2010) human footprint was predicted to reduce critical habitat for caribou within the regional study area to below that necessary to support self-sustaining caribou populations according to both the Environment Canada (2012) and Sorenson et al. (2008) criteria. Within caribou ranges - the most relevant scale for caribou management (Environment Canada 2012) - available habitat was less than the critical 65% level for the majority of the herds, and did not support stable or growing populations (i.e., $\lambda \geq 1$).

Cumulative effects of human footprint on caribou were predicted to increase within the next 50 years, based on our simulations. The amount of disturbed caribou habitat in the study area was predicted to increase by 14% and 17%, 25 and 50 years into the future, respectively. This would result in caribou λ being well below 1.0 throughout the majority of their range in the region. Much of the increase in disturbed habitat and decrease in λ was expected to occur in the next 25 years, and λ may stabilize, or even increase, in some areas by 50 years into the future as vegetation regrows in recently disturbed areas. However, the limitations of our future simulation models (see Chapter 4) should be kept in mind when interpreting these results . In particular, our simulations did not consider reclamation of linear industrial features, which could be an important factor in the amount of future disturbed habitat. Nevertheless, our results highlight the negative effects that development trajectories could have on caribou populations in the region.

Fire also made a contribution to cumulative effects on caribou. At larger scales (regional and subregional), current fire regimes did not reduce caribou critical habitat below the self-sustaining threshold for populations (i.e., <65% critical habitat and λ <1.00). However, within some caribou ranges, fire disturbance was sufficient to result in caribou population declines (i.e., the ESAR Egg Pony and ESAR Wiau ranges). Caribou are a wide ranging species and thus the effect of fire on caribou populations should ideally be considered at larger scales (i.e., the region and subregion) and over longer time periods. Predicting and simulating the effect of different fire regimes on caribou habitat disturbance levels was outside the scope of the present project. However, if fire regimes change due to fire suppression and/or climate change, then the effect of fire on caribou populations could become of lesser or greater concern.

Human footprint development within burned areas may reduce the relative impacts of footprint on caribou populations at local scales. Consequently, it might be attractive to propose development of in-situ footprint within burned areas as mitigation for caribou. However, fire is relatively stochastic over space and time, whereas footprint is expected to persist on the landscape for a minimum of 50 years. Therefore burned areas may naturally succeed to critical caribou habitat prior to reclamation of human footprint.

The effect of location and type of human footprint on caribou populations was not accounted for in the Environment Canada (2012) and Sorenson et al. (2008) cumulative effects models. Rather, all footprint types and locations were treated equally. However, the mechanism for caribou decline (see Chapter 12) suggests that location and type of footprint may be important. For example, linear features adjacent to a developed forestry area with high wolf density might have greater influence on caribou than developing linear features in an area without forestry and with low wolf density.

Advantages of this approach to modelling cumulative effects

We used existing models to predict cumulative effects of human development on caribou. These models were appealing because they explicitly linked human footprint to caribou population dynamics (λ) and we could measure disturbance on the landscape based on human footprint and estimate impacts on caribou populations. We recommend adopting existing models (or developing ones if necessary) that link habitat to population dynamics for focal species in cumulative effects assessments.

We predicted critical habitat and population growth at a much smaller scale (quarter section) than the scale for which the Environment Canada (2012) and Sorenson et al. (2008) models were developed (i.e., the caribou range). To estimate critical habitat and population growth in areas larger than a quarter section, we simply added up the quarter section estimates within the area of interest. We believe this approach was appropriate because we considered disturbance as proportion of an area, which was easily scaled-up within any defined area.

Improvements to modelling cumulative effects of human footprint on caribou

A mechanistic understanding of the cause-effect relationships between human disturbance and caribou populations is desirable as it allows for developing more detailed and targeted mitigation. However, determining mechanistic relationships is often expensive, and may be impossible in complex ecosystems, particularly for wide-ranging wildlife species such as caribou. In such cases accurate and precise correlative relationships between simple measures of human disturbance and population dynamics, such as the Environment Canada (2012) and Sorenson et al. (2008) models we used, provide a useful tool for predicting the cumulative effects of development on a species. However, these tools focused solely on habitat–mediated effects on caribou and thus fail to explicitly account for predator densities. Predation is the proximal factor limiting caribou abundance in the study region, and direct and indirect effects of humans on predators and caribou predation rate (i.e., predator culling or caribou fencing) will also influence caribou abundance. An understanding of both habitat- and predator-mediated effects of humans on caribou is needed to fully assess cumulative effects on caribou.

12.0 Caribou and the Large Mammal Predator-Prey Community

12.1 Introduction

Caribou are a priority species of concern in the regional study area and declining in the area (Chapter 11; Alberta Sustainable Resource Development and Alberta Conservation Association 2010; Environment Canada 2012). The current paradigm was that changes to habitat resulting from resource development resulted in greater predation of caribou by wolves through apparent competition (Holt 1977; Wittmer et al. 2007; DeCesare et al. 2010). Specifically, early-seral vegetation created by forestry created food for moose and deer, which in turn provided more prey for wolves, supporting wolf population growth and expansion. Linear features created by oil and gas developments further facilitated wolf expansion into caribou range. These numerical and functional mechanisms contributed to increased wolf predation rate on caribou and ultimately to caribou population decline. Precise assessment of the cumulative effects of human activity on caribou populations in the oil sands region required an understanding of how human activity influenced ungulate and predator population dynamics.

