APPENDIX 6H

CARIBOU ENERGETICS

Energy-Protein Modeling of North Baffin Caribou in Relation to the Mary River Mine Project

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Executive Summary

This report is in response to commitments 186, 208, and 209 related to conducting energetics modeling to assess the impacts of the Mary River mine project on the North Baffin Caribou population. The requests directed Baffinland to not only assess impacts of the current low population of caribou in the area, but also project impacts into the future when the caribou population is expected to expand and begin to re-use existing trail systems.

In fulfilling these requests we used an existing energy-protein model and updated it to include protein dynamics. This model simulated food intake based on the seasonal quantity and quality of forage available, followed energy and protein kinetics through the rumen and allocated the resultant metabolizable energy intake and metabolizable nitrogen intake into maintenance, activity, growth, lactation and gestation.

Model inputs were obtained to best reflect the conditions in the North Baffin region. Cover types were obtained from a circa-2000 land cover map of northern Canada at 30 m resolution, biomass corresponding to the cover types were obtained from the Canada centre for Remote Sensing for Sirmilik National Park, just north of the study area. The distribution of these cover types were compiled separately for the North Baffin caribou range, the Regional Study Area (RSA) and the Zone of Influence (ZOI). The biomass values obtained were for a 25 year period at 10 day intervals throughout the growing season. Using a breakdown of plant group types used in the model that were associated with each cover type, we derived plant group biomasses for each plant group throughout the year. We derived the biomass of non-green vegetation (lichens, some mosses, mushrooms) and all plant groups through winter from similar work done on the Bathurst caribou range, but scaled to the smaller biomass in the North Baffin region. Climate variables used to drive the model were obtained from NASA's Modern Era Retrospective-Analysis for Research and Applications (MERRA) site and manipulated to conform to caribou-relevant climate variables derived by the Circum Arctic Rangifer Monitoring and Assessment (CARMA) Network. Diet and activity budgets were generated in the model based on climate, snow depth, insect abundance, hours of twilight and seasonal energy and protein requirements of the female caribou. Body condition to initiate the model runs was obtained from four caribou collections in 1965, 1992, 1993, and 1999. From these data we also obtained pregnancy rates and confirmed the functional response between probability of pregnancy and fall body weight of the adult female. Timing of calving and thus timing of peak rut activity was derived from movement characteristics of parturient collared females on the calving grounds.

We developed five test scenarios in the model. All five scenarios were considered beyond what we would predict to happen if the Mine project were to proceed, but we felt that it was important to test the outside bounds and compare with basleine conditions.

Scenario 1. Basleine – no development

Scenario 2. The impact of caribou abandoning the ZOI completely

Scenario 3. The impact of a caribou abandoning 35% of the RSA which includes all of the ZOI and an additional 25% of the RSA north and west of the development.

Scenario 4. The impact of a caribou abandoning 65% of the RSA which includes all of the ZOI and all of the RSA north and west of the development.

Scenario 5. At low population levels, a proportion (3.8%) of caribou remain in the ZOI all year, having their activity budgets affected.

To test the first four scenarios, and assess impacts on an expanding north Baffin caribou population, scenarios were modeled over a 50 year time period (at 5 year intervals). The initial population was allowed to grow and thus with each iteration (time step) the biomass per individual was reduced as a response to increasing density and for Scenarios 2, 3, and 4 with increased density due to abandoning portions of the range.

Output body condition variables that link directly to rates of herd productivity were used to compare Scenarios. These were: 1) birth weight (calf survival), 2) late june growth rate of the calf (post-natal weaning, calf dies), 3) mid summer protein gain of the cow (summer weaning, calf dies), late summer fat weight of the cow (early weaning, calf survival reduced, cow increases probability of pregnancy), cow weight at rut (prenancy rate, cow overwinter survival), and calf weight at rut (normal or extended lataction, calf survival, age of first reproduction).

In all model runs, cows did better with no development. With the ZOI abandoned, 35% of the RSA abandoned, and 65% of the RSA abandoned, cows did progressively worse in terms of the key variables. In general terms with increasing density, birth weight remained high until 35 years then dropped, June weight gain stayed high 25 years before dropping, summer protein gain dropped after 30 years, September fat weight and cow weight at rut declined immediately, while calf weight at rut declined after 15 years. The additional impact for Scenarios 2, 3, and 4 varied through time and among Scenarios.

We feel that the least severe impact modeled, abandoning the entire ZOI, is unlikely. For that Scenario the changes to the key variables from baseline values at the highest densities were:

Variable	Change from baseline
Birth weight	-2.9%
June calf weight gain	-4.7%
Summer protein gain	-4.8%
September fat weight	-5.9%
Rut cow weight	-1.7%
Rut calf weight	-3.2%
Pregnancy rate	-6.4%

Differences of all scenarios at low densities never exceeded -3.5%. Scenario 4 — abandoning all areas of the RSA north and west of the infrastructure imposed in the most severe stress on the animals, resulting in up to a 17.7% decline in pregnancy rate in the years just prior to the declines in birth weights, calf growth, summer protein loss, and fall calf weight. In those years (25–30 years into the simulation), the model predicted that the cow would sacrifice her own condition to ensure the survival of her calf, but only until it increased the probability of her not surviving. At that point the survival of the calf suffered with reduced birth weights and growth rates. Scenario 5, impacting activity in the ZOI, resulted in small changes when considered at the population level. Birth weight declined by 1 gram, June weight gain declined by 2.2 grams per day, summer protein declined by 1.3 g per day, September cow fat decreased by 0.3 kg, cow weight at rut decreased by 0.8 kg, calf weight at rut decreased by 0.4 kg, and pregnancy rate was reduced by 2.3% for the population as a whole.

This analysis allows us to better understand the impacts of human activity on the energy-protein relations of caribou. When new North Baffin specific data become available, more monitoring of impacts on activity and distribution is conducted, and a better understanding of the population dynamics of this population is achieved, we can use this modeling approach to re-assess impacts of this development and others that may occur in the future. This modeling did not assess the role of climate in exacerbating or ameliorating the projected impacts of development.

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1 PREAMBLE

In response to feedback from the environmental review of the Mary River Mine project, Baffinland made specific commitments to provide additional analysis and review. Among the commitments are the following:

- *#186: Identify and describe the potential for indirect effects on caribou health and mortality such as loss of body condition, reproduction and calf survival; loss of habitat; and increased harvesting access.*
- *#208: Additional analysis of potential impacts to caribou health (i.e. body condition, reproduction and calf survival) will be undertaken. Consider indirect effects on caribou energetics.*
- *#209: Categorize the RSPF to quantity habitat quality and quantity and impacts associated in the ZOI. Design and apply multiple scenarios of caribou abundance…*

This report directly addresses these commitments and during the process of compiling relevant information for the energetics modeling, additional baseline information is presented.

