

APPENDIX F:

Methods and Summary of Key Results for Bathurst Caribou Range Plan using the CircumArctic *Rangifer* Monitoring and Assessment (CARMA) Integrated Caribou Model

1. Caribou computer model

While traditional and scientific knowledge provide us with an understanding of the dynamics of caribou populations in the past and present, computer models based on this knowledge provide a way of simulating real world processes to learn how key factors and stressors may influence caribou populations in the future. The BCRP Working Group used a computer simulation model to explore and understand the relative effects of different natural and human-caused disturbances that may influence the population health of the Bathurst caribou. Figure 1 illustrates an important impact pathway of human land use to barren-ground caribou, which was simulated in the model as the cumulative disturbance that caribou are subjected to when they encounter multiple anthropogenic footprints¹ and associated disturbances on their annual range.

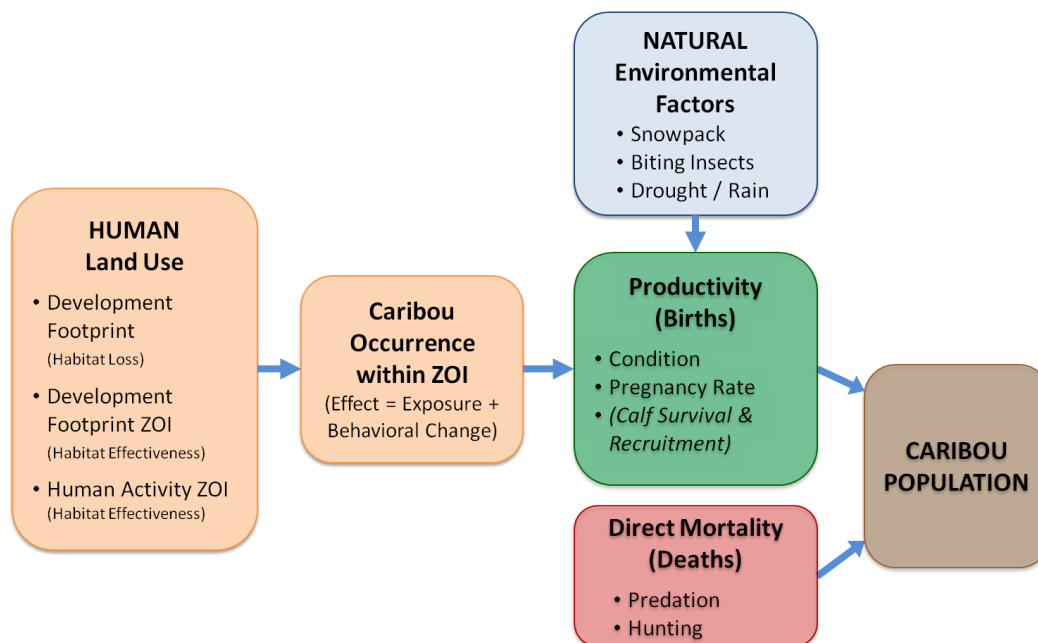


Figure 1. Conceptual impact pathway of human land use disturbance and other key factors that influence vital rates and caribou population health

¹ Anthropogenic footprints are the human-made permanent or temporary features that occupy space on the landscape such as winter and all-season roads, towns, cities, mineral exploration sites, transmission lines, mines, and industrial plants.

In the model, each footprint type on the range was assigned a zone of influence (ZOI), which was the associated area around the direct footprint that corresponds with an avoidance response by caribou. The model simulated and tracked the cumulative number of encounters that a caribou may have with each type of anthropogenic footprint and associated ZOI on its annual range. Thus the cumulative number of days a caribou encountered a footprint ZOI throughout a year, represented the total time when a caribou's daily food intake (i.e., energy and protein intake) and activity budget may be influenced by human-caused disturbance. This encounter rate provided a means of simulating how seemingly small impacts to daily food intake and activity budgets on individual caribou may have cumulative population-level effects on herd productivity through reductions in pregnancy rate and/or early calf survival (Figu).

The CircumArctic Rangifer Monitoring and Assessment (CARMA) integrated caribou model (Russell et al. 2005, Gunn et al. 2013, White et al. 2013, White et al. 2014) was the simulation tool used by the Working Group to develop a deeper understanding of the potential cumulative effects of industrial development and anthropogenic footprints on Bathurst caribou. The CARMA caribou model was comprised of several interacting components including a movement model, energy-protein model and a population model. In addition to evaluating the magnitude of disturbance effects to population productivity (and potentially mortality), the CARMA modeling framework permitted an assessment of the relative contributions of natural environmental factors, as well as assumptions about direct sources of mortality that were attributed to predation and/or hunting (Figu).

The methodology and assumptions adopted for running the integrated model on the Bathurst herd were described by Russell et al. (2015) in their project report commissioned by the Northwest Territories Cumulative Impact Monitoring Program (NWT CIMP), and are summarized below.

The initial inputs were satellite or GPS collar movement data, spatial layers for vegetation, climate, harvest risk areas, the initial industrial development footprint, and future development rates and the ZOI. These inputs were then integrated in to several modeling components.

- 1) A caribou movement model estimated the daily environment encountered by an individual caribou and included activity budgets, forage biomass and climate variables. Based on telemetry data, the movement model used observed caribou migration patterns across the herd's range, and tracked all encounters with development footprints (and associated ZOIs), and harvest risk areas. The model estimated the consequences of those daily movement patterns on caribou behaviour (i.e., activity budgets) and available forage. For example, when caribou encountered a ZOI, their daily activity budget is adjusted in the model through reductions in feeding time (6%) and feeding intensity (3%) and an increase in activity (3%) (D. Russell pers. comm.).
- 2) Those data become inputs in to an individual caribou energy-protein (body condition) model, which tracked daily food intakes and metabolic requirements, combined with any future projections of vegetation change, to predict changes in body condition of an individual caribou over time.
- 3) The output of the body condition sub-model was then used to simulate changes in caribou fecundity and survival which, along with the harvest risk projections of the movement model, became inputs to a population model that was used to simulate dynamics in future size and age-sex composition of the caribou herd.

For the Bathurst Range Plan, scenarios were designed by the range planning team in collaboration with the modelers (D. Russell and A. Gunn). The goals of the scenario analyses were to:

- address broad questions about the CARMA caribou model and report (Russell et al. 2015), which had been posed and discussed by the Bathurst Range Plan Working Group (September 2015);
- provide simulation results to illustrate and discuss educational value of the CARMA caribou model and scenario modeling to the Working Group; and
- engender support from the Working Group to conduct additional analyses with the CARMA caribou model (and modelers) and further explore relative potential impacts of industrial development and disturbance to caribou within a cumulative effects context.

2. Scenarios

Two sets of scenario analyses were conducted. The first focused on using the model as a learning tool and to address questions posed by the BCRP Working Group, and the second set of analyses were conducted to further explore effects of development and disturbance to caribou. Although both sets of scenario analyses were based on contrasting different future trajectories of landscape development, a key distinction was that in the first set of analyses the anthropogenic footprints remained constant over the entire 16-year simulation period within each level of development². Whereas in the second set of analyses, footprint amounts changed over a 24-year simulation period according to development lifecycle assumptions that were defined for all mining projects, which included the different stages of construction, operations, closure and reclamation (see **Section 3.4** of main report).

Scenario Set 1

The simulations conducted in Scenario Set 1 were designed to learn more about the model, the relative importance of key factors on a caribou population, and to address questions discussed and posed by the BCRP Working Group, which included the following:

1. What is the relative importance of initial population size, population trend, and development scenario (i.e., footprint) on a caribou population?
2. How do predation and hunting affect caribou population trend?
3. How do environmental conditions affect a caribou population?

