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To the reader:

In December 2010, the Government of British Columbia committed to develop a plan to manage the 7 northern ecotype caribou in the South Peace River area.

One project undertaken to assist development of the Peace Northern Caribou Plan was a modelling exercise to develop alternate development scenarios. This project integrated the available scientific information and expert opinion to predict the future abundance of caribou. It predicted future caribou numbers based on projections of industrial build-out by the coal, forestry, wind and oil and gas sectors. The report from this project, entitled " South Peace Northern Caribou Management Model", was completed under contract and received internal review. Government will need to consider results outlined in the report and decide where and when they are appropriate for use. The results from the model projections will need to be incorporated into caribou planning and management activities.

This report is a significant accomplishment and will guide Government in moving forward with management of northern caribou in the South Peace area. If you have any questions on the attached report or the PNCP, please feel free to contact me (250-614-9917).

Sincerely,

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South Peace Northern Caribou Management Model

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Executive Summary

The Province is developing management options for northern caribou (*Rangifer tarandus caribou*) in the South Peace (SP). Most herds are currently in decline and there is considerable interest in expanding industrial activity in the region. This report presents a management model that integrates available scientific information and expert opinion to predict the future abundance of caribou, based on projections of industrial build-out by the coal, forestry, wind and oil and gas sectors.

The working hypothesis of the model is that the population growth rate of caribou herds is driven proximately by predation and ultimately by habitat condition. The density of wolves is the most significant determinant of survival and recruitment of caribou, and the abundance of early seral habitat indirectly influences the density of wolves by influencing the abundance of their primary prey (primarily moose, but also elk and deer).

In general, predictions of the model align with observed population growth rates when current conditions are used as model inputs. Based on an estimate of future industrial build-out, the population of northern caribou in the SP area is expected to decline from 1100 currently to approximately 800 in 20 years, if no further management actions are taken. Three of seven herds could be extirpated during that time.

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Acknowledgements

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Introduction

The Province of British Columbia is developing management options for northern ecotype caribou (*Rangifer tarandus caribou*) herds occupying the South Peace (SP) region. These herds include the Graham, Scott, Kennedy Siding, Moberly, Burnt Pine, Quintette, and Narraway (including Bearhole/Redwillow; Figure 1). Collectively the Committee on the Status of Endangered Wildlife in Canada has listed these herds and others in the Southern Mountains National Ecological Area as "Threatened" (COSEWIC 2002).

All of the herds in the SP area except the Quintette and Graham are in decline (Seip and Jones 2011, Seip et al. 2012) and there is considerable interest in expanding industrial activity in the region. The area has a long history of mineral, petroleum natural gas and forestry development. In the boreal portion of woodland caribou range these developments are correlated with population declines, likely caused by changes in the broader predator-prey system that result in lower caribou survival (Sorensen et al. 2008, Environment Canada 2011, Latham 2011).

This report presents a management model that hypothesizes the dynamics of northern caribou population ecology in the SP. The model integrates available scientific information and expert opinion to estimate the future abundance of caribou, based on forecasts of industrial build-out.

Methods

Model Development

The model developed for this project is best described as a management model rather than as a scientific model because it focuses on aspects of the system that are under management control, rather than focusing on explaining the detailed behaviour of the system. The need for precision is lower with a management model because predictions need only reflect the probability of achieving a particular outcome. Management models are informed by the broadest possible information, including available scientific and management literature, as well as expert opinion. As additional research and/or data become available, the model can be updated to ensure that management is always being guided by the best available information.

The model was based on a working hypothesis, which represented a consensus among the technical experts regarding the general behaviour of the system. The hypothesis was then formalized as a Bayesian Network (Marcot et al. 2006), which has a number of advantages:

1. The model is presented intuitively as a series of variables or "nodes", parameters or "states" and arrows showing the relationships among them;
2. Rather than a purely conceptual model, the Bayesian Network is fully parameterized and can predict quantitative outcomes;
3. Bayesian Networks can accept a mix of quantitative and qualitative information, based on both existing data and on expert opinion;
4. Output is robust to missing data;
5. The model can be updated with data as they become available; and,
6. Uncertainty is accommodated explicitly.

