CARIBOU PROTECTION AND RECOVERY PROGRAM (PREDATOR EXCLOSURE) COST EFFECTIVENESS ANALYSIS

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FINAL
September, 2014

PREPARED FOR

Canada's Oil Sands Innovation Alliance

ACKNOWLEDGEMENTS

The authors would like to thank Canadian Oil Sands Innovation Alliance, and particularly Scott Grindal of ConocoPhillips Canada Resources Corp. for sponsoring and coordinating the caribou protection and recovery (predator exclosure) cost effectiveness analysis. Thanks also to Dr. Stan Boutin, University of Alberta Biological Sciences, who provided valuable advice and insight on the predator exclosure strategy and modeling assumptions. John Nishi, EcoBorealis Consulting Inc., conducted a literature review on caribou population response that helped to confirm modeling and sensitivity analysis assumptions.

EXECUTIVE SUMMARY

This study and others have demonstrated that woodland caribou in the oil sands area of northeast Alberta will be extirpated if recovery management initiatives are not undertaken. Our cost effectiveness analysis focuses on the economic tradeoffs associated with four different recovery management strategies for woodland caribou: *(i)* predation management using predator exclosures, *(ii)* predation management using wolf control, *(iii)* habitat management through reclamation, and *(iv)* habitat management through the deferral of resource extraction. We use a temporal/spatial model to estimate which recovery management strategy (or combination of strategies) represents the least cost approach to achieving self-sustaining caribou herds.

Our analysis considers four caribou herds (the size of the predator exclosure is listed in brackets): *(i)* Egg-Pony herd (2,085 km^2), *(ii)* Cold Lake Air Weapons Range herd (1,464 km^2), *(iii)* West Side of the Athabasca herd (1,875 km^2), and *(iv)* the Audet herd (1,530 km^2).

For a caribou herd to be considered self-sustaining, it must satisfy two criteria within the first 50 years of the 100-year modelling period: *(i)* the population density must be greater than 4.5 animals per 100 square kilometers[1] (km^2), and *(ii)* the habitat lambda must be greater than 1. Habitat lambda is defined as the relative population growth rate that would occur in the absence of predation management strategies (predator exclosures and/or wolf control), based on a statistical model that incorporates the amount of linear disturbances and the area of forest older than 30-years. This statistical model was correlated with actual population growth rates in the oil sands area.

Given that habitat lambda is currently so low, our modelling results are consistent with others who have concluded that caribou will be extirpated from all four ranges unless predation management strategies are employed to reduce unsustainable caribou predation. In other words, since habitat lambda recovers so slowly, extirpation occurs even when habitat management via deferred land use (oil sands and forestry deferrals) and reclamation are employed. Predator exclosures and/or

[1] Similar to Schneider et al. (2010), we use 4.5 caribou per 100 km^2 as a target recovery density, since it is the mean estimated density of caribou in Alberta in 1996 (Alberta Woodland Caribou Conservation Strategy Committee, 1996). But we also conduct sensitivity analysis on densities of 3 and 6 caribou per 100 km^2 to see how different target densities impact the cost of the recovery program.

wolf control thus serve as a necessary bridge to sustain caribou populations for the five decades required for habitat and habitat lambda to recover.

Habitat management through reclamation and/or deferred land use will ultimately be required to restore habitat lambda and allow caribou populations to persist without population management. Our results confirm that habitat management required to achieve a habitat lambda greater than 1.00 will be expensive (approximately $8 billion for required reclamation and deferred land use).
This cost is dominated by the opportunity costs of delaying development of high value oil sands projects (approximately 99% of total value). It should be noted that although this cost is approximately $8 billion (all monetary measures are expressed as net present values), it represents a decline of less than 1% from the estimated $973 billion in total benefits that would be generated from hydrocarbon and forest resource development in the modelling area in the absence of caribou management.

Our model suggests that predator exclosures are effective enough to completely eliminate the need for wolf control within the Audet, West Side of the Athabasca, and Cold Lake Air Weapons Range herds—and drastically reduce the level of wolf control for the Egg-Pony herd in the East Side of the Athabasca range. This finding implies that there are three possible predation management strategies: *(i)* wolf control, *(ii)* predator exclosure, and *(iii)* predator exclosure with reduced wolf control. In other words, predator exclosures on their own are *feasible* as approaches for maintaining caribou populations in three of the four study areas. However, they may not be the most cost effective in a financial analysis.

Wolf control for all four herds costs approximately $7 million in the absence of any predator exclosures. If all four exclosures were built (at a minimum cost of $50 million), then the cost of wolf control outside the exclosures drops to approximately $100,000—i.e., wolf control is almost completely eliminated. Wolf control alone is clearly the cheaper of the two options, but its long-term social acceptability has been questioned. The net cost of the exclosures is estimated to be between $46 million (using the lower-bound cost of constructing and maintaining the exclosures) and $325 million (using the upper-bound cost), but there could be additional social license benefits generated from the significant decline in wolf control that are not considered in this economic analysis. Given current uncertainty around the assumptions for translocated caribou population dynamics, there is also the chance that exclosures would result in the end of wolf control entirely.

TABLE OF CONTENTS

Glossary

Dynamic Optimization: In this case, the dynamic optimization model attempts to find the optimal resource development plan that provides the maximum value for the objective function (total benefits minus total costs) when the entire 100-year planning period is considered. Costs and benefits that occur in the future are discounted to present values. The optimization process involves a number of sequential stages (steps) corresponding to various moments in time. At each stage the model must satisfy all constraints (e.g., habitat lambda and caribou density) for the plan to be feasible.

Habitat Lambda: An equation developed for boreal caribou in Alberta (Schneider et al. 2010) that relates population growth to two factors: *(i)* percentage of caribou range that has been burnt or harvested in the last 30 years (i.e., young forest); and *(ii)* linear feature density in the caribou range (total km of seismic lines, roads, and pipelines/km^2 of range, expressed as km/km^2).

Herd: A sub-population or group of animals that are habitually found within a given area. These may interact with other caribou in the same range.

Lambda: A finite rate of population growth. Values of 1.00 indicate population stability, values less than 1.00 indicate population decline, and values greater than 1.00 indicate population growth. In Alberta, lambda is estimated for each caribou herd from annual recruitment and mortality of female caribou and summarized for each study period as the geometric mean of annual estimates.

Opportunity Cost: The value of the "best" alternative that is foregone when a choice must be made between mutually exclusive alternatives given limited resources.

Range: A defined area including one or more critical habitats or herds. The Athabasca Landscape area is divided into four ranges: Richardson, East Side Athabasca River (ESAR), West Side Athabasca River (WSAR), and Cold Lake Air Weapons Range – Alberta (CLAWR).

Wolf Control: A large-scale program to reduce wolf density by shooting them from helicopters.

1 Introduction

Canada's Oil Sands Innovation Alliance (COSIA) wishes to explicitly evaluate the costs of establishing a fenced woodland caribou predator exclosure in the oil sands region of northeast Alberta. This project continues work initiated by the Oil Sands Leadership Initiative Land Stewardship Working Group (OSLI LSWG) to evaluate the technical and biological feasibility of an exclosure managed to reduce predation, increase caribou numbers within the fenced area, and provide a source of surplus animals to supplement other declining herds. This initiative is referred to as the Caribou Protection and Recovery Program predator exclosure (CPAR).