In this Chapter we presented a conceptual model of how cumulative effects of human footprint development influenced caribou populations in the regional study area. We highlight how existing research and data informed our understanding of cumulative effects of human footprint on caribou. We also illustrated the data that will be required to provide a mechanistic understanding of how cumulative effects influenced caribou populations. Second, we tested for relationships between human footprint and large mammal co-occurrence within caribou range and the oil sands region of Alberta using ABMI data (Figure 12.1). We tested whether forestry and agriculture footprint was positively related to deer, moose, coyote and wolf occurrence and negatively related to caribou occurrence, and whether linear features were positively related to wolf and caribou co-occurrence.

12.2 Methods

Conceptual model of cumulative effects of human activity on caribou

We developed a conceptual model of the current hypothesis of how human footprint development influenced caribou populations. We identified direct and indirect relationships between the effects of human footprint on caribou and existing research and data that may be used to inform the model. The conceptual model was developed to provide a broad framework for guiding management of cumulative effects of human footprint development on caribou populations.

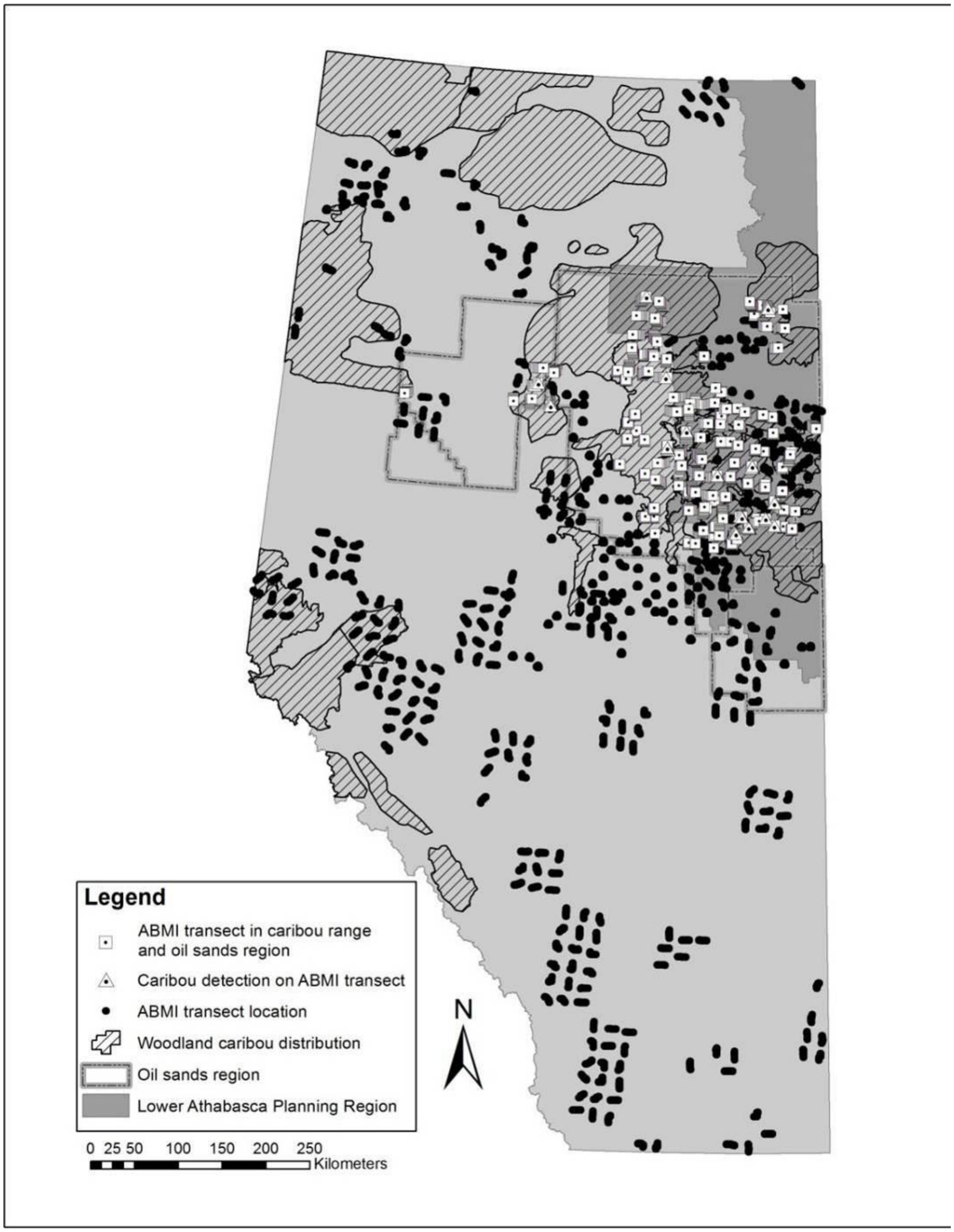


Figure 12.1. Transects used in the analyses of large mammal co-occurrences in caribou range and the oil sands region of Alberta.

