Conservation Planning in Northwest Alberta

Northern Alberta Conservation Area Working Group

June 13, 2016

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Executive Summary

The Alberta Land-use Framework (LUF) was developed as a regional planning framework to manage growth and balance the economic, environmental, and social goals of Albertans (GOA, 2008). One of the main mechanisms for achieving environmental goals under the LUF is the establishment of new conservation areas, following the precedent established with the Lower Athabasca Regional Plan. These conservation areas also contribute towards the Government of Alberta's commitment to protect 17% of ecosystems under Aichi Target 11 of the Convention on Biological Diversity, which was reconfirmed in the Alberta Environment and Parks 2016 business plan.

The Northern Alberta Conservation Area Working Group was established in March 2015 to undertake a study of conservation options to support the province's regional planning process in the Upper Peace, Lower Peace, and the Upper Athabasca planning regions. Our objective was to provide scientifically-grounded information on conservation planning, including the optimal location of new conservation areas, leaving the decision of how much of the landscape to protect (i.e., the balance between economic and environmental goals) to the regional planning process.

The Working Group was comprised of conservation scientists from the University of Alberta and representatives from most of the major conservation organizations in the province, bringing together ecological and planning expertise from multiple subdisciplines (see pg i). The group also included a Government of Alberta liaison linked to the regional planning process. The Alberta Biodiversity Monitoring Institute, Alberta Fish and Wildlife, and Alberta Parks provided information and feedback. The group's efforts were supported by a grant from Alberta Ecotrust and in-kind contributions from group members and their organizations.

Our approach to identifying conservation priorities was grounded in the principles of systematic conservation planning. We also sought alignment with the Convention on Biological Diversity, the LUF's planning criteria for conservation areas, and the planning approach used by Alberta Parks. Our working objective was to design a reserve system that provided the greatest overall conservation benefit given limits on the amount of protection available. Not knowing how much land would ultimately be available for protection, we produced reserve designs across a range of sizes.

To ensure that the reserve system provided the most benefit for the most species, we used a "coarse-filter" approach to represent the full range of habitat types that exist in northwest Alberta, favouring areas with the least human disturbance. To do this, we assembled data layers describing ecological diversity across a range of scales (from Natural Subregions to basic vegetation and wetland types), along with disturbance intensity. We then used the Marxan computer program to identify optimal reserve designs for representing these features. Marxan is the most widely used software for conservation planning.

A key aspect of conservation planning is accounting for protection that already exists. Wood Buffalo National Park and the mountain parks, in particular, make important contributions to biodiversity protection in northern Alberta. However, these existing parks over-represent certain ecosystem types, such as Alpine, while under-representing other types, such as Foothills. The new reserves identified by Marxan are intended to fill the remaining gaps in representation, providing a comprehensive reserve system.

Some species may be missed by the coarse-filter approach, and species of conservation concern may require individualized consideration. Therefore, in a second stage of our Marxan analysis, we included 45 species of conservation concern in the modeling process as fine-filter elements. In further analyses we also included fine-scale wetlands and boreal climate refugia as fine-filter elements. We found that the habitat of most of these fine-filter features could be represented with only minor adjustments to the coarse-filter designs.

Our base design, which included both coarse and fine-filter elements, is shown in Fig. 1.[1] To generate this map, we ran Marxan with successively higher representation targets for all of the desired features (see Appendix 1) and then combined the resulting conservation designs into a single map. Representation targets are the proportion of each feature, such as marsh, that Marxan was asked to include in the design. In Fig. 1, the darkest shades of red represent areas that were consistently selected across all target levels. The lightest shades of red represent areas that were only selected in model runs with high target values. In effect, shading provides an indication of priority, with the darkest shades being most important.

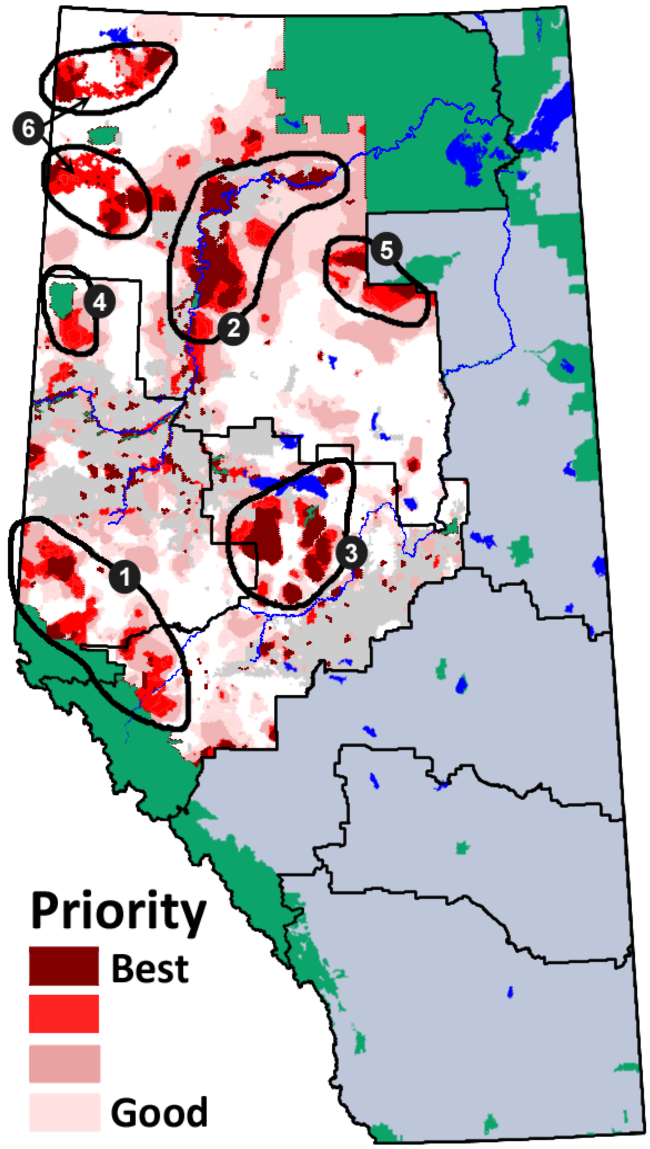

Fig. 1. Base design including coarse and fine-filter elements. Red = selected sites, with priority regions circled in black; green = existing protected areas; grey = private land and land outside of our core study area. LUF planning zone boundaries are outlined in black.

[1] A GIS version of this map is available at: http://www.ace-lab.org/index.php?page=asca&atlas=12

In the base scenario shown in Fig. 1, Marxan was limited to selecting areas that were on public lands. Alternative scenarios are provided in the main report.

Although all of the sites identified in our base design have significant conservation value, the LUF planning process may place constraints on the number of conservation areas that can be established. Therefore, we identified a set of regional priorities (numbered circles in Fig. 1). In addition to providing core representation of ecological features across multiple scales, each of these priority regions provides a unique set of conservation benefits, described below. It was not possible to assign a specific ranking to each region, as they contribute to different biodiversity objectives. However, the representation gaps are greatest in the Foothills and Dry Mixedwood regions.

Priority Region 1: Foothills. The Foothills Natural Region has one of the lowest rates of protection in the province — just 1.4% — and has been heavily impacted by industrial activities and off-road vehicle use. Yet it holds some of the highest conservation values in Alberta. Because of its complex topography and varied climate this region is a provincial hotspot of species diversity for both animals and vascular plants. It is also the location of many of Alberta's headwaters, including those feeding the Peace and Athabasca Rivers. Another important feature is its proximity to the mountain parks, which will serve as an ecological anchor for any new foothills parks, enhancing their integrity. Finally, looking forward to the future, the Foothills are projected to be a critical climate change refuge for forest species, especially boreal species that are expected to lose much of their existing habitat to the encroachment of parkland and grassland ecosystems onto the boreal plain. Within the broad Foothills region that we have identified, priority should be given to the protection of the high-profile species at risk that are present, including woodland caribou, grizzly bear, bull trout, Athabasca rainbow trout, and Arctic grayling (additional detail is provided in the main report).

Priority Region 2: Peace River. This area provides representation of the Dry Mixedwood Subregion, which has little existing protection (just 1.6%). It is also the only low-elevation ecosystem among all of our regional priorities. The Dry Mixedwood is the most threatened ecosystem type in northern Alberta because the majority of the region has been converted to agricultural use, including crop and hay production and ranching. Much of the agricultural conversion took place early in Alberta's history, but even as late as the 1990s, Environment Canada described the region as "Canada's fastest advancing agriculture frontier." Today, public lands continue to be auctioned off for conversion to agriculture use. Forestry and oil and gas development are also very active in this region. There is little scope for substitution in the Dry Mixedwood, because only a limited amount of this ecosystem remains intact, and it is concentrated in the northern reaches of the Peace Country. When defining the boundaries of a conservation area in this region, an effort should be made to establish connectivity with Wood Buffalo National Park, along the Peace River.

Priority Region 3: Swan Hills. This area includes both the Swan Hills and the Marten Hills northeast of Lesser Slave Lake. It represents the convergence of Foothills and Boreal ecosystem types and as a result, contains many unique ecosystems. It also provides habitat for several fine-filter species, including core habitat for grizzly bears. Large parts of the Swan Hills remain relatively intact, in contrast to most other parts of the Foothills region. This high level of integrity is unlikely to be maintained in coming decades without formal protection. In the future, given its varied terrain and higher elevation, this region will also serve as an important climate refuge for boreal forest species, many of which do not currently extend into the Foothills proper.

Priority Region 4: Chinchaga. This area provides representation across a gradient of ecosystem types, from Upper Boreal Highlands at high elevations to Dry Mixedwood at lower elevations. Protection in this region would support the Chinchaga caribou herd, and in the future would serve as a climate refuge for boreal forest species. Establishing a large conservation area here would enhance the integrity of the existing Chinchaga Wildland Park, by increasing its size to the point where most natural ecological processes could be maintained. As an alternative, most of the attributes just described could also be represented in the lands immediately north of the existing Chinchaga Wildland Park. This area is less intact, and representation would not be quite as good; however, no forestry tenure exists here, so it has the benefit of having less conflict with forestry.

Priority Region 5: Birch Mountains. This area provides additional representation of the Upper Boreal Highlands and associated finer-scale features. Protection in this region would support the Red Earth and West Side Athabasca caribou herds and in the future would serve as a climate refuge for boreal forest species. Establishing a large conservation area here would also enhance the integrity of the existing Birch Mountains Wildland Park, by increasing its size to the point where most natural ecological processes could be maintained. Connectivity to Wood Buffalo National Park is an important consideration of conservation planning in this region. This could be accomplished by providing a higher level of protection to the intervening Birch River Conservation Area, which currently does not have full park status.

Priority Region 6: Bistcho. This area was consistently selected by Marxan in the base scenario for one specific reason: to achieve the representation target for the Lower Boreal Highlands Open Coniferous vegetation type. Most of this vegetation type is actually found in northeast Alberta, but is not protected there. Filling this representation gap in the northwest required large areas to be added to the reserve design because this vegetation type is only found at low density in this region. Protection in this region would also support the Bistcho caribou herd and in the future it would serve as a climate refuge for boreal forest species.

The priority regions we have identified are consistent with the key criteria for conservation area planning identified under the LUF. They are representative of the biological diversity of northwest Alberta, they are of sufficient size to maintain most ecological processes and integrity, and they are among the areas least impacted by industrial activity. These sites also achieve excellent representation of the Natural History Themes used in the planning framework developed by Alberta Parks. Due to time and capacity limitations, we were not able to seek indigenous communities' views on identifying priority reserve areas. But given the broad spatial distribution of the identified sites, many communities could potentially benefit.

By emphasizing areas that are least disturbed, our modeling process automatically minimized conflict with resource values. This was confirmed in modeling scenarios that formally included resource value as an opportunity cost to protection. It should be noted, however, that total resource value is driven mostly by the oil and gas sector, and is not reflective of the distribution of forestry tenure.

A limitation of our approach to reserve design is that the "big picture" perspective it provides may leave some fine-scale conservation gaps. In particular, unique landforms and rare species were not included in the modeling process. A finer-resolution process will be needed to identify and protect these types of features. Input from regional biologists, indigenous communities, and others with local ecological knowledge would also be very helpful in refining the designs. Another limitation of our study is that we were unable to address connectivity among sites in any detail. Additional effort will be needed to identify methods for managing the intervening landscapes so that connectivity among reserves is maintained.

The base model provides representation of several caribou ranges; however, the priority areas for coarse-filter conservation lie mostly outside of caribou ranges. This is mainly because caribou in northern Alberta utilize specific habitat types, mostly involving peatlands, whereas the base model was designed to achieve representation of all habitat types. The implication is that a reserve system designed to achieve broad biodiversity objectives will not fully meet the needs of caribou, and conversely, that protecting caribou habitat will not achieve broad biodiversity objectives. Determining the best approach for protecting caribou will require further study.

Climate change is another factor that is both important and challenging to incorporate. Given the amount of CO_2 that is already in the atmosphere, Alberta's climate is predicted to warm by more than 2°C by the end of the century, even with aggressive mitigation measures. That is the difference in mean temperature that currently exists between Edmonton, which is in the Parkland Region, and Fort McMurray, which is in the Boreal Region. The implication is that ecosystems and species are destined to shift from their current locations in coming decades. This does not invalidate the need for conservation areas — they will continue to provide refugia from industrial impacts for whichever species reside within them at any given time. Our coarse-filter approach, which represents fundamental diversity patterns, is designed to ensure that the main "arenas" for future biodiversity are protected.

Protection of individual fine-filter species under a changing climate presents a greater challenge. The distribution of these species is likely to shift as a result of climate change, making it difficult to meet their habitat needs through static protected areas. Fortunately, habitat for the 45 species we examined appears to be represented with the coarse-filter design, so species-specific reserves may not be required. More detailed modeling of future distributions would be helpful to verify this. Consideration also needs to be given to maintaining connectivity among reserves, as this will be required for these species to respond effectively to the changing climate.