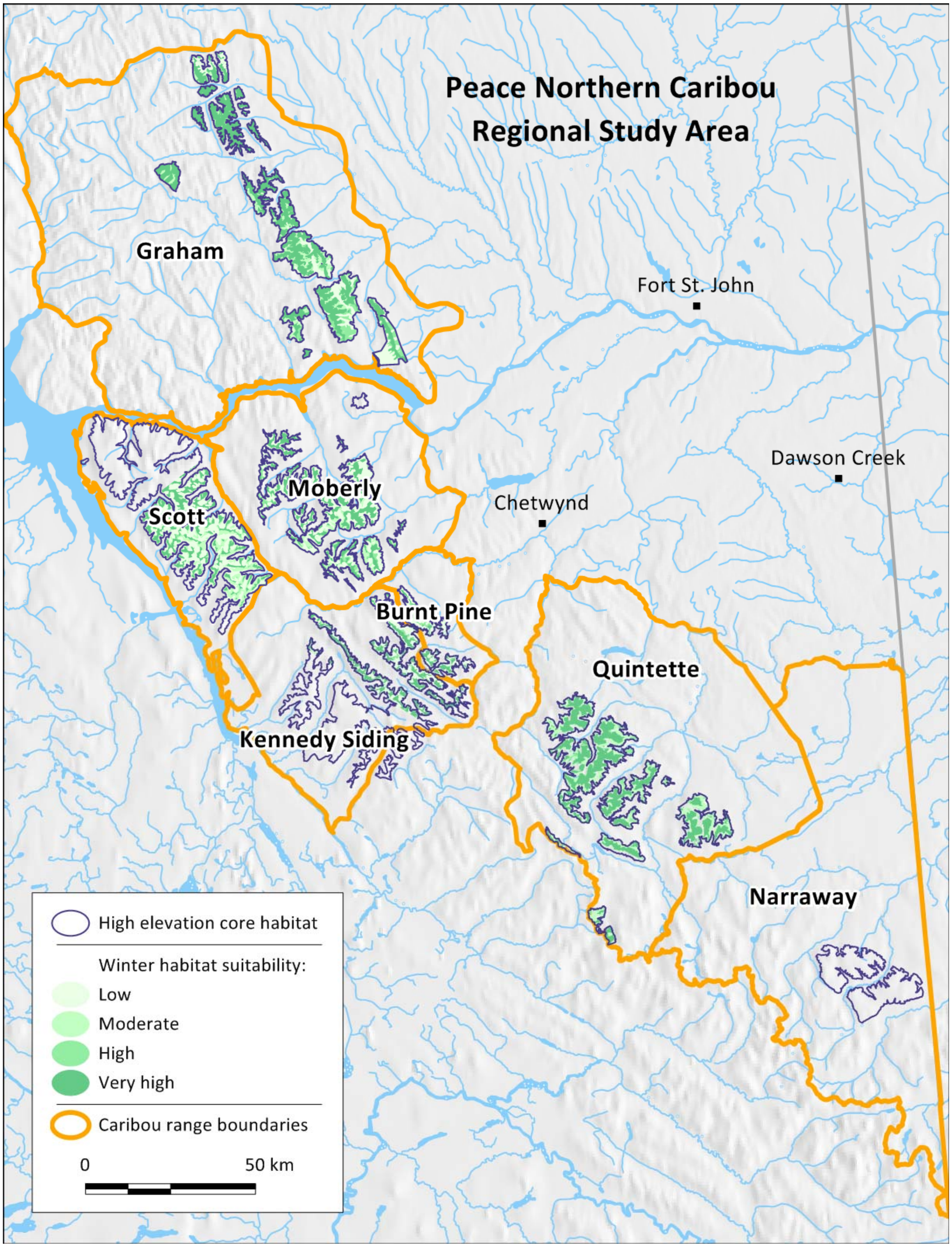

Figure 1. Northern caribou herd ranges and winter core habitat in the South Peace.

Bayesian Networks are becoming increasingly common in resource management where they are used to model systems using a mix of quantitative and qualitative information (e.g., Amstrup et al. 2010).

The model was parameterized using available data and then tested to determine the correspondence of model output with current conditions.

Future Development Scenario

Individual companies and sector representatives provided 20-year build-out estimates for:

1. Coal mine footprints;
2. Wind power developments;
3. Forestry activity; and,
4. Oil and gas development.

Estimates were necessarily coarse and varied in detail and spatial explicitness. Data were interpreted in the context of the habitat model (D. Seip, unpublished; Figure 1) to estimate the impacts of planned development on northern caribou habitat. The estimated habitat impacts generated model inputs that were used to predict the future abundance of northern caribou, by range.

Results

Working Hypothesis

The working hypothesis of the model is that the population growth rate, commonly denoted as lambda (1 + (births – deaths)) is driven proximately by predation and ultimately by habitat condition. The density of wolves is the most significant determinant of survival and recruitment of caribou (Bergerud 1988), and the abundance of early seral habitat indirectly influences the density of wolves by influencing the abundance of their primary prey (primarily moose, but also elk and deer; Environment Canada 2011, Latham 2011). Based on emerging research, the density of linear features contributes to the abundance of early seral habitat but is assumed to have no incremental effect on predator efficiency (c.f., Sorenson et al. 2008, c.f., Environment Canada 2011, Latham 2011, DeCesare 2012).