2 THE ENERGY-PROTEIN MODEL

2.1 Model Structure

To model the energy-protein relations of North Baffin caribou and assess the potential impacts of the Mary River Project on caribou in the area, we employed the Energy-Protein (EP) model developed over the last 25 years (Russell, et al 2004; White et al in press, Figure 1). The EP model predicts the daily body weight and body composition change of a caribou cow, her milk production, and the daily body weight change of her calf as a function of milk intake. State variables driving these outcomes are daily activity budgets, forage quality, and forage quantity. The model consists of two sub-models. The first is the Intake Sub-model, partitioned into energy (Figure 2) and protein (Figure 3) components, which predicts daily changes in a cow's metabolizable energy intake (MEI) and metabolizable nitrogen intake (MNI) by calculating the cow's food intake and then simulating the functioning of the cow's rumen and her digestive kinetics on an hourly basis. The MEI and MNI predicted by the intake sub-model is then transferred to an Allocation Sub-model (Figure 4), which calculates the cow's energy and protein requirements, her energy and nitrogen balance, and her daily change in weight, milk production, and hence the daily change in weight of her foetus or calf.

The intake sub-model asks the question: how do changes in activity budgets, forage quality, and forage quantity affect the energy and nitrogen intake of a female caribou? In particular, it is designed to predict effects of environmental conditions on MEI and MNI. Specific objectives of the intake sub-model are:

- To show effects of environmental conditions and movement patterns (as reflected by changes in activity budgets, forage quality, and forage quantity) on MEI and MNI on individual caribou;
- To evaluate effects of human and natural disturbance (e.g., oil development, insect harassment) on MEI and MNI; and
- To evaluate short-term weather and climate trends on MEI and MNI.

The broad purpose of the allocation sub-model is to evaluate effects of changes in seasonal activity, MEI, and MNI on the energetic and reproductive status of a female caribou.

The allocation sub-model has two specific objectives:

- To evaluate the impact of changing activity costs, maintenance costs, MEI, and MNI on the cow's energy balance and subsequent change in body composition and growth; and
- To evaluate effects of the cow's energy and protein balance on the growth of her foetus during gestation and calf during lactation.