Some ecosystem types are expected to contract as the climate warms. The main concern is with Alberta's boreal forest, most of which is expected to convert to parkland and grassland under the anticipated levels of warming. The implication is that boreal forest species, which are common today, may become much rarer in the future. It would be prudent to ensure that the projected remnant patches, termed climate refugia, are protected. As we noted earlier, the Foothills are expected to serve as an important climate refuge for many boreal species, and so this region represents a hotspot for both current and future biodiversity. Other boreal climate refugia include the Caribou Mountains, Birch Mountains, Bistcho area, and Chinchaga area, which will remain cooler and moister than the surrounding lowlands. These hills also constitute important caribou range.

By highlighting boreal refugia, it is not our intent to diminish the importance of low elevation areas. The boreal plain, including the priority region we identified along the Peace River, is expected to convert to parkland and grassland under a warmer climate, and as such will also have an important role in supporting biodiversity under a warming climate. Currently, 75% of Alberta's species at risk are found in the Grasslands, where very little protection exists (even after the completion of the South Saskatchewan Regional Plan). Protecting low-elevation areas in the north, before agricultural expansion becomes a reality, may help ensure the long-term viability of these threatened grassland species.

Ultimately, maintaining fidelity to the coarse-filter approach is likely the best way of achieving an appropriate balance among conservation objectives, both current and future.

Introduction

The Alberta Land-use Framework (LUF) was developed as a regional planning framework to manage growth and balance the economic, environmental, and social goals of Albertans (GOA, 2008). One of the main mechanisms for achieving environmental goals under the LUF is the establishment of new conservation areas, following the precedent established with the Lower Athabasca Regional Plan. These conservation areas also contribute towards the Government of Alberta's commitment to protect 17% of ecosystems under Aichi Target 11 of the Convention on Biological Diversity, which was reconfirmed in the Alberta Environment and Parks 2016 business plan.

The experience gained with the first two regional plans indicates that short timelines limit the amount of research and analysis that can be done once the actual planning process begins. The planning teams must generally work with the information that is available to them at the time. In the case of the Lower Athabasca Region, considerable conservation planning had already been done through development of the Terrestrial Ecosystem Management Framework, and this effort was of significant benefit to the LUF planning process. No equivalent planning framework exists for northwest Alberta.

The Northern Alberta Conservation Area Working Group was established in March 2015 to undertake a study of conservation options to support the province's regional planning process in the Upper Peace, Lower Peace, and the Upper Athabasca planning regions. Our objective was to provide scientifically-grounded information on conservation planning, including the optimal location of new conservation areas, leaving the decision of how much of the landscape to protect (i.e., the balance between economic and environmental goals) to the regional planning process.

The Working Group was comprised of conservation scientists from the University of Alberta and representatives from most of the major conservation organizations in the province, bringing together ecological and planning expertise from multiple subdisciplines (see pg i). The group also included a Government of Alberta liaison linked to the regional planning process. The Alberta Biodiversity Monitoring Institute, Alberta Fish and Wildlife, and Alberta Parks provided information and feedback. The group's efforts were supported by a grant from Alberta Ecotrust and in-kind contributions from group members and their organizations.

Methods

Our approach to identifying conservation priorities was grounded in the principles of systematic conservation planning (Margules and Pressey, 2000). We also sought alignment with the Convention on Biological Diversity, the LUF's planning criteria for conservation areas, and the planning approach used by Alberta Parks. Our working objective was to design a reserve system that provided the greatest overall conservation benefit given limits on the amount of protection available. Not knowing how much land would ultimately be available for protection, we produced reserve designs across a range of sizes. Because it is most efficient to conduct conservation planning across broad areas we combined the three northwest LUF zones into a single core study area for our analysis (Fig. 2).

Coarse-Filter

To ensure that the reserve system provided the most benefit for the most species, we used a "coarse-filter" approach to represent the full range of habitat types that exist in northwest Alberta, favouring areas with the least human disturbance. To do this, we assembled data layers describing ecological diversity across a range of scales (Table 1), along with disturbance intensity, and then used the Marxan computer program to identify optimal reserve designs for representing these features.

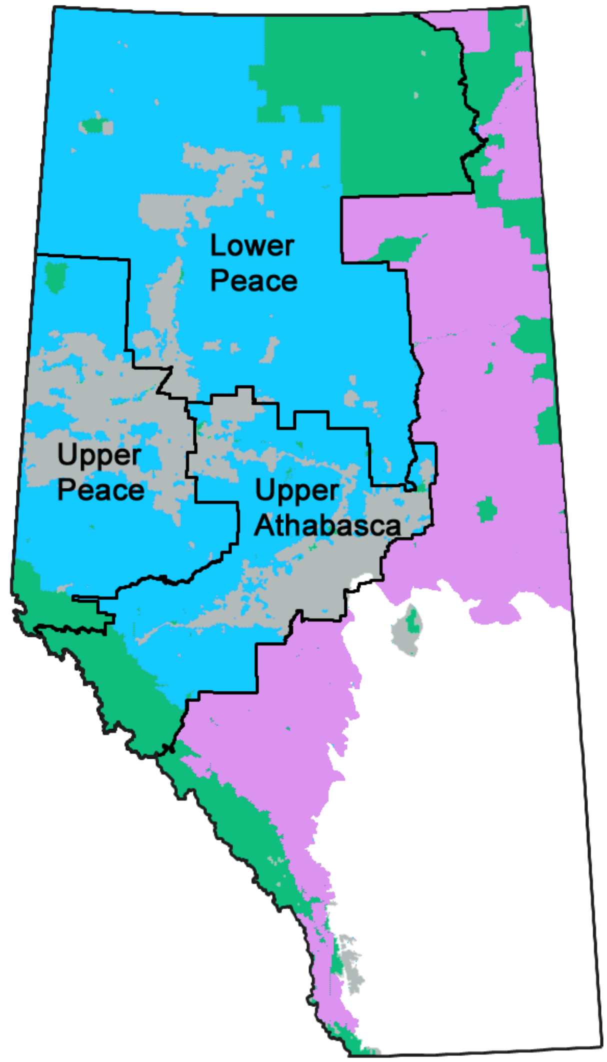

Fig. 2. Study area. Blue = core study area, available for selection. Purple = extended study area, modeled, but not available for selection. Green = existing protected areas. Grey = private and other non-crown land. The northwest LUF planning zones are outlined in black.

Marxan is the most widely used conservation planning software (Game and Grantham, 2008). It is an optimization program that seeks to represent desired conservation features at the least cost. For our purposes, cost was defined by total reserve area and disturbance intensity. That is, Marxan sought to achieve defined targets for all conservation features while minimizing the overall size of the reserve system and while selecting the least disturbed sites as much as possible. Our proxy for disturbance intensity was the density of linear features (i.e., roads, pipelines, and seismic lines), obtained from the Alberta Biodiversity Monitoring Institute (ABMI; Fig. 3). Additional detail concerning our implementation of the Marxan program is provided in Appendix 1.

A key aspect of conservation planning is accounting for protection that already exists. Wood Buffalo National Park and the mountain parks, in particular, make important contributions to biodiversity protection in northern Alberta. However, these existing parks over-represent certain ecosystem types, such as Alpine, while under-representing other types, such as Foothills. We verified this in supplemental runs provided in Appendix 2.

Table 1. Coarse-filter inputs.

Feature	Categories	Source
Natural Subregions of Alberta	Alpine	Government of Alberta (2006)
	Boreal Subarctic	
	Central Mixedwood	
	Dry Mixedwood	
	Lower Boreal Highlands	
	Lower Foothills	
	Montane	
	Northern Mixedwood	
	Subalpine	
	Upper Boreal Highlands	
	Upper Foothills	
Major vegetation types	Conifer: dense	ABMI (2000)
	Conifer: open	
	Deciduous: dense	
	Deciduous: open	
	Herbaceous	
	Mixedwood: dense	
	Mixedwood: open	
	Shrub	
Wetland classification	Bog	Ducks Unlimited (2016)[1]
	Fen	
	Marsh	
	Swamp	
	Open water	
Land facets	Dry and cool	Scott Nielsen (2014)
	Dry and hot	
	Dry and normal	
	Incised valley, Cool	
	Incised valley, Hot	
	Incised valley, Normal	
	Mesic	
	Water	
	Wet	
Surficial geology	Sand dunes only[2]	AB Geological Survey (2013)

[1]A data gap within Wood Buffalo National Park was filled using peatland inventory data from Dale Vitt at the University of Alberta (1996)
[2]Other components of surficial geology were tracked in the model, but targets were not set.

To account for the contributions of existing protected areas we expanded our study area to include all Natural Subregions that intersected with the three planning zones of interest (shown in purple in Fig. 2 – previous page). Marxan calculated the contribution of existing protected areas towards our representation targets, and sought to fill the gap that remained for each feature. New conservation areas were only selected from within the three core planning zones (shown in blue in Fig. 2, page 8), and in most scenarios, Marxan was limited to selecting areas that were on public lands.

Because the total amount of land available for protection was not known, we directed our efforts to identifying regional priority areas that could serve as foci of protection regardless of the eventual size of the reserve system. To do this, we conducted our analysis across a wide range of representation targets, from 5% to 30%. This produced reserve designs of progressively larger size, allowing us to identify core areas that were consistently selected. Appendix 1 provides additional detail about this process.

Our representation targets were based on the distribution of conservation features across the entire study area (blue and purple in Fig. 2). For Subregion targets we used an equal-area approach so that large Subregions, like the Central Mixedwood, would not dominate the results. For example, the 10% target for Subregions was 3,616 km^2 (for each Subregion), calculated as the 10% of the overall study area divided by the number Subregions present in the study area. For all of the other features we used proportional targets, stratified by Natural Subregion. For example, the 10% target for fens in the Lower Foothills was 364 km^2, calculated as 10% of the amount of fen present in the Lower Foothills.

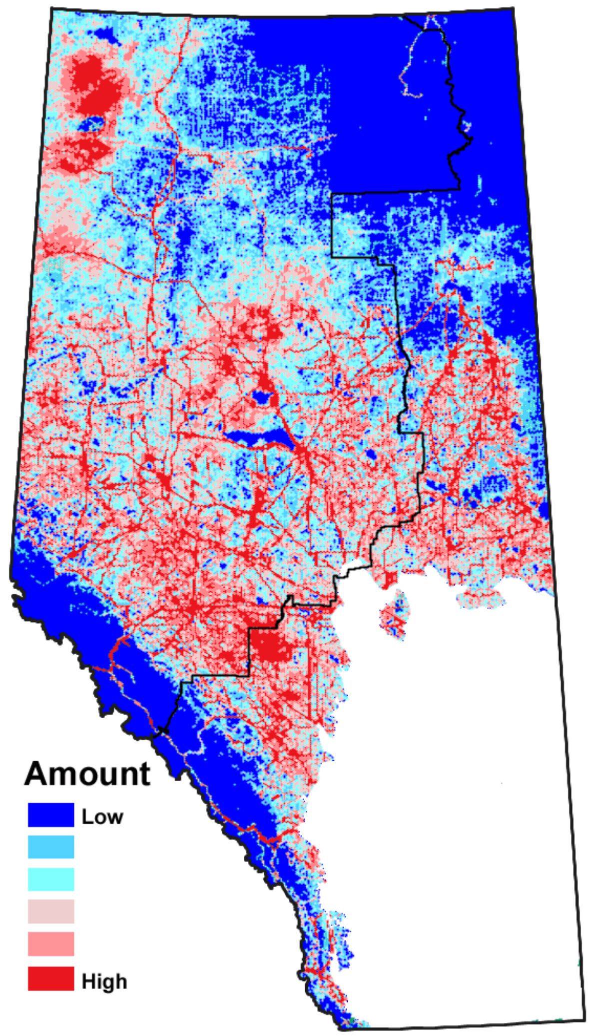

Fig. 3. Density of disturbance, based on the area of linear features per cell. Source = ABMI human footprint layer (2010).

Fine-Filter

By ensuring representation of all major habitat types, the coarse-filter approach provides for the needs of most species. However, some species may have specialized needs that are not met with this broad-brush approach (by analogy, they slip through the coarse mesh of the initial screening). To ensure that this was not happening we added 45 species of conservation concern to the model (Table 2). We called these our fine-filter inputs.

Table 2. Fine-filter inputs.