A large fenced predator-free exclosure for woodland caribou is a predation management option that has been frequently discussed, but had not been formally evaluated or attempted for conservation of woodland caribou. Phase One of the CPAR was initiated in 2011, when the OSLI LSWG commissioned four independent feasibility evaluations (Golder 2011, Hab-Tech 2011, Matrix 2011, Terrain FX 2011) with the following objectives: *(i)* identify the risks and opportunities of constructing, maintaining, and monitoring a fenced predator exclosure, and *(ii)* assess the overall practicality and likelihood of implementing a successful fencing program.

Phase Two was completed in 2012, when a workshop with 43 technical experts was held. The objective of the workshop was to discuss the appropriate ecological guidelines that would be required to successfully implement a predator exclosure, or, conversely, to discuss science-based reasons why this approach should not be considered further. Workshop participants generally agreed that a large fenced predator exclosure would be technically feasible, but challenging and costly to implement. Many experts questioned the viability of a large predator exclosure, and recommended rigorous financial analyses to compare a more refined cost estimate of this option and its known risks with other technically feasible population management options (Antoniuk et al. 2012).

This cost effectiveness analysis constitutes Phase Three of the CPAR initiative. The analysis focuses on the tradeoffs associated with four different recovery management strategies for woodland caribou: *(i)* predation management using predator exclosures, *(ii)* predation management using wolf control, *(iii)* habitat management through reclamation, and *(iv)* habitat management through the deferral of resource development. The objective of this report is to answer the questions: *Does a predator exclosure make it cheaper to conserve caribou herds? And if so, by how much?* To answer these questions we use a temporal/spatial model to estimate which management strategy (or combination of strategies) within an overall recovery program offers the least cost approach to achieving different levels of caribou recovery. In other words, our results suggest a range of costs for a range of different levels of caribou recovery. We present the total cost required to reach a particular target level of caribou recovery, and in cases where multiple strategies are used—predator exclosure, wolf control, habitat reclamation, land use deferral—we break out the cost for each of the strategies that are employed to reach the target. Hence, the results explore which recovery strategies (in combination) are most cost effective for achieving a particular level of caribou recovery.

The different levels of caribou recovery are based on the number of self-sustaining herds in the study area. Our analysis considers four of the predator exclosures identified in the feasibility studies: *(i)* Egg-Pony herd and a 2,085 km^2 exclosure option within the East Side of the Athabasca range as identified by Golder (2011), *(ii)* Cold Lake Air Weapons Range herd and a 1,464 km^2 exclosure option identified by Golder (2011), West Side of the Athabasca herd and a 1,875 km^2 exclosure option identified by Golder (2011), and *(iv)* the Audet herd and a 1,530 km^2 exclosure option within the Richardson range identified by Hab-Tech (2011).

To be considered self-sustaining, a herd must satisfy two criteria: *(i)* the population density must be greater than 4.5 animals per 100 km^2, and *(ii)* the habitat lambda must be greater than 1.00. Habitat lambda is defined as the relative population growth rate that would occur in the absence of predation management strategies (exclosures and/or wolf control), based on a statistical model that incorporates the amount of linear disturbances and the area of forest older than 30-years. This statistical model was correlated with actual woodland caribou population growth rates in the oil sands area (Schneider et al. 2010).

Predation management strategies such as exclosures and wolf control serve as a bridge to sustain caribou populations in times when habitat lambda is less than 1.00 (because of habitat disturbances from fire and land use), and until such a time when habitat lambda increases above 1.00. By showing a range of different costs for different levels of caribou recovery, it is possible to evaluate how sensitive the total project cost is to changes in the number of self-sustaining herds, as well as to changes in timing. By expressing the results in this way, it is possible to evaluate the economic trade-offs between the various recovery options.

In the next section we explain the general modelling approach. In Section 3 we discuss the assumptions used within our model. Section 4 contains a detailed description of the model. Section 5 presents the results of our analyses. Section 6 concludes our analysis with a brief discussion.

2 Modelling Approach

We calculate the total project cost for each caribou recovery option using a mathematical programming model that considers:

- profits from the extraction of bitumen/oil/gas/timber;
- costs of each caribou management option (construction and maintenance of predator exclosure, wolf control, reclamation, land use deferral);
- caribou habitat quality as related to stand age (the model considers fire and harvest areas less than 30 years of age, as well as linear disturbances such as seismic lines, pipelines and roads);
- impact of wolf predation/control on caribou survival; and
- caribou density.

Our model estimates the net present value of bitumen/oil/gas/timber extraction given the costs associated with the particular level of caribou recovery (density target and number of herds) and the particular recovery management program being modeled (exclosure, wolf control, reclamation, land use deferrral). In other words, the model optimizes profits, royalties, and taxes over time subject to the attainment of a particular caribou recovery target by a particular time. We vary the time period and recovery management program required to achieve a particular habitat lambda and caribou density, and then examine the costs of the achieving the targets.

Our analysis of total project cost considers two types of costs: *direct costs*, which arise from wolf control, predator exclosure, and habitat reclamation, as well as *opportunity costs*, which arise from a loss in resource revenue because of deferred land use. We calculate the total project cost using a three-step “with and without” analysis.

Step 1. Calculate the net present value of resource extraction in the modelling area under the current business-as-usual scenario. This is the calculation “without” the recovery management program (i.e., without the exclosure, wolf control, habitat reclamation, or deferred land use).

Step 2. Calculate the net present value of resource extraction in the modelling area considering both the direct costs and the opportunity costs. Depending on the recovery management program being modelled, the direct costs might include the costs of the exclosure, wolf control, or reclamation. This is the calculation “with” the recovery management program.

Step 3. Calculate the difference between the above two values. The difference represents the total project cost of that particular recovery management program.

We employ this approach because it expresses the costs of caribou recovery when the dynamics of caribou, timber, and subsurface energy resources are all integrated in the analysis. This approach also directly compares the total project cost of the exclosure option with the three other technically feasible habitat and predation management options—wolf control, habitat reclamation, and deferral of land use. It also examines the cost and implicit risk of extirpation relative to the time involved in achieving a particular caribou density target. To address the uncertainties in how fencing will affect caribou densities and the length of time required to achieve the caribou density target, we run the model multiple times and perform sensitivity analysis on some key parameters.

3 Modelling Assumptions

This section provides a simplified overview of the structure of our model. For a more thorough technical description, please refer to Hauer et al. (2012). The modelling approach is dynamic optimization over a 100-year time horizon. With this approach the linear programming optimization algorithm maximizes the total net benefits of resource extraction (oil, gas, bitumen, forest products) given specified constraint equations (one or more caribou recovery options, resource extraction constraints, and extraction profiles). The spatial data in the study area are partitioned into the four herd ranges (WSAR, ESAR, CLWR and Richardson) and the four candidate exclosures situated within the herd ranges. We also have an additional partition that covers areas in between/outside the herd ranges so that the model may shift resource development to outside the herd range boundaries.

The structure of the model is:

1. **Objective:** The model maximizes the following objective over the 100-year planning horizon:

   Total Net Benefits = Total profits + taxes + royalties generated from oil, gas and bitumen extraction and forest harvesting – costs of reclamation of seismic lines – costs of wolf control – costs of predator exclosure(s)

2. **Activities:** The model maximizes the above objective by scheduling/choosing oil, gas, and bitumen extraction and forest harvesting activities over time, both in areas within the herd ranges and outside the herds. The model simultaneously schedules wolf control and reclamation activities. The timing and length of exclosure projects are activities within the model, however, they were fixed to start immediately and last for a period of 50 years. Time is represented by 20 five-year planning periods. The net value of these activities in terms of profits, taxes, royalties and program costs are based on the same data sets used in Schneider et al. (2010) and Schneider et al. (2011). However, the data sets are used here in a dynamic modelling approach rather than the static approach applied by Schneider et al. (2010, 2011).