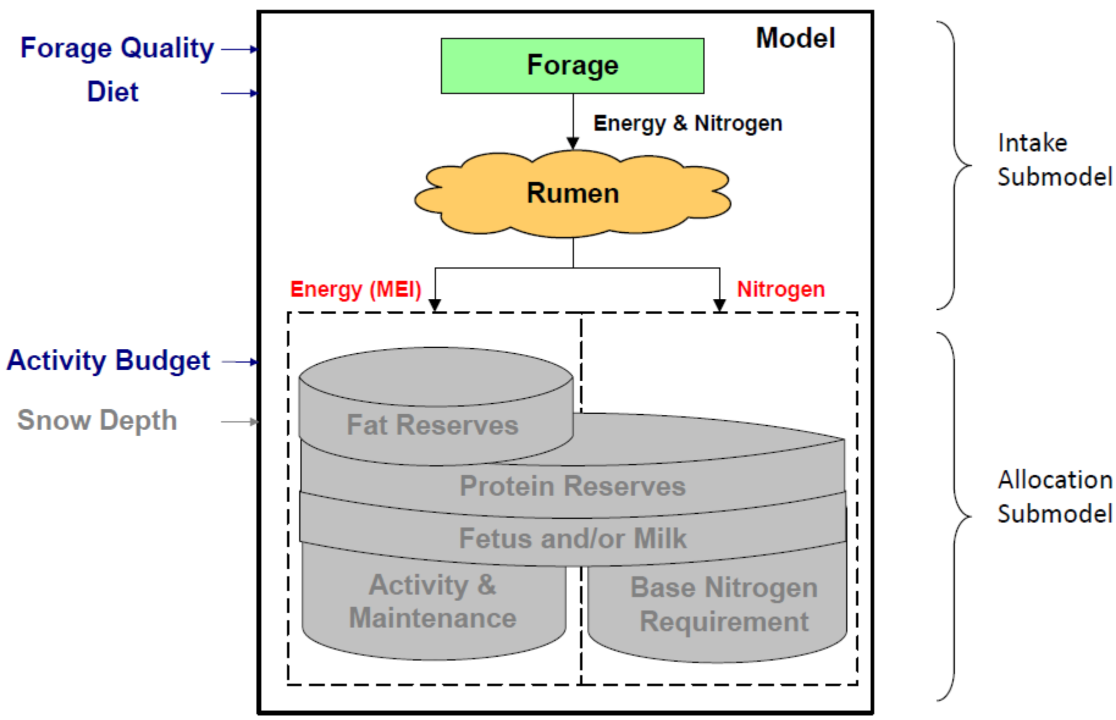

Figure 1. Simplified overall Energy-Protein model structure

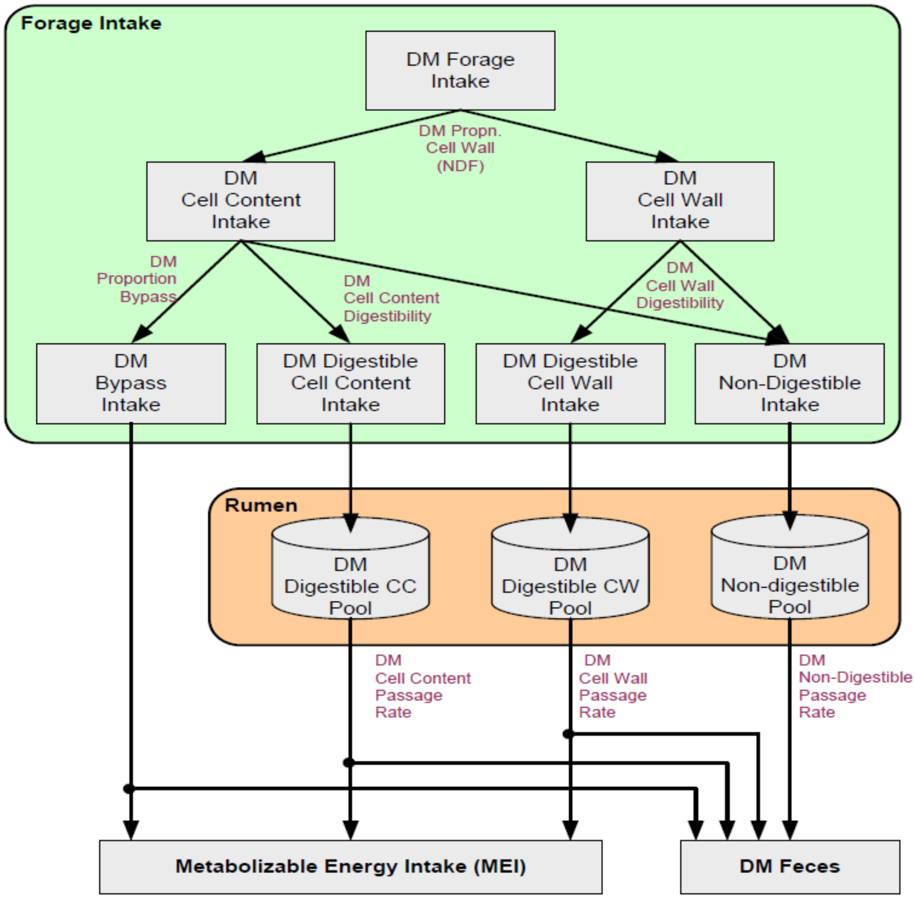

Figure 2. The energy components of the Intake sub-model

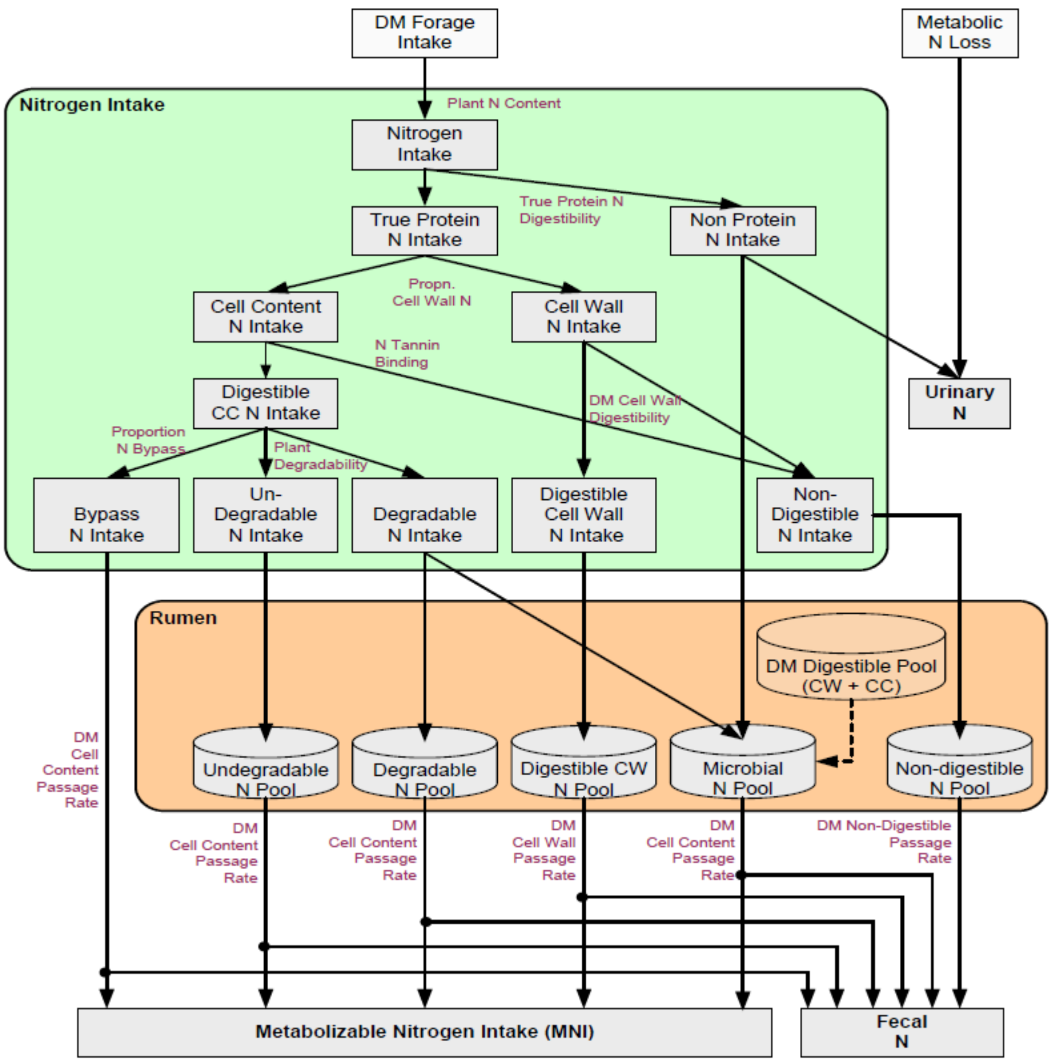

Figure 3. The protein components of the Intake sub-model

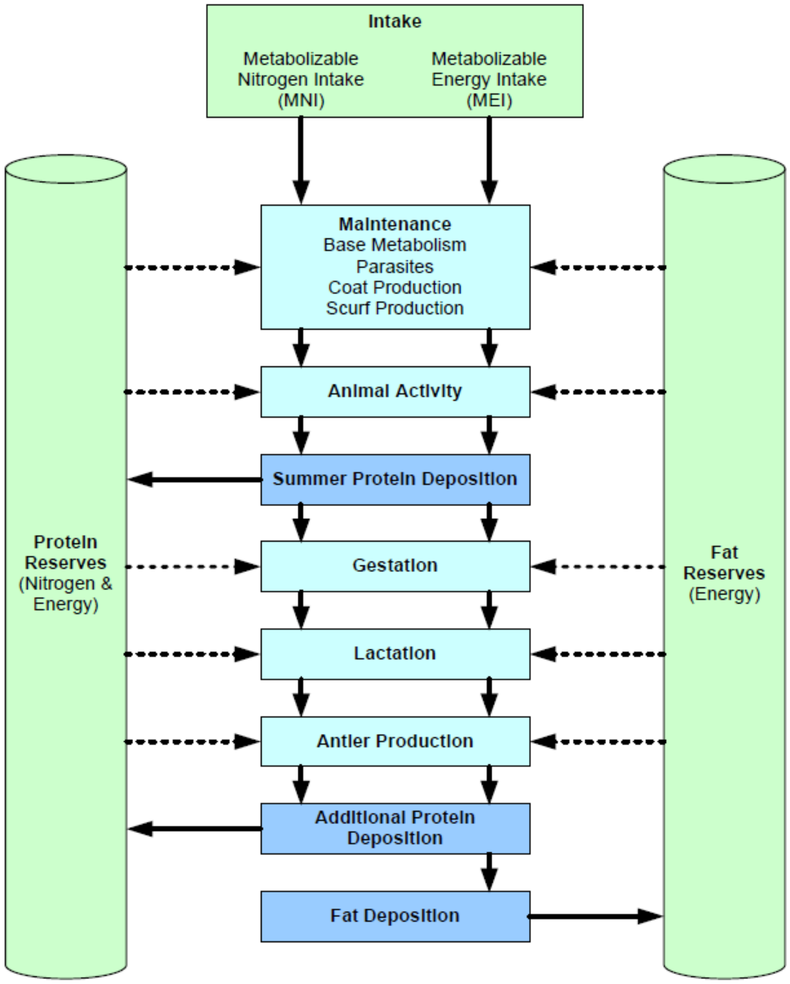

Figure 4. The Allocation sub-model

Model runs are set up using a "Scenario Builder." This spreadsheet model generates the input values required to run any scenario. Climate and weather data specific to the herd from 1979–2010 is obtained from the Circum Arctic *Rangifer* Monitoring and Assessment (CARMA) Network's climate database (Russell et al in press). These data combined with vegetation and biomass attributes specific to a particular region are used to generate seasonal forage quantity, quality, activity, and diet.