Common Name	Scientific Name	Taxonomy
Canada lynx	*Lynx canadensis*	Mammals
Grizzly bear	*Ursus arctos*	Mammals
Pine marten	*Martes americana*	Mammals
Woodland caribou	*Rangifer tarandus*	Mammals
American bittern	*Botaurus lentiginosus*	Birds
Bay-breasted warbler	*Setophaga castanea*	Birds
Black-throated green warbler	*Setophaga virens*	Birds
Brown creeper	*Certhia americana*	Birds
Canada warbler	*Cardelina canadensis*	Birds
Cape May warbler	*Setophaga tigrina*	Birds
Common yellowthroat	*Geothlypis trichas*	Birds
Least flycatcher	*Empidonax minimus*	Birds
Olive-sided flycatcher	*Contopus cooperi*	Birds
Pied-billed grebe	*Podilymbus podiceps*	Birds
Pileated woodpecker	*Dryocopus pileatus*	Birds
Rusty blackbird	*Euphagus carolinus*	Birds
Sandhill crane	*Grus canadensis*	Birds
Sora	*Porzana carolina*	Birds
Trumpeter swan	*Cygnus buccinators*	Birds
Western tanager	*Piranga ludoviciana*	Birds
Waterfowl priority areas	—	Birds
Arctic grayling	*Thymallus arcticus*	Fish
Athabasca rainbow trout	*Oncorhynchus mykiss*	Fish
Bull trout	*Salvelinus confluentus*	Fish
Athabasca Willow	*Salix athabascensis*	Vascular plants
Limber Pine	*Pinus flexilis*	Vascular plants
Northern Wood Fern	*Dryopteris expansa*	Vascular plants
Spotted Coralroot	*Corallorhiza maculata*	Vascular plants
Veiny Vetchling	*Lathyrus venosus*	Vascular plants
Whitebark Pine	*Pinus albicaulis*	Vascular plants
Birdnest Jellyskin Lichen	*Leptogium tenuissimum*	Lichens
Hooded ramalina	*Ramalina obtusata*	Lichens
—	*Phaeocalicium compressulum*	Lichens
Camouflage lichen	*Melanohalea trabeculata*	Lichens
Variable wrinkle lichen	*Tuckermannopsis orbata*	Lichens
Reindeer lichen	*Cladonia stygia*	Lichens
Lustrous Beard Lichen	*Usnea glabrata*	Lichens
Eyed Starburst Lichen	*Imshaugia placorodia*	Lichens
Yellowhorn Pixie Lichen	*Cladonia bacilliformis*	Lichens

Table 2 (continued)

Common Name	Scientific Name	Taxonomy
Blue-footed Pixie Lichen	*Cladonia cyanipes*	Lichens
Spangled Horsehair Lichen	*Bryoria simplicior*	Lichens
Liverwort	*Lophozia excisa*	Mosses
Liverwort	*Barbilophozia kunzeana*	Mosses
Liverwort	*Scapania glaucocephala*	Mosses
Flat-brocade Moss	*Platygyrium repens*	Mosses
Liverwort	*Riccardia latifrons*	Mosses
Open Water	—	Wetland
Aquatic Bed	—	Wetland
Mudflats	—	Wetland
Emergent Marsh	—	Wetland
Meadow Marsh	—	Wetland
Graminoid Rich Fen	—	Wetland
Graminoid Poor Fen	—	Wetland
Shrubby Rich Fen	—	Wetland
Shrubby Poor Fen	—	Wetland
Treed Rich Fen	—	Wetland
Treed Poor Fen	—	Wetland
Open Bog	—	Wetland
Shrubby Bog	—	Wetland
Treed Bog	—	Wetland
Shrub Swamp	—	Wetland
Hardwood Swamp	—	Wetland
Mixedwood Swamp	—	Wetland
Tamarack Swamp	—	Wetland
Conifer Swamp	—	Wetland

The list of fine-filter species was derived from the Biodiversity Management Framework, currently being developed as a component of the Lower Athabasca Regional Plan, adjusted to reflect differences in the species mix found in northwest Alberta. The list includes species recognized as Endangered, Threatened, or Special Concern under the federal *Species at Risk Act* and under Alberta's species at risk program. It also includes some species listed as S1 or S2 in the Alberta Conservation Information Management System (ACIMS). Not all species of conservation concern could be included because distribution data is lacking for many of the rare species. The species data we used for the analysis were obtained as modeled abundance distributions from ABMI.

As part of our fine-filter analysis we also included 19 fine-scale wetland classes, available in the enhanced wetland classification developed by Ducks Unlimited Canada (Table 2). Ducks Unlimited also provided us with the modeled distribution of high-density waterfowl areas, which we used as another fine-filter input.

As before, we ran the models across a range of targets, from 5-30%. In all cases we used a balanced approach, setting the fine-filter targets equal to the coarse-filter targets.

Focal Species

The fine-filter approach was useful for determining whether any species of concern were being inadequately represented in the coarse-filter designs. But there are some high-profile species in northwest Alberta, including woodland caribou, grizzly bear, Athabasca rainbow trout, bull trout, and Arctic grayling, that call for additional individualized attention. We called these focal species. Additional modeling was conducted to explore opportunities for providing enhanced protection of these species, while minimizing trade-offs with coarse-filter conservation objectives.

Climate Change

At least 2°C of warming is expected in Alberta because of the excess CO_2 already in the atmosphere. Even more warming is likely if continued CO_2 emissions are not brought under control. A 2°C rise in temperature may not seem like much, but the ecological implications are significant. For example, the difference in mean annual temperature between Edmonton, in the Parkland Region, and Fort McMurray, in the Boreal Region, is only 2°C. The implication is that ecosystems and species are destined to shift from their current locations in coming decades. These changes need to be taken into account in the conservation planning process.

The most pronounced changes are predicted to occur in the Boreal Natural Region, because this area is already near the tipping point between forest and grassland. This is evident in the existence of parkland and even some grasslands in the Peace Country. It will not take much of a rise in temperature for these ecosystems to expand onto the boreal plain. Current projections suggest that, by the end of the century, the only places where a boreal type of climate will still be found in northern Alberta will be on the tops of the boreal hill system and in parts of the Foothills (Fig. 4). These areas can be considered climate refugia. Vegetation and wildlife responses will lag behind the changes in climate, but boreal ecosystems are expected to eventually be relegated to these high-elevation sites. Fig. 5 illustrates the priority areas for boreal birds under the anticipated future climate.

Research suggests that the coarse-filter approach should be fairly robust to climate change (Beier and Brost, 2010). The ecosystem composition of each reserve will change over time; however, proportional representation of ecosystem types is expected to be maintained (assuming sufficient connectivity exists; Schneider and Bayne, 2015). Conservation areas will continue to serve their core purpose, which is to provide refuge from industrial impacts, even though the inhabitants will change over time. Static reserves established to protect the habitat of specific fine-filter species are more problematic.

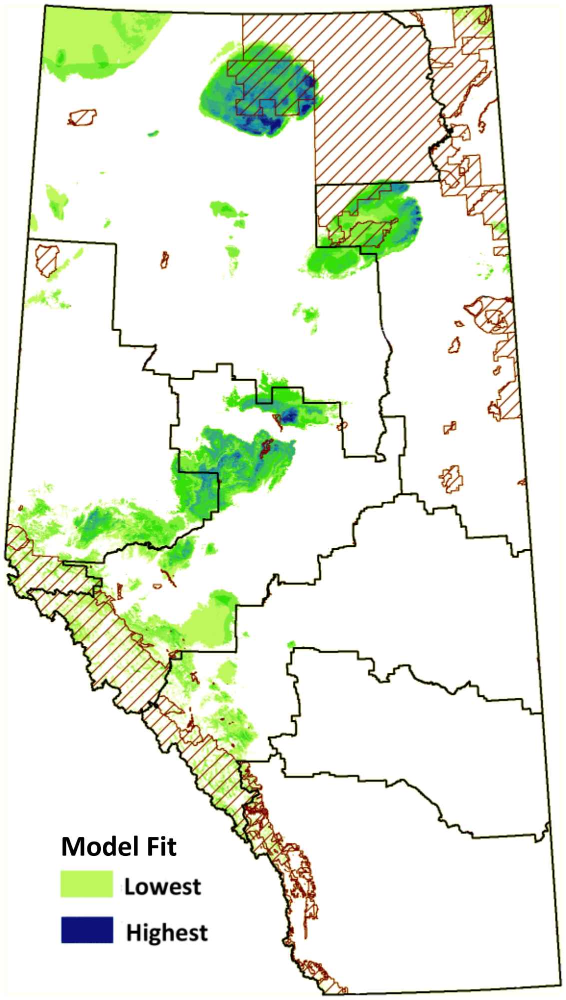

Fig. 4. Projected distribution of the Boreal Subregion climate at the end of the century, averaged over 9 climate models and weighted by proximity to current Subregions. Source: Diana Stralberg.

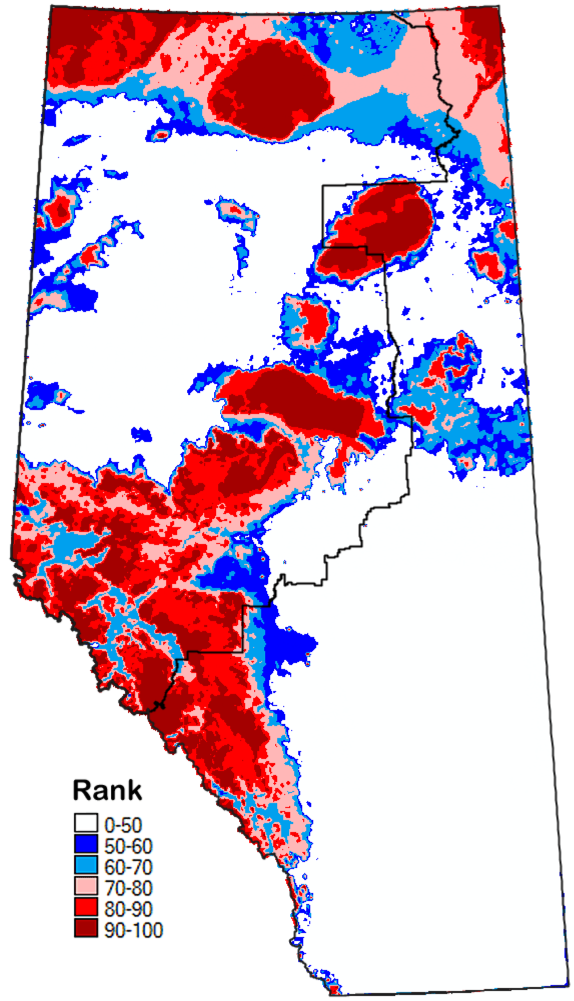

Fig. 5. Priority areas for boreal forest birds based on species-based modeling of climate refugia (Stralberg et al., 2015).

In one of our exploratory scenarios we added boreal climate refugia, derived from projections shown in Fig. 4, as a fine-filter element. We also considered the anticipated effects of climate change when identifying regional priorities.

Additional detail concerning the Marxan modeling process is provided in Appendix 1.

Results and Discussion

Coarse-Filter and Fine-Filter Scenarios

As is typical of optimization models, Marxan usually finds many alternative reserve configurations that work equally well. Therefore, we ran the model 100 times at each target level to determine which areas were selected most consistently. The output maps presented in this report are composites of all these runs. The shading reflects conservation importance — the darker shades are the areas selected most consistently, across the full range of target levels.

It should be noted that the size of the reserve system generated by Marxan is larger than the input representation targets (Table 3). Setting a 10% target for each feature does not mean the overall reserve system will be 10% of the study area. This is mainly because existing protected areas over-represent many features. It also has to do with how the features are distributed and how efficiently they can be represented (see Appendix 1 for additional information). Our main interest was to prioritize the landscape in terms of its conservation potential, and this is what is emphasized in this report.

Table 3. Total reserve size for the base model as a function of the representation target.[1]

Target	Reserve (km^2)[2]	Reserve (%)[3]
Existing Parks	93,739	18.4
5	103,950	20.4
10	123,964	24.4
20	166,216	32.7
30	209,206	41.1

[1]The base model includes all coarse and fine-filter elements.
[2]The total area of the reserve, including existing protected areas across the entire study area.
[3]Calculated as the total reserve area divided by the total study area (509,000 km^2; see Fig. 2) *100

We began our analysis with a scenario that included only Natural Subregions (Fig. 6). This scenario illustrates the most efficient designs for filling gaps in ecosystem representation at a coarse scale. The Foothills, Dry Mixedwood, and Upper Boreal Highlands are the main areas selected for additional protection, which is expected given the low level of existing protection in these Subregions.

Fig. 7 provides results for a scenario that included all coarse-filter features. The main difference here is that the Lower Boreal Highlands are now selected (in the northwest) and there is a bit more emphasis on northern areas in general. This change arises mainly because some specific vegetation features are difficult to achieve once targets are stratified by Subregion. A case in point is the Open Coniferous category in the Lower Boreal Highlands. Much of this feature is located in the Lower Athabasca planning zone, where planning has already been completed. To fill the representation gap for this feature, Marxan was forced to assemble what it could in northwestern Alberta, where the density of this feature is low. As a result, many planning units were needed. To illustrate this, Fig. 8 shows a coarse-filter scenario in which the Open Coniferous target specific to the Lower Boreal Highlands was set to zero. With this single change, the Lower Boreal Highlands were no longer the focus of selection. These insights were incorporated when we developed our list of conservation priorities.

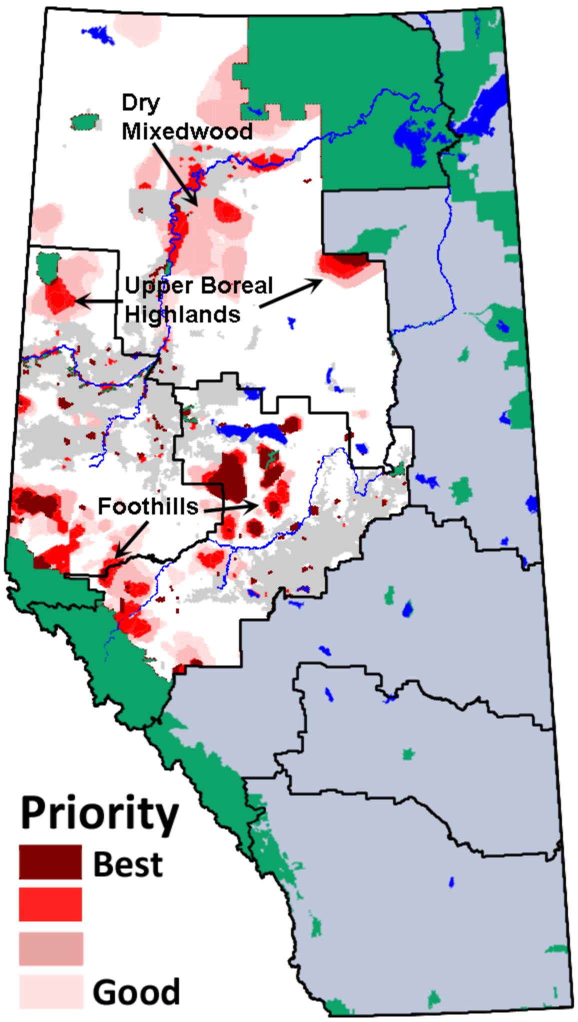

Fig. 6. Coarse-filter designs including only Natural Subregions as inputs. Red shading indicates conservation priority, based on progressively higher representation targets.