3. **Constraints:** The model schedules the activities subject to a number of constraints and parameter settings. Constraints are discussed here and key parameter settings are discussed Section 3.

   a. **Caribou Population and Habitat Dynamics and Targets**

      i. Caribou population dynamics (outside the exclosure): The model uses the habitat lambda model by Schneider et al. 2010 as the base population growth model but modifies lambda for each herd depending on whether wolf control and/or exclosure alternatives are specified. For example, if wolf control is turned on, habitat lambda can be increased to a maximum of 1.1, representing comparatively rapid caribou population increase (see Schneider et. al. 2010).

      ii. Caribou population dynamics of the exclosure: The model uses a separate lambda of 1.16 (the theoretical maximum under natural conditions [Schneider et al. 2010]) for animals inside the exclosure. Surplus animals from the exclosure are translocated back out into the range so that the target population of 150 animals inside the exclosure is maintained. The net contribution of additional translocated animals is calculated based on the current habitat lambda in the translocation area and an additional adjustment to account for lower survival rates for translocated animals. Modelling assumes that surplus animals are translocated into the same range, but outside the exclosure. While the exclosures are in place, the computations of habitat lambda do not consider the area the area inside the exclosure. However, once the exclosures are removed at the end of 50 years, the habitat lambda is computed based on the whole herd area (i.e., the model now considers the forest age and linear features that exist where the exclosures had been).

iii. Habitat lambda requires inputs that specify the length of linear features and the proportion of the forest area in the range that is less than 30 years of age. The model tracks lengths of linear features and forest age class distributions by range. The model adjusts the length of linear features according to equations that add linear features when new wells are built based on relationships developed for the Athabasca Landscape Team (2009) and subtracts linear features when reclamation activities occur. There is a 30-year lag between when the reclamation occurs and when the linear feature is removed from the linear features account. Similarly, when forest harvesting occurs area is added to the less than 30-year age category, which is removed only when the areas removed and replanted reach 30 years of age. Future forest fires are accounted for in the model using a deterministic approach (a constant rate), which probably results in an overestimation of future habitat lambda and woodland caribou sustainability.

iv. Caribou population "self-sustaining herd" constraints: These constraints require that the habitat lambda be greater than or equal to 1.00 and that the population be above 4.5 individuals/100 km2 within 50 years (this represents the mean estimated density of caribou in Alberta in 1996 [Alberta Woodland Caribou Conservation Strategy Committee, 1996]). These constraints can be modified for alternative target densities (i.e. different from 4.5).

b. Oil, Gas and Bitumen Extraction Profiles and Capacity Constraints

i. Oil, gas and bitumen extraction profiles: These activities include drilling followed by production or extraction (hereafter referred to as extraction). Extraction is modeled using a fixed curve that specifies how much volume is generated from wells over time. Oil and gas wells tend to generate more volume early in the life of the well, which falls off over time (see Hauer et. al 2010).

ii. Oil, gas and bitumen capacity/demand constraints: The model incorporates capacity or demand constraints that limit the amount of these products that the model can extract in each planning period (see Hauer et. al 2010).

c. Forest Sector Constraints

i. Age Class and Harvesting Dynamics: The model considers age class distributions for different tree species within each herd range, as well as within the study area outside the range. The age classes are tracked over time and modified due to harvesting activities. Forest less than 30-years-old is also tracked for input into the habitat lambda model (Schneider et. al. 2010).

ii. Forest Sector capacity constraints: Harvesting volumes are limited by the amount demanded at mill locations. Harvesting typically equals the capacity constraints but may fall below the constraints if there is not enough volume or if is too costly to harvest and transport the wood to the mills. Harvesting levels may also fall short of capacity if age class requirements to achieve habitat lambda levels of 1.00 make wood unavailable for harvest (see Hauer et. al 2010).

d. Basic Land Use and Resource Constraints

i. This set of constraints ensures that the total extraction of resources over the time horizon is less than or equal to the available resources. In other words, the model cannot allocate more land than is available, or extract more bitumen than is available, etc.

ii. Seismic line reclamation: Some seismic lines require reclamation and some do not because natural regeneration is underway. The model assumes that 50% of lines require reclamation, as per Schneider et al. (2010)

4 Modelling Method, Net Benefit Function, and Opportunity Costs

We use the model described in Section 3 to generate results by first conducting a baseline run without any caribou constraints. In this case the model is only concerned with scheduling resource extraction to maximize profits, taxes and royalties—i.e., it ignores reclamation, predation management, and exclosure costs. This gives us a baseline value for the total net benefits that could potentially be generated in the study region.

The opportunity costs of meeting caribou targets is determined by running the model again, this time with the caribou constraints turned on, then subtracting this revised value for the total net benefits from the value obtained in the baseline run. The difference between these two values will be due to the direct and indirect opportunity costs required to meet the caribou constraints. Direct costs are for wolf control, reclamation of seismic lines, and the cost of the predator exclosures. Indirect opportunity costs are the costs that arise from a decline in the profits, taxes and royalties generated from oil, gas and bitumen extraction and forest harvesting. These indirect opportunity costs occur for two main reasons: *i)* energy projects or forest harvesting is deferred to achieve habitat lambda targets, and *ii)* the model selects alternative extraction projects outside the herd range that are of lower value, and therefore generate less profits, taxes and royalties. Since the model is an optimization model, it will select a new schedule of activities relative to the baseline to minimize the size of the opportunity costs.

Different results can be obtained by changing constraint target levels and/or parameters in the model. For example, the density target can be changed from 4.5 to 6.0 caribou/100 km^2 and the difference in opportunity costs observed.

4.1 Model Assumptions and Parameter Assumptions

As mentioned above, the four independent feasibility evaluations (Golder 2011, Hab-Tech 2011, Matrix 2011, Terrain FX 2011) identified the risks and opportunities of constructing, maintaining, and monitoring a fenced predator exclosure. Generally speaking, these four studies identified the same parameters as being important to the success of the CPAR predator exclosure. When it came to quantifying these parameters, however, there was variation between the studies for major parameters such as exclosure size and cost. Such variation could be expected given the lack of empirical data for such a project, but it imposes a significant level of risk into our cost effectiveness analysis. The variation between the feasibility studies makes it more difficult to make estimates about: *(i)* the effect the exclosure will have on the surrounding caribou herd, and *(ii)* the cost of the exclosure.

In order to determine appropriate values to incorporate into our analysis, we once again turn to the four feasibility studies. The remainder of this section presents the key parameters of our model, and for many of the parameters specifies the lowest and highest values found within the four feasibility studies.