Unlike woodland caribou herds in the boreal plains, northern caribou herds that spend part of the year in alpine or parkland habitats are largely protected from predation because wolves rarely venture into these areas where prey are less abundant than at lower elevations (Table 1; D. Seip, *pers. comm.*). Loss of high elevation habitat can increase the risk to caribou if key foraging areas are lost and caribou are forced into marginal habitats, particularly at lower elevations where the risk of predation is higher. The risk of displacement is assumed to be higher in winter because the abundance of suitable habitat at high elevations (in particular, windswept ridges with abundant terrestrial lichens) is limited compared to suitable high-elevation habitat in the snow-free season.

Table 1. Relative proportion of northern caribou mortalities (n = 37) recorded among elevation strata in the South Peace area. The proportions of mortalities were normalized to the total number of telemetry locations in each stratum and season.

Biogeoclimatic zone	Summer	Winter	Total
Boreal Altai Fescue Alpine (BAFA)	0.02	0.00	**0.02**
Engelmann Spruce Subalpine Fir (ESSF), above 1200 m	0.14	0.08	**0.22**
Low elevation forest	0.57	0.19	**0.76**
Total	**0.73**	**0.27**	**1.00**

Model Structure

A Bayesian Network was developed to represent the working hypothesis (Figure 2), based on guidance provided by Marcot et al. (2006). The logic associated with each node of the model is presented in the following sections.

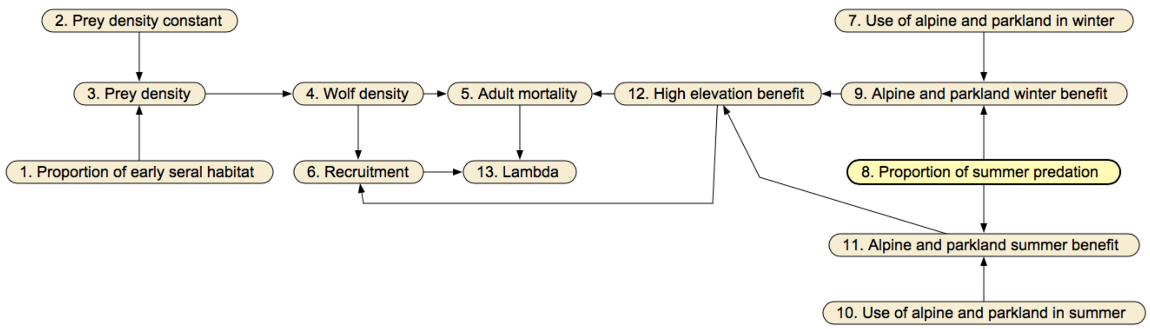

Figure 2. Bayesian Network developed to capture the working hypothesis describing the relationship between northern caribou population growth rates (lambda) and habitat, predator and prey conditions in the South Peace area.

1. Proportion of early seral habitat

The proportion of early seral habitat (*Early_seral*) is a model input and is expressed as proportion of the northern caribou herd range <1200 m. This elevation cut-off recognizes that early seral habitat at low elevations disproportionately contributes to the population of ungulates that benefit from early seral habitats (D. Seip, *pers. comm.*). Early seral habitat includes cutblocks and burns <40 years old, seismic lines, roads and other anthropogenic modifications.

2. Prey density constant

The relationship between the proportion of early seral habitat and prey density is uncertain and variable. This is represented in the model by the prey density constant (*Prey_constant*), which can be scaled depending on the results of moose, elk and/or deer surveys. Little data in the SP area are available to inform this relationship. Rowe (2006) estimated a density of 300 moose/1000 km^2 in the Murray and Wolverine River area (Management Unit 7-21). This density was used to benchmark the prey density constant at 0.25.

3. Prey density

Prey density (*Prey*) is expressed in moose equivalents/km^2 and is a function of the low-elevation proportion of a caribou range in an early seral condition (*Early_seral*) and the prey density constant (*Prey_constant*; Figure 3). The equation is:

*Prey (Early_seral, Prey_constant) = (Early_seral * 4 + (1 – Early_seral) * 0.2) * (Prey_constant)*

There are few empirical studies available to parameterize the relationship between early seral habitat and the density of prey. The model follows the results of Collins and Schwartz (1998) who found that moose densities in early seral forests were 20 times higher than in late seral. Serrouya et al. (2011) estimated that, if the landscape near Revelstoke, BC was governed by natural disturbances rather than industrial forestry, the abundance of suitable habitat for moose would decline by >80%. These studies inform the relative relationships expressed in the model and the prey constant then scales the density to approximate currently observed conditions.