Analysis of ABMI data

We used hierarchical cluster and ordination analyses (e.g., Bowman et al. 2010; Muhly et al. 2011), to examine species and human footprint co-occurrence patterns at 110 ABMI transects in caribou range within the oil sands region of Alberta. Large mammal occurrence (presence/absence) was measured along 10 km long winter transects divided into 1 km segments. Species' relative abundances were scored from 0 (no detections) to 10 (one detection in every 1 km segment). Human footprint was measured within 150 m buffers around segments using the backfilled vegetation layer (Section 4). We caution that our analyses did not explicitly test the mechanisms of caribou decline. Rather they determined whether there were patterns in the data to suggest such a mechanism existed.

We conducted hierarchical cluster and ordination analyses using presence/absence data at the segment level and relative abundance counts (0 to 10) at the transect level. Species matrices were transformed into dissimilarity matrices using the Bray-Curtis and Jaccard distance methods. Then hierarchical cluster analyses were conducted on each matrix using average and Ward's distance linkages. Dendrograms were created to compare results from each method. Ordinations were conducted on Bray-Curtis and Chao dissimilarity species matrices using non-metric multi-dimensional scaling (NMDS). A Chao distance matrix (Chao et al. 2005) was used because it was more robust to data with species that are under-sampled or rarely occur, as was the case for caribou. We ran 300 iterations with random starting points to identify a 2-dimensional solution. We then fitted human footprint and latitude covariates on the ordination plot and tested their fit with each ordination axis using permutation tests (1,000 permutations) and Kendall's rank correlation tau. R^2 and tau values indicated the strength of the relationship and p values indicated their statistical significance.

Finally, we conducted a partial constrained ordination of the transect data (Bowman et al. 2010). Latitude may have a significant effect on species occurrence; and partial constrained ordination was used to test for human footprint effects on species occurrence after removing the effects of latitude. All analyses were done in R 2.15.1 using the 'vegan' package 2.0-5 (Oksanen et al. 2012).

12.3 Results

Conceptual model of cumulative effects of human footprint on caribou

The current hypothesis for how cumulative effects of human footprint contributed to caribou decline in northeastern Alberta was described in Figure 12.2. The decline of caribou populations was linked to low calf recruitment rates, likely due to predation (Figure 12.2 – D; McLoughlin et al. 2003), a dominant factor limiting caribou populations in North America (Bergerud and Ballard 1988; Seip 1992; Bergerud and Elliott 1986; Stuart-Smith et al. 1997; Bergerud and Elliott 1998; Rettie and Messier 1998; Schaefer et al. 1999; McLoughlin et al. 2003; Wittmer et al. 2005a). Research identified strong correlations between anthropogenic footprint (e.g., roads) on the landscape and caribou decline at the caribou range scale (Schaefer 2003; Wittmer et al. 2005b; Vistness and Nelleman 2007; Vors et al. 2007; Bowman et al. 2010; Environment Canada 2012), including in northeast Alberta (Figure 12.2 – A; Sorensen et al. 2008; see Chapter 11 of this report).

The leading hypothesis for this negative relationship was that anthropogenically-caused habitat change converted low-productivity vegetation (e.g., old growth forest) to high-productivity early seral forest and agriculture. This high productivity vegetation increased populations of moose (*Alces alces*) and deer (*Odocoileus spp.*) (Figure 12.2 – B; Fisher and Wilkinson 2005). The increased ungulate prey density subsequently increased predator density (particularly wolves, *Canis lupus*), effecting a predator numerical response (Figure 12.2 – C; *sensu* Holling 1959). The result was a case of *apparent competition* (Holt 1977, 1984; Holt and Kotler 1987), wherein an increase in density of moose and deer caused a decline in caribou that was actually mediated through increased abundance of wolves, their shared predator (DeCesare et al. 2010). In addition, construction of linear features (i.e., roads, pipelines and seismic lines) made it easier for predators to traverse the landscape, which increased predator-caribou encounter rates and caribou predation (Figure 12.2 – E; i.e., a predator functional response; James and Stuart-Smith 2000; McLoughlin et al. 2003; Latham et al. 2011).