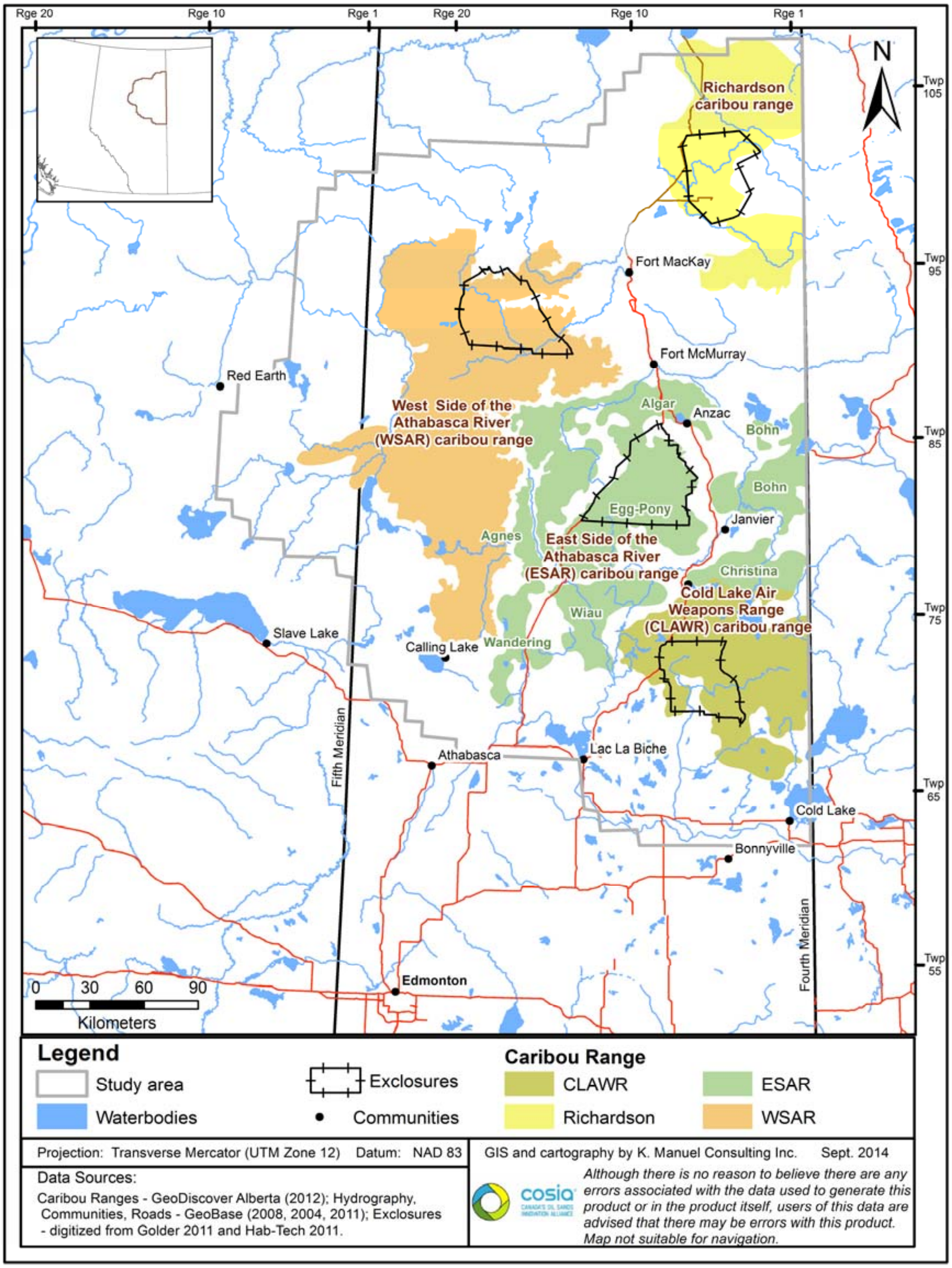
4.2 Candidate Areas

Our analysis is designed to answer the questions: *Does a predator exclosure make it cheaper to conserve caribou herds than wolf control? And if so, by how much?"* To answer these questions, our model requires spatial data on the proposed exclosure for a particular caribou herd, as well as the herd's range. Figure 1 shows the four Athabasca Landscape herds that were modelled (with exclosure size from the feasibility study that proposed the exclosure included in brackets):

1. Egg-Pony herd range (2,085 km^2 exclosure defined by Golder 2011) within the East Side Athabasca Range (ESAR).
2. Cold Lake Air Weapons Range (CLAWR; 1,464 km^2 exclosure defined by Golder 2011)
3. West Side of the Athabasca (WSAR; 1,875 km^2 exclosure defined by Golder 2011)
4. Audet herd range (1,530 km^2 exclosure defined by Hab-Tech 2011) within the Richardson range (Richardson).

Although these potential exclosure areas are all situated within the oil sands regions, they were selected because they represent a variety of biophysical characteristics. Our results suggest the lowest cost means of achieving a sustainable density of caribou within one herd, two herds, three herds, and all four herds. It is important to note that when the model uses habitat management through deferred land use (i.e., deferring oil sands and forestry development) as a means of increasing the habitat lambda, it selects alternative development projects that are outside the herd range but within the modelling study area. In cases where these alternative developments are of less value, the decrease in profits, royalties, and taxes is expressed as an opportunity cost.

Figure 1. Map of the caribou herd ranges and modelled predator exclosures.



4.3 Caribou Population Maintained Inside Exclosure

The major contribution of our analysis is the linkage between a particular caribou exclosure and its surrounding herd. An important aspect of the analysis is the temporal aspect—i.e., the target date when we wish to achieve herd sustainability. A key component to the rate at which the sustainability target is achieved will be the size of the breeding population within the exclosure. There was some variability in breeding population among the four feasibility studies, as shown below (the feasibility study that proposed the value is included in brackets):

- Lower bound: 30 cows, ~2 bulls (Golder 2011)
- Upper bound: 150 cows, ~10 bulls (Terrain FX 2011)

For this evaluation, modelling assumes that each exclosure initially contains 30 cows (the lower bound), but the population will be allowed to expand until each exclosure contains 150 cows (the upper bound). At that point surplus animals will be translocated into the adjacent herd.

4.4 Predator Control Inside and Outside the Exclosures

1. ***Exclosure construction and ongoing cull of deer, moose, wolves, and bears inside exclosure.*** The model can construct any combination of the four aforementioned exclosures to optimize total net benefits. The exclosure cost includes the cost of initially culling predators within the fence, as well as the ongoing costs of ensuring that any predators that might make their way into the exclosure are culled (explained in detail below). The exclosure is modelled as a temporary solution until habitat reclamation activities return habitat quality to the level whereby the herd is sustainable on its own. At this point the exclosure would be decommissioned and all predator control activities would cease.
2. ***Ongoing cull of wolves outside exclosure.*** The model can consider the costs and benefits of predator control within the caribou ranges of any (or all) of the four aforementioned herds. Once again, this activity is continued as required until habitat reclamation activities return habitat quality to the level whereby the herd is sustainable on its own. At this point all predator control activities would cease.

4.5 Biological Assumptions Inside Exclosure

Our model assumes that all calves are translocated except for those required to maintain the target population within the exclosure. For the model runs presented here we assumed that initially there are 30 animals in the exclosure and that the population growth rate (lambda) inside the exclosure is conservatively established at 1.16. This was conservatively based on an assumed natural recruitment rate of 45 per 100 females and an adult survival rate of 95%. Lambda is estimated as adult survival rate divided by (1-recruitment rate of female calves) where the females are assumed to make up ½ of the calves. Recruitment rate of female calves is computed as (45/2)/(100+45/2) = 0.18. The final lambda is computed as: lambda=0.95/(1-0.18)=1.16. Using the lamda of 1.16 the 30 animals increase to 154 animals in 11 years. The number of animals available for translocation is equal to the net growth of animals within the enclosure from year to year, assuming that 154 animals are left in the enclosure, which is computed as 1.16*154-154=24. Therefore, 24 animals per year are available to translocate for 39 years.

4.6 Biological Assumptions Outside Exclosure

Population growth rates will be based on a combination of habitat lambda (computed using the habitat lambda model by Schneider et. al. 2010) and additional assumptions related to the effect of wolf control and the survival of translocated animals. Translocated animals are assumed to have survival rates that are 30% lower than animals born outside the exclosure. With these assumptions the population dynamics can be expressed as:

*Pop(t+1) = Pop(t)*Lambda + Trans-located Animals(t)* Lambda*SurvivalAdjustment*

where *SurvivalAdjustment* is equal to 0.7.