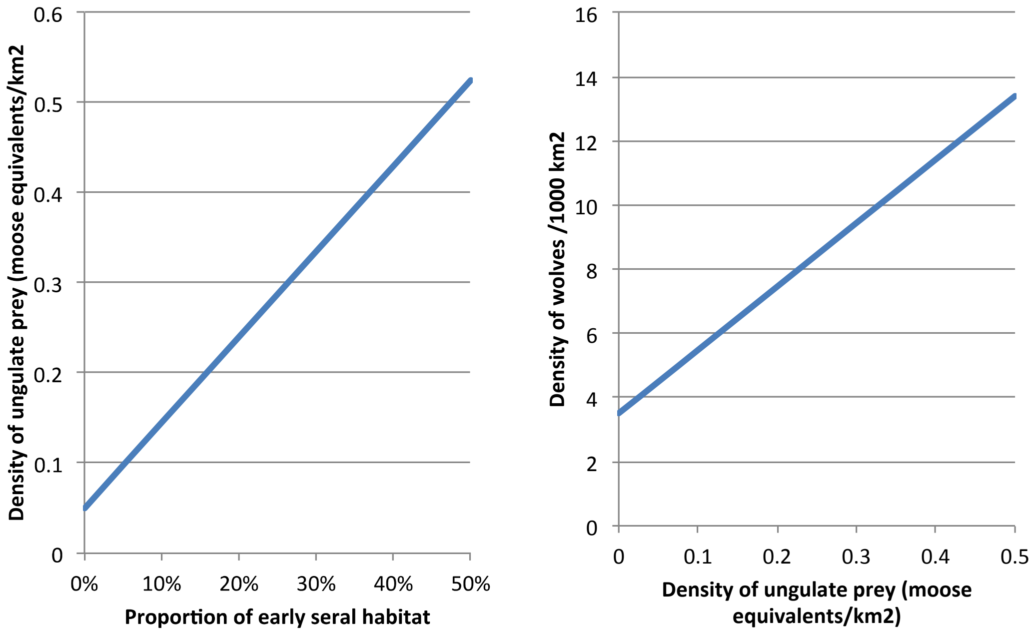

Figure 3. Modelled relationships between the proportion of caribou range in an early seral condition and the density of ungulate prey, and the density of ungulate prey and the density of wolves.

4. Wolf density

Wolf density (*Wolf*) is expressed as a density per 1000 km^2 and is a function of prey density (*Prey*; Figure 3). The equation is:

*Wolf (Prey) = 3.5 + 3.3 * Prey * 6*

The model uses the equation developed by Fuller et al. (2003), based on a meta-analysis of wolf and prey densities from North American studies. The equation is based on prey biomass units, where one unit is equal to a deer and 6 units is equal to a moose.

5. Adult mortality

The adult mortality rate (*Adult_mort*) is a function of wolf density (*Wolf*; Figure 4) and the survival benefit derived from spending a portion of the year at high elevation where predation is rare (*High_elevation_benefit*: see below):

*Adult_mort (Wolf, High_elevation_benefit) = (4.766 + 0.699 * Wolf ^ 1.275) * (1 – High_elevation_benefit)*

Bergerud (1988) developed the relationship between adult caribou mortality and wolf density based on a literature review of caribou and reindeer population studies. Other predators and mortality causes are captured in the constant (4.766), which agrees with work from west-central Alberta, where non-wolf mortality was estimated to be 4.8% (West Central Alberta Caribou Landscape Planning Team 2008).

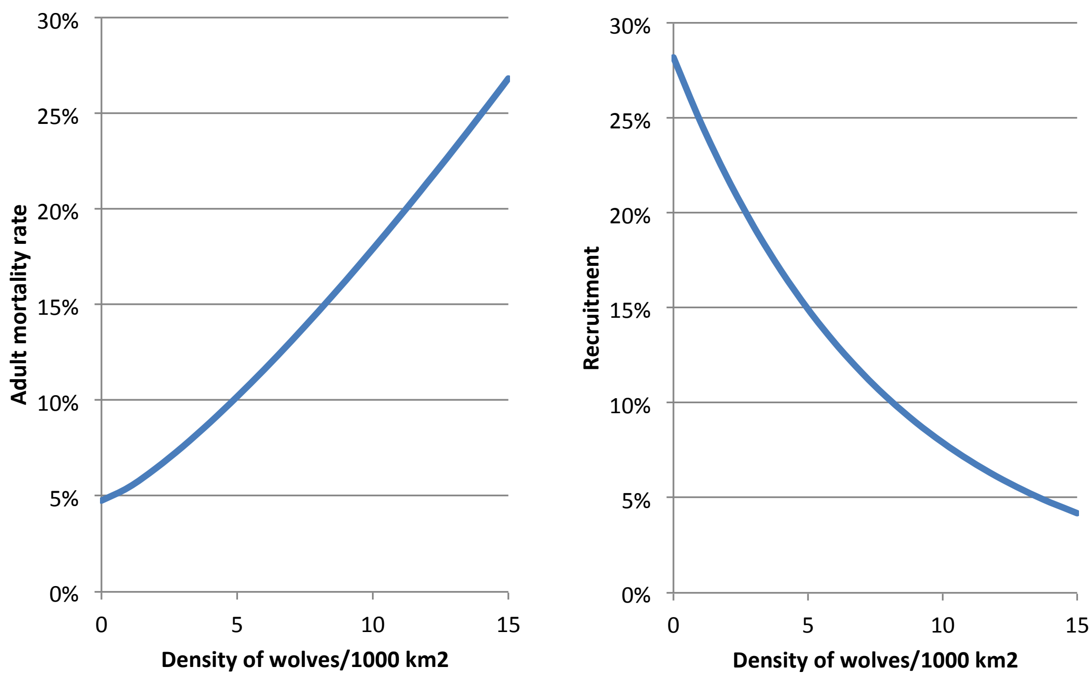

Figure 4. Modelled relationship between wolf density and caribou adult mortality and recruitment, from Bergerud (1988).