2.2 Model Input Data

2.2.1 Vegetation classes

We downloaded 30 m resolution land cover types produced by Natural Resources Canada (Olthof et al 2009) The 15 vegetation classes defined by Olthof et al (2009) and that were present in the study area were:

Graminoid:

1. (tt-gr) *tussock graminoid tundra* (< 25% dwarf shrub): Moist tussock tundra with < 25% dwarf shrubs < 40 cm tall and moss. May also include lichen.
2. (wt sdg) *wet sedge* (graminoids and bryoids): Wet sedge including cottongrass that is saturated for a significant part of the growing season, also includes moss and may include < 10% dwarf shrubs < 40 cm tall.
3. (non-t gr) *moist to dry non-tussock graminoid / dwarf shrub tundra* (50–70% cover): Moist to dry non-tussock tundra with 50–70% vegetated cover. Vegetation includes a mixture of graminoids, dwarf erect < 40 cm and prostrate dwarf shrubs. May also include tract amounts of lichen and moss.
4. (gr pros shb) *dry graminoid prostrate dwarf shrub tundra*(70–100% cover): Upland or well drained non-tussock graminoid tundra with low to prostrate dwarf shrub heath greater than 70% cover.

Shrub

7. (pros dwf shb) *prostrate dwarf shrub* (dryas / heath, usually on bedrock or till): Generally dry > 50% vegetated cover consisting of prostrate dwarf shrubs, graminoids and may contain < 10% lichen and moss.

Sparse vegetation

8. (sp veg rock) *sparsely vegetated bedrock:* Barren surfaces with 2–10% vegetation cover on acidic, igneous, mostly consolidated bedrock. Vegetation cover generally consists of graminoids and prostrate dwarf shrubs.
9. (sp veg coll) *sparsely vegetated till-colluvium* (2–10% cover): Barren surfaces with 2–10% vegetation cover on non-acidic and calcareous bedrock and colluvium. Vegetation cover generally consists of graminoids and prostrate dwarf shrubs

10. (bare soil) *bare soil with cryptogam crust* (frost boils): Unconsolidated barren surfaces having experienced significant cryoturbation with 2–10% vegetation cover consisting of graminoids and cryptogam plants.

Wetlands

11. (wetland) *wetlands:* Vegetated areas where the water table intersects the land surface all or part of the year. This class is represented by moss dwarf-shrub wetlands at the latitude of south-central Baffin Island.

Non-vegetated

12. (barren) *barren*: < 2% vegetation cover on non-acidic and calcareous parent material.

Types 13, 14, 15 are shadow, ice/snow, and water. Shrub types 5 and 6 were not in the North Baffin Caribou range and therefore are not listed above.

Separate summary statistics were compiled for the North Baffin caribou range (NBC), the Regional Study Area (RSA) and the Zone of Influence (ZOI, Figure 5). In this summary only the relative abundance of vegetated cover types are presented; water, ice/snow, shadows and missing pixels were not included. This analysis reveals that vegetated cover types comprise 86%, 90%, and 89% of the NBC, RSA and ZOI areas, respectively ,and that cover types considered to have higher biomass (Cover types 1, 2, 3, 4, 7, 11) comprise 28% of the NBC, 34% of the RSA, and 40% of the ZOI. Even though the RSA comprises 15% of the NBC range, it contains 18% of the high vegetation cover types while the ZOI, comprising 3.8% of the NBC, contains 5.4% of the high vegetation cover types. The primary difference in high vegetation cover types among study areas is the relatively higher amount of the prostrate dwarf shrub type in the ZOI over the RSA and the NBC.

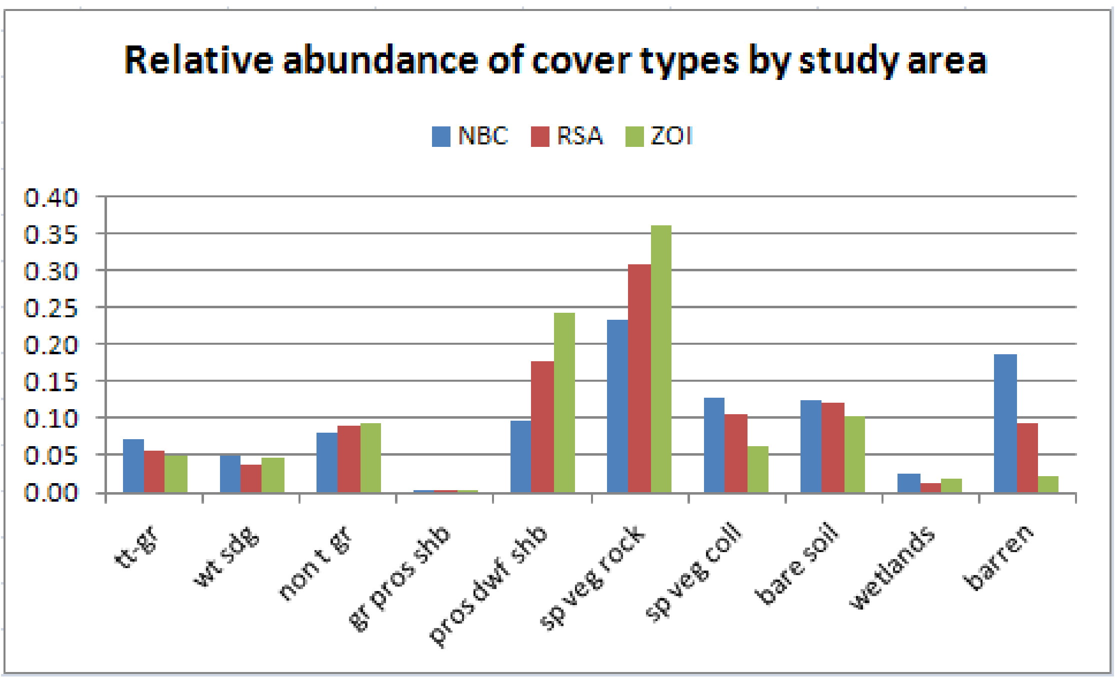

Figure 5. The relative abundance of cover types within the Zone of Influence (ZOI), Regional Study Area (RSA), and the whole North Baffin caribou range (NBC)

2.2.2 Habitat use

We overlaid the relative occurrence of caribou across the landscape as determined from the project's RSPF study (Volume 6, Appendix 6F) with the cover types to determine the relative use of vegetated cover types within the NBC, RSA, and ZOI study areas (Figure 6).

Figure 6. North Baffin Caribou relative use of cover types in the three study areas

2.2.3 Cover type biomass

We obtained leaf biomass data for Sirmilik National Park (north of the study area) from the Canada Center for Remote Sensing. The data from Landsat 5 and 7-TM imagery is derived as a component of Normalized Vegetation Difference Index (NDVI,) and thus represents an index of above ground green biomass (Fraser et al 2011). Thus lichen, mushrooms, some of the moss layer, and standing dead graminoid biomass (all components of caribou diet) are not captured in the data. The data covers the period from 1985 to 2010 at 10 day intervals between May 5 and October 26, and was available for all of the vegetated cover types in our study areas, with the exception of type 4, graminoid prostrate shrub, rare in our area, and not found in Sirmilik National Park. For the purposes of our modelling, we assume the total green biomass in the graminoid prostrate shrub type was similar to the tussock tundra graminoid type.