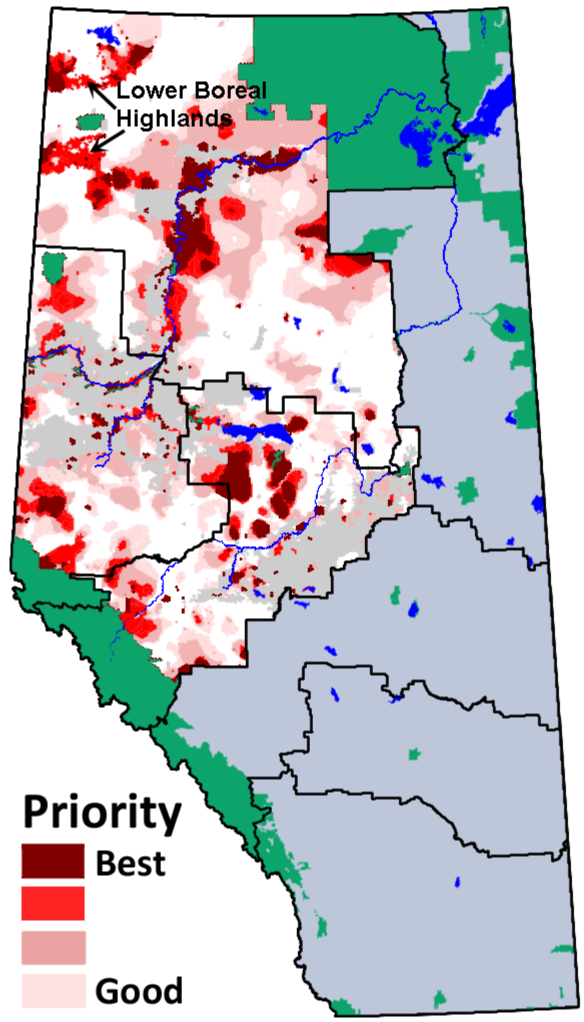

Fig. 7. Designs including all coarse-filter inputs. Red shading indicates conservation priority, based on progressively higher representation targets.

Adding fine-filter species to the coarse-filter model did not result in any substantive changes (Fig. 9). This indicates that the coarse-filter approach is working as intended, representing a broad range of habitat types and meeting the needs of most species, including those on our list of species of conservation concern. It should be understood that most of the species we included in our analysis were fairly widely distributed, mainly because we chose to focus on species for which reliable spatial distribution data were available. It would be advisable to incorporate the protection needs of some of Alberta's truly rare species and unique landscape features in a follow-up study, if additional research capacity can be brought to bear.

The results of the fine-filter analysis allay various concerns about accommodating fine-filter species, at least for those we examined. If significant changes in design had been required, it would have

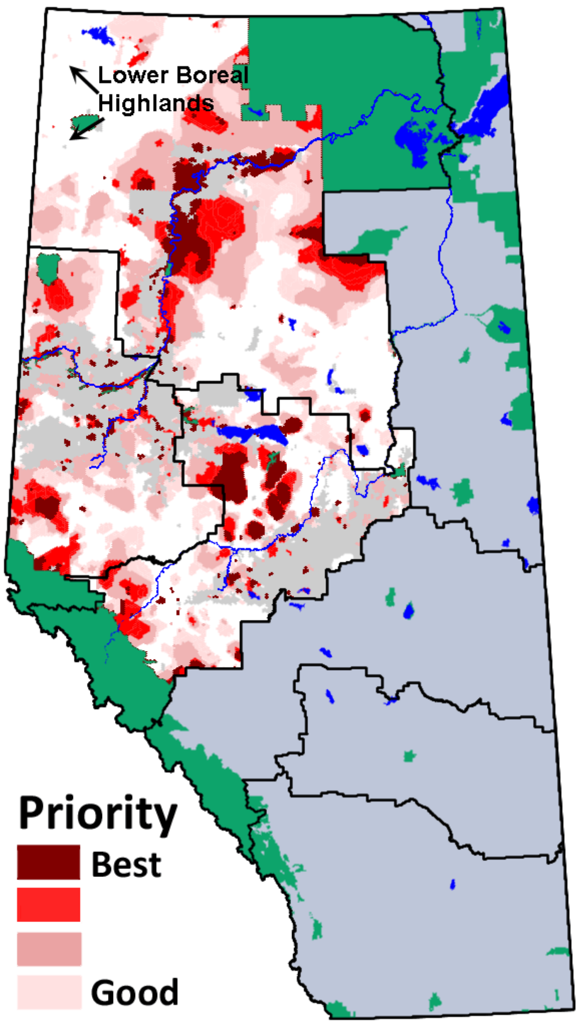

Fig. 8. Coarse-filter designs in which the Open Coniferous category within the Lower Boreal Highlands was excluded. Red shading indicates conservation priority, based on progressively higher representation targets.

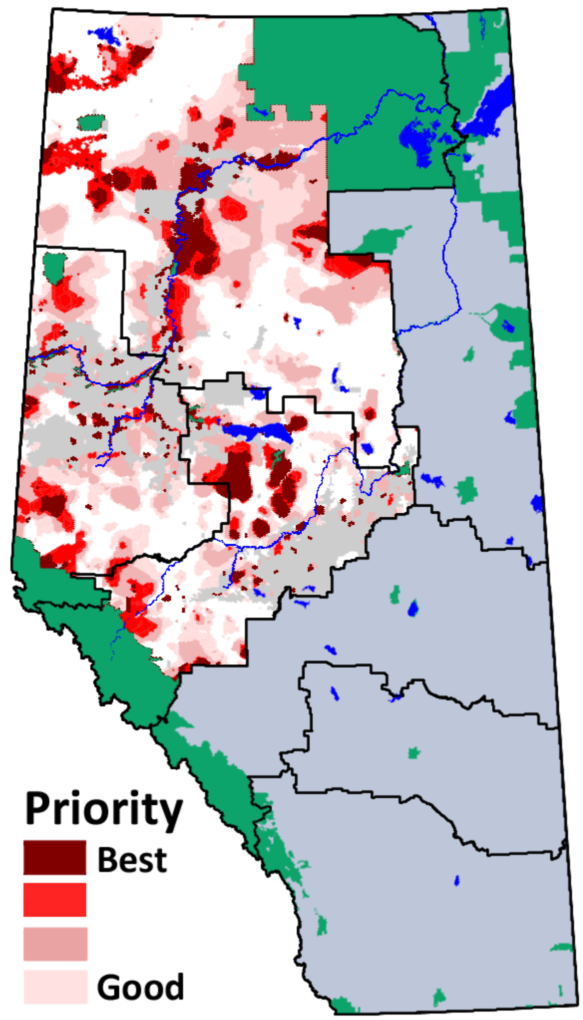

Fig. 9. Designs including all coarse-filter and fine-filter inputs. Red shading indicates conservation priority, based on progressively higher representation targets.

been necessary to assess trade-offs between fine-filter and coarse-filter objectives, or among species. We would also have had to grapple with the logic of protecting the habitat of individual species knowing that their ranges would likely eventually shift out of their dedicated reserves as a result of climate change. Finally, we may have been confronted with the logistical challenges inherent in a design that featured many small reserves dedicated to many individual species.

When we included boreal climate refugia as a fine-filter element, we found that targets for this feature were also achieved through the coarse-filter design.

Focal Species in the Foothills

Core habitat for most of our focal species, including woodland caribou, grizzly bear, bull trout, Athabasca rainbow trout, and Arctic grayling, are all found in the foothills adjacent to the mountain parks. The coarse-filter designs capture some of this habitat; however, more can be achieved through minor shifting of the default reserves in this region. For example, in the scenario shown in Fig. 10, we forced into the model the area where the habitat of three or more of the focal species overlap. This increased the representation of the focal species with little impact on the rest of the reserve design (which included both coarse and fine-filter inputs).

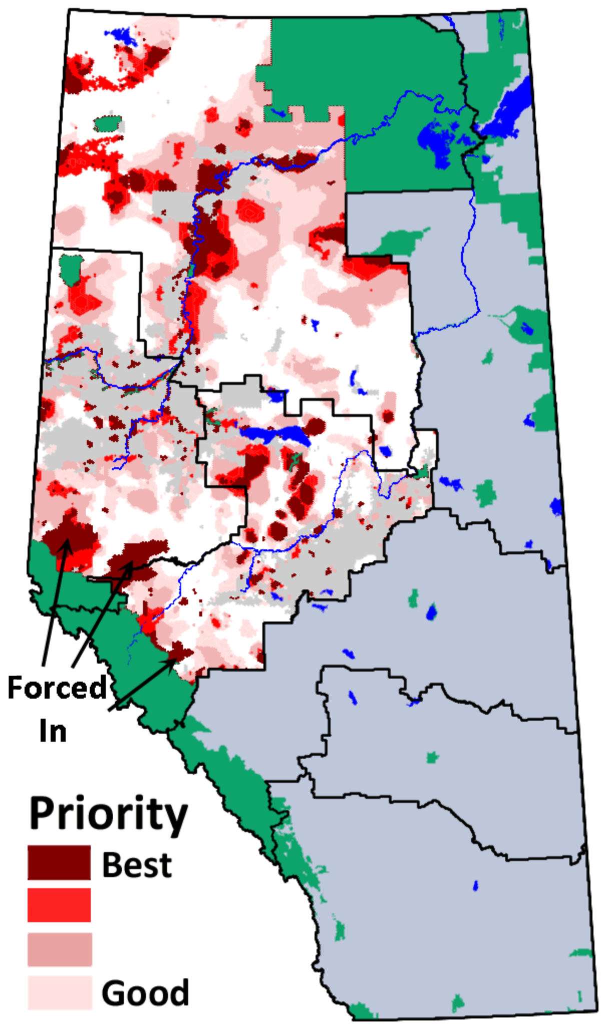

Fig. 10. Coarse and fine-filter scenario in which the area of overlap among focal species in the foothills was forced into the model. Red shading indicates conservation priority, based on progressively higher representation targets.

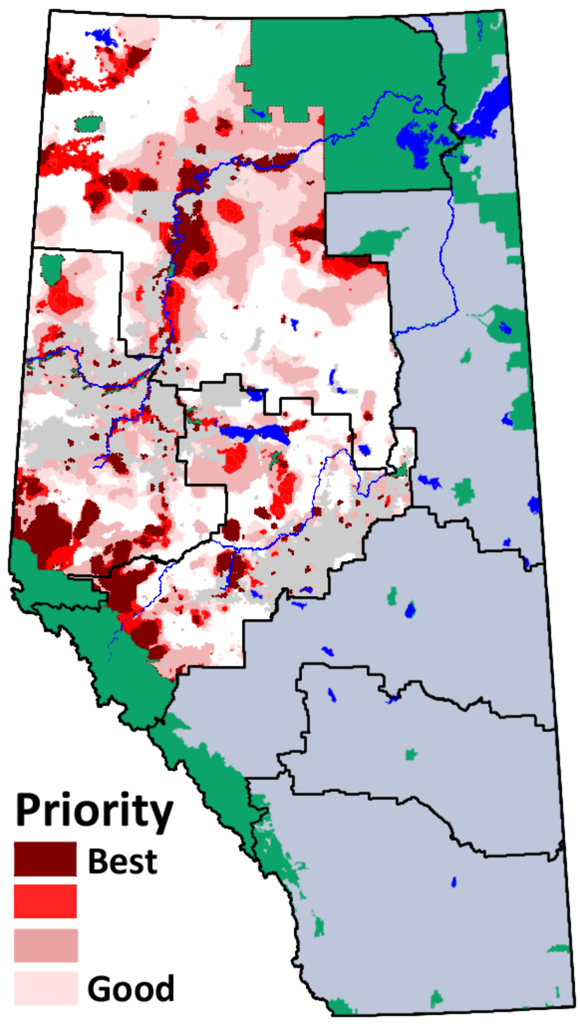

Fig. 11. Coarse and fine-filter scenario with augmented target levels for foothills focal species. Red shading indicates conservation priority, based on progressively higher representation targets.

In another scenario, rather than forcing in the zone of habitat overlap we increased the targets of the focal species, leaving all other targets unchanged (see Appendix 1 for details). This provided even more representation of the focal species; however, doing so reduced the size of reserves in the Swan Hills (Fig. 11 – previous page). This trade-off between sites must be carefully considered, since the Swan Hills provides important contributions of its own (see Identifying Priorities section)

Woodland Caribou in the Boreal

The base model provides some representation of several caribou ranges. However, when caribou ranges are overlaid on the base model (Fig. 12), it is apparent that the priority areas for coarse-filter conservation lie mostly outside of caribou range. This is mainly because caribou in northern Alberta utilize a specific range of habitat types, mostly involving peatlands, whereas the base model was designed to achieve representation of all habitat types. The implication is that a reserve system designed to achieve broad biodiversity objectives will not fully meet the needs of caribou, and conversely, that protecting caribou habitat will not achieve broad biodiversity objectives.

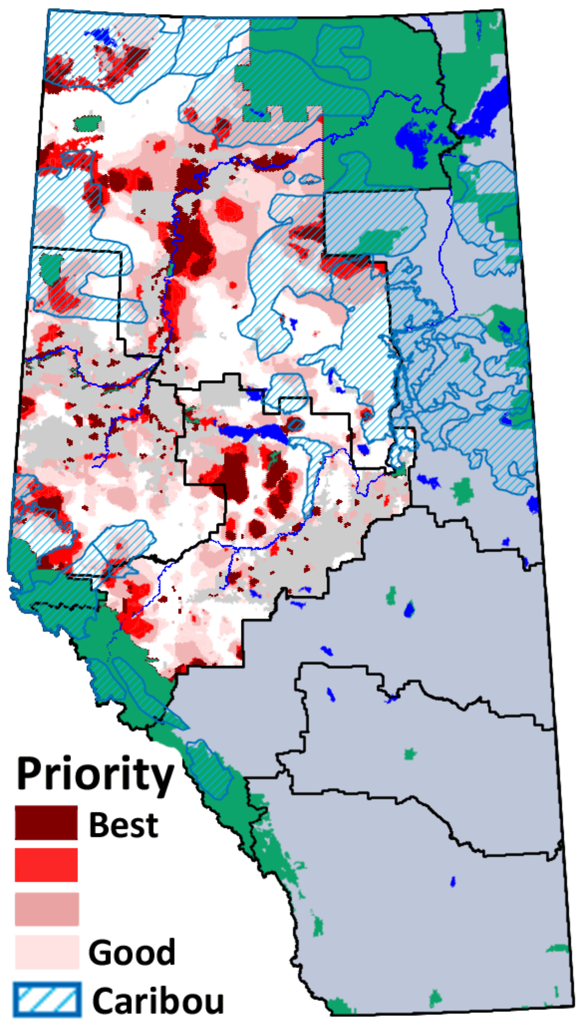

Fig. 12. Coarse and fine-filter base scenario with caribou ranges overlaid. Red shading indicates conservation priority, based on progressively higher representation targets.