Caribou Population and Other Model Input Assumptions

Table 1 summarizes the key risk factors, along with associated input assumptions and caribou response variables for the scenario modeling. Table 2 summarizes the respective scenario designs and specific input assumptions that were used to address the three questions posed by the Working Group.

² The initial analyses were conducted using an early version of the Development Scenarios, where a Current, Future Low, and Future High scenario was created. These three scenarios included project assumptions and timelines very similar to the later CASE 1, CASE 2 and CASE 3 scenarios but did not incorporate changes in footprint dynamics over the duration of the scenario period.

For the caribou population assumptions, the input variables centered on the initial population size and mortality rates. Three options were used for initial population sizes that included 50,000, 15,000, and 7500 caribou respectively (Table 2). Assumptions for high, medium, and low mortality rates are summarized according to five age classes for female and male caribou in Table 3, with corresponding population growth rates shown in Figure 2. The mortality assumptions were considered to largely be a reflection of natural mortality rates primarily due to predation.

A “low” hunting level resulted in an annual offtake of 200 caribou with a sex ratio of three bulls to every cow (i.e., 150 bulls and 50 cows); and “high” hunting was determined as 3% of the population removed every year with 2 females taken for every male (Table 2). Environmental conditions were based on average temperatures from mid-May to early August and expressed as average growing degree days (GDD) for that period. A low GDD condition was based on 1.5°C cooler than average temperatures, and the high GDD level was 1.5°C warmer than average (Table 2) in spring and summer months.

Table 1. Key factors, input assumptions, and response variables for caribou model simulations in Scenario Set 1.

Key Factors for Model Simulations	Input Variable Assumptions	Caribou Population Response Variables
Initial Population Conditions	<ul style="list-style-type: none"> Population Size Population Trend (mortality) 	Population Trend Pregnancy Rate Calf Mortality Encounter Rate
Development Scenarios	<ul style="list-style-type: none"> No Development Current Development Future – Low Future – High 	
Population Risk Factors	<ul style="list-style-type: none"> Mortality <ul style="list-style-type: none"> Predation & Harvest Productivity Environmental conditions (climate) 	

Table 2. Comparative summary of scenario designs in Scenario Set 1 to address three modeling questions posed by Bathurst Caribou Working Group.

a) Question 1: relative importance of initial population size, trend, and development		b) Question 2: predation and hunting		c) Question 3: environmental conditions	
Key Factors	Input Assumptions	Key Factors	Input Assumptions	Key Factors	Input Assumptions
1) Initial Population Size	<ul style="list-style-type: none"> 50,000 (50K) 15,000 (15K) 7,500 (7.5K) 	1) Initial Population Size	<ul style="list-style-type: none"> 15,000 (15K) 7,500 (7.5K) 	1) Initial Population Size	<ul style="list-style-type: none"> 50,000 (50K) 15,000 (15K) 7,500 (7.5K)
2) Population Trend (Mortality)	<ul style="list-style-type: none"> Low Mortality Medium Mortality High Mortality 	2) Population Trend (Mortality)	<ul style="list-style-type: none"> Low Mortality Medium Mortality High Mortality 	2) Population Trend (Mortality)	<ul style="list-style-type: none"> Low Mortality Medium Mortality High Mortality
3) Development Scenarios	<ul style="list-style-type: none"> No Development Current Future-Low Future-High 	3) Development Scenarios	<ul style="list-style-type: none"> Current 	3) Development Scenarios	<ul style="list-style-type: none"> Current
3 x 3 x 4 = 36 simulations		4) Hunting	200 caribou (1F:3M) High Hunting: 3% of population (2F:1M)	4) Environmental Growing Degree Days (GDD)	<ul style="list-style-type: none"> Low (-1.5°C) Average High (+1.5°C)
		2 x 3 x 1 x 3 = 18 simulations		3 x 3 x 1 x 3 = 27 simulations	

Table 3. Annual mortality rate assumptions for female and male Bathurst caribou in five age classes.

Sex	Age Class	High Mortality			Medium Mortality			Low Mortality		
		mean	min	max	mean	min	max	mean	min	max
Female	Calves	0.450	0.405	0.495	0.430	0.387	0.473	0.350	0.315	0.385
Female	Yearlings	0.130	0.117	0.143	0.100	0.090	0.110	0.080	0.072	0.088
Female	2-yr olds	0.160	0.144	0.176	0.130	0.117	0.143	0.080	0.072	0.088
Female	3-8 yr olds	0.300	0.270	0.330	0.160	0.144	0.176	0.100	0.090	0.110
Female	9+ yr olds	0.350	0.315	0.385	0.210	0.189	0.231	0.150	0.135	0.165
Male	Calves	0.500	0.450	0.550	0.480	0.432	0.528	0.400	0.360	0.440
Male	Yearlings	0.200	0.180	0.220	0.150	0.135	0.165	0.130	0.117	0.143
Male	2-yr olds	0.210	0.189	0.231	0.180	0.162	0.198	0.130	0.117	0.143
Male	3-8 yr olds	0.350	0.315	0.385	0.210	0.189	0.231	0.150	0.135	0.165
Male	9+ yr olds	0.400	0.360	0.440	0.260	0.234	0.286	0.200	0.180	0.220

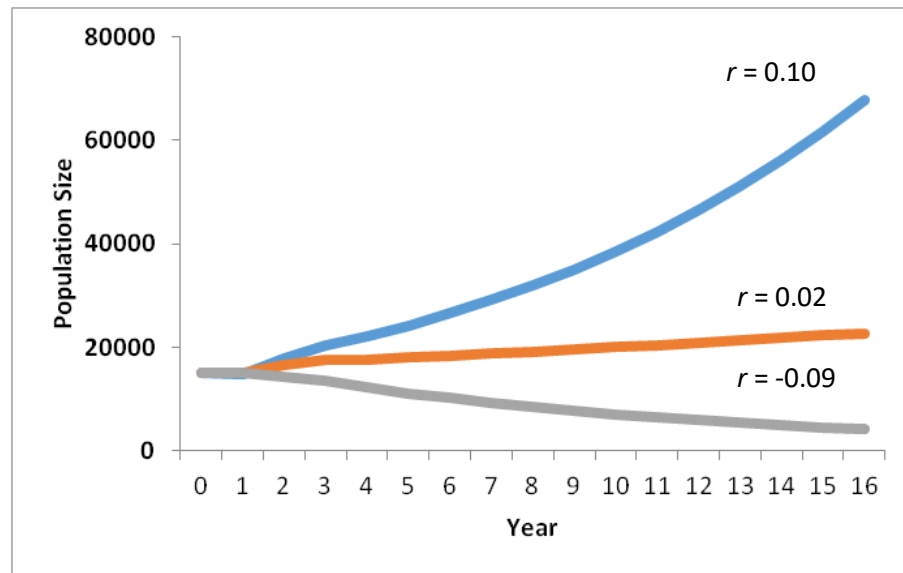


Figure 2. Mean annual exponential rates of increase for a modelled caribou population starting at 15,000 individuals and corresponding to simulated levels of low ($r = 0.10$), medium ($r = 0.02$), and high ($r = -0.09$) mortality rates from Table 3.