Average plant biomass for most types peaked by Julian day 217 (August 5; Figure 7). Plotting the maximum biomass throughout the growing season indicates a shift to later plant growth rather than earlier spring green-up (Figure 8).

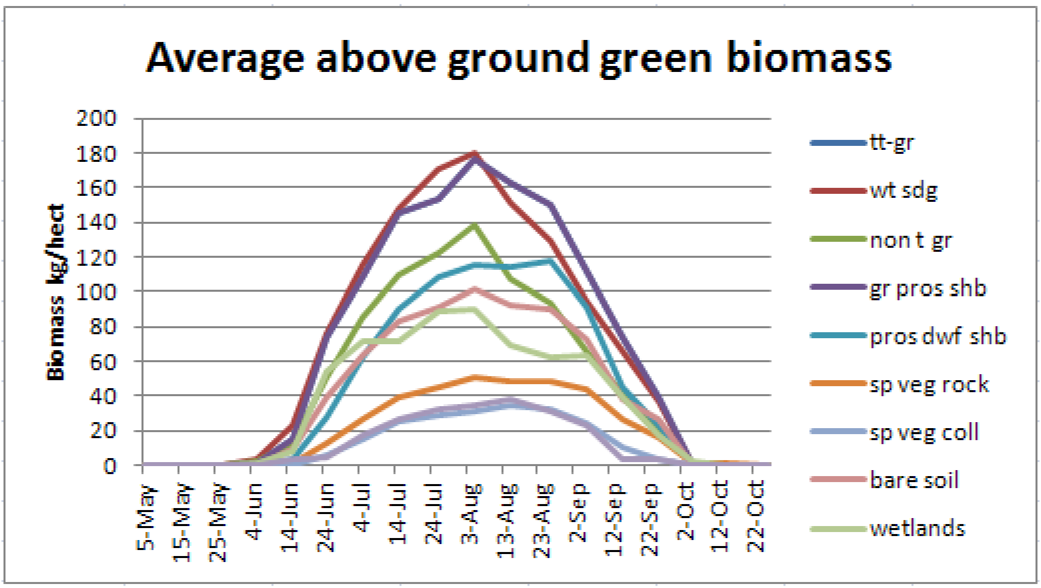

Figure 7. Average above ground leaf biomass in Sirmilik National Park obtained from Canada Center for Remote Sensing (Fraser et al 2011)

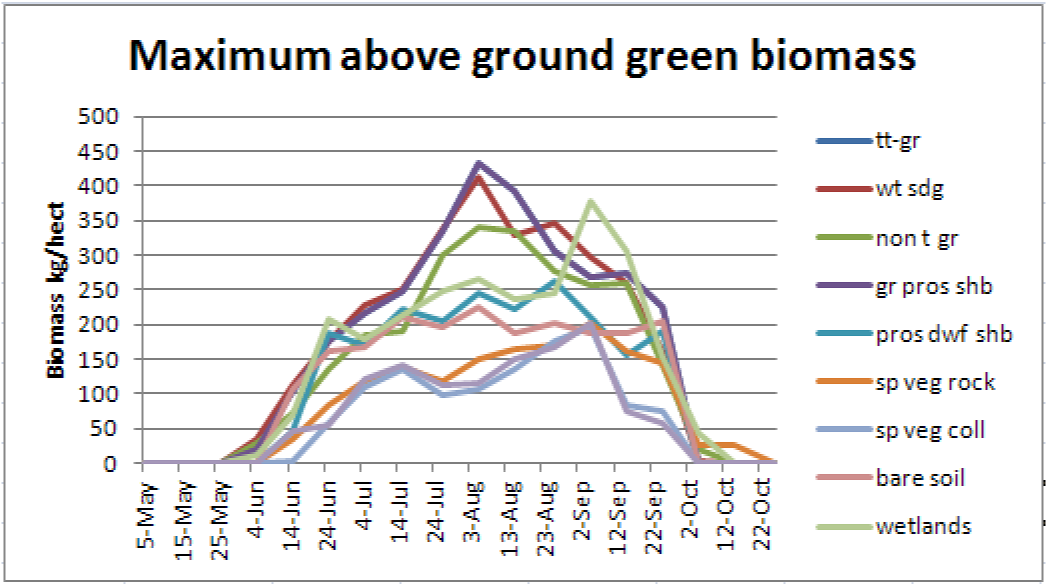

Figure 8. Maximum above ground leaf biomass in Sirmilik National Park obtained from Canada Center for Remote Sensing (Fraser et al 2011)

Because our modeling is being projected in the future we examined whether there were any trends in biomass. Although there is a lot of annual variability among years, total biomass among high (r=0.40) and low (r=0.38) biomass cover types significantly increased between 1985 and 2011 (Fraser et al 2011, Figure 9). The slopes of the lines in Figure 9 suggests that the cover types with higher biomass increased at a higher rate than types associated with lower biomass (1.98 versus 0.85 kg/ha per year, respectively). Assuming these trends continue, we used maximum biomass estimates in our simulations.