Staff with Alberta Fish and Wildlife are now working to identify priority areas for caribou conservation that will feed into the LUF planning process. These efforts involve specialized datasets (e.g., data on movement patterns and home ranges) and the development of habitat models. Our group did not have access to these data, limiting our ability to explore caribou protection options in our Marxan analysis.

Climate change will be an important consideration in the context of caribou reserve design. Several of the northern herds, including the Chinchaga, Bistcho, and Caribou Mountains herds, have a large proportion of their range in areas expected to become future boreal climate refugia. Thus, protection of these herds will serve a dual purpose. Conversely, caribou ranges in lowland areas are unlikely persist over the long term under the parkland-like climates projected for Alberta's boreal plain (Hogg and Hurdle, 1995; Schneider and Bayne, 2015). We provide some exploratory Marxan runs that prioritize caribou range on the basis of disturbance intensity and future climate in Appendix 2.

Another point worth noting is that the caribou habitat adjacent to WBNP and the Caribou Mountains Wildland Park is also high priority habitat for Arctic grayling.

Resource Conflicts

Our modeling analysis indicates that some flexibility exists for achieving representation targets, at least at the Subregion scale. This flexibility can be used to potentially minimize conflict with resource development objectives. To explore such opportunities we ran a scenario in which the net present value of oil and gas and forestry resources (Schneider et al., 2011) was included as an additional cost layer. In this scenario, Marxan had to avoid both disturbance and high-value resources while selecting cells to achieve representation targets.

The resulting reserve design (Fig. 13) was not appreciably different from the base scenario design. This was because the distribution of resource values (Appendix 1) is highly correlated to linear disturbance intensity, reflecting the fact that most of the disturbance footprint is related to access for resource development. By having Marxan avoid linear disturbances, which we did from the outset, we were automatically avoiding areas with the highest resource potential in the base scenario.

An important caveat to our analysis of resource conflicts is that total resource value mainly represents oil and gas resources, since the relative value of forest resources is more than an order of magnitude lower. As a result, our designs may not have effectively minimized conflict with the forestry sector.

Settled Areas

In our base scenario, Marxan was prevented from selecting sites within privately owned land, municipal land, federal land, First Nation reserves, and Metis settlements. This was because we received guidance from the government indicating that the province would not be establishing new conservation areas on such settled lands under the LUF. This does not imply that these lands lack conservation values that merit protection; rather, other approaches, such as land purchases and offset programs, may be needed to secure the protection of these values.

To provide “big picture” guidance regarding the priorities for protection within non-public lands we ran a Marxan scenario in which all lands within the three northwest planning regions could be selected (Fig. 14). It should be noted that this map provides only very coarse guidance, since the resolution and methodology of our analysis were geared to large intact landscapes, rather than fragmented agricultural landscapes. For example, our model could not incorporate small habitat patches or unique landscape features.

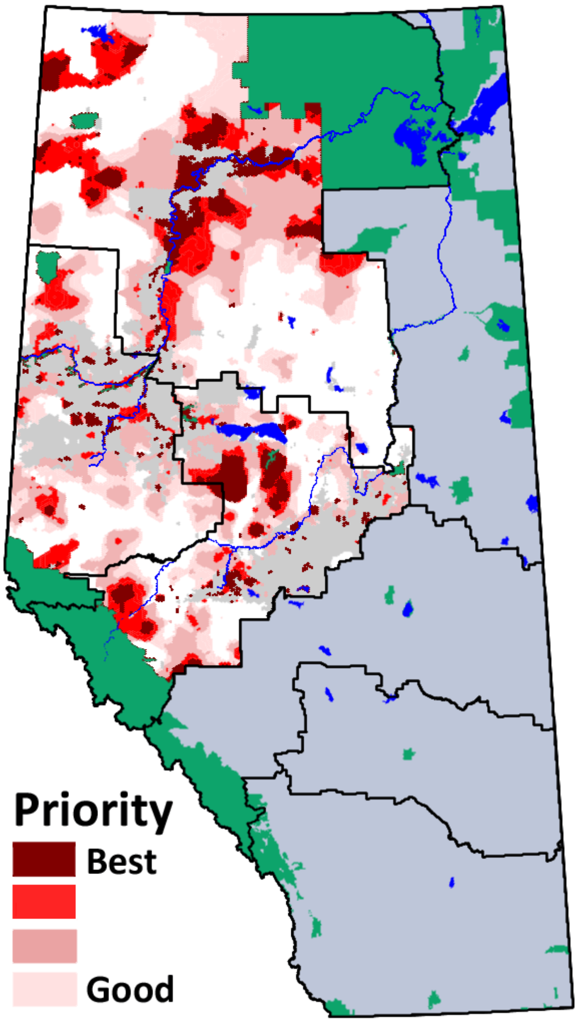

Fig. 13. Coarse/fine-filter design using both disturbance and resource value as cost layers. Red shading indicates conservation priority, based on progressively higher representation targets.

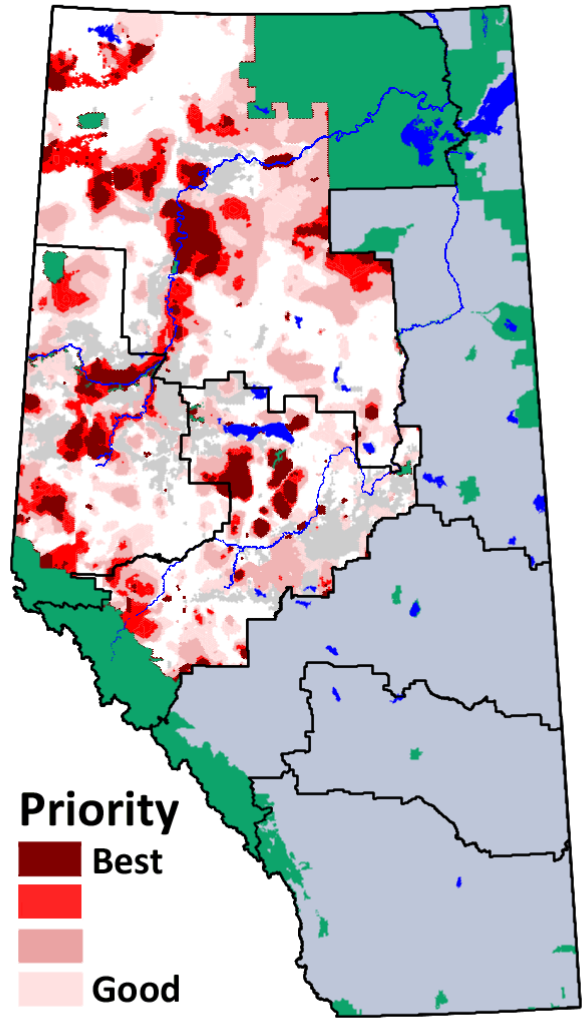

Fig. 14. Coarse/fine-filter design in which private land is available for selection. Red shading indicates conservation priority, based on progressively higher representation targets

Identifying Priorities

The Marxan analysis identified several regions that were consistently selected and should be considered priorities for protection under the regional planning process (Fig. 15).[2] Here we describe the conservation values that each region contributes. The outlines shown in Fig. 15 are broad, which is meant to indicate that flexibility exists locally for defining the actual conservation area boundaries. In doing so, consideration should be given to the guidance provided by Marxan

[2] A GIS version of this map is available at: http://www.ace-lab.org/index.php?page=asca&atlas=12 .

as well as factors related to ecological function, including minimum reserve size and connectivity to nearby reserves. Larger reserves and those near other parks will be better able to maintain ecological integrity. Consideration should also be given to local conservation features, such as riparian corridors, that we were not able to model directly. Input from regional biologists, indigenous communities, and others with local ecological knowledge would be very helpful in this regard.

The sites highlighted in Fig. 15 are consistent with the key criteria for conservation area planning under the LUF: they are representative of the biological diversity of the region, they are of sufficient size to maintain most ecological processes and integrity (Leroux et al., 2007), and they are among the areas least impacted by industrial activity in each planning region. These sites also achieve excellent representation of the Natural History Themes used in the planning framework developed by Alberta Parks (Appendix 2). Due to time and capacity limitations, we were not able to seek indigenous communities' views on identifying priority reserve areas. But given the broad spatial distribution of the identified sites, many communities could potentially benefit.

It was not possible to assign a specific ranking to each region, as they contribute to different biodiversity objectives. However, it should be noted that the representation gaps are greatest in the Foothills and Dry Mixedwood regions.

Priority Region 1: Foothills. The Foothills Natural Region has one of the lowest rates of protection in the province — just 1.4% — and has been heavily impacted by industrial activities and off-road vehicle use. Yet it holds some of the highest conservation values in Alberta. Because of its complex topography and varied climate this region is a provincial hotspot of species diversity for both animals and

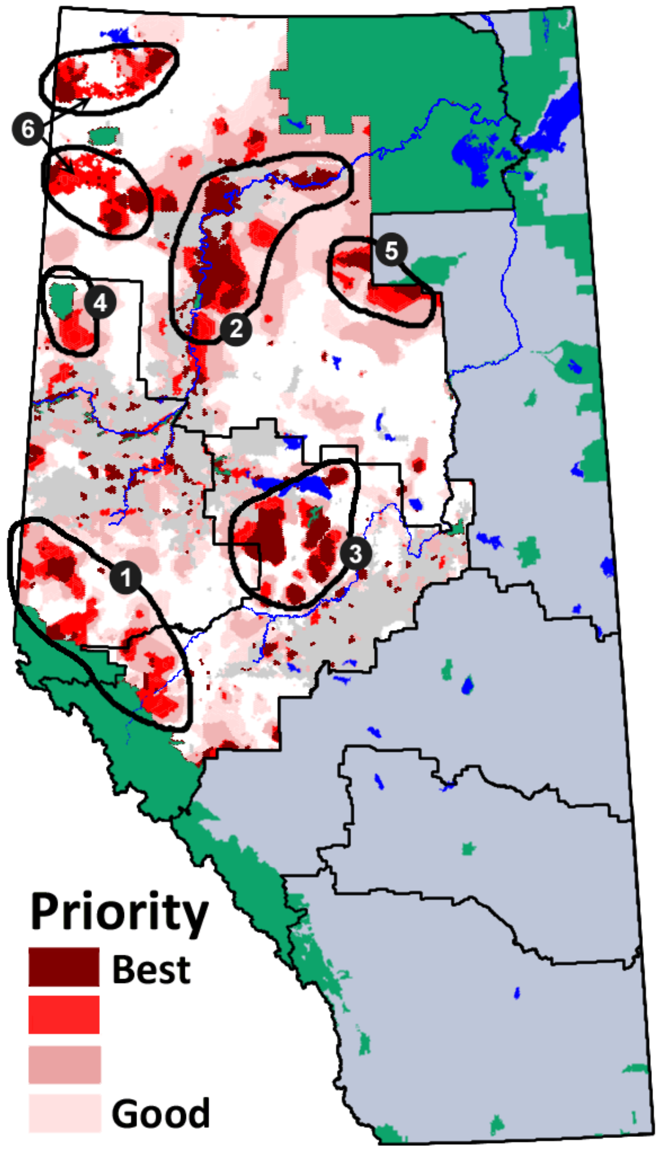

Fig. 15. Base design including coarse and fine-filter elements. Red = selected sites, with priority regions circled in black; green = existing protected areas; grey = private land and land outside of our core study area. Planning zone boundaries are outlined in black.

vascular plants. It is also the location of many of Alberta's headwaters, including those feeding the Peace and Athabasca Rivers. Another important feature is its proximity to the mountain parks, which will serve as an ecological anchor for any new foothills parks, enhancing their integrity. Finally, looking forward to the future, the Foothills are projected to be a critical climate change refuge for forest species, especially boreal species that are expected to lose much of their existing habitat to the encroachment of parkland and grassland ecosystems onto the boreal plain. Within the broad Foothills region that we have identified, priority should be given to the protection of the high-profile species at risk that are present, including woodland caribou, grizzly bear, bull trout, Athabasca rainbow trout, and Arctic grayling (additional detail is provided in the main report).

Priority Region 2: Peace River. This area provides representation of the Dry Mixedwood Subregion, which has little existing protection (just 1.6%). It is also the only low-elevation ecosystem among all of our regional priorities. The Dry Mixedwood is the most threatened ecosystem type in northern Alberta because the majority of the region has been converted to agricultural use, including crop and hay production and ranching. Much of the agricultural conversion took place early in Alberta's history, but even as late as the 1990s, Environment Canada described the region as "Canada's fastest advancing agriculture frontier." Today, public lands continue to be auctioned off for conversion to agriculture use. Forestry and oil and gas development are also very active in this region. There is little scope for substitution in the Dry Mixedwood, because only a limited amount of this ecosystem remains intact, and it is concentrated in the northern reaches of the Peace Country. When defining the boundaries of a conservation area in this region, an effort should be made to establish connectivity with Wood Buffalo National Park, along the Peace River.

Priority Region 3: Swan Hills. This area includes both the Swan Hills and the Marten Hills northeast of Lesser Slave Lake. It represents the convergence of Foothills and Boreal ecosystem types and as a result, contains many unique ecosystems. It also provides habitat for several fine-filter species, including core habitat for grizzly bears. Large parts of the Swan Hills remain relatively intact, in contrast to most other parts of the Foothills region. This high level of integrity is unlikely to be maintained in coming decades without formal protection. In the future, given its varied terrain and higher elevation, this region will also serve as an important climate refuge for boreal forest species, many of which do not currently extend into the Foothills proper.

