The West Central Alberta Woodland Caribou Landscape Plan: Using a Modeling Approach to Develop Alternative Scenarios

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Abstract: Woodland caribou (*Rangifer tarandus*) are classified as threatened in Alberta. In support of Canada's Species at Risk Act, a Recovery Plan for Woodland Caribou in Alberta was completed in 2004 which required local implementation plans to be completed within 5 areas of the province. The West Central Alberta Caribou Landscape Plan (WCCLP) is the first of these to be initiated and it addresses the recovery strategies for 4 herds. Two aspatial computer models built on the STELLA© modelling platform (ISee Systems, 2007) were used to assist the planning team in evaluating cumulative effects and alternative scenarios for caribou conservation. The ALCES© (Forem Technologies 2008) modelling tool was used to forecast potential changes in the west central Alberta landscape over time. Yearly landscape condition outputs from ALCES© were then exported into a caribou-specific population model, REMUS© (Weclaw, 2004), that was used to project potential population responses by woodland caribou, other primary prey species [moose (*Alces alces*), elk (*Cervus elaphus*) and deer (*Odocoileus* sp.)] and wolves (*Canis lupus*) (Weclaw & Hudson, 2004). Simulated habitat management strategies that resulted in the highest likelihood of caribou recovery included the maintenance of a high proportion of old forest, the aggregation of industrial footprints and the reclamation of historic seismic lines (although the latter took decades to provide real dividends). Sharing of industrial roads, protection of fragments of old-growth, and expanding an already aggressive fire control strategy in Alberta had little additional effect on caribou recovery. Simulated population management strategies that were successful all involved decades of intensive wolf control, either directly or indirectly through intensive primary prey control (with the exception of woodland caribou) until old-growth forests recovered to densities that provided caribou habitat and decreased alternate prey of wolves. Although this modelling approach makes broad assumptions, it provides simple fundamental relationships that were useful in a multi-stakeholder team setting when evaluating the efficacy of different management strategies for the conservation of woodland caribou.

Key words: Alberta; anthropogenic features; computer modeling; caribou habitat; modeling; predator-prey; landscape planning; woodland caribou.

Introduction

Woodland caribou (*Rangifer tarandus*) are classified as threatened in Alberta. In support of Canada's Species at Risk Act, a Recovery Plan for Woodland Caribou in Alberta was completed in 2004. It established the need for 5 individual range teams to assess and determine recovery actions at local scales within Alberta. In the province of Alberta, woodland caribou ranges are experiencing expanding oil and gas and timber harvesting activity that is dramatically altering habitat. The purpose of each range team was to develop and recommend strategies that would guide the recovery and management of woodland caribou populations and habitats within each caribou landscape. It was intended for these plans to fulfill the requirement of the federal *Species at Risk Act* (*SARA*) to develop an action plan for woodland caribou conservation. The West Central Caribou Landscape Planning Team (WCCLPT) was the first of these teams to be initiated.

The WCCLPT represented a cross-section of stakeholders with an interest in caribou recovery and management in the west central area of Alberta: Alberta Sustainable Resource Development (Chairperson, plus two members); and one member each from Alberta Tourism, Parks, Recreation and Culture; Alberta Energy; Aseniwuche Winewak Nation of Canada (Grande Cache); Treaty 8, First Nations of Alberta; Alberta Forest Products Association; Canadian Association of Petroleum Producers; Canadian Parks and Wilderness Society (CPAWS) – Edmonton Chapter; and Parks Canada (Jasper National Park). The WCCLPT reported directly to the Alberta Caribou Committee (ACC) Governance Board. The ACC is also a multi-stakeholder advisory committee whose mandate is to provide advice to the Government of Alberta (through the Deputy Minister of Alberta Sustainable Resource Development) and to implement or support "approved caribou population and habitat conservation and recovery programs" (Alberta Woodland Caribou Recovery Team, 2004).

Two aspatial computer models built on the STELLA© platform were used to assist the planning team in evaluating alternative scenarios for caribou conservation. The primary objectives of the exercise were to examine strategies that would conserve woodland caribou herds in west central Alberta.

Methods

The study area is located in west central Alberta, Canada (54°N, 119°W) and it encompasses 4 herds (Fig. 1). The area includes the upper foothills, subalpine and alpine ecoregions (Beckingham *et al.*,
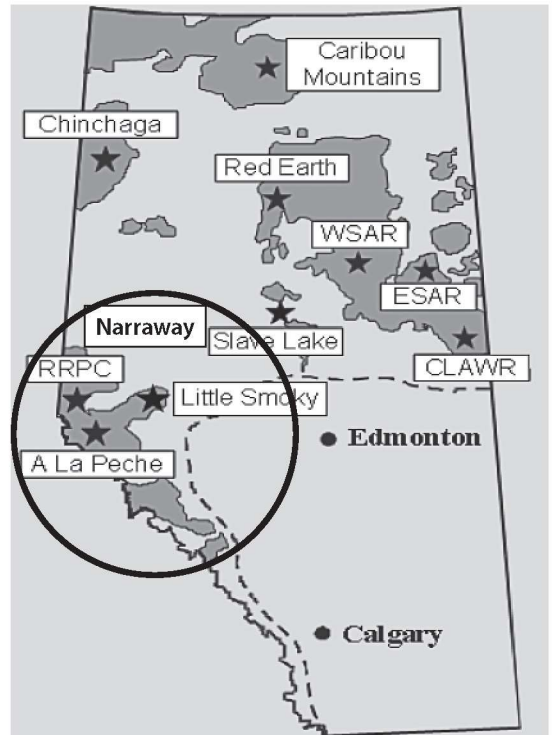

Fig. 1. Locations of woodland caribou herds in west central Alberta, Canada. Herds in west central Alberta that were examined in this study are indicated within the bold circle.

1996). The upper foothills ecoregion is characterized by an overstory of lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) with small patches of trembling aspen (*Populus tremuloidies*). The subalpine ecoregion is characterized by an overstory of Englemann Spruce (*P. Englemannia*) and subalpine fir (*Abies lasiocarpa*), while the alpine ecoregion has little overstory and is characterized by graminoids, sedges (*Carex* spp.) and bare ground. The A La Peche (ALP), Narraway (NAR) and Redrock-Prairie Creek (RPC) herds are categorized as *mountain ecotypes* (summer in the mountains, winter in the subalpine forest) while the Little Smoky (LSM) herd is categorized as a boreal ecotype (spends the entire year in the subalpine and upper foothills natural region). All of the mountain types (the NAR is the exception) spend at least part of the year in a National Park and/or a wilderness area where industrial activities are not permitted. The majority of the ALP herd resides for part of the year in Jasper National Park/Willmore Wilderness Park (WWP) while a small portion of the herd ~30) lives outside of these protected areas on forested lands available for oil/gas and timber development. The RPC herd spends the summer in the

WWP and winters in forested foothills which experience all industrial activities while the NAR herd winters on the border of Alberta and British Columbia and summers in the mountains of British Columbia (only the Alberta winter range portion was modeled). In general, there is a higher density of ungulates and more wolves in the eastern part of the study area compared to the west. The LSM herd experiences the highest density of industrial activity, primary prey and wolves.