Industrial Development and Anthropogenic Footprint

- Landscape disturbance was simulated based on plausible and contrasting range-scale mine development trajectories over a 16-year period (i.e., 2 caribou generations).
 - With the assistance of a mineral task group, the BCRP Working Group defined future development scenarios to explore plausible patterns and amounts of development footprint within the Bathurst range. In summary, four development scenarios were defined to compare different relative amounts of future industrial activity including: “No Development”, “Current Development”, “Future-Low”, and “Future-High” (see **Footnote 2**, above).
 - A ZOI was attributed to each identified project and anthropogenic footprint, as described in **Appendix D**. The disturbance for each development trajectory was represented by the

- anthropogenic footprint (& ZOI) and was held constant for the duration of the simulation period.
- To estimate the potential encounter rates of caribou to anthropogenic footprints in each of the development trajectories, 100 movement paths were randomly selected from the 2007-2014 GPS collar locations of Bathurst caribou.

Scenario Set 2

The simulations in Scenario Set 2 were conducted to describe relative potential impacts of industrial development and disturbance to caribou. The development scenarios were updated by the mineral task group and BCRP Working Group to reflect more plausible temporal trajectories for mineral development projects based on a simplified mine life-cycle approach that consisted of three phases including construction, operations, and reclamation (see **Section 3.4** of main report)

Caribou Population and Other Model Input Assumptions

Table 4 shows that the focus of Scenario Set 2 was on the relative effects of development scenarios on caribou population response variables. The initial population size was set at 20,000 caribou to reflect results from the 2015 Bathurst calving ground photographic survey (Boulanger et al. 2016). Population trend was based on assumptions for high, medium and low natural mortality rates (Table 3), and hunting was assumed to be zero. Environmental conditions reflected average temperatures and GDD's for the period of mid-May to early-August. Table 5 summarizes the scenario design and specific input assumptions that were used to further assess potential impacts of industrial development scenarios on caribou.

Table 4. Key factors, input assumptions, and response variables for caribou model simulations in Scenario Set 2.

Key Factors for Model Simulations	Input Variable Assumptions	Caribou Population Response Variables
Initial Population Conditions	• Population Trend (mortality)	Population Trend Pregnancy Rate Encounter Rate
Development Scenarios	• No Development • Case 1 – Declining Development • Case 2 – Continuing Development • Case 3 – Increasing Development	

Table 5. Summary of scenario design in Scenario Set 2 to explore relative effects of development scenarios on caribou.

Key Factors	Input Assumptions
1) Initial Population Size	• 20,000 (20K)
2) Population Trend (Mortality)	• Low Mortality • Medium Mortality • High Mortality
3) Development Scenarios (5 time steps per Case)	• No Development • Case 1 - Declining • Case 2 - Continuing • Case 3 - Increasing
4) Hunting	• None
5) Environmental Growing Degree Days (GDD)	• Average
1 x 3 x (5 x 4) x 1 x 1 = 60 simulations	

Industrial Development and Anthropogenic Footprint

- Landscape disturbance was simulated from four industrial development scenarios that were based on plausible mine life cycle trajectories over a 24-year period from 2016 to 2040 (i.e., 3 caribou generations) for the annual Bathurst range.
 - In addition to a “No Development” base-case, three development cases represented plausible future scenarios for industrial development in the Bathurst range, and each case represented a different relative amount of future industrial activity. The scenarios were created using information based on known or reasonably foreseeable future mineral development and transportation projects that may occur in the next 24 years. CASE 1 represented a situation of declining development, where the existing operating diamond mines and TCWR cease operations by 2040, and no new mines were brought to production. CASE 2 projected a similar level of development into the future as current, where the existing diamond mines are replaced by new mineral development projects in the coming decades, and the southern part of the TCWR is replaced by an all-season road. CASE 3 represented an increasing level of development with new all-season road infrastructure in Nunavut and several new mines being developed, both in Nunavut and Northwest Territories. **Figure 11** of main report shows the results of each scenario on the range map at year 2040 and **Section 3.4** of main report provides a more detailed description of the scenarios.
- The ZOIs described in **Appendix D**, were attributed to each of the anthropogenic footprints represented within each development trajectory of Scenario Set 2. To reflect the changing amount of industrial footprint over the 24-year simulation period, each development trajectory was broken into five discrete time steps that occurred at 6-year intervals. Thus, the disturbance during each time slice was represented by the anthropogenic footprint (and associated ZOI) that occurred at 2016, 2022, 2028, 2034, and 2040 respectively.
- Fifty movement paths were selected from the 2009-2015 GPS collar locations of Bathurst caribou to simulate potential encounter rates of caribou to anthropogenic footprints at each of the five time steps within the respective development trajectories.

3. Key Results and Findings

Future land use scenarios provide insight into the amount of human-caused change that may occur in different parts of the range in the future.

Scenario Set 1 - Results

The key results in this section are organized according to the three questions posed by BCRP Working Group.

1) What is the relative importance of initial population size, population trend, and development scenario (i.e., footprint) on a caribou population?

Based on model runs to address this question, the key finding was increased levels of industrial development reduced population growth by reducing pregnancy rates and herd productivity. This effect was small compared to assumptions on direct mortality rates, but the effect is significant and important especially when a population would otherwise be stable or declining in the absence of industrial development (i.e., during a declining phase of a natural population cycle).

Within a development level, population trend was not affected by initial population size and was driven primarily by mortality levels (Figure 3). Similarly when comparing scenarios across development levels, population trend was not affected by initial population size and was driven primarily by mortality levels. However, development levels had a synergist effect with mortality levels and reduced population trend further, as shown by the declining slopes in population growth rate (r) as development levels changed from no development to a future-high scenario (Figure 4). This was most clearly shown for populations that had a medium level of mortality (red lines in Figure 4), where under a no development scenario the population would be increasing (i.e., it had a positive r value) but when the population was simulated with the same assumptions except that it was in a future-high development scenario the population switched to a declining trend (i.e., it had a negative r value).

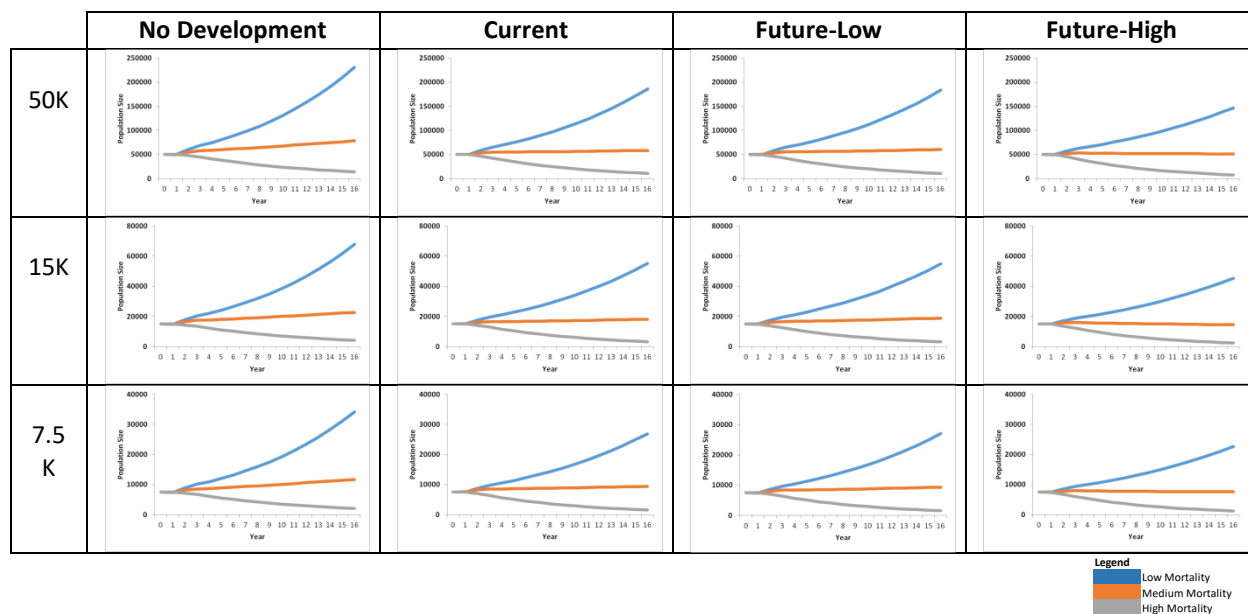


Figure 3. Comparison of simulated caribou population trends showing the relative influence of industrial development levels (no development, current, future-low, and future-high), initial population sizes (50K, 15K, and 7.5K), and different rates of natural mortality (low, medium, and high).