6. Recruitment

Recruitment of yearlings into the population (*Recruitment*) is expressed per 100 caribou and is a function of wolf density (*Wolf*; Figure 4) and the survival benefit derived from spending a portion of the year at high elevation where predation is rare (*High_elevation_benefit*: see below):

*Recruitment (Wolf, High_elevation_benefit) = (e ^ (3.34-0.127 * Wolf)) *(1 + High_elevation_benefit)*

Bergerud (1988) developed this relationship based on a literature review of caribou and reindeer population studies.

7. Use of alpine and parkland in winter

The proportion of time a caribou herd spends at high elevations in winter (*Alpine_winter_use*) determines the proportion of winter predation that northern caribou is protected from.

8. Proportion of summer predation

The distribution of predation between summer and winter (*Summer_predation*) is used to determine the proportions of predation that northern caribou are protected from.

9. Alpine and parkland winter benefit

The survival benefit (*Winter_benefit*) derived by a northern caribou herd's use of alpine habitat during winter is a function of the proportion of time spent in the alpine (*Alpine_winter_use*) and the proportion of predation (*Summer_predation*) that occurs there:

Winter_benefit (Alpine_winter_use, Summer_predation) = *Alpine_winter_use * (1 – Summer_predation)*

10. Use of alpine and parkland in summer

The proportion of time a caribou herd spends at high elevations during summer (*Alpine_summer_use*) determines the proportion of summer predation that northern caribou is protected from.

11. Alpine and parkland summer benefit

The survival benefit (*Summer_benefit*) derived by a caribou herd's use of alpine habitat during summer is a function of the proportion of time spent in the alpine (*Alpine_summer_use*) and the proportion of predation (*Summer_predation*) that occurs there:

Summer_benefit (Alpine_winter_use, Summer_predation) = *Alpine_winter_use * (1 – Summer_predation)*

12. High elevation benefit

The sum of winter and summer survival benefits is the total high elevation benefit (*High_elevation_benefit*):

High_elevation_benefit(Winter_benefit, Summer_benefit) = Winter_benefit + Summer_benefit

13. Lambda

Lambda is defined as the net birth rate per individual and is the output node of the model. It is a function of the adult mortality rate (*Adult_mort*) and recruitment of calves into the adult population (*Recruitment*):

Lambda (Adult_mort, Recruitment) = (100 +Recruitment – Adult_mort) / 100

Current and Future Population Growth Rate Estimates

Model parameters estimating current conditions were derived from analyses of available landscape disturbance information (see Appendix for detailed assumptions). Telemetry data indicated that northern caribou in the SP occupy areas with variable industrial footprints (Table 2).

Table 2. Model input parameters to characterize current conditions for northern caribou herds in the South Peace area.

Range	Early seral habitat <1200 m (% of low elevation range)	Use of BAFA/parkland in winter (% of telemetry locations)	Use of BAFA/parkland in summer (% of telemetry locations
Burnt Pine	24.0	69	39
Graham	12.0	42	46
Kennedy Siding	16.2	3	13
Moberly	26.6	64	47
Narraway	13.3	35	57
Quintette	17.3	69	76
Scott	15.4	48	30

Model output generally agreed with population growth rates derived from field data (Culling and Culling 2009, Alberta Sustainable Resource Development and Alberta Conservation Association 2010, Seip and Jones 2011; Figure 5).

Model runs based on the estimated future industrial build-out (see Appendix for detailed assumptions; Table 3) generated population growth rates that were lower than current for all herds except Kennedy Siding, where the creation of new early seral habitat is expected to be less than estimated forest regrowth.

Credibility intervals (the Bayesian equivalent of confidence intervals) were overlapping for all projections, suggesting considerable uncertainty (Figure 6).

Table 3. Estimated impact of future industrial build-out (20 years) and corresponding model parameters for the Bayesian Network developed to predict future population growth rates of northern caribou herds in the South Peace area.