ALCES (A Landscape Cumulative Effects Simulator: Forem Technologies) is a modeling tool that forecasts changes in a landscape over time and allows the user to assess the effects of different management scenarios on a series of indicators (e.g. Schneider *et al.*, 2003). Detailed, spatially explicit information about the initial WCCLPT planning area was obtained from GIS data layers and included in the ALCES model. Non-spatial forecasts of human and natural disturbance were performed over a 100-year period (March 2006 was the initial month/year). These forecasts were evaluated by the equation developed for boreal herds in Alberta (including the LSM herd) (Sorenson *et al.*, 2008), which links the finite rate of caribou population growth rate (λ) to habitat condition:

λ = *1.191 - (0.314 * amount of area within 250 m of an anthropogenic footprint) - (0.291 *proportion of stands < 50 years old of fire origin)*

This provided an assessment of "habitat lambda" or the projected change in a woodland caribou population growth rate based on habitat alone (without any special predator and/or primary prey management intervention). The ALCES model used information provided from the Alberta Vegetation Inventory, forest inventory, hydrology and the anthropogenic footprint interpreted from landsat imagery. Future projections were made based on: 1)timber harvesting activities that would reduce the amount of older forests, 2) accelerated harvest of lodgepole pine designed to reduce the probability of mountain pine beetle (*Dendroctonus ponderosae*) spread, 3) estimates of energy development, 4) the natural range of variability, 5) wildfire and 6) mountain pine beetle spread projections.

Mitigation options that were explored in ALCES included: 1) reforestation and the reduction of access on existing anthropogenic footprint (5-8m wide seismic lines), 2) the aggregation of anthropogenic footprint to reduce fragmentation, 3) shared access

Table 1. Moose densities[1] used in the REMUS Model based on forest type and age in west central Alberta.

Forest Type	Forest Age (years)	Moose Density (per km²)
Upland Lodgepole Pine – Like	0 – 30	Medium density (0.5)
	31 – 80	Low strata (0.05)
	> 80	Low strata (0.05)
Lowland Black Spruce – Like	0 – 30	Med. Strata (0.5)
	31 – 80	Low to Med. strata (0.3)
	> 80	= Low strata (0.1)
Riparian – Like	0 – 30	= High strata (1.35)
	31 – 80	= High strata (1.35)
	> 80	= High strata (1.35)

[1] Moose densities are based on aerial survey results.

to reduce potential fragmentation, 4) reducing the width of anthropogenic footprints to reduce the total area affected, 5) establishing protected areas where industrial activity would be eliminated, 6) the retention of older forest (caribou habitat) and, 7) enhancing fire suppression (to maintain older forests).

Sensitivity analysis was conducted on a number of parameters that were anticipated to influence any/all of the objectives for woodland caribou maintenance and/or recovery. These included: 1) mitigation options reported above, 2) seismic lifespan, 3) fire rates, 4) energy & Annual Allowable Cut projections, 5) Mountain Pine Beetle outbreak rates and 5) forest conversions post-Mountain Pine Beetle outbreak.

Following the examination of future habitat scenarios, landscape projection data from ALCES (doesn't include the "habitat lambda" calculations) were exported to the program REMUS. REMUS is a population model also built on the STELLA platform that was used to project potential population responses by woodland caribou, other primary prey species (moose, elk and deer) and wolves (Weclaw & Hudson, 2004). REMUS was used to test different options with regard to predator and primary prey management against the habitat and anthropogenic footprint projections provided through ALCES and to identify knowledge gaps.

REMUS bases projections on predator/prey relationships with the basic premise of habitat affecting primary prey (either positively or negatively) and wolves responding to prey availability. Primary prey population response can either be generated through estimates of forage or through changes in primary prey density based on forest age. Neither forage

estimates nor population responses of primary prey to changes in forage were available for west central Alberta or anywhere in the province. Consequently, primary prey projections were based on changes in density of these species relative to forest age (e.g. moose; Table 1). These density estimates reflected aerial survey results from the study area and the upper limits were obtained from the published literature where available (Table 2 in Appendix).

At the strategic level of assessment, a decision was made to lump the number of forest types (within the "managed" portions of each of the 4 herd ranges using provincial lands) into 3 primary categories:

a. Upland Pine Like Habitat - includes all coniferous upland sites. This category provides the majority of terrestrial lichen production, which is the main winter forage for woodland caribou in west central Alberta.

b. Lowland Black Spruce Like Habitat – includes all coniferous lowland sites. This category provides the majority of arboreal lichens, which are an important component of woodland caribou forage in late winter when the daily freeze/thaw temperature change compromises "cratering" by woodland caribou for terrestrial lichens.

c. Riparian Like Habitat – includes any ecosite where the forest overstory is influenced by water. This category includes grasslands and white spruce stands that may contain some arboreal lichens.

Based on these forest categories, the following assumptions were included in REMUS to project primary prey response to forest age:

a. All forests between 0 and 30 years old would have the highest density of primary prey other than caribou (i.e. moose, elk and deer) because of the presence of suitable forage (Usher, 1978; Peek *et al.*, 1976; Potvin *et al.*, 2005; Rempel *et al.*, 1997). The density of moose would be highest in riparian, moderate in lowland spruce and lowest in upland pine. Riparian was also the most important to deer and elk, with upland pine and lowland spruce at this age being of secondary and tertiary importance for these 2 species, respectively. This forest category would have the lowest density of caribou and the highest occurrence of wolves. In the presence of wolf predation this forest category would be the area where woodland caribou would have the highest probability of encountering wolves and presumably suffering mortality as a result of these encounters. Consequently, new footprint was included in early seral for assessing habitat effectiveness for primary

prey other than caribou and significantly reduced as caribou habitat

b. All forests between 31 and 80 years old would be of lower importance to moose, elk and deer as the forest overstory grew resulting in a corresponding reduction in palatable forage. Woodland caribou density would be higher than in the previous category as a result of lower primary prey densities resulting in fewer wolves (and encounters).

c. All forests older than 80 years would have the lowest density of primary prey, the lowest encounter rate of woodland caribou and wolves, the best availability of terrestrial and arboreal lichens (Szkorupa, 2002) and the highest density of woodland caribou.