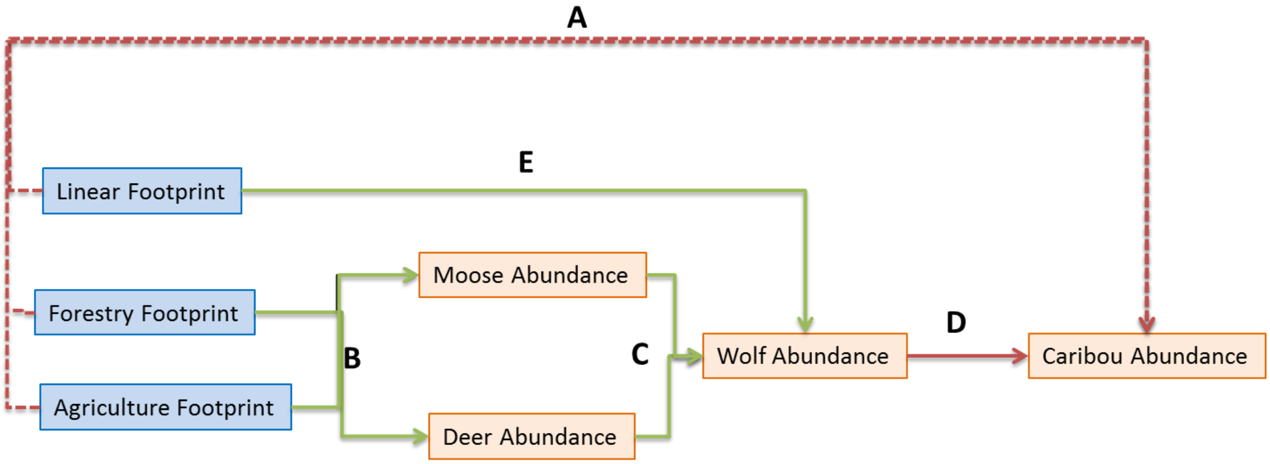


Figure 12.2. Conceptual model of hypothesized direct (solid lines) and indirect (dashed lines) effects of human footprint development on caribou abundance. Positive effects were indicated as green lines, negative effects indicated as red lines. Letters indicate relationships that were explained in detail in the text. A indicated the negative indirect relationship between human footprint and caribou abundance. B indicated the positive numerical response of moose and deer to forestry and agriculture footprint. C indicated the positive numerical response of wolves to moose and deer. D indicated increased predation rate by wolves on caribou. E indicated the increased landscape permeability that linear features provide for wolves.

Analysis of ABMI data

Hierarchical cluster analysis of species by transect segment indicated that deer and moose tended to cluster in space (Figure 12.3). Coyotes were most closely associated with this cluster, followed by wolves. Caribou did not cluster with the other species. The dissimilarity matrices and linkages tested provided similar results. However, the Jaccard dissimilarity matrix provided slightly different results than the Bray-Curtis dissimilarity matrix, indicating that wolves clustered with caribou. Similar patterns were found when the species data were aggregated by transect.

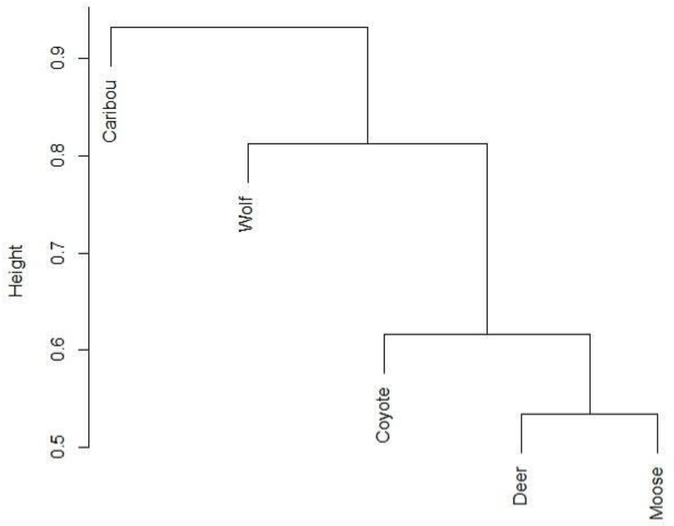


Figure12.3. Dendrogram of species hierarchical cluster analysis using Bray-Curtis dissimilarity matrix and average linkage. Species that cluster together in space have branches with lower height values.

Non-metric multidimensional scaling (NMDS) ordination of species by transect segment supported the results of the cluster analysis: moose and deer tended to co-occur more than they co-occurred with coyotes and wolves (Figure 12.4). Furthermore, caribou tended not to occur with other species. Although two dimensions were illustrated, stress values for NMDS were very low (stress = 2.5e-15) and only a single dimension was needed to describe the data. As with the hierarchical cluster analyses, similar patterns were found when the species data were aggregated by transect.

Non-metric multidimensional scaling (NMDS) ordination of transect segment data indicated that deer and wolves tended to co-occur at sites with more forestry and agriculture footprint (Figure 12.5). Once again, caribou tended not to co-occur with other species. Caribou typically avoided soft linear and forestry footprint types. However, there was a strong latitudinal effect on species occurrences, where wolves and caribou tended to occur at northern sites whereas coyotes and deer occurred at southern sites (Figure 12.6). We found a significant relationship between latitude and both NMDS axes based on the permutation test (Table 12.1; $R^2 = 0.097$, p-value = 0.001) and Kendall's rank correlation (Axis 1: $\tau = 0.143$, p-value = <0.001, Axis 2: $\tau = -0.100$, p-value = <0.001). Hard linear ($R^2 = 0.014$, p-value = 0.005) and soft linear ($R^2 = 0.016$, p-value = 0.004) features were also significantly related to Axis 2 ($\tau = -0.068$, p-value = 0.025) and 1 ($\tau = -0.054$, p-value = 0.035), respectively. Forestry was significantly related to Axis 1 ($\tau = -0.062$, p-value = 0.037) and agriculture was significantly related to Axis 2 ($\tau = 0.063$, p-value = 0.042).