4.7 Resource Extraction Assumptions Inside Exclosure

The model assumes forest harvest and hydrocarbon extraction continue inside the exclosure.

4.8 Lower-bound Direct Cost of Exclosures

The lowest cost estimate for each part of the project from the feasibility studies are as follows:

- Fence construction: $4.64 million (Terrain FX 2011)
- Maintenance: $0.088 million per year (Golder 2011)
- Cull: $0.053 million per year (Hab-Tech 2011)
- Translocation/monitoring: $0.23 million per year (Golder 2011)
- Fence/road removal: $6.27 million (Hab-Tech 2011)

4.9 Upper-bound Direct Costs of Exclosure

The highest cost estimate for each part of the project from the feasibility studies are as follows:

- Fence construction: $33 million (Hab-Tech 2011)
- Maintenance: $2 million per year (Matrix 2011)
- Year 1 aerial cull: $1.5 million (Matrix 2011)
- Year 2 aerial cull and scat monitoring: $3 million (Matrix 2011)
- Year 3 scat monitoring: $1.3 million (Matrix 2011)
- Ongoing aerial surveys and culling: $0.25 million per year (Matrix 2011)
- Fence/road removal: $15.14 million (Hab-Tech 2011)

4.10 Discounted Direct Costs of Exclosure

If the above costs are discounted over a 50-year project period at a discount rate of 4%[2], the following results are generated:

- Lower bound direct costs: $12.9 million
- Upper bound direct costs: $83.9 million

Given the significant difference between these two values, in the results below we present the total cost of caribou recovery using both the lower bound direct costs and the upper bound direct costs.

[2] When analyzing the feasibility of environmental protection projects, developed countries typically use social discount rates of between 3% and 7% (Zhuang et al. 2007).

4.11 Costs of Management Treatments Outside Exclosure

These costs were obtained from Schneider et al. (2010):

- Wolf control = \$35/km² per year
- Cost of reclaiming seismic lines = \$4,000/km

5 Results

5.1 Baseline Run: No Caribou Constraints

The model calculates the total benefits from profits, taxes and royalties of gas, oil, bitumen and forestry to be \$973 billion. Bitumen (\$624 billion) is by far the largest contributor to the total benefits, followed by natural gas (\$331 billion), conventional oil (\$16 billion), and forestry (\$2 billion). There are no costs to caribou conservation, because caribou constraints are turned off. In the absence of caribou conservation measures, the model predicts that all four caribou herds will be extirpated.

5.2 Recovery Costs Without Predator Exclosure

Table 1 shows that there are significant recovery costs when caribou constraints are imposed on the model. The largest cost, by far, is the opportunity costs of lost royalties, profits and taxes that are incurred from temporal and spatial changes to resource extraction. In other words, the model no longer develops the resources according to the original "optimal" extraction plan identified in the baseline scenario. This new "optimal" extraction plan has been revised to satisfy the constraint that habitat lambda must be equal to 1.00 and the caribou density must be at least 4.5 per 100 km^2 at 50 years.

Table 1 also includes the results for scenarios where 2, 3, or 4 herds are conserved. Please note that the costs for conserving multiple herds at the same time is not the same as adding the costs for conserving each herd separately. This is because the model allows for substitution and rescheduling of deferred projects to areas outside the herd ranges but within the modelling area. Since the modelling area is finite, there are interaction effects that increase the costs as more herds are conserved. In other words, it becomes more costly to conserve multiple herds because the model must look for more places to relocate projects among the same number of possible substitutes.

Table 1. Cost of recovering caribou herds without the predator exclosure* ($ million)

	Wolf control	Recla-mation	Lost royalties, profits, taxes	Total cost	% of total benefits in base run ^
Caribou constraints imposed on single herd:					
ESAR	4.6	51.2	483.2	539.1	0.1
Richardson	0.9	12.8	730.6	744.3	0.1
WSAR	1.3	45.7	1,757.1	1,804.1	0.2
CLAWR	1.5	18.5	2,966.0	2,986.0	0.3
Caribou constraints imposed on multiple herds:					
ESAR+Rich.	5.5	64.1	1,308.2	1,377.8	0.1
ESAR+Rich. +WSAR	6.9	109.7	3,493.4	3,610.0	0.4
All herds	7.8	127.7	7,667.4	7,802.8	0.8

**Recovery means achieving the density target of at least 4.5 animals per 100 km^2 and a habitat lambda target of at least 1.00 at 50 years, and maintaining these targets until the end of the 100-year planning horizon.*

^ The final column was computed by taking total cost and dividing it by the total benefits (i.e., the objective function value) calculated in the base run of $973 billion, and then multiplying by 100 to express it as a percentage.

Improvements to habitat lambda are achieved by reducing linear features and cleared/burned areas less than 30-years-old on the landscape. The most immediate improvement of habitat lambda is generated from deferring resource extraction (gas, oil, bitumen, forestry) within the caribou ranges. Comparatively large opportunity costs are incurred because the deferred projects are shifted to new "suboptimal" areas—i.e., areas that have lower resource values. Hence, the royalties, profits and taxes within the objective function decrease from the baseline run without caribou constraints. These opportunity costs range from $483 million for ESAR to almost $3 billion for the CLAWR. The opportunity cost is $7.7 billion if all herds are conserved, which represents a decline of less than 1% from the estimated $973 billion in total benefits that would be generated from the modelling area in the absence of caribou management. When estimating these opportunity costs, the model does not terminate projects that are already producing. Specifically, the model allows existing wells to continue extracting resources until the end of their production cycle (e.g., bitumen wells are assumed to produce for 9 years), but expansion beyond existing wells within caribou range is deferred to improve habitat lambda.

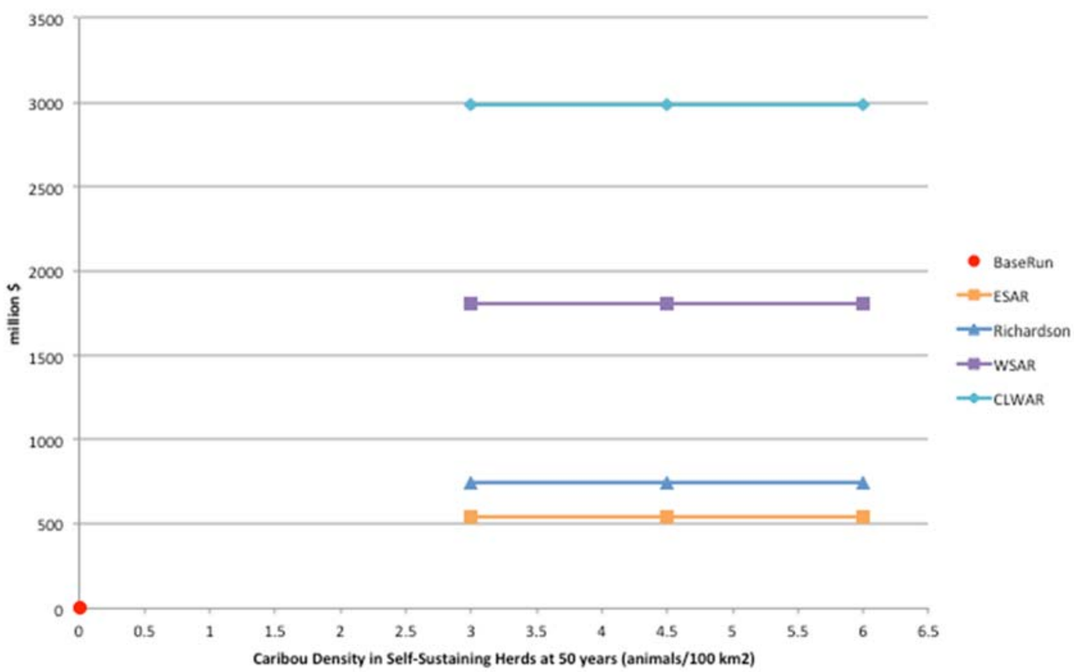
Reclaiming linear features and cleared/burned areas can also increase habitat lambda. However, as can be seen in Table 1, reclamation costs are much less than project deferrals. Reclamation costs range from $12.8 million for Richardson to $51.2 million for the ESAR.