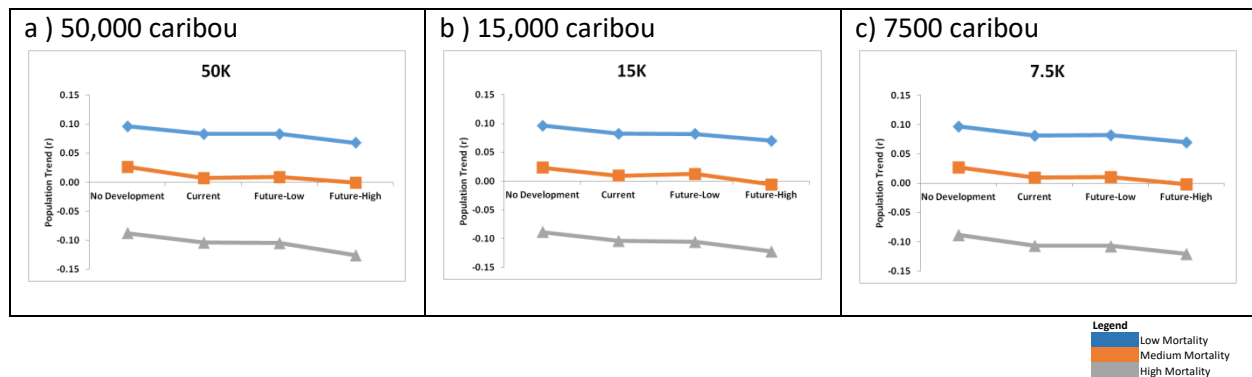


Figure 4. Influence of industrial development levels and rates of natural mortality on simulated caribou population growth rates (r), with scenarios started at different population sizes.

Increased industrial development levels resulted in incrementally higher encounter rates of caribou with human footprints (Figure 5a), which in turn imposed higher energetic costs to adult females and reduced their fall pregnancy rates (Figure 5b). The reduction in pregnancy rates reduced overall population productivity and had a synergistic effect with mortality rates, which together resulted in higher rates of population decline in scenarios with more industrial development.

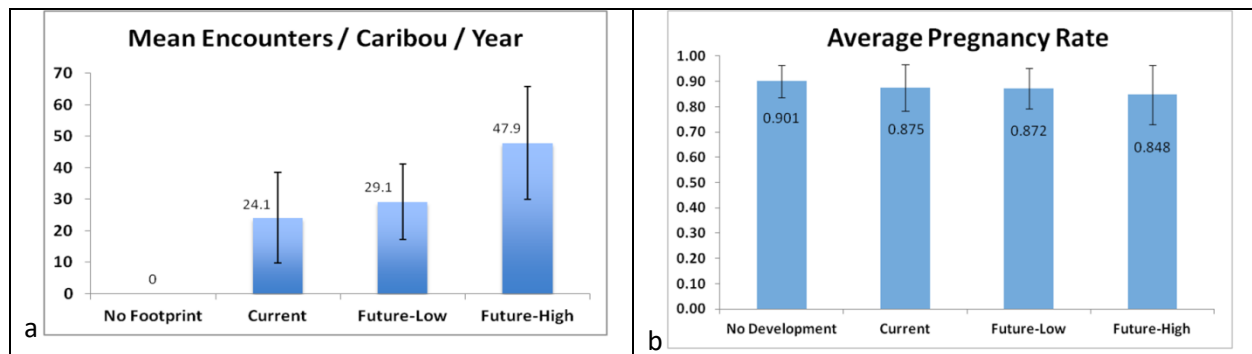


Figure 5. Influence of industrial development scenarios on a) average encounter rates (± 1 standard deviation) of caribou with a human footprint, and b) average pregnancy rate (± 1 standard deviation).

2) How do predation and hunting affect caribou population trend?

The model simulations to explore this question provided three key findings:

- Predation and hunting may have additive effects on population health by increasing total mortality in a caribou herd. In the simulation model, the additive effect of hunting may accelerate a decline for a population that has pre-existing medium and/or high rates of natural mortality from predation (and other causes) (Figure 6).
- A harvest that removes the same number of animals annually may accelerate a rate of decline as the population gets smaller, because a constant harvest rate may result in an increasing proportion of animals that are removed as a population declines (Figure 7).
- High and selective harvest mortality of females may have strong additive and negative effects on population trend (Figure 7) because it not only contributes to increasing mortality rates, but also reduces future rates of productivity (i.e., numbers of newborn calves).

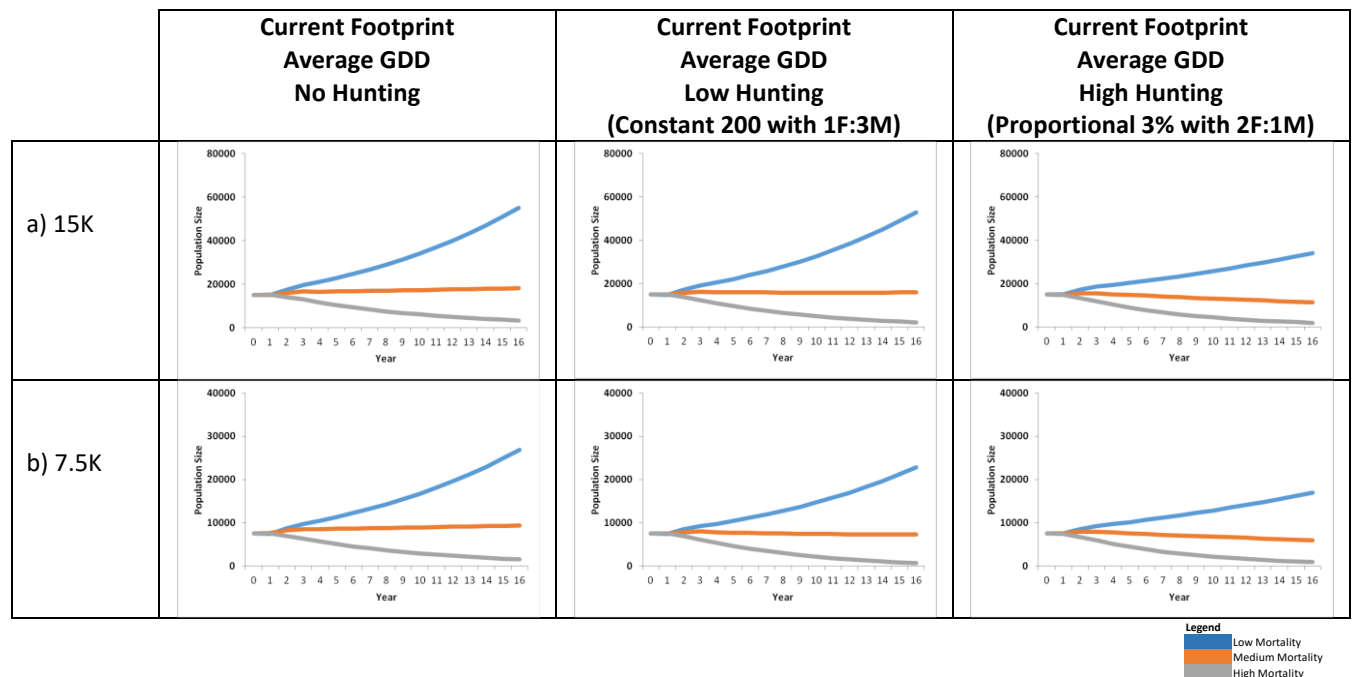


Figure 6. Comparing the influence of mortality and hunting levels on caribou population trend over time with initial population size at a) 15,000 caribou and b) 7500 caribou.