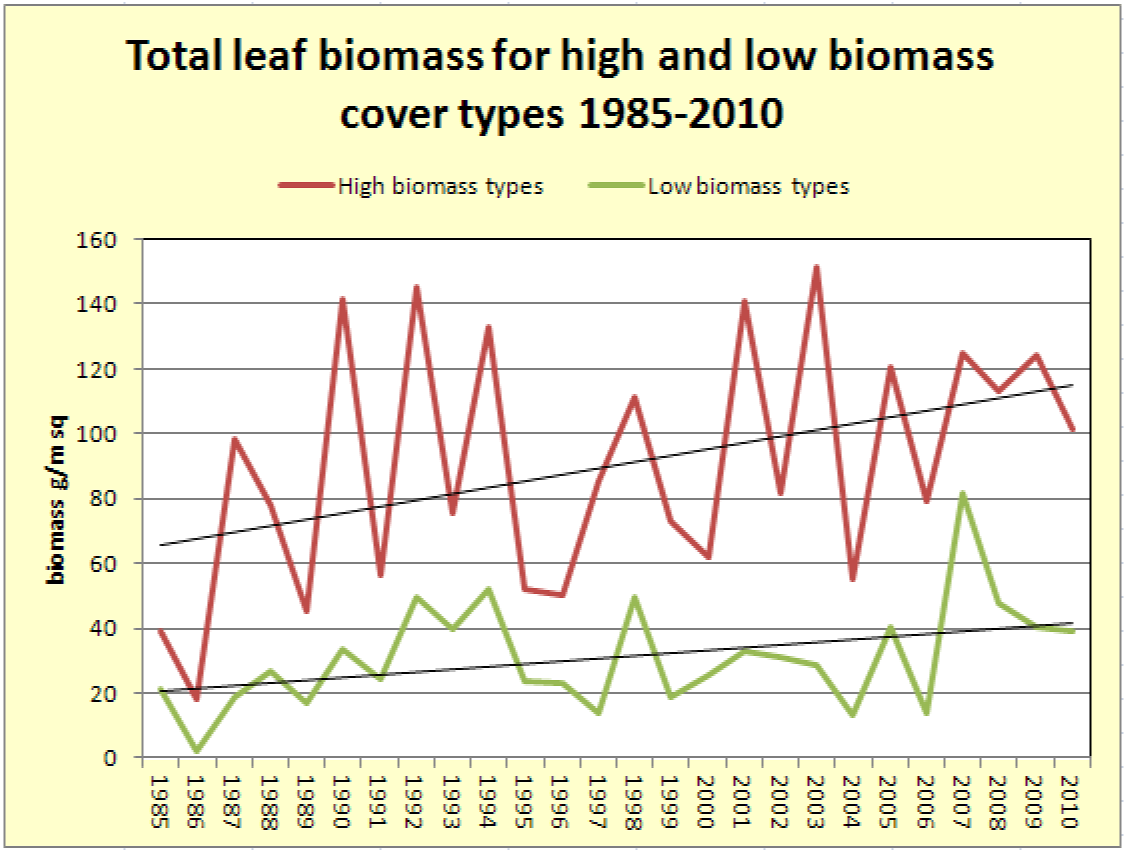

Figure 9. Total green biomass for high versus low biomass cover types from 1985 to 2010

Note: Data is for Sirmilik National Park from a study by Fraser et al 2011, and provided by W. Chen, Canada Centre for Remote Sensing.

2.2.4 Plant group quantity

In the Energy-Protein model we track 10 plant groups that are eaten by caribou:

1. Moss
2. Lichens
3. Mushrooms
4. Horsetails
5. Deciduous shrubs
6. Evergreen shrubs
7. Forbs
8. Graminoids
9. Standing dead graminoids
10. Cotton grass heads

Thus we needed to disassociate the cover type biomass into these plant groups. Descriptions of plant groups within these cover types were determined for the study of diamond mine impacts on the

Bathurst caribou range (Gunn et al 2010). Therefore, we used the relative abundance of plant groups from that study and scaled to the lower community biomasses in the North Baffin region. From this process we then determined the above ground green biomass and used the relative difference in community biomass in the Baffin region compared to Bathurst caribou range and assumed similar scaled values for non-green biomass of lichens, some moss, mushrooms, and standing dead graminoids. We then weighted plant group by cover types based on the relative use of cover types during the calving, summer, and winter periods for the NBC, RSA, and ZOI study areas. Figure 10 presents the initial biomass in the range of the North Baffin Caribou.

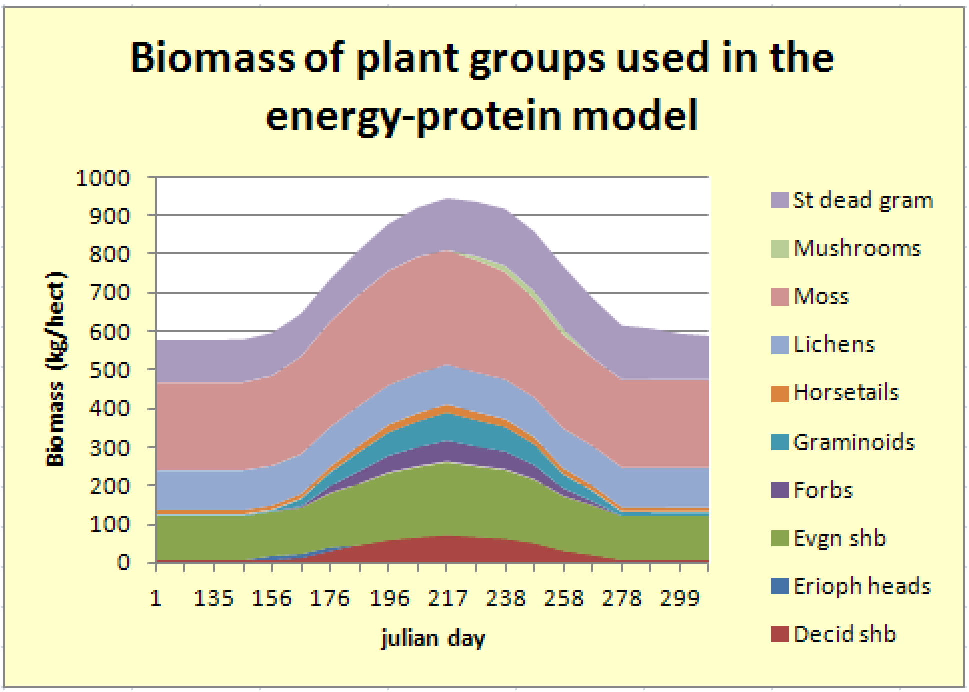

Figure 10. Biomass of 10 plant groups used as input into the energy-protein model

2.2.5 Plant group quality

The Energy-Protein model requires seasonal values by plant group for 1) Nitrogen concentration, 2) Neutral Detergent Fibre (NDF), 3) Acid Detergent Fibre (ADF)[1], and 4) secondary compounds of shrubs (BSA). A "Scenario Builder" spreadsheet was developed to generate model inputs. Within that spreadsheet we used existing published data (Johnson et al 2004; Finstad 2005) to associate plant nutrients with phenological stage, primarily dictated by growing degree days and biomass.

[1] NDF and ADF are products from the chemical digestion of plants (Van Soest 1994) that first separate cell wall from cell contents (NDF) and separate more digestible components of cell wall from the indigestible components (ADF). *Van Soest, P. J. (1994) Nutritional Ecology of the Ruminant, 2nd ed. Cornell University Press, Ithaca, NY.*

2.2.6 Climate variables

Climate data for the North Baffin region was downloaded from the NASA's Modern Era Retrospective-analysis for Research and Applications (MERRA) website. Data were then used to produce caribou-relevant variables to conform to the Circum Arctic *Rangifer* Monitoring and Assessment (CARMA) Network's climate database (Russell in press). Figure 11 presents the region-specific variables used by the Scenario Builder spreadsheet to generate input data for the Energy-Protein model.

herd	variable	julian	value w/cc	value
PCH	Snow depth	1	39	39
PCH	Snow depth	32	43	43
PCH	Snow depth	72	47	47
PCH	Snow depth	106	48	48
PCH	Snow depth	130	22	22
PCH	Snow depth	146	6	6
PCH	Snow depth	156	0	0
PCH	Snow depth	193	0	0
PCH	Snow depth	320	27	27
PCH	Snow depth	356	37	37

- snow depth for winter
- snow accumulation and melt
- impacts activity, diet and location

PCH	GDD	146	41	41
PCH	GDD	156	90	90
PCH	GDD	167	190	190
PCH	GDD	177	296	296
PCH	GDD	190	448	448
PCH	GDD	208	651	651

- growing degree days spring-summer
- dictates plant growth, plant quality
- impacts habitat selection, diet, activity

PCH	GDD Jy15-GDD jn15	208	368	368

- accumulated GDD June 15 to July15 in previous year - dictates cottongrass flowering – impacts diet

PCH	Mosq index	190	14	14
PCH	Oest index	208	13	13

- insect insects for warbles and mosquitoes (based on temp/wind) – impacts activity

PCH	Mushoom index	260	32	32

- Mushroom index – biomass of mushrooms – based on previous May rainfall and current June rainfall – impacts diet, late summer protein source

Figure 11. Climate variables used in the Scenario Builder to generate input data for the Energy-Protein model

2.2.7 Diet

Winter diet has been determined for caribou on southern Baffin Island (Ferguson et al 2001) in a comparison between a suspected overgrazed study area (Foxe Peninsula) and a region with better forage (Meta Incognita Peninsula). We found no information on calving, summer, and fall diets in the literature. In the model, unless specific data are available, we generate a likely diet based on known nutrient requirements, forage biomass, and forage quality. We have thus developed an algorithm (White et al 1999) that will be applied in this case and use Ferguson et al (2001) as validation data for late winter. Figure 12 illustrates a typical output for seasonal use of the 10 major plant types tracked in the model.