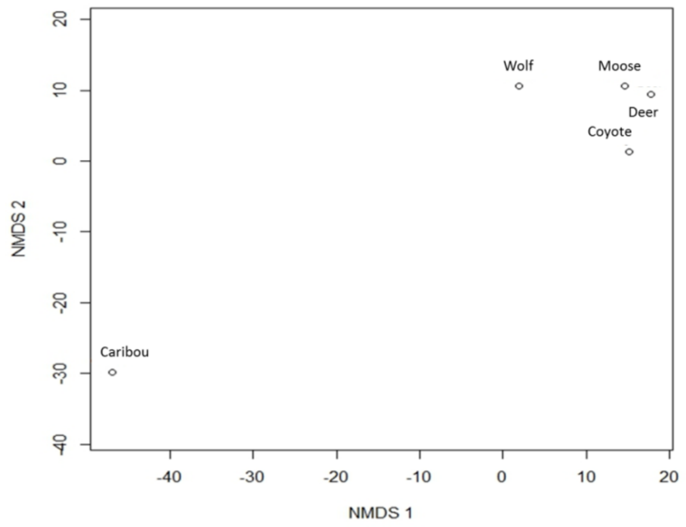


Figure 12.4. Non-metric multi-dimensional (NMDS) scaling of species data using Bray-Curtis dissimilarity matrix. Species in close proximity along axes co-occurred with each other.

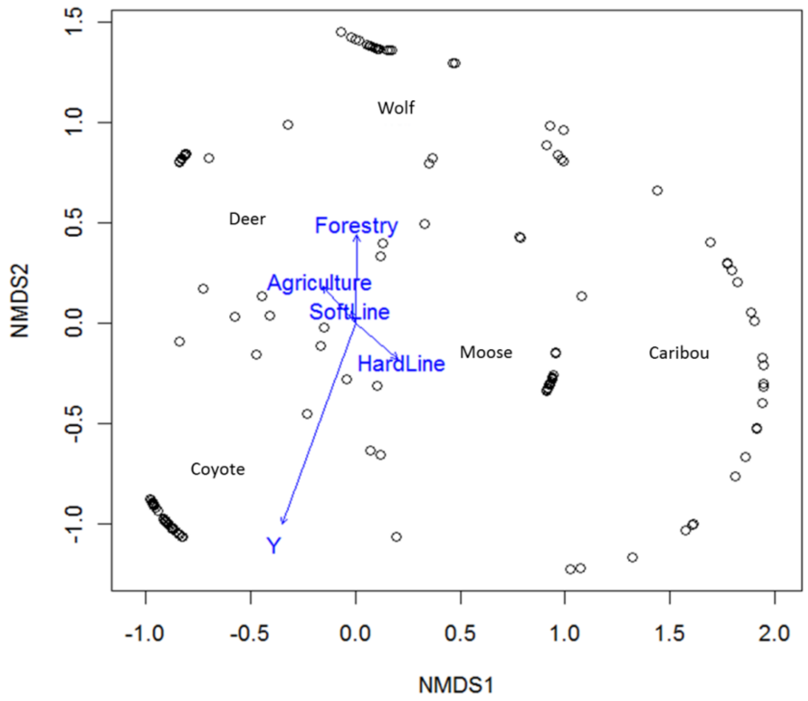


Figure 12.5. Non-metric multi-dimensional (NMDS) scaling of transect segment data using Bray-Curtis dissimilarity matrix. Species in close proximity along axes co-occurred with each other. Human footprint covariates measured at sites were indicated by blue arrows, with arrow direction showing its relationship to the NMDS axes and arrow length proportional to its correlation with NMDS axes.