The additive and interactive effect of hunting with natural mortality rates is illustrated in Figure 7, which summarizes scenarios that applied three harvesting strategies to two populations with different initial sizes and contrasts three levels of mortality. The overall patterns are consistent between Figure 7a and 7b and show that the rates of mortality had the strongest overall influence on population trend. For example under the assumption of low mortality a population will continue to grow under both harvesting strategies regardless of whether the initial population size is 15,000 or 7500 caribou, although the high harvest strategy had the greatest influence on reducing population growth rate (r). Under medium mortality assumptions and no hunting the population increased at $\sim 2\%$ per year (i.e., $r = 0.02$). Population growth rate decreased when the low hunting strategy was applied, and shifted to a declining trend for the small initial population (Figure 7b). In comparison, the high hunting strategy shifted both scenarios (with different initial population sizes) to a declining trend (Figure 7b). Under high mortality assumptions and no hunting, the population was declining at $\sim -9\%$ per year (i.e., $r = -0.09$). Under this mortality assumption, both the low and high hunting strategies increased the rate of decline. In the scenario with a small initial population size, the low hunting strategy had a greater additive effect on the rate of decline because the constant annual harvest rate of 200 became an increasingly larger proportion of the small population as it declined over the 16-year simulation period.

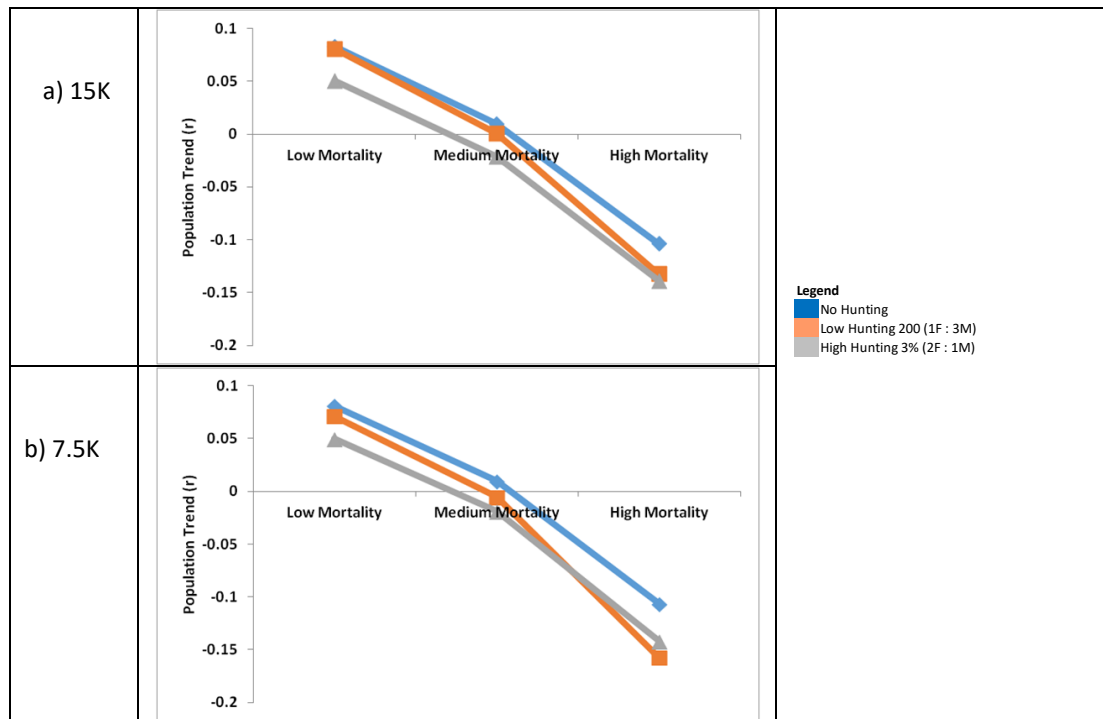


Figure 7. Comparing the influence of mortality and hunting levels on population rate of growth (r) with initial population size at a) 15,000 caribou and b) 7500 caribou.

3) How do environmental conditions affect a caribou population?

The model simulation results to explore the influence of environmental conditions are shown in Figure 8. A key finding was that environmental variability is also an important factor that influences caribou population productivity, through effects on nutrition (i.e., timing of plant green-up which provides early nutrition for lactation and re-gaining body condition, drought impacts on plant biomass and nutritive quality), and activity budgets (i.e., environmental conditions may increase harassment from biting and parasitic insects, which can reduce foraging time and increase energy expenditures).