In order to project the potential outcomes of temporary predator management, the upper limits of primary prey densities were obtained from the literature and adjusted accordingly to reflect the habitat limitations of west central Alberta woodland caribou ranges. Estimates of mortality caused by other predators [i.e. grizzly bears (*Ursus arctos*), black bears (*U. americanus*), cougars (*Felis concolor*), etc] were obtained from the literature, but ultimately these were not included in final model runs in order to simplify the interpretation and explanation of model results.

The REMUS model is parameterized based on the assumption that the influence of primary prey density on wolf density will have a much greater influence on woodland caribou population response than availability of food (lichen). Consequently, forest age is the most important "driver" for the primary prey component and REMUS outputs track this indicator most efficiently. Because all linear features do not contribute significantly to changes in forest age, REMUS does not "properly" account for aggregation vs. dispersion of linear disturbance. Therefore, these metrics are more appropriately tracked in ALCES through the outputs of "Habitat Lambda" and density of linear features (km/km^2). The cumulative changes resulting from both forest harvest and oil and gas development were tracked in ALCES for the RPC and NAR herds. However, there were critical forest harvest variables not made available in the ALP and LSM (i.e. annual allowable cut), so the ALCES outputs for those 2 herds only assess the oil and gas footprint through time.

We elected to use habitat specific moose and woodland caribou densities based on aerial surveys rather than the alternative option of changes in forage abundance available in REMUS to "drive" the model outcomes. This decision was based on: 1) aerial survey inventories being relatively up to date and

Table 3. A comparison of the anthropogenic footprint within the managed1 forest portion of 4 woodland caribou ranges in west central Alberta, March 2006.

Metric	HERD			
	Little Smoky	A La Peche (managed winter range)[1]	Redrock – Prairie Creek (managed winter range)[1]	Narraway (managed winter range)[1]
Area of Range (km²)	2927[2]	1716[2]	3026	1020
Km of Seismic Lines (km/km²)	8640 (3)	1890 (1.1)	1704 (0.6)	950 (0.9)
Area (ha) of Wellsites (ha/km²)	692 (0.2)	105 (0.06)	396 (0.1)	217 (0.2)
Km of Pipelines (km/km²)	1065 (0.4)	312 (0.2)	359 (0.1)	350 (0.3)
Km of Major Roads (>15m) (km/km²)	62 (0.02)	205 (0.1)	17 (0.01)	0.25 (0.00002)
Km of Minor Roads (>8m) (km/km²)	1491 (0.5)	734 (0.4)	1389 (0.5)	634 (0.6)
Ha of cutblocks in the last 30 years (ha/km²)	25844 (8.8)	15134 (8.8)	23584 (7.8)	8011 (7.8)
% Range of Fire Origin < 50 Years	0.1	0	0.5	0
% of forest > 80 years	78%	84%	77%	79%
% of range within 250 m of anthropogenic feature	87%	59%	46%	56%
% of range > 80 years old and > 1000 ha	65%	65%	??	??

[1]Managed winter range refers to that portion of the winter range that occurs outside of protected areas and is managed for multiple use.
[2]Includes the West Fraser Portion of the range; however, the area modeled in the LSM and ALP Range was reduced as a result of West Fraser not providing data.

available; 2) forage information not being available; 3) the relationship between forage availability and population response not being well documented and 4) aerial survey data tending to be more readily available for wildlife managers than forage inventory and it's relationship to population response. Additionally, after altering the REMUS model to predict multiple-prey population responses (elk and deer) to multiple-predators (grizzly bears, black bears, cougars), we eventually decided to focus simply on moose, deer, caribou and wolves in order to make it easier to track changes between model runs and to simplify the explanation of cause and effect relationships to our multi-stakeholder audience and different departments within the Government of Alberta. Although this approach oversimplified the multitude of variables influencing woodland caribou conservation efforts, the main "drivers" of the issue were captured sufficiently to facilitate informed decision making.

Avoidance of anthropogenic features by woodland caribou has been documented in west central Alberta

Table 4. Modified GIS avoidance buffer parameters[1] used in REMUS © simulation modeling for four west central Alberta caribou herds, March 2008.

Feature	Distance Avoided (m)	% Avoidance
Cutblock	1000	100
Seismic Line	100	25
Road	250	50

[1]GIS avoidance buffers were modified by the planning team from those cited in the literature.

(Smith *et al.*, 2000; Oberg, 2001; Neufeld, 2006) and northeastern Alberta (Dyer *et al.*, 2001). These authors argue that avoidance can result in functional habitat loss. Correlations between woodland caribou population response (λ) and the amount of anthropogenic footprint and forest burned have been published for 6 woodland caribou herds in Alberta including the LSM herd (Sorensen *et al.*, 2008) and has recently

been expanded to 10 herds (Boutin & Arienti, 2008). These authors document different "amounts" of avoidance based on the type of feature and the time of year and this was factored into REMUS (Note: only the raw landscape data had been imported from the ALCES model and this didn't include negative coefficients of anthropogenic linear features included in the habitat lambda calculation). In GIS terms, these "buffers" on linear features are not avoided 100% of the time (usually the perceived effect decreases as the distance from the feature increases or as the feature becomes reclaimed) (Oberg, 2001; Neufeld, 2006; James & Stuart-Smith, 2000) and the seasonal effect is often more pronounced during the winter than during the summer (Dyer *et al.*, 2001).Given the densities of features in the respective herd's ranges (Table 3), results often showed that functional habitat limits have been exceeded if woodland caribou continue to avoid anthropogenic features even in the absence of wolves. In order to simplify the number of different "buffers" in REMUS and to understand the implications of these assumptions (sensitivity analysis) "compromise" values were used in the model (Table 4).

A series of multi-variable runs were also made to examine cumulative solutions to conserving caribou in each herd range. The variables that were manipulated included:
1. Primary prey management,
2. Predator control,
3. Both primary prey and predator control,
4. 0 and 10% active reclamation of seismic lines,
5. The age of the forest in 3 categories (0 to 30, 30 to 80, 80+ years)
6. Aggregation of oil and gas footprint (Aggregation of 0.1 = ~ 35% reduction in wellsites, pipelines and roads; Aggregation of 0.3 = ~ 75% reduction in wellsites, pipelines and roads).

The approach was to manipulate primary prey and predator densities against a landscape described by the following habitat and footprint trajectories:
1. The Healthy Pine Strategy (HPS) (a timber management strategy designed to restrict the spread

Table 5. Initial population numbers and management thresholds of species described in REMUS © simulation modeling for 4 west central Alberta woodland caribou herds, March 2008.