Priority Region 4: Chinchaga. This area provides representation across a gradient of ecosystem types, from Upper Boreal Highlands at high elevations to Dry Mixedwood at lower elevations. Protection in this region would support the Chinchaga caribou herd, and in the future would serve as a climate refuge for boreal forest species. Establishing a large conservation area here would enhance the integrity of the existing Chinchaga Wildland Park, by increasing its size to the point where most natural ecological processes could be maintained. As an alternative, most of the attributes just described could also be represented in the lands immediately north of the existing Chinchaga Wildland Park. This area is less intact, and representation would not be quite as good; however, no forestry tenure exists here, so it has the benefit of having less conflict with forestry.

Priority Region 5: Birch Mountains. This area provides additional representation of the Upper Boreal Highlands and associated finer-scale features. Protection in this region would support the Red Earth and West Side Athabasca caribou herds and in the future would serve as a climate refuge for boreal forest species. Establishing a large conservation area here would also enhance the integrity of the existing Birch Mountains Wildland Park, by increasing its size to the point where most natural ecological processes could be maintained. Connectivity to Wood Buffalo National Park is an important consideration of conservation planning in this region. This could be accomplished by providing a higher level of protection to the intervening Birch River Conservation Area, which currently does not have full park status.

Priority Region 6: Bistcho. This area was consistently selected by Marxan in the base scenario for one specific reason: to achieve the representation target for the Lower Boreal Highlands Open Coniferous vegetation type. Most of this vegetation type is actually found in northeast Alberta, but is not protected there. Filling this representation gap in the northwest required large areas to be added to the reserve design because this vegetation type is only found at low density in this region. Protection in this region would also support the Bistcho caribou herd and in the future it would serve as a climate refuge for boreal forest species.

A limitation of our approach to reserve design is that the "big picture" perspective it provides is not comprehensive. In particular, unique landforms and rare species were not included in the modeling process. A finer-resolution process will be needed to identify and protect these types of features.

Connectivity

Connectivity among reserves is an important consideration in reserve design. However, it will be challenging to achieve in our study area, given its vast extent. Many of the priority areas identified by Marxan are separated from each other by more than 100 km. One option is to use major river corridors, such as the Peace River which connects the foothills to Wood Buffalo National Park. The major problem here is that the Peace River runs through an extensive agricultural zone that limits its value as a major wildlife movement corridor. Another option is to use lower priority areas identified by Marxan as connecting zones. To explore this idea we increased the representation targets to see if connecting zones would become apparent. Unfortunately, several of the priority areas remained isolated under this approach.

At the regional scale, there are some obvious candidates for connecting zones that merit consideration. First, any sites that are established within the Zone 1 (Foothills) should connect directly to the mountain parks. Second, a broad connecting corridor should be established within Zone 2 (Peace River), connecting new conservation areas with each other and with Wood Buffalo National Park. Third, new and existing conservation areas within Zone 5 (Birch Mountains) should be connected to Wood Buffalo National Park through the intervening Birch River Conservation Area. Further study will be needed to identify options for connecting the remaining sites.

Literature Cited

Beier, P. and B. Brost. 2010. Use of land facets to plan for climate change: conserving the arenas, not the actors. Conservation Biology 24:701-710.

Game, E.T. and H.S. Grantham. 2008. Marxan User Manual: For Marxan Version 1.8.10. University of Queensland, St. Lucia, Queensland, Australia.

GOA (Government of Alberta). 2008. Land-use Framework. Government of Alberta, Edmonton, AB.

Hogg, E. and P. Hurdle. 1995. The aspen parkland in western Canada: a dry-climate analogue for the future boreal forest? Water, Air, and Soil Pollution 82:391-400.

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

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

Schneider, R. and E. Bayne. 2015. Reserve design under climate change: from land facets back to ecosystem representation. PloS One 10:e0126918.

Schneider, R., G. Hauer, D. Farr, W. Adamowicz, and S. Boutin. 2011. Achieving conservation when opportunity costs are high: optimizing reserve design in Alberta's oil sands region. PloS One 6:e23254.

Stralberg, D., E. Bayne, S. Cumming, P. Solymos, and S. Song. 2015. Conservation of future boreal forest bird communities considering lags in vegetation response to climate change: a modified refugia approach. Diversity and Distributions 21:1112-1128.

Appendix 1: Marxan Methods

To account for the contributions of existing protected areas, we expanded our study area to include all Natural Subregions that intersected with the three planning zones of interest (Fig. 2). The full study area (blue and purple in Fig. 2) was 509,084 km^2 in size. We used hexagonal planning units that were 500 ha in size (n= 103,100). In all but one scenario, existing protected areas were locked-in (i.e., the model was forced to select them). These locked-in areas totalled 93,770 km^2.

In selecting coarse-filter inputs (Table 1), we took into consideration the datasets that were available, the approaches that have been used in other studies, and conservation planning theory. Surficial geology was considered, but we instead opted for the land facet layer developed by Scott Nielsen at the University of Alberta. Both layers attempt to represent enduring landscape features that provide the "arenas" of biological diversity (Beier and Brost, 2010). The land facet layer is a multi-dimensional dataset that incorporates substantially more information about attributes relevant to biotic patterns than the surficial geology layer. It is composed of three sub-layers, including a moisture-stratified terrain layer, a landform layer, and a heat-load (solar) layer. Although surficial geology was not used to set representation targets, we did track it in the model and report on it in Appendix 2.

The enhanced wetland classification provided by Ducks Unlimited Canada did not include Wood Buffalo National Park. To fill this gap we utilized the peatland inventory developed by Dale Vitt at the University of Alberta in 1996. Although the Vitt peat layer is not as detailed as the enhanced wetland classification, it was assessed to be sufficient to account for the wetlands that are protected within the park. Not doing so would have led to misleading Marxan results (i.e., double representation of some wetland classes).

For setting representation targets for Natural Subregions we used an equal-area approach so that large Subregions, like the Central Mixedwood, would not dominate the results. For example, the 10% target for Subregions was 3,616 km^2 (for each Subregion), calculated as the 10% of the overall study divided by the number Subregions present in the study area. Our aim was to provide balanced representation of the major arenas of biological diversity.

The other coarse-filter features were stratified by Subregion to ensure regional representation of these features. The area of many features was quite small after stratification, precluding the use of equal area targets. We used proportional targets instead. For example, the 10% target for Fens in the Lower Foothills was 364 km^2, calculated as 10% of the amount of Fen present in the Lower Foothills.

Our list of 45 fine-filter species was derived from the Biodiversity Management Framework, currently being developed as a component of the Lower Athabasca Regional Plan, adjusted to reflect differences in the species mix found in northwest Alberta. The list includes species recognized as Endangered, Threatened, or Special Concern under the federal *Species at Risk Act* and under Alberta's species at risk program. It also includes some species listed as S1 or S2 in the Alberta Conservation Information Management System (ACIMS). Not all species of conservation concern could be included because distribution data is lacking for many of the rare species. We used a balanced approach for setting the fine-filter targets, making them equal to the coarse-filter targets in all cases.

Most of the species data we used for the fine-filter analysis were obtained as modeled abundance distributions from ABMI (some of these models include data from the Boreal Avian Modelling Project). We removed the marginal parts of each species' range (lowest 20%), but otherwise did not weight the ABMI datasets. The caribou ranges were obtained from the Government of Alberta (current to 2010). The grizzly bear ranges were modeled source habitat, provided by Scott Nielsen at the University of Alberta. The Athabasca rainbow trout, bull trout, and Arctic grayling distributions were derived from priority watersheds identified by Mike Sullivan, with Alberta Fish and Wildlife. Ducks Unlimited Canada provided the modeled distribution of high-use waterfowl areas as well as the fine-scale wetland categories that were included as fine-filter features.

Because we did not know how much of the landscape would be available for protection, we ran Marxan across a range of representation targets, including 5%, 10%, 20% and 30%, for each scenario that we examined. Each scenario and target combination resulted in a different reserve configuration and total size (Table 3). The size of the reserve system generated by Marxan was usually substantially larger than the input representation targets. This is mainly because existing protected areas over-represent many features. It also has to do with how the features are distributed and how efficiently they can be represented (e.g., overlapping features lead to small designs).

In supplemental runs we explored options for providing enhanced protection of focal species in the foothills region (woodland caribou, grizzly bear, Athabasca rainbow trout, bull trout, and Arctic grayling). In one scenario we used a GIS to identify the areas where at least three of these species overlapped in space, and then forced Marxan to build its foothills reserves around these areas of overlap. The intent was to exploit the flexibility that exists for meeting coarse-filter targets in order to achieve enhanced protection of focal species while having little effect on the rest of the design or its overall size. In another scenario we increased the representation targets of the focal species, leaving the targets for other features unchanged.

In another supplemental run we explored options for achieving the 65% target for caribou protection described in the federal caribou recovery plan. In this scenario, caribou range was selected for protection on the basis of disturbance intensity (lower = better), and projected climate at the end of the century (areas expected to retain a forest climate were preferred).

We also explored options for avoiding conflicts with the resource sector. To do this we included the net present value of oil and gas and forestry resources as an opportunity cost in the model (Fig. A2.1). This layer was developed by Grant Hauer, at the University of Alberta (Schneider et al., 2011). In this scenario, we combined linear feature density and net present resource value as a single cost layer, after standardization to ensure equal weighting.

The boundary length modifier (BLM) is used in Marxan to promote clumping of reserves. Without this modifier, reserve designs are characterized by large numbers of very small reserves, sometimes just one planning unit in size (500 ha). To avoid this we conducted a sensitivity analysis of the boundary modifier to identify a setting (BLM=10) that produced reserves as large as possible without significantly inflating the overall area of the design. This setting was used in all of our analyses. We also made adjustments to the boundary settings to ensure that existing protected areas and study area boundaries had a neutral influence on the design (as opposed to the default, in which existing parks act as attractants).

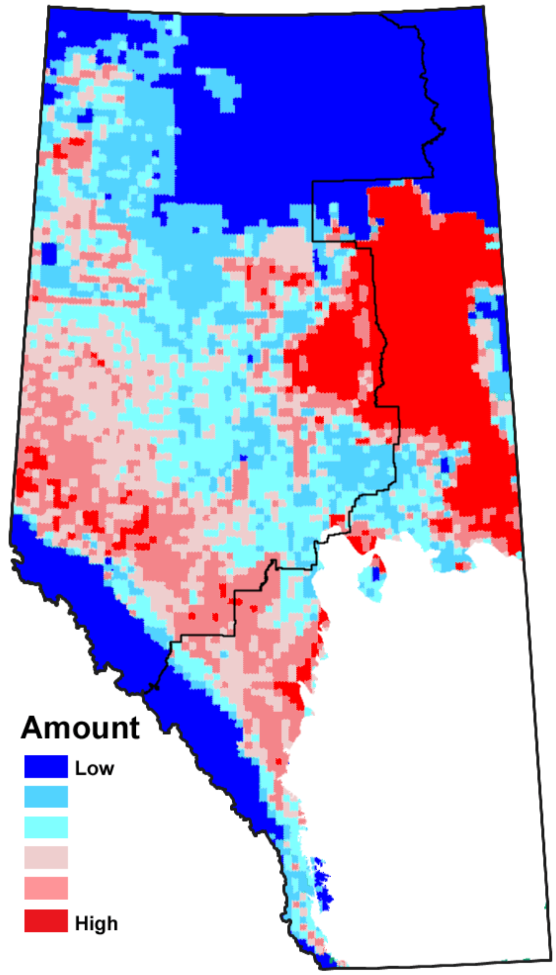

Fig. A2.1. The net present value of oil and gas and forestry resources in northern Alberta. Source: Grant Hauer (2009).

Appendix 2: Supplemental Results

Figures A2.1 to A2.5 are supplemental output maps for scenarios that were referenced in the main text, but omitted to save space. These figures are followed by tabular data from selected Marxan runs. Contact Rick Schneider at NACAWG@gmail.com to request digital data. A raster version of the base map is available at: http://www.ace-lab.org/index.php?page=asca&atlas=12

In Figs. A2.1 and A2.2 we show the base model next to the map of Natural Subregions, to allow visual comparisons to be made.

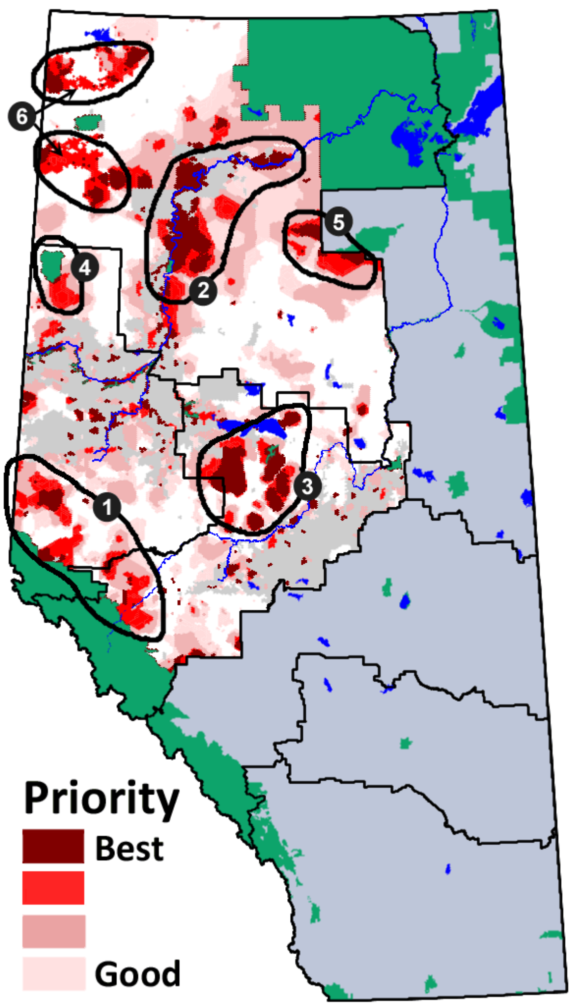

Fig. A2.1. Base scenario with priority areas circled in black. Red shading indicates conservation priority, based on progressively higher representation targets.