Range	Estimated increase in early seral habitat due to forestry (% of low elevation range)	Estimated increase in early seral habitat due to oil and gas activity (% of low elevation range)	Estimated proportion of early seral habitat <1200 m, assuming 25% regrowth of current (% of low elevation range	Estimated impact of mines on BAFA/ parkland habitat (% of high elevation core habitat)	Estimated impact of wind power on BAFA/ parkland habitat (% of high elevation core habitat	Estimated reduction in high elevation habitat use in winter by caribou in response to impact (%)	Estimated reduction in high elevation habitat use in summer by caribou in response to impact (%)
Burnt Pine	6.8	1.2	26.0		2.4	5-25	0-10
Graham	1.4	1.0	11.3		3.8	10-30	5-15
Kennedy Siding	0.2	0.8	13.2		1.3	5-25	0-10
Moberly	7.2	1.2	28.3		1.8	5-25	0-10
Narraway	9.2	0.8	20.3		2.5	5-25	0-10
Quintette	9.7	1.0	23.9	3.4	3.9	15-35	10-20
Scott	5.0	0.7	17.3		0.0	0	0

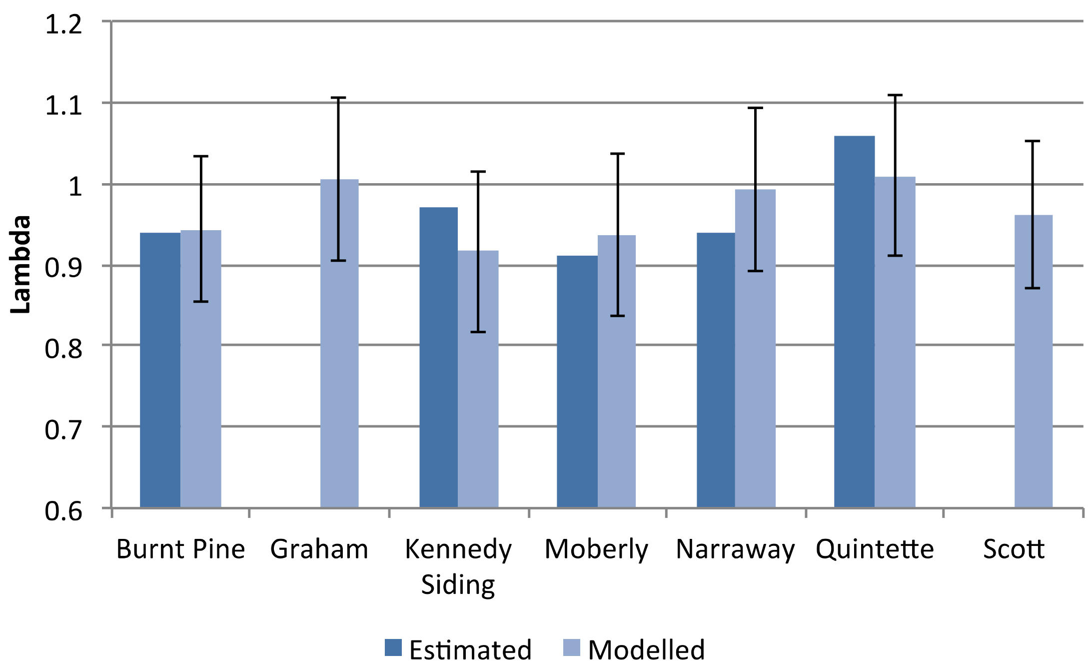

Figure 5. Population growth rates (lambda) estimated from field data (Estimated) and from the Bayesian Network model (Modelled). Lambda >1 indicates that the population is growing. Survival and recruitment data were not available to estimate the current population trend of Graham and Scott herds, although the Graham is considered stable (Culling and Culling 2009).

Estimated Future Population Size of SP Herds

Although the management model is static and deterministic, and designed to inform broad trends, general inferences can be made about the estimated future abundance of caribou in each range under status quo management (i.e., no incremental management actions). Assuming linear rates of development and population decline, the likely outcomes of status quo management include:

1. Extirpation of the Burnt Pine, Moberly and Kennedy Siding herds;
2. Declines in Graham, Narraway and Quintette herds;
3. Unknown outcomes for the Scott herd, until additional inventory can inform the model.

Under status quo management the total population of northern caribou in the SP area is expected to decline from 1100 currently to approximately 800 in 20 years. Of those, >600 would occupy the Graham range (Figure 7).