Herd	Species	Initial Number[a]	Management Threshold
Little Smoky (2616 km²)[b]	Caribou	72	100 - 150
	Moose	905	<250
	Elk	136	No target
	Deer	1812	No target
A La Peche (1396 km²)[b]	Caribou	51	30 - 60
	Moose	252	< 150
	Elk	113	No target
	Deer	511	No target
Narraway (1024 km²)	Caribou	90	100 - 150
	Moose	453	<100
	Elk	296	No target
	Deer	613	No target
Redrock/ Prairie Creek (3026 km²)	Caribou	329	200 - 400
	Moose	1006	<300
	Elk	254	No target
	Deer	2241	No target

[a] Initial numbers of each species derived from known areas (km²) of habitat types and estimated densities within each habitat type.
[b] Does not include the West Fraser portion of the LSM or ALP ranges.

of mountain pine beetle by harvesting 75% of lodgepole pine in the next 20 years) with deferral of harvest in portions of the ALP and LSM ranges. The Healthy Pine Strategy and a "20/30" rule (timber harvest is restricted when more than 20% of the caribou range is < 30 years old) was modeled in the RPC and NAR ranges.
2. Deferral of portions of each caribou range for the entire modeling run (i.e. 100 years).
3. Mountain Pine Beetle "Disaster" Scenario = 80% of pine stands (defined as pine making up > 80% of the overstory) suffering 100% mortality over 20 years.

REMUS runs were made both with avoidance buffers on (Table 4) and off. In order to compare outputs based on standard criteria for population management of both primary prey and wolves, consistent parameters and thresholds (upper and lower limits to initiate wolf control) were used in REMUS (Table 5). In general, wolf numbers had to be kept below 6.5 wolves/1000 km² to provide for woodland caribou stability or increase (Bergerud & Elliot, 1986) and
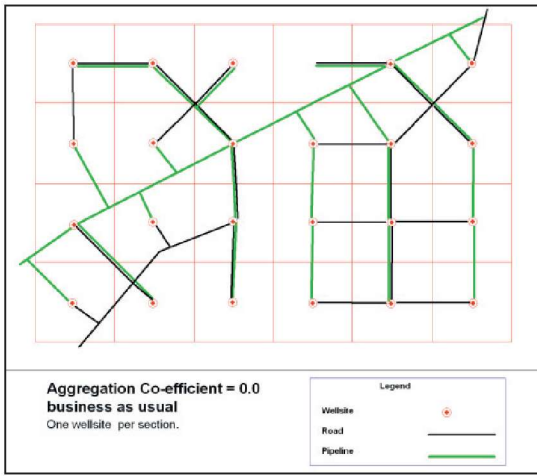
Fig. 2. An illustration of an aggregation co-efficient of 0.0 (Business as Usual) under the current Alberta Energy and Utilities Board guidelines of 1 well per mi² (2.59 km²).
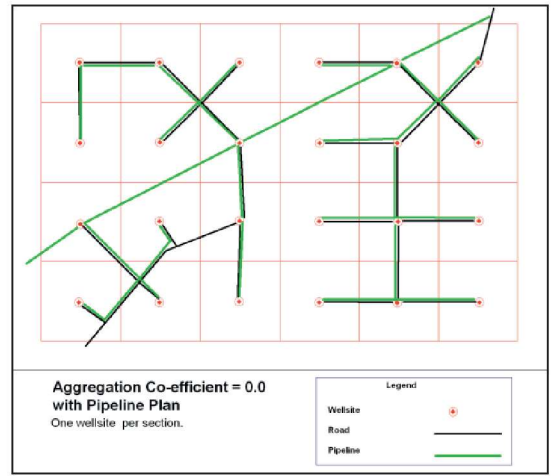

Fig. 3. An illustration of an aggregation co-efficient of 0.0 (Business as Usual) under the current Alberta Energy and Utilities Board guidelines of 1 well per mi² (2.59 km²) combined with a pipeline plan.

moose had to be managed below 100/1000 km² before wolf numbers weren't expected to increase to a level detrimental to woodland caribou (Messier, 1995). Woodland caribou herd-specific goals were set to compare management strategies proposed by the team. For example, wolf management was initiated whenever the LSM herd fell below 100 individuals and it was terminated once the herd had grown to 150 individuals (Table 5). The number of years that wolf control was required to keep wolf densities below 6.5 wolves/ 1000 km² during a 100 year modelling projection was used as the common indicator when evaluating different scenarios evaluated through REMUS.

Results

Habitat Lambda

The 2 main habitat strategies that provided the most benefit for habitat lambda were the maintenance of older forest age and minimizing habitat fragmentation. Univariate simulations indicated that reclamation of the existing anthropogenic footprint (5-8m wide seismic lines) held promise over the long term. While reclamation strategies such as planting coniferous seedlings will not benefit caribou habitat in the short term, the anticipated long-term benefits are the reduction of palatable browse species (that support primary prey species) as the coniferous canopy "closes in", the reduction in Off Highway Vehicle access (and human disturbance) as lines are reforested and become impassable and a reduction in wolf traveling efficiency as a result of the elimination of packed
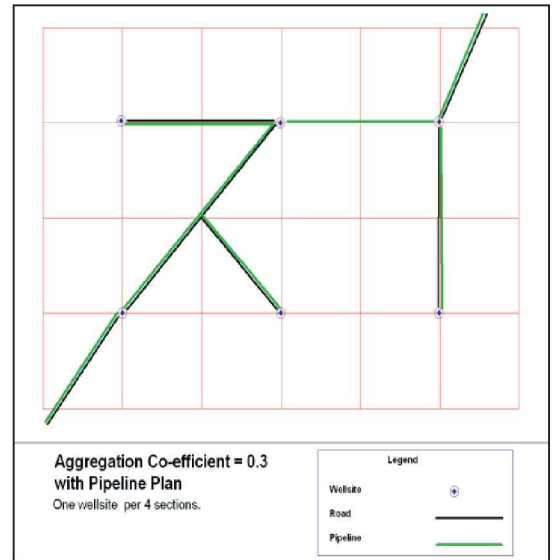

Fig. 4. An illustration of a wellsite aggregation of 0.3 complete with a pipeline plan. The average "industrial footprint" reduction compared to Fig. 3 is 75%.

snowmobile trails along these lines during winter and/or as tree density increases to impede travel. Ultimately, the lines will "blend" into the surrounding cover types over time, but even initial benefits may take in excess of 30 years to achieve.

The aggregation of industrial "footprint" was directed principally at oil and gas activity. [To a certain degree, timber harvest is much more aggregated given the exclusive tenure of forest management

agreements and the ability to plan over decades, although the need to average haul distances (harvest wood both proximally and distally to the mill) does compromise the ability to aggregate timber harvest]. The metric of aggregation is described as a "Dispersion Coefficient" with 0 being complete dispersion and 1 being complete aggregation (ALCES). On average, the density of wellsites for natural gas in the province of Alberta is 1 per mi^2 (2.59 km^2) (Alberta Department of Energy, pers. comm.). Imposing a strategy of restricting pipelines to existing right-of-ways (rather than allowing them to join wells via the shortest distance) has the potential to reduce the industrial footprint by up to 25% (Fig. 2 vs. Fig. 3). Applying a dispersion coefficient of 0.1 [1 per 2 mi^2 (5.18 km^2)] has the potential to reduce the overall footprint of the oil and gas sector by up to 35%, when combined with a pipeline plan. Moreover, a dispersion coefficient of 0.3 [1 per 4 mi^2 (10.36 km^2)] may reduce the footprint by up to 75% when combined with a pipeline strategy, resulting in a significant reduction in fragmentation (Fig. 4).