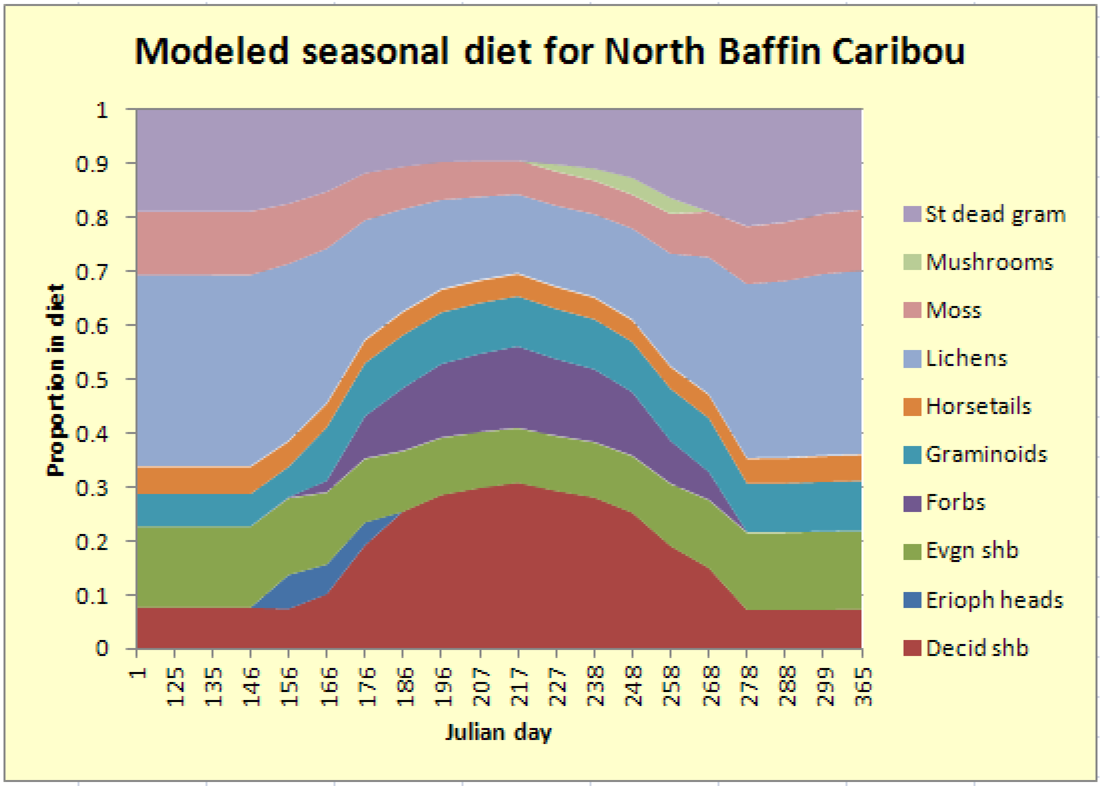

Figure 12. Modeled seasonal diet of the North Baffin caribou herd

2.2.8 Activity budgets

There have not been any studies to document the seasonal activity budgets of North Baffin Caribou. At these higher latitudes it is important to capture the 24-hour cycle of active and rest periods as caribou tend to be more inactive at night, although they do have active and inactive periods around the clock. Fortunately, Van Oort et al (2005) documented the seasonal pattern of active/rest cycles for wild reindeer at the same latitude as the North Baffin Caribou herd (71^{o} N) using activity loggers. From their analysis, there was a significant relationship between hours of civil twilight (TWILIGHT; when the sun is at least 6^{o} below the horizon) and the proportion of day spent lying (PLIE):

$$PLIE = -0.0053 * (24 - TWILIGHT) + 0.4254$$

Hours of twilight for 71^{o} N were obtained from the U.S. Naval Observatory, Astronomical Observations Department website http://aa.usno.navy.mil/data/docs/RS_OneYear.php

To proportion out the active period into foraging, standing, walking, and running for the annual cycle and to determine PLIE during periods of 24 hours of civil twilight, the model uses climate data for snow depth, plant growth, and insect harassment (mosquitoes and oestrids). These factors largely dictate the changes in activity during the active period (Russell at al 1993). Figure 13 illustrates activity budgets generated by the model for average weather conditions on the North Baffin Caribou range.

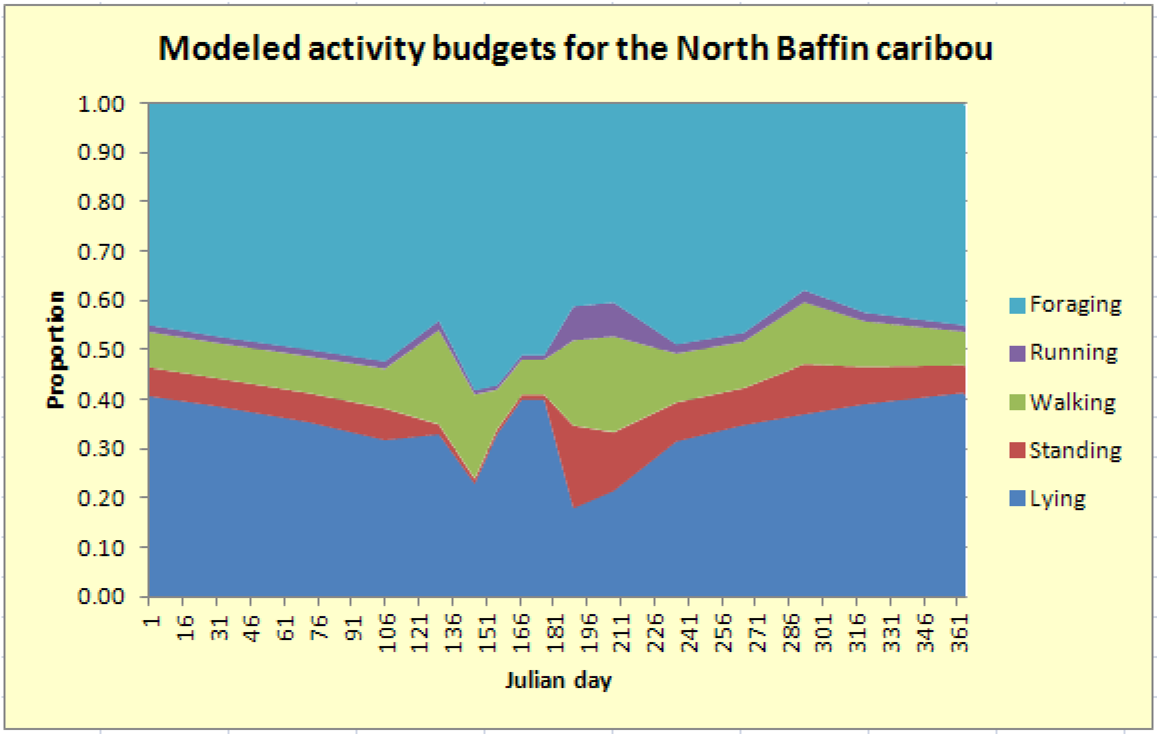

Figure 13. Activity budgets generated by the Energy-Protein Scenario Builder under average weather conditions for the North Baffin caribou