Table 1 also shows that wolf control is the least expensive component of caribou recovery. Wolf control is required to recover caribou herds to the self-sustaining status of 4.5 animals per 100 km^2 at 50 years. In the absence of wolf control, the model predicts that all four caribou herds will be extirpated, even if lambda is brought up to 1.00 by 50 years.

Figure 2 shows total costs for each caribou herd at different population target densities. The cost curves with respect to density are very flat because the increase in caribou density from 3.0 to 6.0 animals per 100 km^2 is achieved through wolf control. This sensitivity analysis of the target density shows that wolf control is very inexpensive in comparison to getting habitat lambda to 1.00. In addition, to maximize total economic benefits, wolf control is deferred as long as possible while still achieving the target density at 50 years, which further reduces costs because of financial discounting.

In Figure 2, the vertical distance between the zero cost baseline run and the cost to achieve 3.0 animals per 100 km^2 for each herd is due to the cost of achieving a habitat lambda of 1.00 by 50 years. As mentioned above, habitat lambda improvements are achieved in the model by reducing linear features and cleared/burned areas that are less than 30-years-old on the landscape. This is done through reclamation of existing linear features and by reducing the creation of new linear features and clearcuts. Since there is a long lag time between reclamation actions and improvement of habitat lambda, the costs must be incurred immediately or the 50-year habitat lambda target would not be achieved.

Figure 2. Cost of recovering caribou herds to self-sustaining status for varying caribou populations and densities by herd



It should also be noted that the vertical distance between the baseline scenario (BaseRun) and 3 animals per 100 km^2 is much larger than the imperceptible vertical distance from 3 to 6 animals per 100 km^2. This difference reiterates that the opportunity costs of deferring development (and, to a lesser extent, the reclamation and exclosure costs) necessary to achieve a lambda equal to 1.00 are significantly higher than the costs of wolf control used to achieve target caribou density.

5.3 Recovery Costs Using Predator Exclosures

Table 2 shows the impact of having the model immediately construct predator exclosures in order to achieve the same caribou constraints as for the previous scenarios without the exclosures. The total costs are presented using both the lower-bound and upper-bound costs for constructing and maintaining the exclosures (as per Sections 3.8 and 3.9).

Table 2. Cost of recovering caribou herds using predator exclosures for the lower-bound and upper-bound exclosure costs ($ million)

	Wolf control	Recla-mation	Lost royalties, profits, taxes	Total cost ($12.9 million exclosure cost)	Total cost ($83.9 million exclosure cost)	% of base run benefit for $83.9 million exclosure
Caribou constraints imposed on single herds:						
ESAR	0.1	51.2	483.2	547.3	617.7	0.1
Richardson	0.0	12.8	730.6	756.2	826.6	0.1
WSAR	0.0	45.7	1,757.1	1,815.6	1,886.0	0.2
CLAWR	0.0	18.5	2,966.0	2,997.3	3,067.7	0.3
Caribou constraints imposed on multiple herds:						
ESAR+Rich.	0.1	64.1	1,308.1	1,397.9	1,538.7	0.1
ESAR+Rich. +WSAR	0.1	109.7	3,493.3	3,641.5	3,852.7	0.4
All herds	0.1	127.7	7,667.4	7,846.3	8,127.9	0.8

**Recovery means achieving the density target of at least 4.5 animals per 100 km² and a habitat lambda target of at least 1.00 at 50 years, and maintaining these targets until the end of the 100-year planning horizon.*

Table 3 and Figure 3 show the overall change in caribou recovery cost with the predator exclosure compared to the cost with no exclosure. These results suggest that the predator exclosure increases the cost of recovery for each herd compared to wolf control only. For example, if the direct cost of the exclosure is $12.9 million, the total cost for caribou recovery increased from $539.1 to $547.3 million, or a net increase in total cost of $8.3 million for the predator exclosure compared to the no exclosure scenario (see Tables 1, 2 and 3). However, the exclosures eliminated the need for wolf control within the ranges of three of the four herds—Richardson, WSAR and CLAWR—and drastically reduced the level of wolf control for the ESAR herd. Predator exclosures also slightly reduced the losses to profits, royalties and taxes for the ESAR and WSAR herds. The cost reductions occur because some high-value oilsands projects that were deferred in the no exclosure scenario are able to proceed in the exclosure scenario—i.e., these deferred projects can now proceed within the exclosure, since the fenced areas are not included in habitat lambda calculations when the exclosure is in place. As a result of these cost reductions, the total cost increases for the predator exclosure scenarios were less than the construction and maintenance cost of the exclosures themselves.

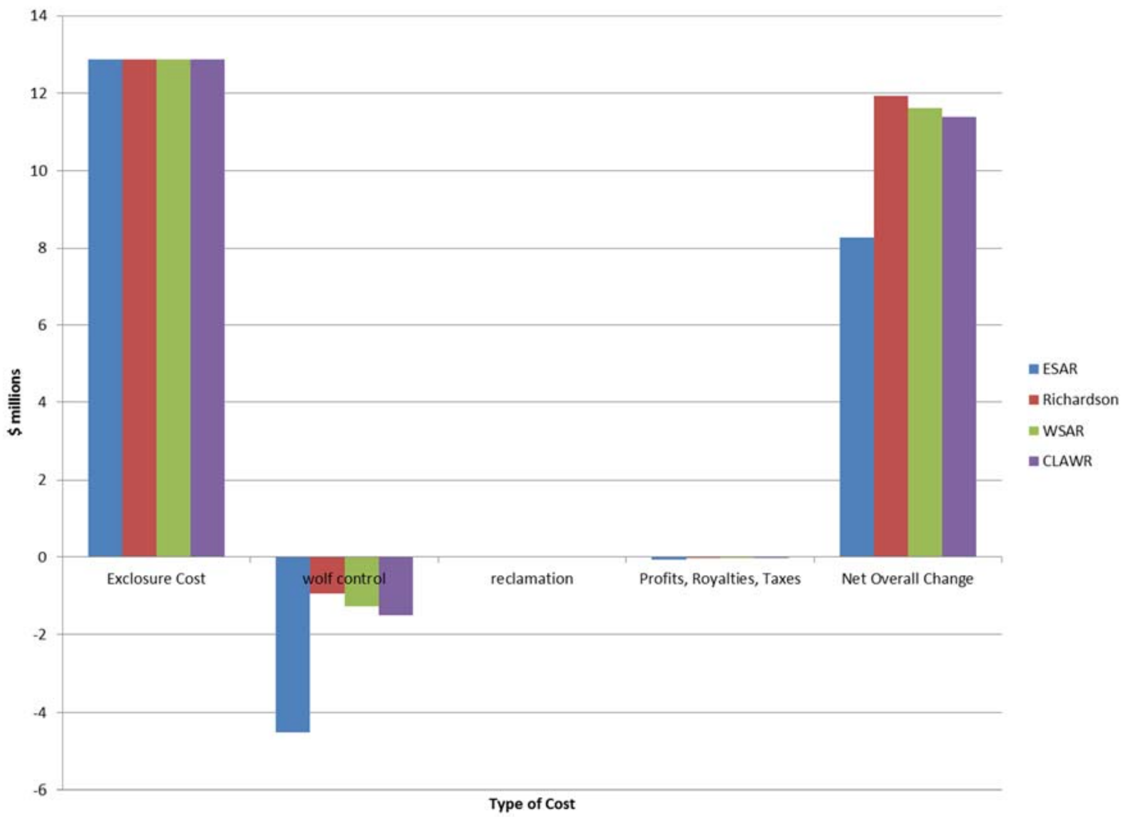
Table 3. Net change in cost of caribou recovery for the predator exclosure compared to scenarios with no exclosure, for both the lower-bound and the upper-bound exclosure costs ($ million)