Sharing of access is a sound strategy; however, > 50% of the existing access is already shared in most ranges and consequently, there was little room for improvement unless oil and gas activities were restricted to timber harvesting areas. This mitigation option did not provide any further benefits than those that have already been achieved and it becomes less significant as the overall footprint increases. Reducing the lifespan or width of the anthropogenic footprint was only modeled for a few "footprint" types because no options were provided by industrial participants and reducing the width of footprint had little to no effect. Establishing protected areas does provide caribou habitat benefits through a reduction in industrial activity and anthropogenic footprint. However, these benefits are only significant in the currently fragmented landscapes modeled if fire control (to maintain forest age), primary prey control (though hunting) and predator control are all available management options within the protected area. Old growth forest retention contributes to the maintenance of forest age by establishing targets for the amount of forest in the older age category. It can address both the principle of maintaining a proportion of forest > 80 years old and doing so in large patches. This strategy is one of the primary means of providing habitat for caribou at a landscape scale. Enhanced fire suppression is obviously very important to maintaining forest age. Alberta is one of the most aggressive fire-fighting jurisdictions in North America. Consequently, there is little room for improvement; however, maintaining this effort is very important.

A mountain pine beetle (MPB) outbreak would further compromise the ability of any of the other strategies to provide for woodland caribou habitat over time. The obvious implication to woodland caribou habitat is that the primary forest types that provide terrestrial lichens (pine forests) would suffer high mortality over a relatively short time period. To examine the potential significance of a MPB outbreak, we modeled 80% of pine stands (defined as pine making up > 80% of the overstory) suffering 100% mortality in 20 years. In order to populate the model, experts were asked for their opinion on ecological projections for each of the pine ecosites found in woodland caribou range. It is important to note that many of the pine ecosites have an understory and/or a subordinate species in the overstory that would remain following a MPB outbreak. Consequently, the ecological projections suggest that these stands would revert to a very open forest type of the understory/subordinate species (i.e black spruce, sub-alpine fir, etc) in contrast to a complete loss of the canopy. Terrestrial lichens often favour more open stands, therefore in the stands not dominated exclusively by pine; terrestrial lichens may not disappear immediately and in a few instances, may even be enhanced. There are at least 3 reasons to be concerned about a MPB outbreak: 1) Do the affected stands cease to provide either food or cover for woodland caribou, 2) Do the affected stands enhance habitat for primary prey (i.e. moose, elk and deer) thereby prompting a response by wolves? (Given the high % of stands that have other overstory species present, the projection is for these stands to be set back to a very open stand of the something other than pine which shouldn't result in a significant benefit to primary prey in most cases) and 3) Do the affected stands essentially stagnate as caribou habitat if they fail to regenerate for longer periods than clearcuts or fire regenerated stands? If a MPB outbreak occurs with the magnitude and speed that has been projected in these runs, the estimate is that only 30% of the stands can be salvaged (based on mill capacity and market) before the wood is no longer suitable for processing with current lumber milling. (It is possible that these stands may be suitable for pulp or other biomass harvesting in the future). Therefore a major consideration in terms of providing for long-term woodland caribou habitat is what to do with the remaining stands of dead pine. Options include some management action designed to regenerate a new pine stand (i.e. prescribed burn and/or scarification restoration treatment) or leave as is. The option of intervening with a management action benefits woodland caribou in the long term by re-establishing a new coniferous forest as soon

as possible. However, this doesn't pay dividends for caribou until ~ 80 years. Conversely, leaving MPB killed stands to regenerate to another overstory type can pay immediate dividends if a) the stand doesn't generate forage for primary prey, b) it continues to produce at least some of the benefits of the previous stand and c) by leaving the stand, the level of "intactness" is maintained. A strategy of managing a third of the stands affected with each treatment (salvage, actively regenerate, leave) appears to be a good compromise.

Relative to habitat lambda, industrial business-as-usual (BAU) scenarios were very detrimental to caribou habitat. Reclaiming 10% of the seismic lines annually provided benefits as did aggregating wellsites. In terms of forest age, the "Healthy Pine Strategy" was most detrimental followed by BAU and the Pine Beetle "Disaster" scenario. Maintaining a constant forest age (~80% ≥ 80 years old) was the most optimum. However, given the existing fragmentation of some of the ranges (particularly LSM), none of the "habitat scenarios" were sufficient to conserve caribou over time without some population management intervention.

Population Management
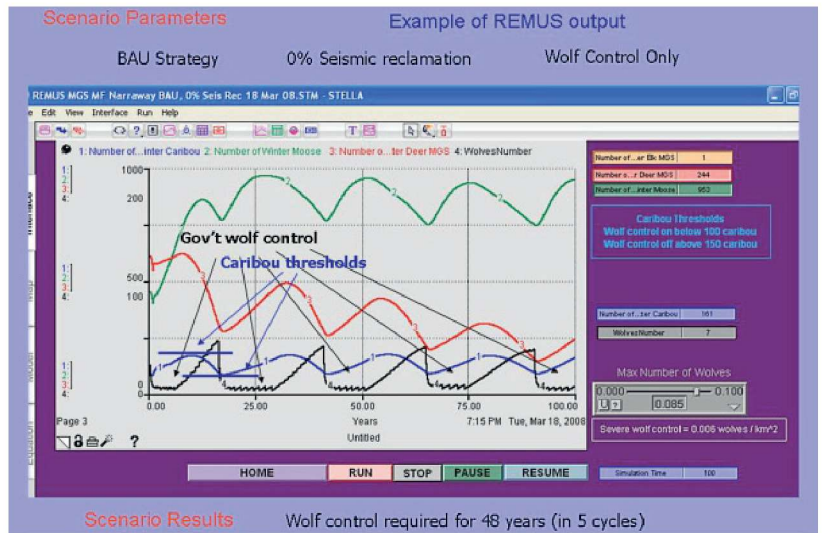To provide a consistent comparison between herds and between sce-