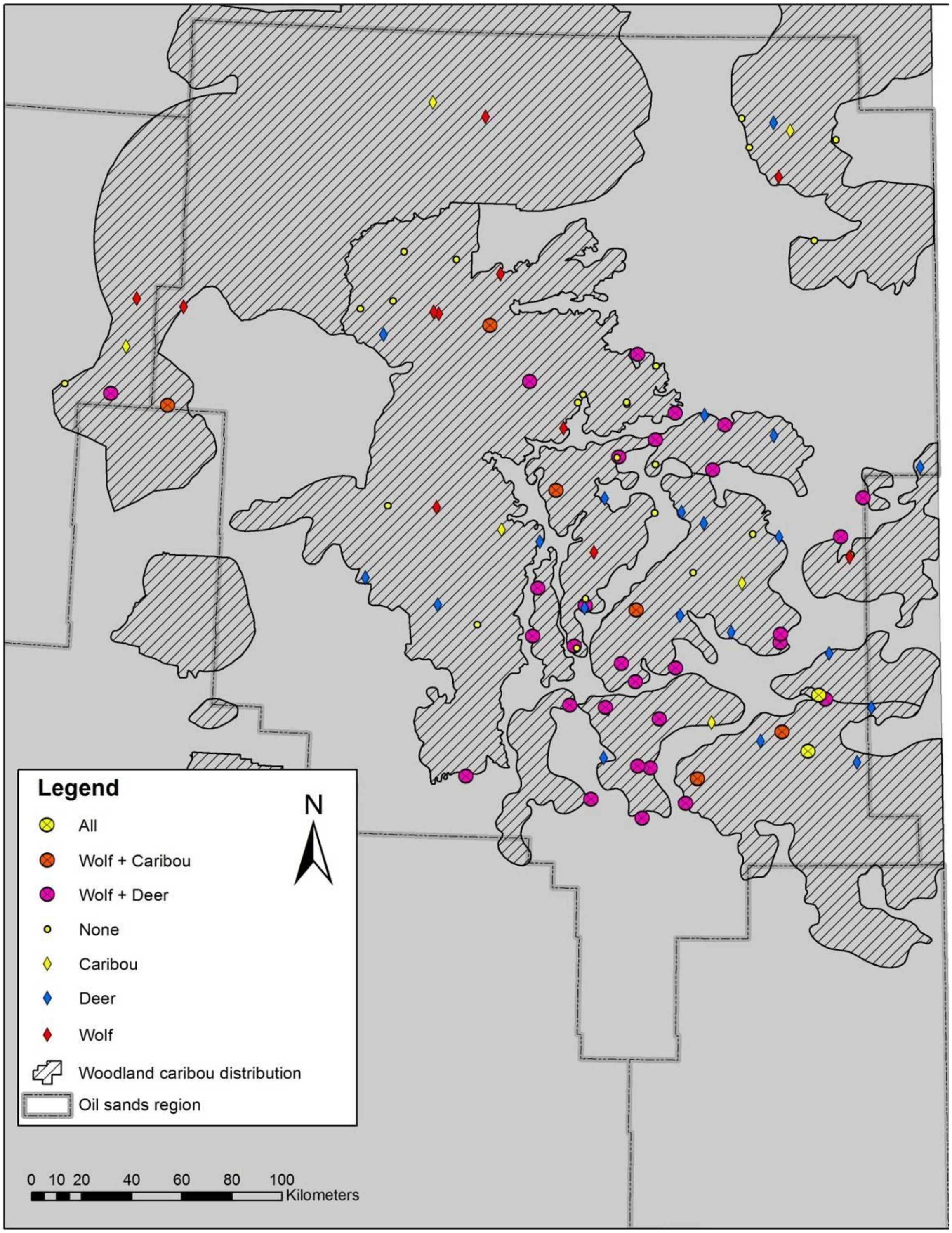


Figure 12.6. Wolf, deer and caribou detections in caribou range within the oil sands region of Alberta. Data were for entire transects. Single species detections were indicated by diamonds and species co-occurrences were indicated by cross-hatched circles.

Table 12.1. Statistical relationship between NMDS axes and human footprint covariates measured at transect segments in caribou range in the study area. R^2 values indicated strength of relationship and p-values indicated statistical significance.

Footprint Covariate	Axis 1	Axis 2	R^2	p-value
Forestry	-0.574	0.819	0.002	0.485
Agriculture	-0.360	0.933	0.005	0.158
Hard Linear	-0.412	-0.911	0.014	0.005
Soft Linear	-0.805	0.594	0.016	0.004
Latitude	0.929	-0.370	0.097	0.001

12.4 Discussion

Much research and conservation attention has focussed on stabilizing and reversing caribou population declines in Alberta by reducing predation through direct and indirect management actions. The correlative relationship between human footprint and caribou population has been well established (e.g., Sorenson et al. 2008; Environment Canada 2012) and serves as a useful prediction of cumulative effects. However, this approach tends to focus on habitat-mitigation towards reduction and strategic placement of footprint, whereas there also are direct means to manage predation on caribou. For example, wolf and ungulate culls and caribou protection measures (e.g., fencing) may reduce wolf predation on caribou. Furthermore, the cumulative effects described in Chapter 11 do not account for the important habitat context of footprint placement. For example, creating linear footprint in peatlands adjacent to forestry cut blocks may have a greater effect on caribou predation than linear features in peatlands on their own.

We used ABMI data to test for deer, moose, wolf and caribou co-occurrence relative to human footprint to see if it was consistent with the relationships hypothesized in the conceptual model. Caribou tended to be spatially separated from other ungulates (i.e., deer and moose) and predators (i.e., wolves and coyotes) in the region. More importantly, we found statistically significant evidence of human footprint effects on species occurrence similar to the hypothesized patterns. Deer and wolves were positively related to forestry and agriculture, indicating a habitat-mediated effect of human footprint development on ungulate prey and their predators. Conversely, caribou were detected in areas with less forestry, agriculture and soft linear features, also consistent with the hypothesis. We caution that species co-occurrence data by itself does not indicate mechanisms of predator-prey interactions.

A coarse-scale correlative indirect link has been made between human footprint and caribou decline (Figure 12.2, A). However, there is a need to better understand the direct mechanisms generating this relationship (Figure 12.2, B-E) and explore alternative cumulative effects mitigation options for footprint reduction. Indeed, some of these relationships and mitigation options have already been explored by the Athabasca Landscape Team (Athabasca Landscape Team 2009). They tested for the effects of footprint reduction (i.e., reclamation of existing footprint and restriction of future footprint development), wolf, deer and moose culls and caribou penning on caribou population recovery in northeast Alberta. They concluded that a combination of restricted development areas, habitat restoration, and wolf culling applied together for 30-50 years were necessary to conserve caribou. Wolf control, land-use planning to minimize destruction of caribou habitat and habitat restoration were the primary management options being proposed by the Government of Canada to mitigate cumulative effects of human footprint on caribou (Environment Canada 2012).

Monitoring caribou and predator densities in a region is a challenge. Research on caribou predation requires tracking predators with telemetry collars. Given time and cost constraints, it may be more efficient to test the outcomes of recommended management actions at the range scale and monitor caribou population responses. This would provide management "experiments" where various management actions are implemented in different areas and caribou populations are monitored. As an added benefit, mechanistic understanding of the system may be achieved by monitoring these management experiments, while still taking action to conserve caribou.