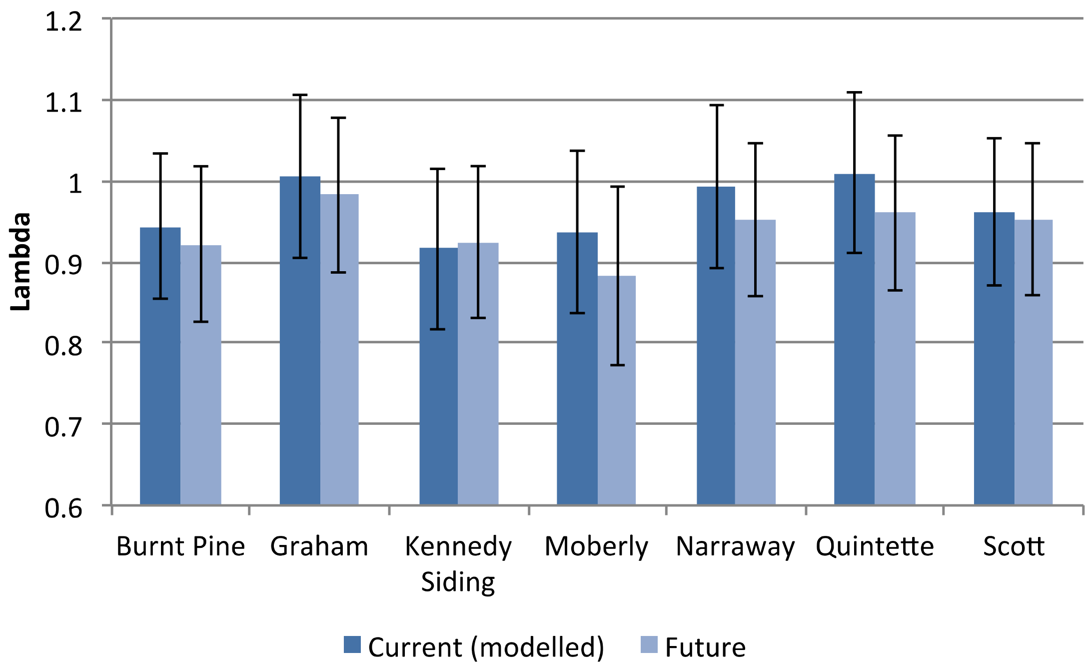

Figure 6. Expected future growth rates of South Peace caribou herds, based on an estimate of future industrial development.

Discussion

Limitations of the Model

A consequence of the working hypothesis is that it predicts that a herd could stabilize at a lower population size if a caribou herd increases their proportional use of higher elevations, thereby avoiding the demographic "sink" habitat at low elevations. There is some evidence that a larger proportion of northern caribou in the South Peace region are wintering at high elevations now than in the past (Sopuk 1985), and this strategy appears to have stabilized the Quintette and Graham herds, albeit at lower population sizes than observed 20-30 years ago (Backmeyer 2000). But other herds have experienced dramatic declines in the past 10-15 years and show no evidence of stabilizing.

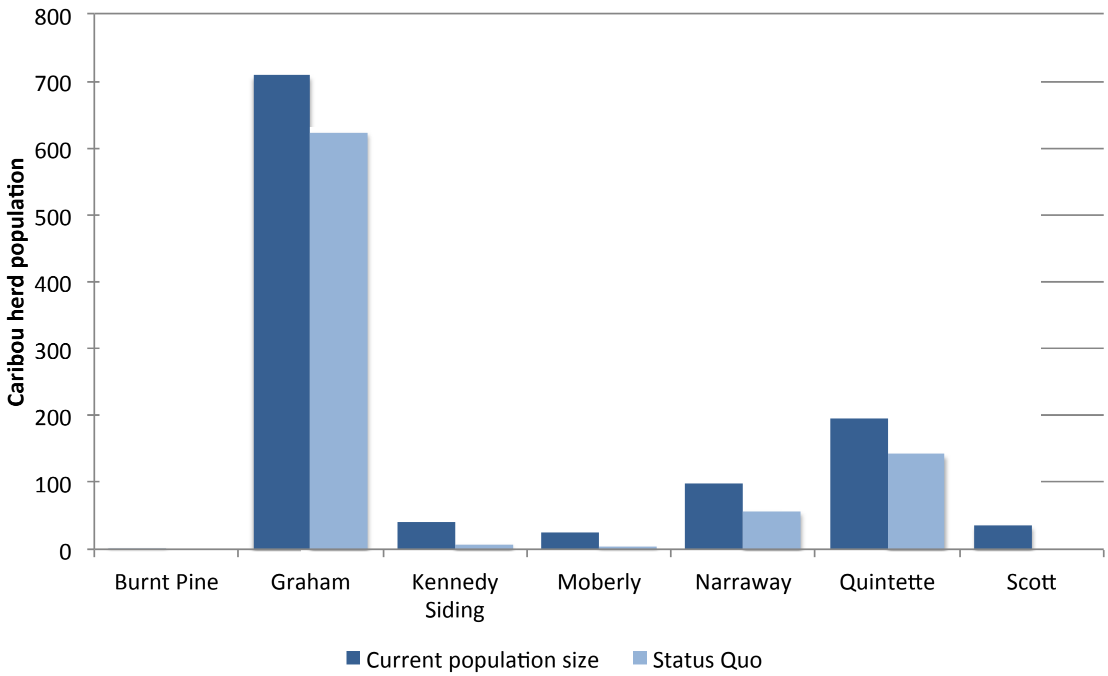

Figure 7. Current and estimated 20-year range populations in the South Peac, based on status quo management (i.e., no incremental management actions).