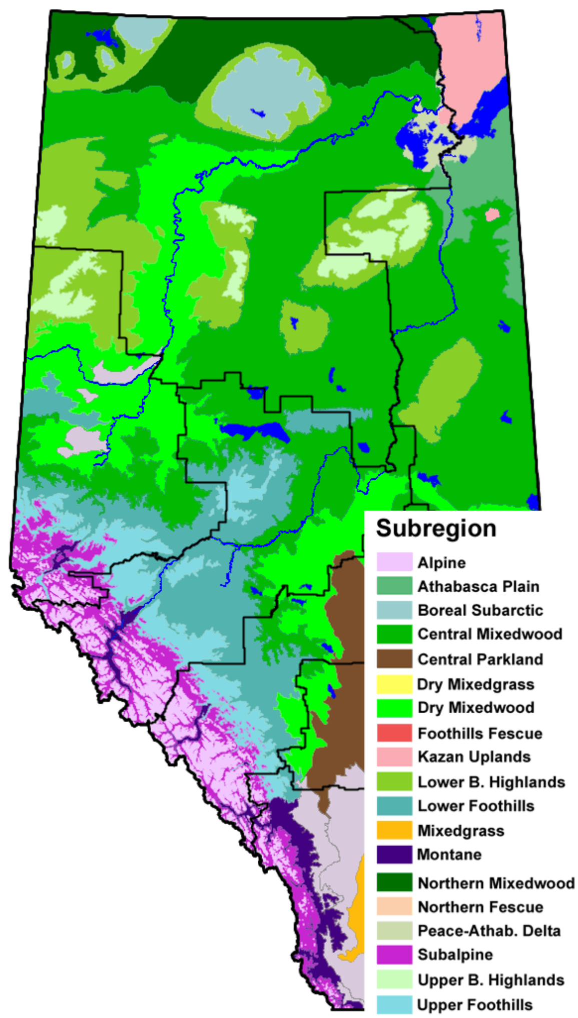

Fig. A2.2. Natural Subregions of Alberta. LUF regions are outlined in black.

A key aspect of conservation planning is accounting for protection that already exists. The existing parks over-represent certain ecosystem types within our study region and so are not necessarily indicative of the most efficient areas to place a reserve system. Therefore, we ran a scenario that allowed Marxan to select any planning unit within the unrestricted study area to better assess the distribution of each feature. This scenario, shown in Fig. A2.3, illustrates how much of a role the current protected areas are playing in achieving conservation targets and highlights important areas for conservation regardless of private land or current protection status.

It is also important to understand whether the planning units selected change when access to the existing protected areas is restricted. This allows the model to consider all options within the region but treats protected areas similar to bordering provinces or bordering land-use planning regions that are not considered in the analysis. Such a scenario is shown in Fig. A2.4.

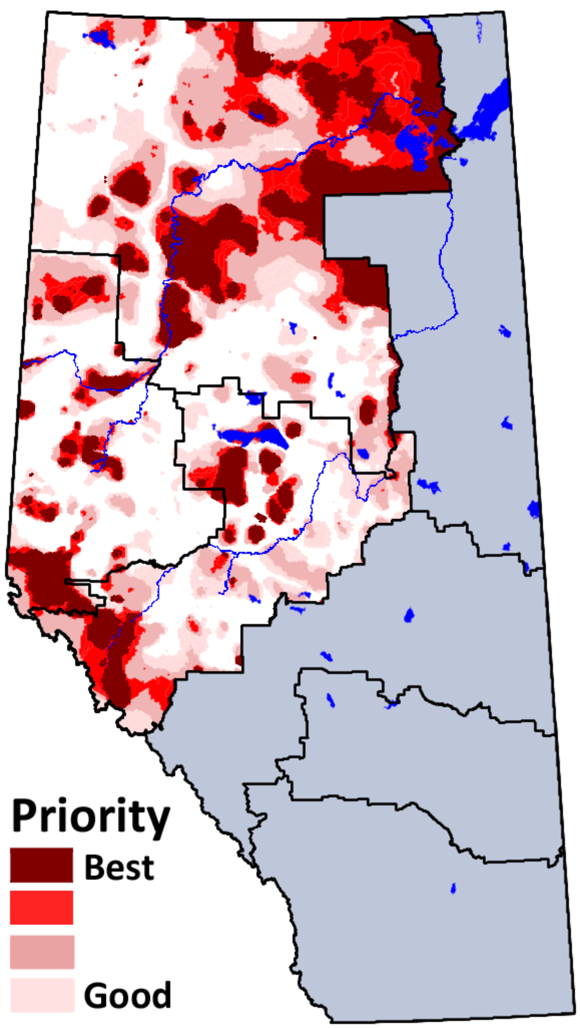

Fig. A2.3. Base scenario in which existing parks were not locked in.

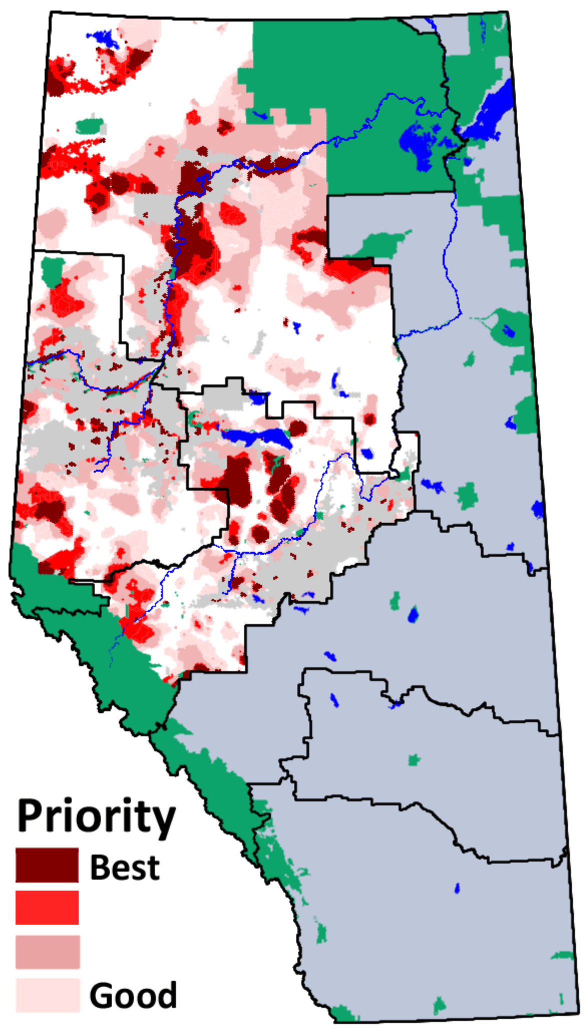

Fig. A2.4. Base scenario in which existing parks were locked out.

Fig. A2.5 shows the extent of caribou range that is expected to retain a boreal or foothills climate in the 2080s, based on ecosystem projections by Schneider and Bayne (2015).

Fig. A2.6 illustrates a scenario in which we explored options for achieving the 65% target for caribou protection as described in the federal recovery plan. The representation targets for each of the caribou herds was increased to 65%, with priority of selection given to the least disturbed sites as well as the sites most likely to retain a boreal/foothills climate at the end of the century (as per Fig. A2.5).

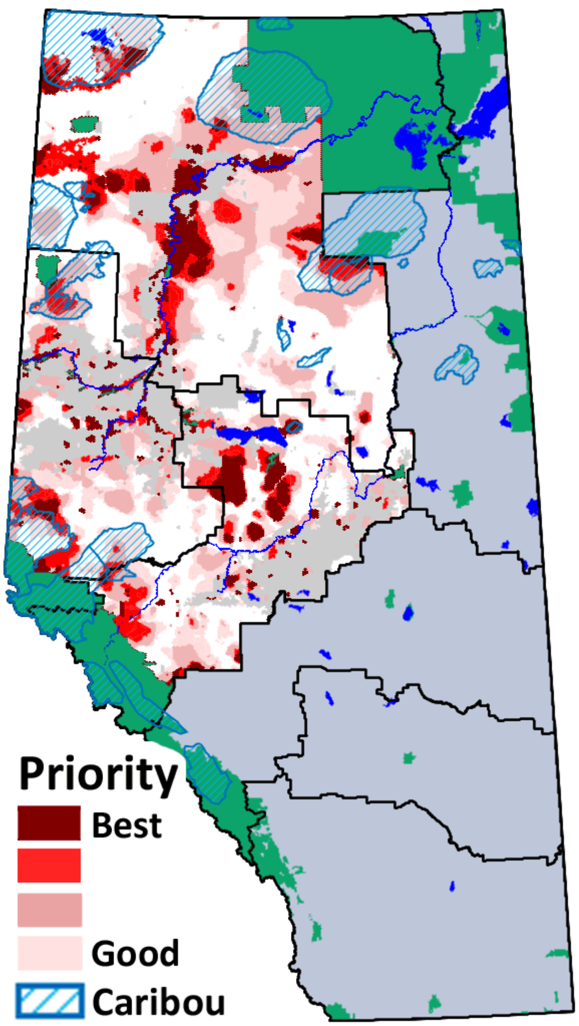

Fig. A2.5. Base scenario overlaid with caribou zones expected to retain a boreal or foothills climate in the 2080s.

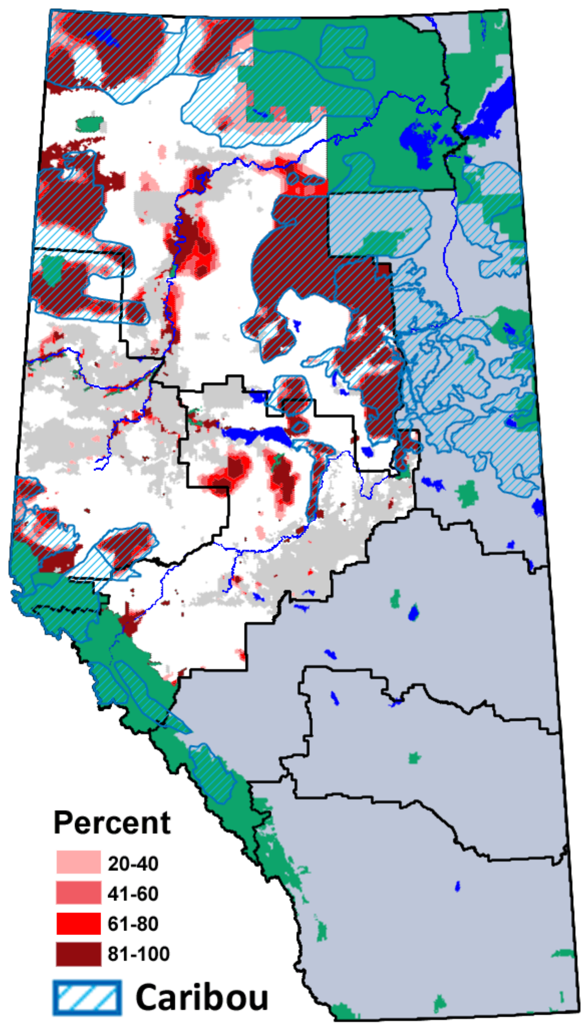

Fig. A2.6. Base scenario with caribou targets set to 65% per herd. Red shading probability of selection. Current caribou ranges shown in blue.

Table A2.1. Total reserve area for each of the Marxan scenarios discussed in the text.[1]

	5% Target		10% Target		20% Target		30% Target	
Figure[2]	(km²)	(%)[3]	(km²)	(%)	(km²)	(%)	(km²)	(%)
1/9/15	103,950	20.4	123,964	24.4	166,216	32.7	209,206	41.1
6	97,891	19.2	107,093	21.0	127,273	25.0	147,610	29.0
7	103,841	20.4	123,722	24.3	165,001	32.4	205,721	40.4
8	102,494	20.1	119,687	23.5	164,026	32.2	204,634	40.2
10	107,860	21.2	126,238	24.8	168,180	33.0	211,126	41.5
11	108,398	21.3	127,489	25.0	172,781	33.9	212,354	41.7
13	105,327	20.7	126,805	24.9	171,113	33.6	210,305	41.3
14	105,719	20.8	127,381	25.0	165,583	32.5	212,116	41.7
A3.1	34,254	6.7	69,898	13.7	133,390	26.2	191,419	37.6
A3.2	10,145	20.6	29,103	24.1	69,267	32.0	109,493	39.9

[1]The total area of the reserve includes existing protected areas across the entire study area and is provided for each of the four target levels.
[2]The scenarios are identified by the corresponding map in the main text, identified by Figure number. See text for details about each scenario.
[3]Percentages refer to the total area of the reserve divided by the study area (509,000 km^2)*100.

Table A2.2. Amount of Natural Subregion representation achieved in existing parks and in the base scenario (Fig.1), across three target levels.

Natural	Area[1]	Existing Parks		5% Target		10% Target		20% Target	
Subregion	(km²)	(km²)	(%)[2]	(km²)	(%)	(km²)	(%)	(km²)	(%)
Alpine	15,080	12,936	85.8	12,956	85.9	12,993	86.2	13,029	86.4
Boreal Subarctic	11,820	5,840	49.4	5,879	49.7	5,977	50.6	7,234	61.2
Central Mixedwood	167,848	22,454	13.4	23,053	13.7	25,109	15.0	38,260	22.8
Dry Mixedwood	85,306	1,083	1.3	5,010	5.9	9,806	11.5	21,271	24.9
Lower Boreal Highlands	55,615	3,266	5.9	4,930	8.9	10,077	18.1	13,508	24.3
Lower Foothills	44,898	274	0.6	2,376	5.3	4,763	10.6	9,478	21.1
Montane	8,437	2,451	29.1	2,468	29.3	3,175	37.6	3,175	37.6
North Mixedwood	29,496	13,217	44.8	13,281	45.0	13,583	46.1	13,803	46.8
Peace Delta	5,535	5,180	93.6	5,218	94.3	5,228	94.5	5,271	95.2
Subalpine	25,217	14,129	56.0	14,236	56.5	15,025	59.6	15,666	62.1
Upper Boreal Highlands	11,859	1,489	12.6	1,810	15.3	3,617	30.5	7,233	61
Upper Foothills	21,538	548	2.5	1,809	8.4	3,617	16.8	7,233	33.6

[1]Total area of each Natural Subregion.
[2]Percentages are relative to the full study area.