Fig. 5.   Example of a REMUS computer model output for the Narraway woodland caribou herd in west central Alberta based on a 100 year scenario of business as usual for the oil and gas industry, no reclamation of seismic lines, wolf control initiated when the Narraway herd declines below 100 animals and wolves are controlled at 6/1000 km² until the caribou herd increases to 150 animals. Moose and deer are available for sport hunting, but aren't controlled.
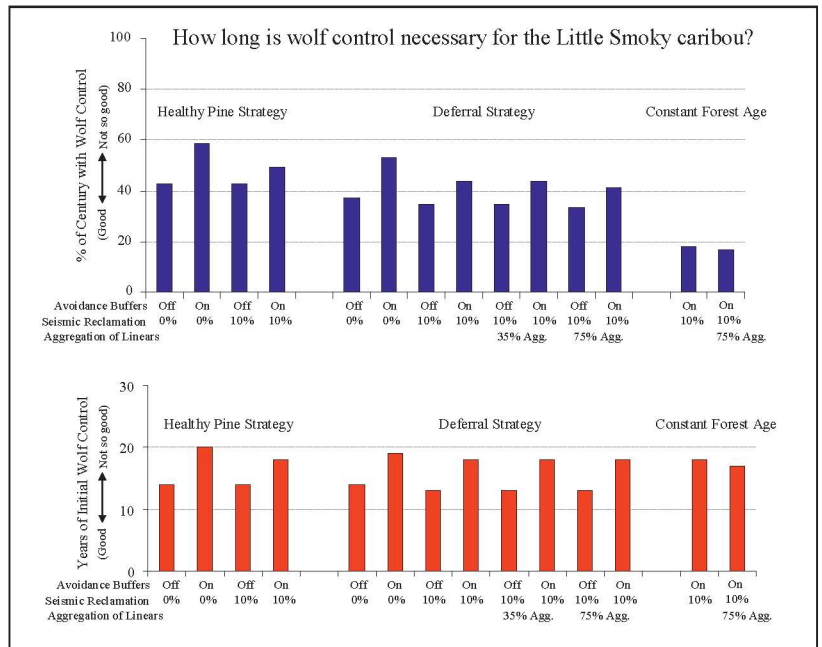

Fig. 6.   A comparison of REMUS modeling results between the Health Pine Strategy, the 100 year Deferral Strategy and an Old Growth Strategy in the Little Smoky Range. The blue bars illustrate the number of years out of 100 when wolf control would be necessary and the red bars illustrate how many years would be *initially* required to achieve 150 caribou.

narios, "the number of years where wolf control was required to maintain woodland caribou numbers above management thresholds" (Table 5) was used as the common denominator. The outputs from the REMUS runs illustrated the timing and duration of wolf control, and the anticipated response by caribou, moose and deer (e.g. Fig. 5). The results of different scenarios were combined by herd to access the benefits (e.g. Fig. 6). The number of bouts of wolf control is not included in Fig. 6; however, the constant forest age scenario only requires 1 bout compared to other scenarios, but due to the current forest condition, the first bout is the same length as those strategies that have multiple bouts. For the runs in Fig. 6, the benefits of aggregating industrial footprint were not captured in the REMUS outputs because of lack of data for this herd. Running the analysis with GIS buffers on (simulating avoidance of anthropogenic features) suggests that a more prolonged period of wolf control is required. The buffer doesn't affect the age of the stand (i.e. the age remains the same regardless of the GIS buffer), but it does reduce the amount of older forest available to caribou to avoid predation, thereby making them more vulnerable in the model and reducing their rate of increase. The question remains whether avoidance of anthropogenic features by caribou would continue or be reduced during a period of wolf control. For example, woodland caribou might be avoiding anthropogenic features because the lines were frequented by more primary prey and thus wolves associated with them and/or because wolves use them as travel routes (James, 1999; James & Stuart-Smith, 2000). Conversely, human activity may be driving avoidance (Dyer *et al.*, 2001) and therefore wolf control may not have any effect on caribou response to anthropogenic features.

Given the densities of wolves and primary prey in all woodland caribou ranges outside of the protected areas and the amount of anthropogenic footprint that already exists, there were no scenarios where the reduction of primary prey was sufficient to recover caribou in the short term, even with total exclusion of forest harvest and limited oil and gas development (i.e. The amount of existing early seral stage forest would continue to attract primary prey and therefore wolves at densities that wouldn't support woodland caribou until forest age recovered). However, as expected, concurrent primary prey/predator management did provide marked benefits in terms of reducing the number of years where predator control was required. To examine the difference between initiating only wolf control vs. wolf and primary prey control, wolf densities in the NAR range were reduced to $6/1000$ km^2 and/or in combination with moose

densities reductions to $< 100/1000$ km^2 whenever caribou numbers dropped below 100. Wolf control was removed whenever caribou exceeded 150. Invoking different levels of an old growth strategy reduced the need to control wolves when the only aggressive population management strategy was wolf control. Significant moose management (i.e. moose reduction over and above sport hunting – a.k.a. aerial gunning) dramatically reduced the duration of wolf control and increasing the old growth strategy reduced the number of years that "government" moose management was required in response to a reduction in young moose-producing forests (Fig. 7). (Note: The modeling results for the NAR herd do not have the benefit of 1) current landscape condition, 2) projected future landscapes or 3) predator/primary prey densities for the portion of the range that is located in British Columbia. Consequently, these results should be viewed with additional caution).

To compare similar strategies across herds, REMUS modeling results were categorized into those where recovery of woodland caribou required the least amount of wolf control, the best and worst scenarios for each herd with continued forest harvest and the Mountain Pine Beetle (MPB) Disaster Scenario. Each end of the spectrum was examined relative to seismic reclamation and aggregation of footprint (Fig. 3 & 4) although, as pointed out earlier, those 2 parameters do not contribute significantly to changes in forest age. Primary prey management wasn't included in this comparison, but as pointed out previously, it should reduce the number of years that wolf control was required if done aggressively. (MPB outputs were not available for the NAR or RPC herds during the preparation of this document).

Across herds, REMUS results indicate that maintaining forest age at the current level without any further forest harvest (Recovery), with 10% seismic reclamation and with a 75% reduction in linear footprint would require the fewest years of wolf control (Fig. 8). From the standpoint of wolf control, the next best scenario modeled in the LSM and ALP ranges would be if the more intact areas were deferred from forest harvest for 100 years, 10% seismic was reclaimed annually, anthropogenic footprint was minimized (75%) and there was no avoidance exhibited by caribou of any anthropogenic features (Best). The Healthy Pine Strategy without seismic reclamation and without aggregation of footprint required the largest amount of wolf control if there was avoidance by woodland caribou (Worst). Finally, the MPB Disaster Scenario (MPB) without seismic reclamation and aggregation of footprint required the most years of wolf control. Similar modeling results were

observed for the NAR and RPC with the fewest years of wolf control being predicted for a scenario of maintaining forest age at the current level (Recovery) and the most years of wolf control being associated with the Healthy Pine Strategy (Fig. 8).