The reasons why the fates of different herds have been so different in the same region are unknown. In response to changing ecological conditions caribou can pursue different strategies:

1. Continue to use traditional areas where conditions are now suboptimal, leading to energetic stress and/or higher predation rates;
2. Move to other suboptimal habitats where energetic stresses or predation risks are higher; or,
3. Move to other suitable habitat and persist with minimal consequences.

Which strategy or strategies a caribou herd is likely to follow cannot be predicted. All three strategies have been observed in different areas; however, a decline in population size is often the result.

Caribou herds are also subject to stochastic events that are difficult to model. Significant declines in some herds have been recorded in a single year or over a few years, without any obvious change in habitat or predator–prey conditions (e.g., Kennedy Siding, Seip and Jones 2011). These rapid declines are likely caused by discrete predation events. For example, particular snow conditions may allow wolf packs to penetrate into core caribou habitat. If they encounter sizable caribou groups the effect on a small caribou population can be very significant. Of course the likelihood of these encounters increases as the wolf population grows.

Model Performance

Output of the management model generated predictions of current conditions that generally agreed with estimated population growth rates, although the credibility intervals (Bayesian equivalents of confidence intervals) were wide. The biggest discrepancies between modelled and estimated lambdas occurred for the Kennedy Siding, Narraway and Quintette herds (Figure 5). The model predicted a lower lambda than estimated for Kennedy Siding because the herd makes extensive use of low-elevation range in early winter. The model assumed this carries a high risk of predation, but in fact the predation on early winter range is very rare (D. Seip, *pers. comm.*).

Also, high-elevation habitat use by the Kennedy Siding herd is generally in the upper ESSF but below the parkland and alpine habitat that the model considers to be a refugium from predation. The modelled lambda for the Quintette herd was also lower than estimated, although in this case the calculated lambda from field data of 1.06 might be higher than the actual population growth rate because a significant increase in population size during the period used to calculate the lambda has not been evident. The modelled lambda for the Narraway herd was higher than the estimated. The distribution of telemetry data among elevation strata in the Narraway were similar to those observed in the Quintette, although a component of the Narraway herd remains at low elevations year-round (i.e., Bearhole/Redwillow). In this case the distribution of telemetry data might not reflect an unbiased sample of habitat use by the entire range population.

Any errors and biases in predictions of current conditions are also expressed in predictions of future population sizes and growth rates. In addition, the estimates of future industrial development were necessarily coarse and in some cases incomplete. Because development is market driven, the pace, extent, and mix of industrial activities will likely differ from predictions.

Despite these limitations, the qualitative conclusion of worsening population trends for all herds is likely valid, given that most herds are declining now and there is little evidence that conditions will improve in the next 20 years.

Implications of Status Quo Management

Future development at low elevations is predicted to increase the abundance of early seral habitats and therefore the density of moose and wolves. This is expected to increase the risk of predation on northern caribou. Development at high elevations is predicted to displace caribou from preferred range into suboptimal habitats where they are likely to face higher predation rates, although how strongly caribou will respond to this development by moving to lower elevations is uncertain. The result could be a 25% decline in the population of caribou throughout the SP area over the next 20 years, depending on the pace and scope of industrial development, the behavioural reaction of caribou to high-elevation development, as well as the effects of stochastic events. In addition, several herds are likely to be extirpated. The Burnt Pine herd is effectively extirpated now (D. Seip, *pers. comm.*). The Moberly is declining very rapidly, as is the Bearhole/Redwillow portion of the Narraway herd (D. Seip, *pers. comm.*). The Kennedy Siding herd has stabilized after a recent significant decline, and it may persist, barring any further significant stochastic events.

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Appendix: Industrial Build-out Assumptions

Forestry

- Estimates incorporate the size and distribution of cut among ranges, where provided
- 10-year estimates were doubled
- Aspatial estimates were allocated proportionally among ranges
- Cut in areas where harvest plans were not provided were estimates from areas where harvest plans were available, based proportionally on area.
- Assumed 25% regrowth of existing early seral habitat during the next 20 years

Mining

- Included all spatial estimates of expected mine footprints provided by MABC

Oil and Gas Development

- Assigned 10 m width to linear features
- Assumed 3D seismic does not contribute to early seral habitat
- Assumed all future seismic is 3D
- Defined area of current development as current area tenured but undeveloped:
    - Buffered all well sites in the project area, regardless of status, by 725 m (slightly larger than a gas spacing unit)
    - Dissolved the buffers and included slivers less than the size of a gas spacing unit
    - Subtracted the buffered area from the total area of all current PNG tenures (after dissolving overlapping tenures)
- Assumed build-out density of one 1.44 ha well pad and 1220 m of new linear development per gas spacing unit (159 ha)
- Assumed build out would occur over 75% of undeveloped tenure over the next 20 years

Wind Power Development

- Based on Table 4 of letter from Clean Energy BC to Nick Crisp dated 30 April 2012
- Assumed all impacts occur in BAFA or parkland habitats