Monitoring cumulative effects of human footprint on caribou requires a regional perspective. While resource developers can minimize footprint, conservation of intact caribou range and caribou populations cannot be managed at small scales. To be effective, habitat and predators must be managed at the regional scale.

13.0 Discussion

Our analyses and maps described cumulative effects (as measured by the change in relative abundance, intactness and habitat suitability for species, species groups, and biodiversity in general) that have already occurred, and those that are predicted in the future throughout the study area. Current cumulative effects were assessed based on current maps of the vegetation and human footprint in the region. Human development was projected 25 and 50 years into the future, and those projections were used to predict future cumulative effects on species, species groups and biodiversity. Projections of future conditions were uncertain because social, economic and environmental constraints influence resource development and the resulting habitat changes that will ensue. As such, predictions of future cumulative effects must be interpreted with caution.

13.1 Summary of Results

Under current conditions, 6% of the vegetation in the region has been converted by human development; this was expected to grow to 11% in the next 50 years. Edge effects were common, and greater than 50% of the region was currently within 200 m of human footprint. Approximately 50% of the human disturbance was due to forest harvest, with seismic lines, well sites, and pipelines accounting for 10-15% each. Three vegetation types (grassland/herbaceous, deciduous forest, mixedwood forest) had disproportionate amounts of conversion to human footprint, and species relying on these habitats may be disproportionately affected. However, vegetation recovery in the disturbed areas was not accounted for in the present study, and many native biota are expected to recolonize and use disturbed areas as vegetation recovers.

Cumulative effects for caribou and black-throated green warbler were higher than those for species groups or biodiversity in general. Based on Environment Canada’s model for caribou habitat suitability, only 32% of the study area was presently suitable for caribou and this was projected to decline to 15% by 50 years into the future. For black-throated green warbler, old-forest birds, weedy plants, forest plants and biodiversity in general we found much lower cumulative effects in the study area; intactness was currently above 85% for all of these indicators. Cumulative effects for black-throated green warblers were projected to increase over time with intactness projected to be 72% by 50 years into the future. For species groups and biodiversity in general, intactness was projected to remain above 80% for the next 50 years. For all species and species groups, cumulative effects were slightly lower at the scale of the regional study area than the subregional area.

For all indicators, cumulative effects varied spatially. Not surprisingly, cumulative effects were greatest at locations with abundant human footprint, especially where the footprint disturbed both the vegetation and soil (note that disturbance of both the vegetation and soil has been labeled “alienating footprint” in this report). The magnitude of cumulative effects, and the degree to which cumulative effects spread into adjacent natural habitats, differed among species. To provide a balanced picture of cumulative effects on biodiversity, it will be important to assess some high profile species, specialist species groups and generalist species groups. Key species and specialists respond most strongly at low levels of resource development whereas generalist species and biodiversity in general respond most strongly at higher levels of development.

Although important for cumulative effects assessment, maps of cumulative effects can also be used for other management activities. Conservation offsets require an assessment of the ecological loss in a developed area and the ecological gain that is planned for an offset area – both the loss and gain can be measured by change in cumulative effects. Similarly, reclamation assessment requires that ecological gain in the reclaimed area be evaluated, and that gain can be measured based on change in cumulative effects. These additional uses of cumulative effects were not explored in the present project.

13.2 Adaptive Monitoring

The cumulative effects described in this project were predictions that need to be tested to determine their validity. Long-term monitoring that surveys biodiversity and human footprint over time to reveal actual trends is the only true test of the predicted cumulative effects. Monitoring will show how well the regional changes in species abundances actually match predictions (Burton et al. in review). In addition, monitoring will reveal where modeling assumptions are not met, or effects are not directly caused by footprint. In addition, deviations from the predicted cumulative effects can be used to identify effects that were not included in the model, including effects that are more than the sum of local human footprints. Thus, long-term monitoring is the critical test of cumulative effects assessment and this test will facilitate improved assessment and management over time.

ABMI will continue to monitor a wide diversity of species (including black-throated green warbler, old forest birds, weedy plants, forest plants, biodiversity) plus vegetation and human footprint throughout the regional study area. Caribou and other species of special significance continue to be monitored by the government of Alberta. This monitoring is critical to provide the information necessary to test and update cumulative effects assessment and to facilitate adaptive management. However, funding for long-term monitoring is difficult to achieve and advocacy for these monitoring programs is required on a continual bases.

14.0 A New Method for Cumulative Effects Assessment of Biodiversity

Under the present management system in Alberta, new industrial developments are required to conduct a cumulative effects assessment for biodiversity. To accomplish this, developers typically:

a) Describe the topography, hydrology, soils and vegetation in and near the area they will develop,
b) Sample biota in the area to be developed,
c) Determine associations between biota and habitats in their development area, and
d) Make a coarse assessment of the magnitude of effects that their development will have on species and biodiversity in the region.

Current cumulative effects assessments are inconsistent and inefficient

The present cumulative effects assessment methods are expensive, do not make good use of the abundant information that has been collected by others for biota in the region, and are not well integrated with other regional processes.