Discussion

Simulated habitat management strategies that resulted in the highest likelihood of caribou recovery included the maintenance of a high proportion of old forest and the aggregation of industrial footprints. Sharing of industrial roads, protection of fragments of old-growth, and expanding fire control had little additional effect on caribou recovery. Simulated population management strategies that were successful all involved decades of intensive wolf control, either directly or indirectly through intensive alternate prey control. Recurrent cycles of wolf control appeared necessary until old-growth forests recovered to densities that provided caribou habitat and decreased alternate prey of wolves. Intensive strategies of direct or indirect wolf control are controversial, logistically difficult, and likely unsustainable over the meaningful time frames necessary for caribou recovery.

In REMUS we assumed no "prey switching" (i.e. wolves focusing on woodland caribou when faced
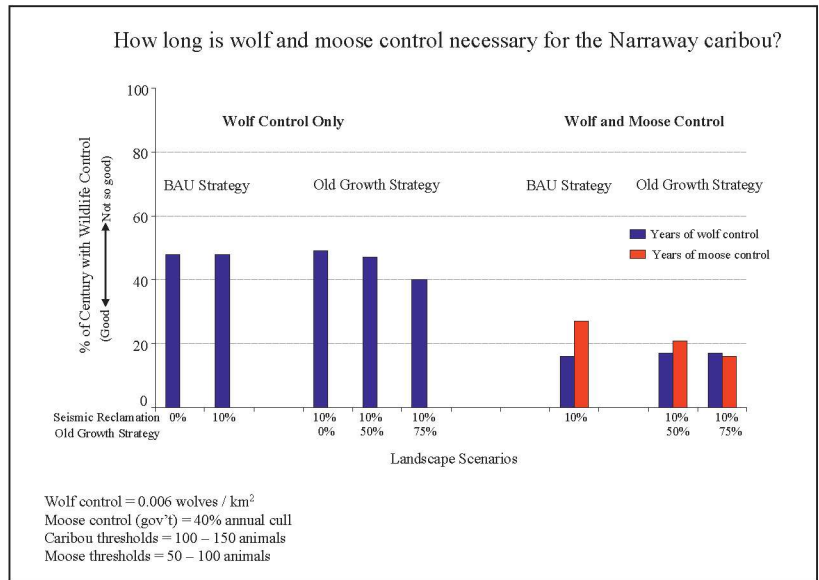

Fig. 7. A comparison of REMUS modeling results between the Business As Usual (BAU)[1] Strategy, Old Growth Strategies that maintain 0%, 50% and 75% of the forest > 80 years old and wolf control only vs. moose and wolf control in the Narraway Range. The blue bars illustrate the number of years out of 100 when wolf control would be necessary and the red bars illustrate how many years out of 100 that government moose control (i.e. probably couldn't be accomplished by sport hunting) would be required to maintain 100 - 150 caribou.

[1]For the NAR herd, BAU is ensuring that no more than 20% of the range is < 30 years of age at any segment of time.
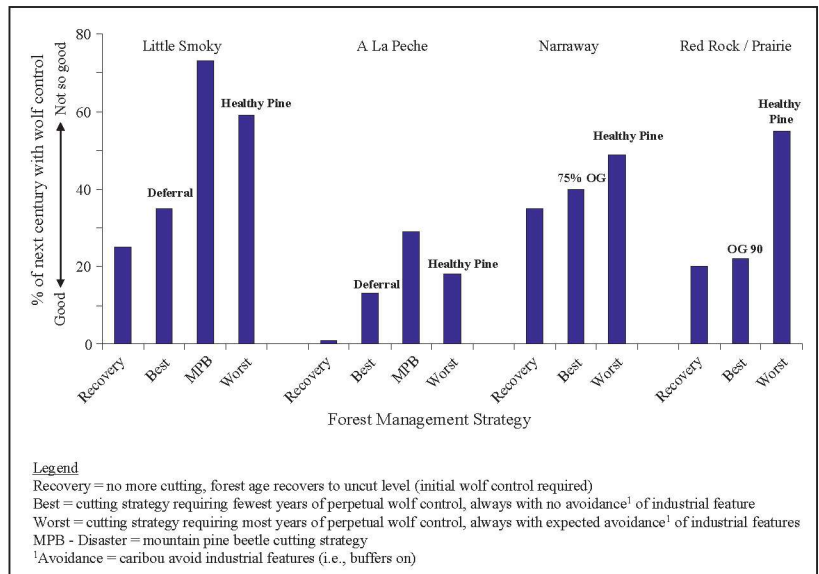

Fig. 8. Summary of both recovery (no further forest harvest) and forestry cutting strategies as functions of years of wolf control required to recover or maintain caribou populations in four west-central Alberta caribou herds.

with reduced moose densities) because it was difficult to find published information to include in the model. The potential for caribou to receive additional predation pressure when other primary prey is in decline is discussed by Hebblewhite *et al.* (2007) and Messier (1995). There is a high likelihood that this will occur since wolves would be expected to continue to hunt primary prey of any type based on the density of the prey's occurrence.

Based on modeling results, wolf control is expected to be effective in maintaining woodland caribou populations until habitat becomes limiting. However, the Recovery Plan for Woodland Caribou in Alberta provides direction that wolf control will be used as a temporary measure to provide for the maintenance of woodland caribou populations until habitat is restored to the extent that caribou can once again avoid predation at a sustainable level (see Lessard *et al.*, 2005). Additionally, the Management Plan for Wolves in Alberta (Alberta Forestry, Lands and Wildlife, 1991) only permits wolf control for durations up to 5 years. Moreover, the logistical challenges of delivering an effective wolf control program over large areas and over long time periods have yet to be addressed. Finally, it is expected that the Alberta public will not support wolf control programs as a viable long-term solution to woodland caribou conservation since it is not a sustainable resource development approach compared to improving habitat condition.

Sensitivity analysis suggested that any additional reduction of primary prey populations over and above current hunter harvest rates would benefit woodland caribou conservation efforts. However, in isolation, upwards of 30% of these primary prey must be harvested annually to maintain wolves at low enough levels to conserve caribou and this requires an initial wolf reduction program to have any effect if prey switching is taken into account. The reduction of primary prey (moose, elk and deer) through hunter harvest is a strategy designed to (1) lengthen the recovery time for wolf populations following initial wolf control and (2) maintain lower densities of wolves post-control. However, controlling white-tailed deer through licensed harvest in the interest of maintaining low densities of alternate prey will be very challenging in woodland caribou ranges of west central Alberta if climate change results in the reduction of average annual snow accumulations.