				$12.9 million exclosure cost		**$83.9 million exclosure cost**	
	Wolf control	**Recla-mation**	**Lost royalties, profits, taxes**	**Net change**	**Share of total cost ^**	**Net change**	**Share of total cost ^**
Caribou constraints imposed on single herds:							
ESAR	-4.51	0.00	-0.07	8.3	1.5%	78.6	16.5%
Richardson	-0.94	0.00	0.00	11.9	1.6%	82.3	12.0%
WSAR	-1.26	0.00	-0.01	11.6	0.6%	81.9	4.7%
CLAWR	-1.50	0.00	0.00	11.4	0.4%	81.7	2.8%
Caribou constraints imposed on multiple herds:							
ESAR+Rich.	-5.4	0.00	0.10	89.7	6.4%	160.9	10.5%
ESAR+Rich. +WSAR	-6.8	0.00	0.06	148.1	4.1%	242.7	6.3%
All herds	-7.7	0.00	0.02	178.9	2.3%	325.1	4.0%

^ Share of total cost is calculated by dividing the net change in caribou recovery cost by the total cost of recovery shown in Table 2, then multiplying by 100 to express as a percentage

Table 3 also shows that the overall change in cost from the use of predator exclosures is less than 13% of the total cost of recovery (including opportunity costs of deferring development projects, habitat reclamation, wolf control, and exclosure costs). Recall from above that the costs associated with increasing habitat lambda above 1.00 represent most of this cost.

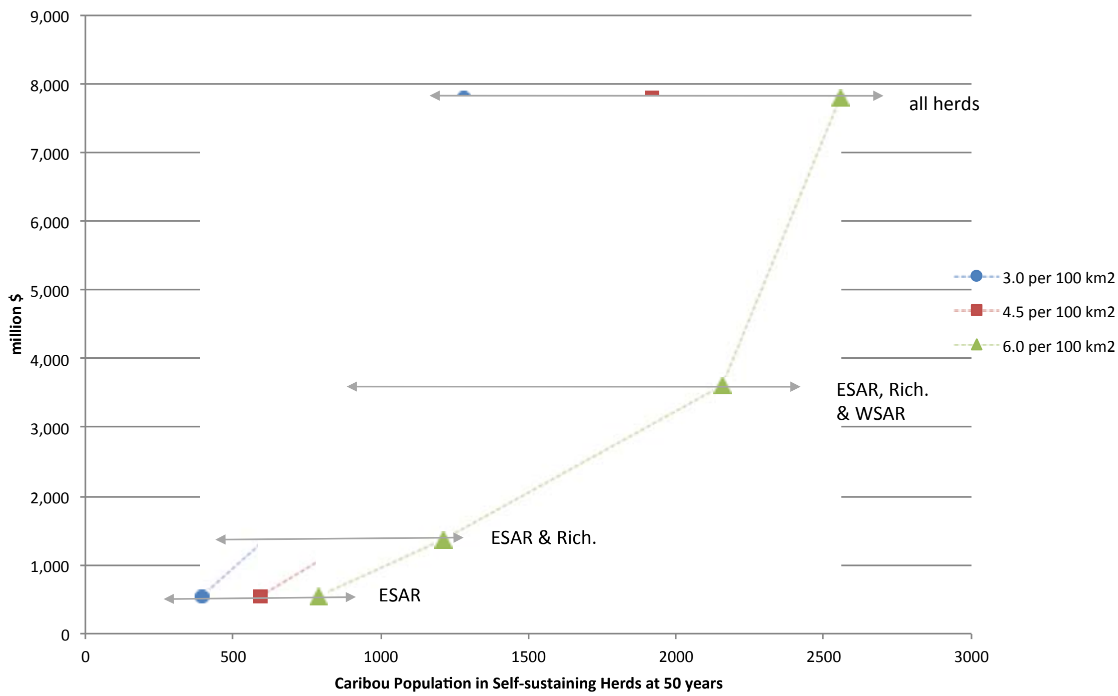
Figure 3. Net change in cost of caribou recovery using predator exclosures ($12.9 million exclosure cost) compared to cost of recovery without predator exclosures



5.4 Recovery Costs for Multiple Herds Using Wolf Control and Predator Exclosures

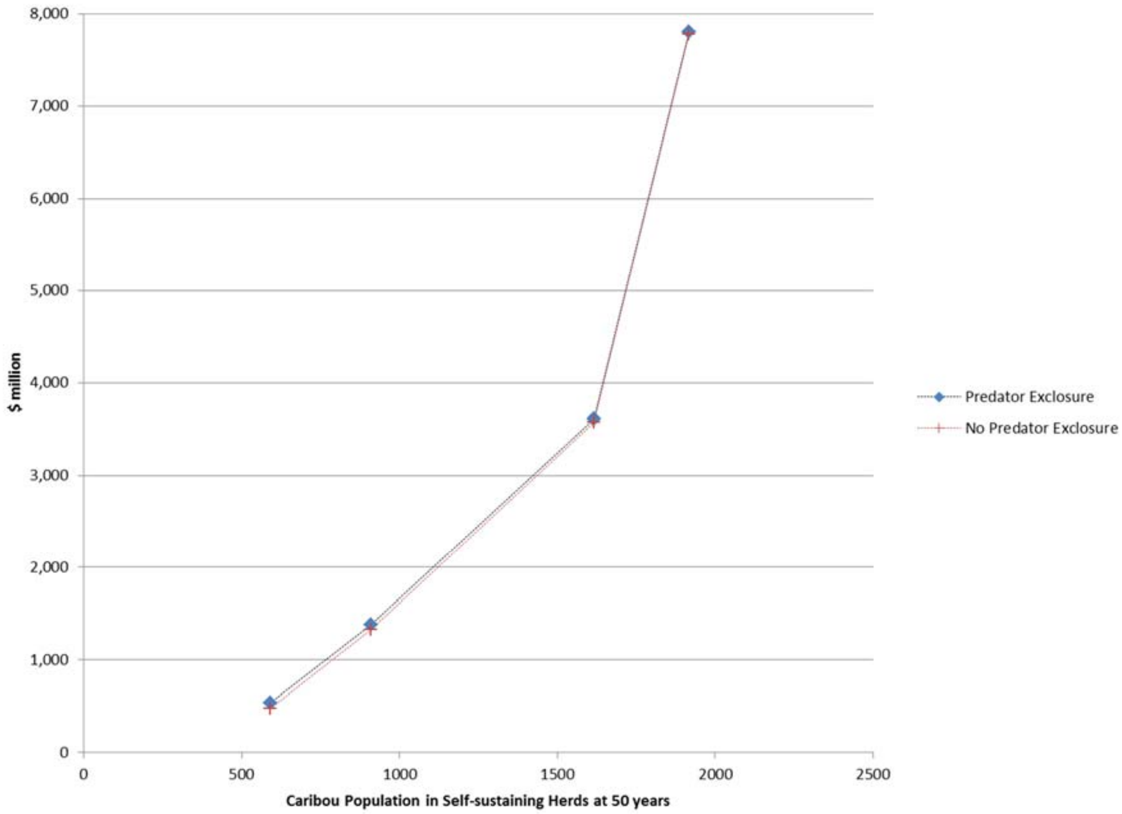
Figure 4 stacks the cost curves from Figure 3 to show the total self-sustaining caribou population at 50 years on the horizontal axis. Each point on the coloured curves is discrete, because each level represents an additional herd (labeled 1, 2, 3 and 4 herds) required to achieve the caribou population according to that particular density (3.0, 4.5, 6.0/100 km^2). Then, each grey curve (these curves are rising, but not noticeably so) represents a density curve and is continuous for that number of herds. The order of the herds from lowest cost to highest is ESAR, Richardson, WSAR and CLAWR—as per Figure 3.