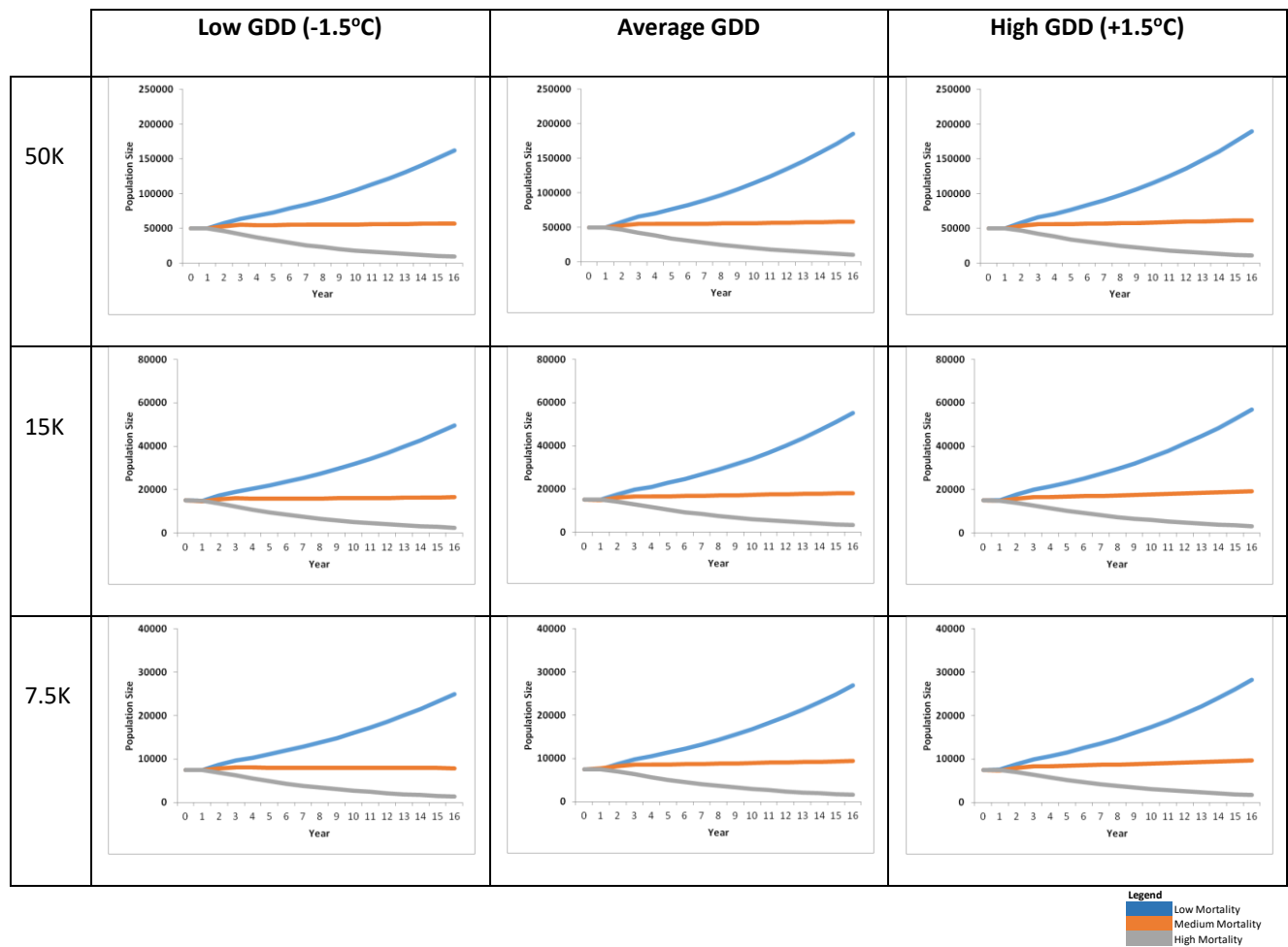


Figure 8. Simulated caribou population trends that compared the relative influence of environmental conditions from mid-May to early August, defined as low growing degree days (GDD), average GDD, and high GDD. Simulations were based on current development with three initial population sizes (50K, 15K, and 7.5K), and three rates of natural mortality (low, medium, and high).

Figure 9 illustrates the relative costs of development and environmental conditions by comparing the numerical difference in caribou population trends at the end of the 16 year simulation period. The middle bar represents the number of caribou that declined over the simulation in comparison to a reference case with identical assumptions except that there was no anthropogenic footprint on the range. Figure 9 expressed the opportunity costs between different scenarios as the number of caribou that were foregone either due to increased development, or the costs associated with the influence of environmental factors.

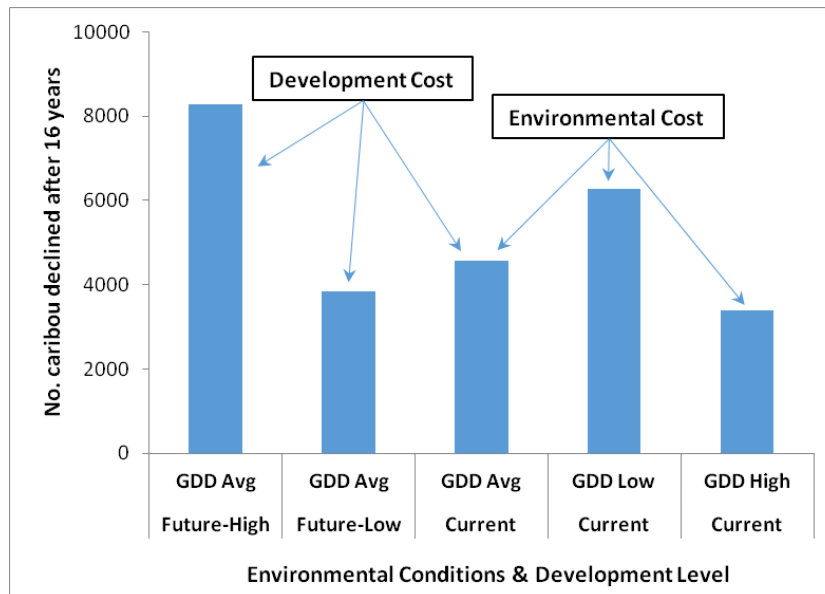


Figure 9. Relative decline in caribou abundance after 16-year simulation period compared to a reference case scenario with average mortality assumptions, average GDD environmental conditions, and no development footprint.

Scenario Set 2 - Results

The simulations in Scenario Set 2 provided insight in to potential effects of development scenarios on Bathurst caribou, and key results are summarized in this section starting with encounter rates of individual animals, followed by an overview of the potential impact on productivity, and concluded with a description of population-level responses.

1) Encounter rates of caribou with anthropogenic footprints

Caribou encounters were simulated in the movement model based on the intersection of 50 Bathurst caribou movement pathways with current and future footprints (including ZOIs) that were defined for each of three development cases over a 24-year simulation period. The average number of encounters was lowest in development Case 1, intermediate in Case 2, and highest in Case 3 (Figure 10). Within a development Case, the temporal pattern of encounter rates across five timesteps reflected the net amount of footprint that was active on the range during the development scenario. The first 5 bars in Figure 10 shows that average encounter rates for caribou declined over time in Case 1, which corresponded to the declining level of industrial activity for this scenario over the 24 year simulation period. In comparison, the trend in encounter rates for Case 2 (timesteps 1-5) showed a rapid increase within the first 6 years, followed by a steady decline in encounter rates for the rest of the simulation period (bars 2-1 to 2-5 in Figure 10). Similarly, under the assumption that industrial development would steadily increase for Case 3, the average encounter rate of caribou also increased from the start of the simulation period to the end (bars 3-1 to 3-5 respectively in Figure 10). Although there was considerable seasonal variability when caribou encountered anthropogenic footprints in the development scenarios, most encounters occurred during fall, summer and winter respectively (Figure 10).

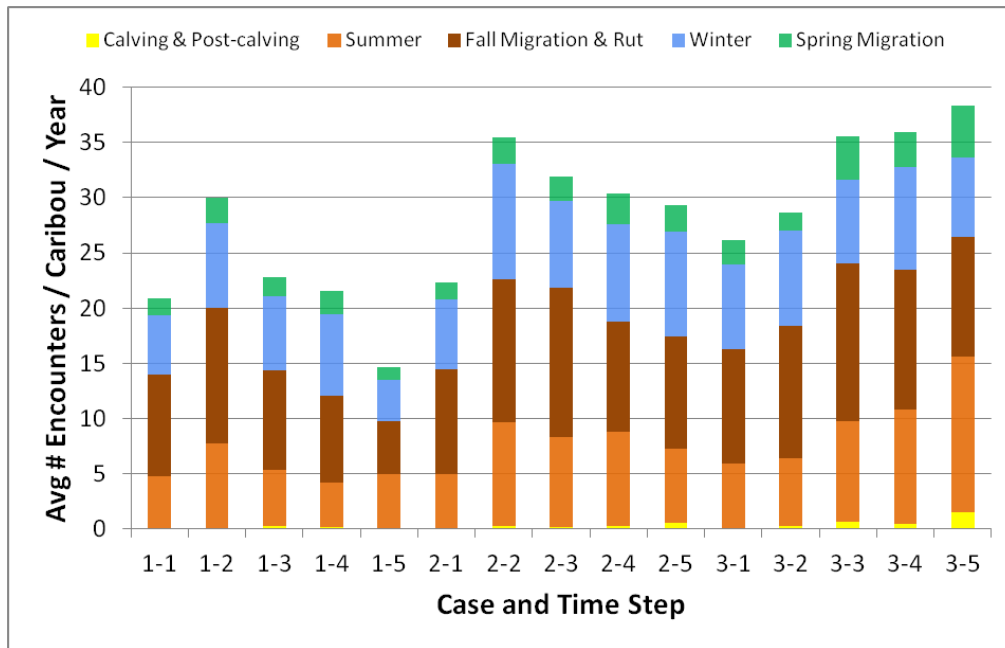


Figure 10. Magnitude and seasonality of encounter rates of caribou with three development case scenarios, with each case comprising of five time steps spanning a 24-year simulation period.