In summary, although over-simplified, this modeling approach provided a good opportunity to examine "what-ifs" in a multi-stakeholder planning team setting and to present the findings to a variety of audiences. Timber harvest was shown by far to have the most significant influence on forest age, while oil and gas development was the most significant influence on "habitat intactness". Although the potential for mountain pine beetle to have a serious impact on woodland caribou habitat is serious, it was not predicted to be as devastating as originally projected. Without significant reductions in forest harvest and development of the oil and gas footprint in west central Alberta, wolf control would be necessary for multiple decades over a 100 year planning horizon. Primary prey reduction should be carried out simultaneously with wolf management to reduce the frequency and duration of wolf control. Given the size of wolf pack territories and immigration from surrounding landscapes, land management decisions that affect caribou habitat must be considered from a much larger area than that based on the current caribou distribution in west central Alberta.

Acknowledgements

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Appendix

Table 2. Summary example of default settings and sources of parameter estimates used in REMUS for the LSM woodland caribou herd in west central Alberta.

PARAMETER	DEFAULT SETTINGS	SOURCE
Forest Trajectories in Pine, Spruce and Riparian REMUS categories	*REMUS Pine-* Pine and Mixed-wood; *REMUS Spruce-* Black Spruce, Tamarack + Bog-fen; *REMUS Riparian-* Hardwood, White Spruce, Up-shrub, Up-grass, Up-moss Note- Alberta Vegetation Inventory (AVI) definitions were: • Pine - (Pl+Pj+Pa+Pf+P) >= 80%) • Mixed-wood- (< 80% for deciduous or coniferous forest types) • Spruce- (Sb+Lt+Bog-fen) >= 80% • Hardwood- (Aw+Pb+Bw+A) >= 80% • White Spruce- (Sw+Se+Fb+Fa+Fd+La) >=80%	West Central Modelling Working Group

PARAMETER	DEFAULT SETTINGS	SOURCE
Footprint Types in Seismic, Well and Road REMUS categories	• *REMUS Seismic*- (Minor Roads, Pipelines, Transmission Lines, Seismic Lines) • *REMUS Well*- (Wells, Gravel Pits, Industrial Plants, Mines) • *REMUS Road*- (Major Roads, Rail-lines) Note- Minor roads = clearing width $\geq$ 8m and $\leq$ 15m; Major roads = clearing width > 15m	West Central Modelling Working Group
Initial Caribou Densities (/km^2) in pine, spruce and riparian habitats	0.032, 0.032, 0.001	Resource selection functions Neufeld (2006); Saher & Schmiegelow (2005); Edmonds (1988); Fuller & Keith (1981); James (1999); Stuart-Smith *et al.* (1997); Shepherd (2006); Szkorupa (2002)
Caribou Carrying Capacity (/km^2) in pine, spruce and riparian habitats	2.0, 2.0, 0.03	Modified from Lessard (2005); Skogland (1985); Klein (1968); Leader-Williams (1980)
Initial Number of Caribou and Management Thresholds	72, 100-150	Initial numbers derived from: a/ known areas (km^2) of habitat types and estimated densities within each habitat type, b/ non-systematic aerial surveys, c/ mark-re-sight surveys for collared caribou, d/ total counts and expert opinion
Initial Moose Densities (/km^2) in pine, spruce and riparian habitats	0.2, 0.4, 0.8	Aerial surveys and expert opinion; Fuller & Keith (1981)
Moose Carrying Capacity (/km^2) in pine, spruce and riparian habitats	0.32, 1.05, 6.0	Osko *et al.* (2004); Lessard (2005); Crete (1989); Skogland (1985)
Initial Number of Moose and Management Thresholds	905, <250	Initial numbers derived from known areas (km^2) of habitat types and estimated densities within each habitat type
Initial Elk Densities (/km^2) in pine, spruce and riparian habitats	0.6, 0.4, 0.07	Aerial surveys and expert opinion
Elk Carrying Capacity (/km^2) in pine, spruce and riparian habitats	0.01, 0.01, 0.3	Stelfox (1993)
Initial Deer Densities (/km^2) in pine, spruce and riparian habitats	0.3, 0.8. 2.0	Aerial surveys and expert opinion
Deer Carrying Capacity (/km^2) in pine, spruce and riparian habitats	0.5, 0.5, 4.0	Estimates from limited aerial survey results.
Initial Wolf Density (/km^2)	0.025	Aerial counts;

PARAMETER	DEFAULT SETTINGS	SOURCE
Wolf Territoriality (Maximum wolf density regulated by territorial behavior; /km²)	0.059	Messier (1994)
Target Maximum Wolf Density (/km²) with Wolf Control	0.006	Bergerud & Elliott (1986)
Maximum Growth Rate of Wolves (no wolf control)	r = 0.875; Max. = 2.40	See Weclaw & Hudson (2004)
Wolf Immigration Rate (/km²)	0.002	Estimated
Wolf Kill Rates	Function of pack size (x- pack size, y- kill rate)	See Weclaw & Hudson (2004)
Territory Size of Wolf Pack (km²)	950	See Weclaw & Hudson (2004); Kuzyk 2002
Wolf Predator Efficiency (P50; density of prey species at half the maximum killing rate)	0.46 (same for all prey species in all 3 habitats)	Messier (1994)
Proportion of Caribou Killed Annually by Other Predators	0.04[1]	Dzus (2001); Weclaw & Hudson (2004)
Prey Switching	Off	
Caribou Avoidance of Cut-blocks (distance avoided-m; % avoidance in buffers)	0 or 1000, 100	Smith et al. (2000); Oberg (2001); Neufeld (2006); James & Stuart-Smith (2000); Dyer et al. (2001)
Caribou Avoidance of Seismic Lines (distance avoided-m; % avoidance in buffers)	100, 25	Smith et al. (2000); Oberg (2001); Neufeld (2006); James & Stuart-Smith (2000); Dyer et al. (2001)
Caribou Avoidance of Roads (distance avoided-m; % avoidance in buffers)	250, 50	Smith et al. (2000); Oberg (2001); Neufeld (2006); James & Stuart-Smith (2000); Dyer et al. (2001)
Caribou Avoidance of Wells (distance avoided-m; % avoidance in buffers)	No avoidance	Smith et al. (2000); Oberg (2001); Neufeld (2006); James & Stuart-Smith (2000); Dyer et al. (2001)
Target Moose Hunting (proportion of antlered and antlerless harvested annually)	0.40 antlered; 0.40 or 0.35 antlerless	Expert opinion on achievable levels when considering access and past hunting statistics
Target Elk Hunting (proportion of antlered and antlerless harvested annually)	0.20, 0.30	Expert opinion on achievable levels when considering access and past hunting statistics
Target Deer Hunting (proportion of bucks, does and young harvested annually)	0.06, 0.06, 0.02	Expert opinion on achievable levels when considering access and past hunting statistics
Caribou Harvest (proportion of calves, yearlings and adults poached, harvested by 1st Nations or vehicle collisions annually)	0, 0, 0.03	Dzus (2001); McLoughlin et al. (2003)

[1]later reduced to 0 to simplify model interpretation.