Table A2.3. **Amount of coarse-filter wetland and vegetation representation achieved in existing parks and in the base scenario (Fig.1), across three target levels.**

Feature	Area	Existing Parks		5% Target		10% Target		20% Target	
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Bog	29,657	2,186	7.4	2,503	8.4	3,598	12.1	5,907	19.9
Fen	53,236	5,425	10.2	6,216	11.7	8,182	15.4	11,925	22.4
Marsh	5,182	602	11.6	791	15.3	1,010	19.5	1,810	34.9
Swamp	42,228	2,814	6.7	3,647	8.6	5,729	13.6	10,616	25.1
Water	16,439	3,041	18.5	3,392	20.6	3,821	23.2	4,844	29.5
Decid Open	1,612	156	9.7	265	16.4	475	29.5	688	42.7
Decid Dense	66,676	4,934	7.4	7,187	10.8	11,469	17.2	20,775	31.2
Grass	2,260	718	31.8	752	33.3	804	35.6	822	36.4
Conifer Dense	79,168	20,120	25.4	21,963	27.7	25,517	32.2	31,639	40.0
Conifer Open	6,804	3,058	44.9	3,122	45.9	3,190	46.9	3,267	48.0
Herbaceous	12,745	1,670	13.1	2,146	16.8	2,844	22.3	4,075	32.0
Mixed Dense	39,314	5,105	13.0	6,088	15.5	8,281	21.1	13,210	33.6
Mixed Open	930	704	75.7	718	77.2	738	79.4	758	81.5
Shrub	15,542	3,731	24.0	4,138	26.6	4,955	31.9	6,698	43.1

Table A2.4. Amount of surficial geology representation achieved in existing parks and in the base scenario (Fig.1), across three target levels.

Feature	Area	Existing Parks		5% Target		10% Target		20% Target	
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Bedrock	19,529	14,274	73.1	14,377	73.6	14,567	74.6	14,817	75.9
Colluvial Deposits	26,783	9,060	33.8	9,976	37.2	11,551	43.1	13,379	50.0
Eolian Deposits	19,165	7,596	39.6	8,378	43.7	9,290	48.5	10,763	56.2
Fluted moraine	32,639	1,178	3.6	1,458	4.5	2,602	8.0	5,207	16.0
Fluvial Deposits	20,719	5,903	28.5	6,582	31.8	7,726	37.3	9,402	45.4
Glaciers	1,008	1,006	99.8	1,006	99.8	1,006	99.8	1,006	99.8
Glaciofluvial	20,659	4,054	19.6	4,193	20.3	4,610	22.3	5,636	27.3
Glaciolacustrine	86,866	5,549	6.4	7,794	9.0	11,112	12.8	19,343	22.3
Ice-Thrust moraine	10,485	908	8.7	1,046	10.0	1,189	11.3	1,666	15.9
Lacustrine Deposits	7,417	2,224	30.0	2,304	31.1	2,381	32.1	2,692	36.3
Moraine	133,155	20,927	15.7	23,900	17.9	31,471	23.6	44,120	33.1
Open Water	15,394	2,865	18.6	3,180	20.7	3,560	23.1	4,513	29.3
Organic Deposits	66,151	17,855	27.0	18,561	28.1	19,794	29.9	24,313	36.8
Preglacial Fluvial	386	15	3.8	187	48.4	254	65.7	279	72.4
Stagnant Ice	64,058	3,223	5.0	4,216	6.6	6,439	10.1	13,616	21.3

Table A2.5. Amount of fine-filter feature representation achieved in existing parks and in the base scenario (Fig.1), across three target levels.

Feature	Area	Existing Parks		5% Target		10% Target		20% Target	
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Boreal Climate Refugia[1]	1,753	409	23.4	493	28.1	605	34.5	823	47.0
Canada Lynx	168,059	40,443	24.1	43,363	25.8	50,395	30	64,752	38.5
Pine Marten	202,251	49,716	24.6	53,902	26.7	62,355	30.8	81,529	40.3
Grizzly bear	7,299	3,509	48.1	3,707	50.8	4,039	55.3	4,511	61.8
Woodland caribou	147,874	30,853	20.9	32,673	22.1	39,451	26.7	51,548	34.9
American bittern	94,276	14,341	15.2	16,753	17.8	20,741	22.0	30,542	32.4
Canada warbler	92,301	7,668	8.3	10,702	11.6	15,355	16.6	27,095	29.4
Brown creeper	99,887	7,258	7.3	9,633	9.6	13,528	13.5	23,237	23.3
Olive-sided flycatcher	83,118	17,729	21.3	19,436	23.4	23,581	28.4	30,586	36.8
Western wood-pewee	88,090	5,141	5.8	7,222	8.2	10,332	11.7	18,381	20.9
Trumpeter swan	2,180	403	18.5	428	19.6	489	22.4	670	30.8
Pileated woodpecker	154,552	12,250	7.9	15,550	10.1	20,342	13.2	33,983	22.0
Least flycatcher	114,687	5,913	5.2	9,270	8.1	14,582	12.7	26,812	23.4
Rusty blackbird[2]	54,338	12,070	22.2	13,155	24.2	15,070	27.7	19,286	35.5
Common Yellowthroat	91,095	4,693	5.2	7,843	8.6	12,099	13.3	23,637	25.9
Sandhill crane	84,681	25,974	30.7	26,933	31.8	28,522	33.7	32,952	38.9
Western tanager	98,996	15,681	15.8	18,196	18.4	22,045	22.3	33,075	33.4
Pied-billed grebe	34,941	6,230	17.8	7,277	20.8	8,266	23.7	12,475	35.7
Sora	71,370	6,338	8.9	8,084	11.3	10,271	14.4	16,193	22.7
Bay-breasted warbler	98,818	13,757	13.9	15,994	16.2	20,271	20.5	31,144	31.5
Cape May warbler	98,585	24,928	25.3	26,703	27.1	29,819	30.2	38,831	39.4
BT green warbler	74,889	1,599	2.1	3,994	5.3	7,826	10.5	16,571	22.1
High Density Waterfowl	39,135	8,908	22.8	10,564	27.0	12,564	32.1	18,347	46.9
Athabasca Rainbow trout – Priority 1	8,262	1,140	13.8	1,309	15.8	1,734	21	3,180	38.5
Athabasca Rainbow trout – Priority 2	5,920	616	10.4	857	14.5	1,259	21.3	2,189	37.0
Athabasca Rainbow trout – Priority 3	19,124	7,755	40.6	7,919	41.4	8,843	46.2	10,103	52.8
Bull trout Priority 1	9,631	1,479	15.4	1,575	16.4	2,251	23.4	3,439	35.7
Bull trout Priority 2	16,408	964	5.9	1,467	8.9	2,542	15.5	6,247	38.1
Bull trout Priority 3	90,507	27,180	30.0	27,926	30.9	30,543	33.7	34,462	38.1
Arctic grayling Priority 1	35,501	14,977	42.2	15,102	42.5	15,570	43.9	19,196	54.1

Arctic grayling Priority 2	29,561	3,581	12.1	4,492	15.2	6,216	21	10,735	36.3
Arctic grayling Priority 3	319,551	28,859	9.0	37,859	11.8	55,352	17.3	88,860	27.8
Bryoria simplicior	187,631	37,017	19.7	41,554	22.1	51,371	27.4	70,655	37.7
Cladonia bacilliformis	140,463	26,523	18.9	29,947	21.3	36,992	26.3	50,871	36.2
Cladonia cyanipes	122,939	26,316	21.4	28,865	23.5	34,324	27.9	45,104	36.7
Cladonia stygia	79,292	19,933	25.1	21,325	26.9	25,036	31.6	31,427	39.6
Imshaugia placorodia	24,130	12,260	50.8	12,297	51	12,379	51.3	12,475	51.7
Leptogium subtile	96,502	8,982	9.3	12,563	13	19,855	20.6	33,690	34.9
Melanohalea trabeculata	84,243	7,592	9.0	11,164	13.3	17,825	21.2	30,688	36.4
Phaeo. compressulum	148,718	23,402	15.7	27,578	18.5	35,724	24	53,441	35.9
Ramalina obtusata	76,121	8,227	10.8	10,740	14.1	15,893	20.9	25,727	33.8
Tuckermannopsis orbata	138,818	11,371	8.2	14,715	10.6	21,505	15.5	36,582	26.4
Usnea glabrata	142,026	6,472	4.6	11,015	7.8	19,915	14	39,492	27.8
Barbilophozia kunzeana	132,924	27,773	20.9	30,446	22.9	35,751	26.9	47,409	35.7
Lophozia excisa	68,212	19,242	28.2	20,427	29.9	23,244	34.1	28,804	42.2
Platygyrium repens	120,996	13,768	11.4	16,530	13.7	21,728	18.0	34,068	28.2
Riccardia latifrons	136,858	28,505	20.8	31,306	22.9	37,555	27.4	50,404	36.8
Scapania glaucocephala	118,657	10,608	8.9	14,144	11.9	20,643	17.4	35,930	30.3
Corallorhiza Maculata	84,147	3,389	4.0	5,961	7.1	10,205	12.1	20,771	24.7
Dryopteris expansa	58,143	1,220	2.1	3,166	5.4	6,087	10.5	13,536	23.3
Lathyrus venosus	70,522	1,875	2.7	3,529	5.0	7,053	10.0	14,697	20.8
Whitebark pine	17,593	13,000	73.9	13,057	74.2	13,244	75.3	13,464	76.5
Limber pine	30,236	9,515	31.5	10,349	34.2	12,081	40.0	14,759	48.8
Open Water	15,394	2,865	18.6	3,180	20.7	3,560	23.1	4,513	29.3
Aquatic Bed	877	118	13.4	131	15.0	162	18.5	225	25.6
Mudflats	173	35	20.3	59	34.0	81	46.8	95	54.6
Emergent Marsh	2,797	365	13.1	464	16.6	595	21.3	963	34.4
Meadow Marsh	2,901	302	10.4	412	14.2	530	18.3	1,011	34.9
Graminoid Rich Fen	1,625	156	9.6	179	11.0	229	14.1	336	20.7
Graminoid Poor Fen	1,536	204	13.2	228	14.9	269	17.5	376	24.5
Shrubby Rich Fen	10,901	843	7.7	1,007	9.2	1,368	12.5	2,216	20.3
Shrubby Poor Fen	3,071	210	6.9	297	9.7	434	14.1	799	26
Treed Rich Fen	14,551	1,702	11.7	1,925	13.2	2,280	15.7	3,213	22.1
Treed Poor Fen	24,817	2,541	10.2	2,859	11.5	3,957	15.9	5,615	22.6
Open Bog	74	10	14.0	10	14.2	11	15.5	15	20.2
Shrubby Bog	2,010	169	8.4	175	8.7	202	10.1	402	20.0

Treed Bog	27,660	2,015	7.3	2,328	8.4	3,415	12.3	5,545	20.0
Shrub Swamp	8,816	803	9.1	959	10.9	1,335	15.1	2,186	24.8
Hardwood Swamp	5,285	275	5.2	423	8.0	701	13.3	1,481	28.0
Mixedwood Swamp	4,241	212	5.0	329	7.8	560	13.2	1,040	24.5
Tamarack Swamp	2,228	115	5.2	162	7.3	261	11.7	517	23.2
Conifer Swamp	25,070	1,568	6.3	2,027	8.1	3,321	13.2	6,281	25.1

[1]Based on the boreal climate refugia shown in Fig. 4.
[2]The rusty blackbird model was provided by the Boreal Avian Modelling Project

Table A2.6. Amount of focal species feature representation achieved in existing parks and in the scenario where the habitat of three or more of the focal species overlap (Fig. 10), across three target levels.

Feature	Area[1]	Existing Parks		5% Target		10% Target		20% Target	
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Grizzly Bear	7,299	3,509	48.1	4,230	58.0	4,421	60.6	4,855	66.5
Little Smoky caribou herd	3,084	0	0.0	1,599	51.9	1,600	51.9	1,607	52.1
Narraway caribou herd	1,041	0	0.0	15	1.4	147	14.1	859	82.6
Athabasca Rainbow Trout Priority 1	8,262	1,140	13.8	1,953	23.6	2,063	25.0	2,818	34.1
Athabasca Rainbow Trout Priority 2	5,920	616	10.4	2,014	34.0	2,107	35.6	2,568	43.4
Bull Trout Priority 1	9,631	1,479	15.4	5,294	55.0	5,375	55.8	5,802	60.2
Bull Trout Priority 2	16,408	964	5.9	2,445	14.9	2,965	18.1	6,442	39.3
Arctic grayling Priority 1	35,501	14,977	42.2	18,154	51.1	18,447	52.0	21,752	61.3
Arctic grayling Priority 2	29,561	3,581	12.1	5,460	18.5	6,287	21.3	10,416	35.2

Table A2.7. Amount of focal species feature representation achieved in existing parks and in the scenario where the targets for the focal species were increased (Fig. 11), across three target levels.

Feature	Area[1]	Existing Parks		5% Target		10% Target		20% Target	
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Grizzly Bear	7,299	3,509	48.1	4,070	55.8	4,283	58.7	5,439	74.5
Little Smoky caribou herd	3,084	0	0.0	644	20.9	935	30.3	2,455	79.6
Narraway caribou herd	1,041	0	0.0	220	21.1	344	33.1	644	61.9
Athabasca Rainbow Trout Priority 1	8,262	1,140	13.8	4,132	50.0	4,958	60.0	6,610	80.0
Athabasca Rainbow Trout Priority 2	5,920	616	10.4	1,481	25.0	1,778	30.0	2,370	40.0
Bull Trout Priority 1	9,631	1,479	15.4	4,964	51.5	5,878	61.0	7,952	82.6
Bull Trout Priority 2	16,408	964	5.9	4,103	25.0	4,924	30.0	8,905	54.3
Arctic grayling Priority 1	35,501	14,977	42.2	17,905	50.4	18,793	52.9	23,115	65.1
Arctic grayling Priority 2	29,561	3,581	12.1	6,900	23.3	7,909	26.8	11,763	39.8