Inefficiencies include:

- Cumulative effects assessments conducted during EIAs are not integrated with other planning and management activities throughout the region.
- Cumulative effects assessment for biodiversity is completed independently by each development using their own methods, and it is difficult to combine this information to determine regional cumulative effects.
- Cumulative effects are assessed multiple times for some areas, and not assessed in other parts of the region.
- Each developer consults with stakeholders to determine which species, biodiversity and habitats need to be included in the assessment.
- Data collected for cumulative effects assessment are often proprietary, and not shared among projects.
- Species and landscape information is collected differently by each developer, and much of the information available from the broader region is not used.
- Due to short timelines, cumulative effects assessments are relatively coarse.
- Cumulative effects assessments are not updated as new developments occur and thus there is little opportunity to refine predictions over time.

New method to assess cumulative effects on biodiversity

In the present project we tested a new method for cumulative effects assessments that better supports land use planning. This integrated method:

- Couples cumulative effects assessment for EIAs with regional assessments so that both local and regional patterns can be determined, and tools to improve biodiversity management can be developed and tested.
- Couples cumulative effects assessment with monitoring to test how the implemented management affects biodiversity over time.
- Assesses cumulative effects for a wide range of species.
- Is conducted at the regional scale using all available information, yet allows users to "drill-down" to the local level.
- Describes cumulative effects that have already occurred for biodiversity, and predicts future cumulative effects from each proposed development.
- Creates a forecasting tool to predict cumulative effects at time-steps into the future based on simulations of user-defined scenarios.

The cumulative effects assessment process we developed includes predictions for small units within the region (e.g., for each quarter section) so that the information can be used by all developers to assess effects on their particular lease. By focusing the assessment at the regional scale, however, the resulting information can also be integrated easily into regional plans. As an added benefit, if all developers contribute to the integrated regional assessment, more resources will be available and that will facilitate robust assessments. Finally, with sufficient resources it will be possible to do detailed modeling and to produce more detailed assessment of cumulative effects on biodiversity than is presently done in EIAs.

The proposed new method for assessing cumulative effects on biodiversity increases value by:

i) Integrating assessments within a region so that local project-scale evaluation, and regional land-use planning and management, use a common suite of information.
ii) Facilitating collaboration and cost sharing, with all developers working together to produce a single assessment for the region.
iii) Ensuring that consistent high-quality information is produced for all areas within the region.
iv) Using all the available species and landscape information for the region to produce a scientifically robust assessment of cumulative effects on biodiversity.
v) Avoiding duplication of effort since the assessment is completed once as a unit rather than a number of piecemeal and potentially overlapping assessments.
vi) Facilitating regular and rapid updating of cumulative effects as new developments occur.
vii) Ensuring that stakeholders can access cumulative effects information from a single location for all developments in a region.
viii) Having assessments done by a neutral third party that focuses on doing a rigorous unbiased evaluation.

Potential Benefits of the New Method to Industry

- Simplifies and clarifies how cumulative effects on biodiversity will be assessed because the methods are standard and consistent throughout the region.
- Reduces costs for each development because the assessment is completed as a collaborative initiative rather than a number of potentially overlapping assessments.
- Shortens the time needed to complete the cumulative effects assessment because it is updated regularly.
- Helps companies mitigate impacts during plan developments (i.e., avoid sensitive sites and integrate footprint creation) and thus reduce reclamation and offset costs.
- Focuses reclamation on areas that are critical to biodiversity.

Potential Benefits of the New Method to Government

- Supports regional land use planning and management by highlighting the amount and spatial pattern of cumulative effects on biodiversity throughout the region.
- Enhances responsible resource development by ensuring that a consistent high-quality assessment for biodiversity is present throughout the region.
- Provides sufficient lead-time to consult with stakeholders and determine a standard suite of species, biodiversity and habitats need to be included in the assessment.
- Is financially self-sustaining by using funding from new developments to update the regional cumulative effects assessment.
- Complements Alberta's new Environmental Monitoring System by incorporating monitoring data into cumulative effects assessment.
- Supports Conservation Offset Management by enabling the modeling of cumulative effects within both the proposed disturbance and proposed offset areas.

Next steps – pilot the proposed method

A shift from each developer assessing cumulative effects on biodiversity independently, to assessments being done as a regional collaborative effort, would be a significant change to the EIA process in Alberta. Although present regulations and policies do not limit the creation of a regional cumulative effects assessment, neither do they facilitate it. A broad initiative will be required to facilitate that change. For example, there is substantial work required to create the data sets that include all of the existing information. In addition, modeling is more difficult if a variety of data sets are incorporated.

There would be value in piloting the new process in a region to understand the costs to doing an integrated regional cumulative effects assessment for biodiversity, and the benefits / weaknesses of the resulting information.

The pilot would:

- Validate the new method to assess cumulative effects on biodiversity.
- Develop and test a delivery model for the new method.
- Determine the costs for implementing the new method.
- Identify changes to the regulatory system that are required to integrate cumulative effects assessment for EIAs with cumulative effects assessment for regional planning and management.
- Develop and test an integrated regulatory system for assessing cumulative effects on biodiversity.

Success of the pilot could be judged based on whether the assessment produces better information at similar or lower costs than the status quo, and whether the resulting information can be easily incorporated into regional planning and management systems. To be successful it will be necessary to create a project delivery team that understands what is required for a cumulative effects assessment of biodiversity, that have the skills required to produce a high-quality assessment and that are able to integrate the new method into existing planning and management systems. In addition, buy-in from government, industry and ultimately the general public will be critical for success.

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