Because encounters are based on the overlap between a sample of caribou movement paths (2009 – 2015 GPS collars) and the spatial extent of the current and future footprints, the absence of one or both of those features results in the absence of an encounter between caribou and footprint. Thus, the virtual absence of current and future anthropogenic footprint in RAA3 and RAA5 results in there being no encounters in either area. Conversely, in areas where there is current and future footprint and is used by caribou, then there is a correlation between total footprint and average encounter rates (Figure 11). There was a stronger correlation between total footprint and encounter rate in RAA1 and RAA2, compared to RAA4 (Figure 11). Although at the annual range-scale the correlation was strong (Figure 11d).

A comparison of temporal trends in encounter rates for the three development cases at the RAA-level suggests: a) encounter rates in RAA1 will increase the most according to the development case assumptions (Figure 12a); b) encounter rates are highest in RAA2 and will likely remain relatively constant especially for development Cases 2 and 3 (Figure 12b); and c) encounter rates in RAA4 are comparatively lower, but encounters are consistent across all cases, with the exception of Case 1, timestep 5, which showed a marked decline (Figure 12c). At the annual range scale, the average encounter rate would remain elevated and increase compared to current conditions for development Cases 2 and 3 (Figure 12d). In contrast, the average encounter rate would decrease over time under assumptions of Case 1 (Figure 12d).

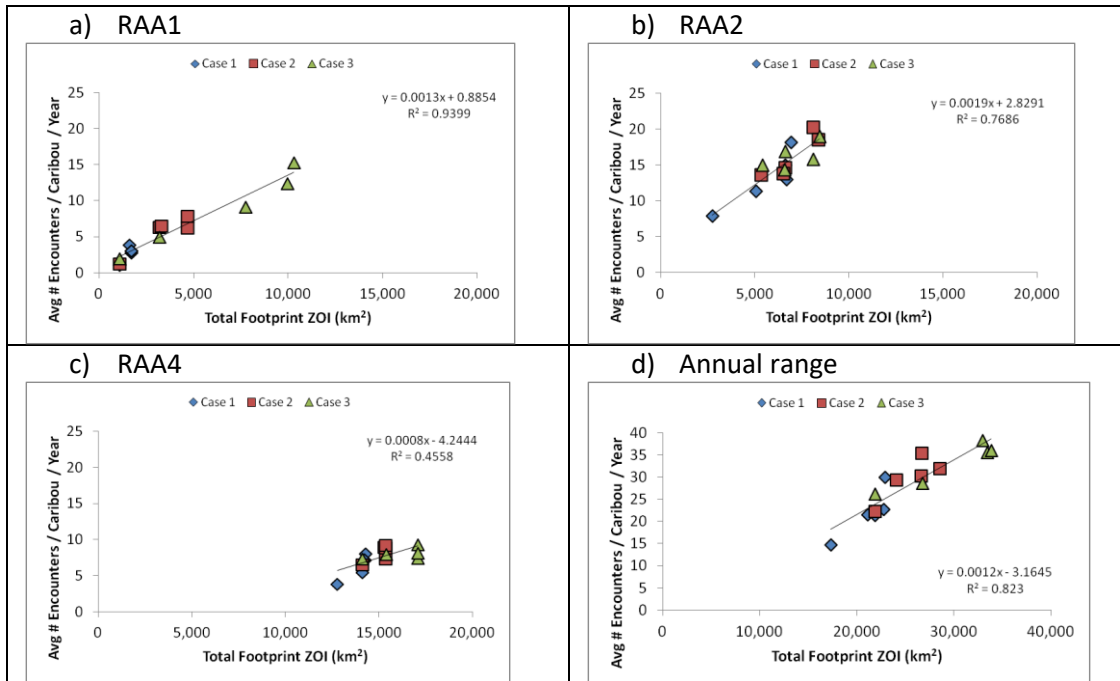


Figure 11. Relationship between average number of encounters/caribou/year and total anthropogenic footprint km² (including ZOI) within RAAs and at the annual range scale.

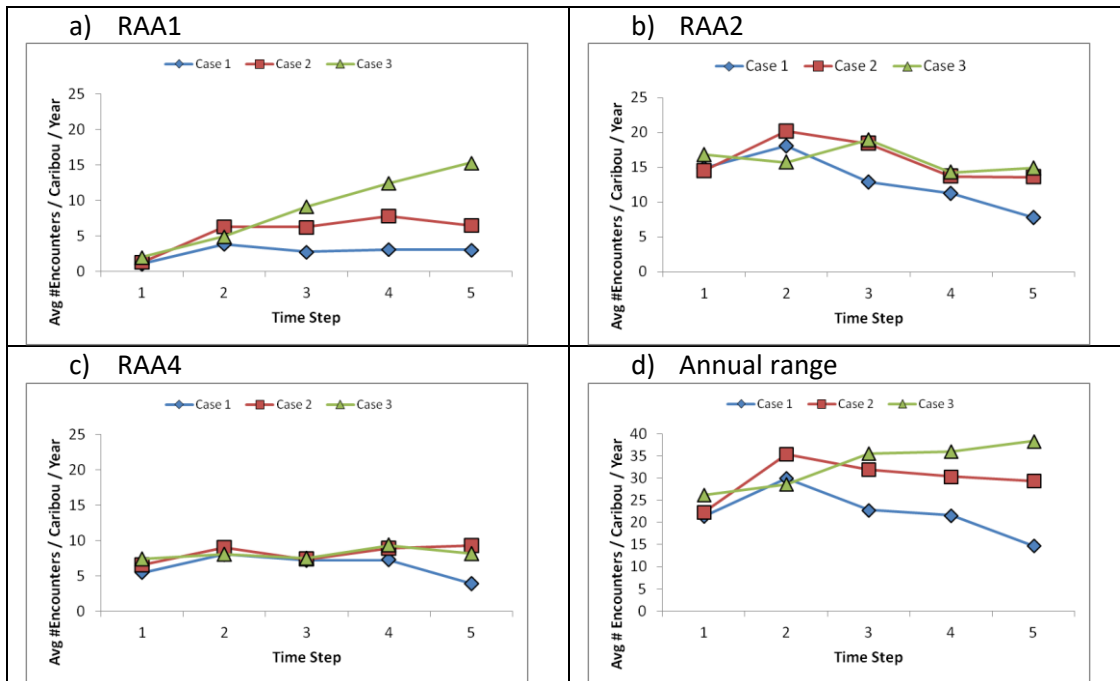


Figure 12. Average number of encounters/caribou/year within RAAs and at the annual range scale for each development case.

2) Productivity of a caribou herd

Productivity reflects the potential for a caribou population to increase and generally refers to the number of surviving offspring produced during a year. Thus, rates of pregnancy or fecundity³ in adult cows are fundamental indicators that establish herd productivity. Calf survival also contributes to herd productivity because it determines what proportion of viable calves that are born may be added to the population in the future. Thus, high calf survival increases herd productivity while low calf survival reduces productivity.