Figure 4. Cost curves for recovering caribou herds to self-sustaining status for varying caribou densities and populations by herd



A similar relationship can be seen once again in Figure 5 (but this time for a density of 4.5 per 100 km^2 only), which shows that the costs of reclaiming habitat and deferring development swamps the costs of increasing caribou density using wolf control and/or predator exclosures. The closeness of the two curves in this graph illustrates that the cost increase incurred by building predator exclosures (versus the scenario with no exclosures) is miniscule compared to the cost of increasing habitat lambda to 1.00 in 50 years, which can only be achieved by deferring development.

Figure 5. Total cost of caribou recovery with and without predator exclosures using the upper-bound exclosure cost of $83.9 million



6 Discussion

Our results suggest that by far the greatest cost to recover caribou is associated with the combination of active reclamation and modified land use required to achieve a habitat lambda greater than 1.00 at year 50. This cost is dominated by the opportunity costs of deferring development of more valuable oil sands projects for less valuable oil sands projects. It should be noted that although this cost is approximately $8 billion, it represents a decline of less than 1% from the estimated $973 billion in total benefits that would be generated from the modelling area in the absence of active caribou management.

To some, this $8 billion total caribou conservation cost may seem low compared to the "total cost" estimated in Schneider et al. (2010), as well as some other similar

Marxan studies. However, these previous studies incorporate a static analysis, and therefore cannot be compared to our dynamic approach. When estimating lost resource values, static analyses unrealistically assume that all profitable resources would have been extracted immediately—i.e., there is no consideration of any limitations on capital and labour. Static cost estimates are appropriate for comparing conservation design scenarios within a particular study (which is how they are used in the respective studies), but one must be careful when discussing the actual values, as these will be grossly inflated. Our new model eliminates this problem by considering temporal capacity constraints. Development is spread out over time according to the capacity of existing oilsands projects in 2009, as well as the future capacity of projects that are planned for development between 2009 and 2025 (see Oilsands Review January 2009). Projects developed later have a lower value because their values are discounted using interest rates to account for the cost of capital, which is why the total cost in this study is much lower than the spurious interpretations of "total cost" from the static analyses.

Given that habitat lambda is currently so low, our results suggest that caribou will be extirpated from all four ranges unless predation management strategies are employed. In other words, since habitat lambda recovers so slowly, extirpation occurs in the absence of predator management, even when deferred land use (oil sands and forestry development) and reclamation are immediately employed. Predator exclosures and/or wolf control are therefore required as a bridge to sustain caribou populations for the five decades necessary for habitat lambda to recover.

Our model suggests that predator exclosures are effective enough to completely eliminate the need for wolf control within the ranges of the Audet, West Side of the Athabasca, and Cold Lake Air Weapons Range herds—and drastically reduce the level of wolf control for the Egg-Pony herd in the East Side of the Athabasca range. This finding implies that there are three possible predation management strategies: *(i)* wolf control, *(ii)* predator exclosure, and *(iii)* predator exclosure with reduced wolf control.

Wolf control for all four herds costs approximately $7 million in present value terms in the absence of any predator exclosures. If all four exclosures were built (at a minimum cost of $50 million), then the cost of wolf control outside the exclosures drops to approximately $100,000—i.e., wolf control is almost completely eliminated. Wolf control alone is clearly the cheaper of the two options, but its long-term social acceptability has been questioned (ALT 2009; Antoniuk et al. 2012). The net cost of the exclosures is estimated to be between $46 million (using the lower-bound cost of constructing and maintaining the exclosures) and $325 million (using the upper-bound cost), but there could be additional social license benefits generated from the significant decline in wolf control that are not considered in this economic analysis. Given current uncertainty around the assumptions for translocated caribou population dynamics, there is also the chance that exclosures would result in the end of wolf control entirely.

The objective of this report was to answer the questions: *Does a predator exclosure make it cheaper to conserve caribou herds? And if so, by how much?* As is explained above, the answer to the first question is "no." It would cost an additional $46 million to conserve all four caribou herds using predator exclosures than using wolf control alone. However, the use of exclosures almost completely eliminates the need for wolf control, which could yield a social licence benefit and reduce the risk to caribou that wolf control will be temporarily or permanently discontinued. Another benefit is related to the uncertainty surrounding the effectiveness of wolf control. Given that the fate of caribou appears to be dependent on an extremely risky wolf control strategy, the most important benefit of caribou exclosures could be that they mitigate this risk somewhat.

During the course of the study it was suggested that our assumption that lambda equals 1.16 within the exclosure might be too conservative for what a caribou population considered to have little or no predation risk. Yet, even if this assumption is conservative, wolf control requirements and costs were almost entirely eliminated with the exclosures. Our model shows that predator exclosures simply replace wolf control as a method to ensure that caribou densities are sufficiently high enough to avoid extirpation over the period necessary to achieve habitat lambda equal to 1.00. There was very little effect on resource extraction or reclamation activities for the model runs with predator exclosures compared to runs for the no predator exclosure scenario. Therefore, increasing lambda above our conservative assumption of 1.16 would have virtually no effect on total recovery cost.

These results raise a number of new questions that could form the objectives for future work:

- What is the impact on costs if, instead of 50 years, we extend the target for herds to be self-sustaining (i.e. lambda = 1) to 75 years? 100 years? This would require the exclosure and/or wolf control costs to be carried out longer, but these costs are small compared to the opportunity costs of deferring development. The main advantage of extending the target date would be to reduce the need to defer energy projects, thus decreasing the opportunity costs.

- These results are based on building predator exclosures immediately, but the optimization model tends to postpone wolf control as long as possible because it reduces the present value of the costs. As a result the caribou density path over time for the no predator exclosure scenario is quite different than for the exclosure scenario. Imposing a constraint that makes the caribou density paths more similar for the two scenarios would reduce the cost differences for the exclosures as compared to wolf control only (but probably not by much). However, it could be helpful to analyze various timing options for construction of exclosures and/or wolf control strategies.

- How much would costs increase if a portion of the predator exclosure was closed to industrial development? By zoning the exclosure area into various control and treatment groups, research could be conducted to test the hypothesis that there is a link between industry and caribou stress, ultimately leading to reduced calf survival (Wasser et al., 2011; although see Boutin et al. 2012).

- What are the possible impacts that forest fires (particularly large fires that affect the predator exclosures) could have on these results?

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