With respect to herd productivity, a key finding of Scenario Set 2 was the relationship between average annual encounter rates of female caribou with anthropogenic footprints and expected pregnancy rates in fall, where pregnancy rate declined inversely to an increase in average encounter rates (Figure 13). This output from the CARMA integrated model was based on the energetic and nutritional consequences of cumulative disturbance to a caribou cow, which was determined from the encounter rate with human footprints and subsequent effects on daily activities.

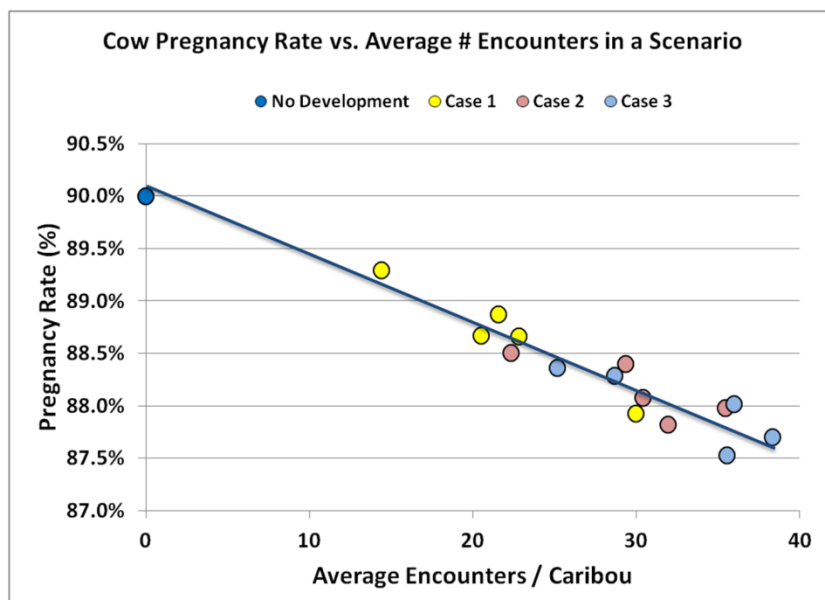


Figure 13. Relationship between expected pregnancy rate and average annual encounter rate of a Bathurst caribou cow with anthropogenic footprints on the annual range.

3) Population-level responses of caribou to disturbance

Modelling results suggested that the effect of anthropogenic disturbance on caribou productivity (primarily pregnancy rates) would result in a reduction in population growth rate, with the magnitude of effect related to the cumulative disturbance the population was exposed to. In those model runs, the level of disturbance encountered by caribou was simulated based on the intersection between a)

³ Fecundity is defined as the proportion of adult females calving in a given year, which is not the same as the proportion of adult females that become pregnant during the rut. Fecundity rates are generally lower than pregnancy rates because not all females that become pregnant will carry the fetus for the full gestation term and produce a viable calf.

current and future anthropogenic footprint on the Bathurst herd's annual range, and b) random selection of multiple ($n=50$) caribou movement pathways that were defined based on previous annual movement patterns of collared individuals. Because the impact pathway was estimated through a spatial intersection of future anthropogenic footprint development scenarios and previously documented movement pathways of caribou, the model simulated plausible and comparable risks of impact to caribou; it was not forecasting or predicting specific population-level impacts.

In this context, Figure 14 illustrates that each development case scenario results in a lower rate of population growth compared to the base case scenario of 'No Development'. Although the curves visually appear to show differing magnitudes of effects across mortality levels, the relative influence of the development cases on population growth rates is similar when scaled to exponential rates of increase (r).

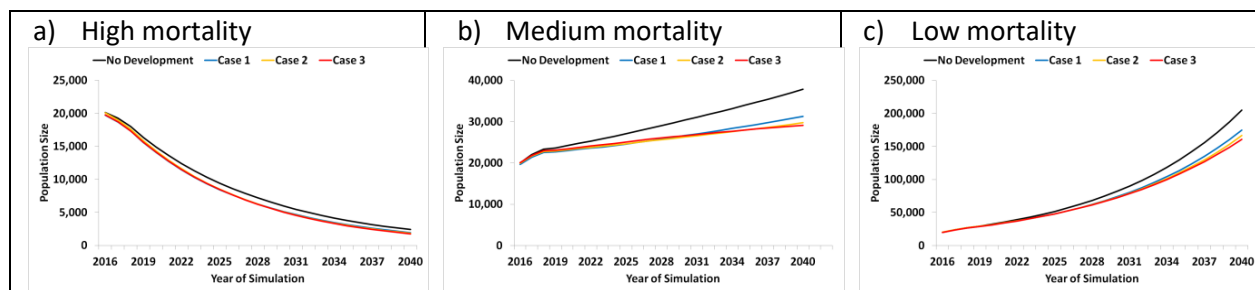


Figure 14. Comparative population trends of Bathurst caribou starting from an initial size of 20,000 animals and simulated 24-years in to the future based on three different industrial development case scenarios, and organized by (a) high, (b) medium, and (c) low rates of natural mortality.

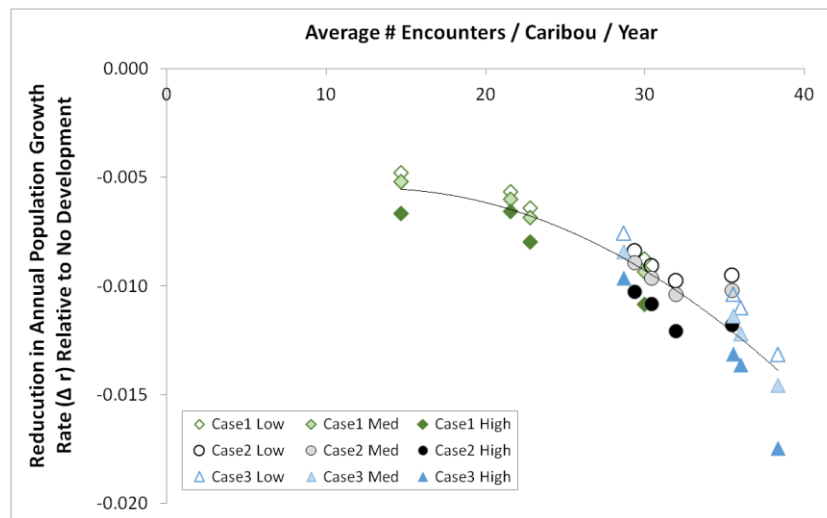


Figure 15. Simulated influence of average annual encounter rates of caribou on reductions in population growth rate (Δr). Encounter rates of caribou to anthropogenic footprints were estimated for each of three industrial development Cases, and paired with annual growth rates at timesteps 2 to 5 in the 24-year development trajectories. Population growth rates were calculated from data in Figure 14.

Figure 15 shows the relative reduction in annual population growth rates (r) imposed by encounter rates of caribou with varying amounts and distributions of human footprints on its annual range, relative to a population with 'No Development' on its range. For these simulation results, the key input variable was the anthropogenic footprint and scenario assumptions for Case 1, Case 2, and Case 3, which were developed by the Mineral Task Group and BCRP Working Group, which was the main influence. The movement pathways of the 50 caribou cows were held constant across the three cases to maximize comparability and minimize any spatial variability and differences in encounter rates, which would have occurred if different movement paths were used for each of the three development cases (D. Russell pers. comm.).

All decisions are based on models...
All models are wrong, but some are useful.

This one is useful

4. References

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