2.2.9 Animal condition

It is important to have an understanding of "normal" caribou condition, especially adult female condition. The model requires initial condition variables and model output benefits from validation data specific for the region. Across the subspecies (*R. t. groenlandicas)* considerable variation exists in mean body size, and seasonal fat and protein levels. Using the CARMA body condition database, four studies provided some information from caribou on Baffin Island: 1) collections by Dauphine in 1965, 2) a 1992 collection of Baffin caribou by Elkin, 3) a 1993 collection by Elkin, and 4) a 1999 collection Elkin (Table 1).

Dauphine 1965 collection: The database contains data on 21 adult females collected in August. Mean body weight was 75.3 kg and 11 of 21 (52%) were lactating.

Elkin 1992 collection: Fifteen adult cows were collected in April 1992. Elkin, in his three collections did not measure body weight (BW), however he did measure chest girth (CHEST). Chest girth is a reasonable predictor of body weight, so we calculated body weights using the relationship derived from a number of studies:

$$BW\ (kg) = 1.0529 * CHEST\ (cm) - 33.521\ (n = 411, rr = 0.46)$$

The average calculated body weight was 80.1 kg and 10 of the 15 (67%) cows were pregnant.

Elkin 1993 collection: Fifteen of the 19 cows were pregnant (79%) and calculated body weight was 89.1 kg- significantly heavier than cows from the 1992 collection.

Elkin 1999 collection: In 1999 Elkin collected 13 cows of which 9 were pregnant (70%). Mean calculated body weight was 81.8 kg.

Table 1. Summary of data collected on adult cows during body condition surveys of Baffin Island caribou

Year	Month	Sample size	Body weight (kg)	% pregnant	% lactating	Mean age
1965	August	21	75.3	-	52	-
1992	April	15	80.1	67	-	5.8
1993	April	19	89.7	79	-	6.9
1999	March	13	81.8	69	-	7.5

The was no significant difference in body weight between lactating (74.1kg) and non lactating (76.7 kg) cows collected in 1995. The mean body weight (75.3) kg was low compared to the other collections. This may be related to three factors:

1) Body weight is typically lowest just after calving, so time of year may explain the low result;
2) It may have been a particularly harsh winter and spring;
3) Pond Inlet harvest records during the mid 1960s indicate there was a period of very low numbers of North Baffin caribou, and the low weight may reflect the poor habitat conditions during this phase of the population cycle.

Although samples sizes are small, it is interesting to note that in the years approaching the current population decline, mean age of the population increased from 5.8 years to 7.5 years, perhaps indicating a lower calf survival prior to the decline.

Mean calculated spring weight of pregnant females was significantly higher than non-pregnant females in the three 1990s collections (81.0 kg and 85.8 kg, respectively).

2.2.10 Probability of pregnancy

The model tracks the body weight of adult cows on a daily basis. In relating individual body condition to population level impacts, one of the indicators we use is the probability of the cow getting pregnant in the fall. It is important that we have validation data on pregnancy rates and ensure there is a relationship with body weight. Using the three spring collection studies described above (Elkin 1992, 1993, and 1999), we classified adult cows by weight class, similar to Bergerud (2008). Figure 14 depicts the mean pregnancy rate for animals collected in the spring by weight class.

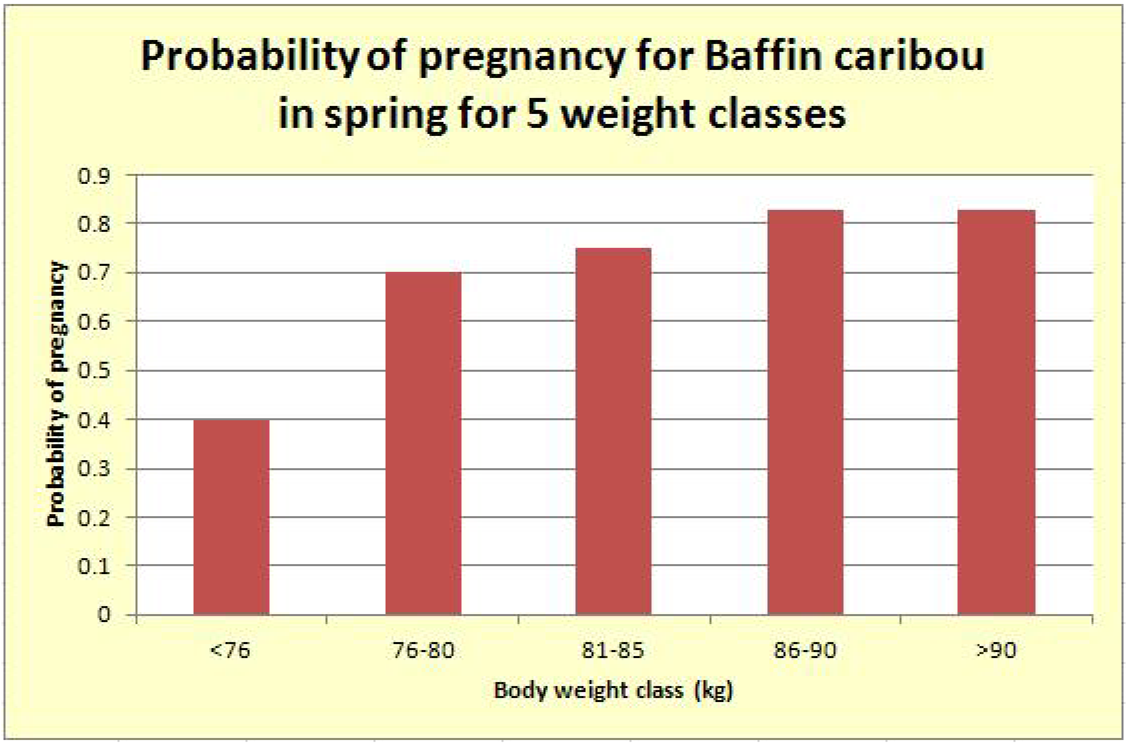

Figure 14. Probability of adult cows pregnant in the spring by weight class

Note: Data from 3 collections conducted by Elkin. Body weights calculated from significant correlations with chest girth as Elkin did not collect body weights.

We then plotted the results from Figure 14 as well as the mean pregnancy by collection year as presented in Table 1, to determine if North Baffin caribou had a similar functional response between body weight and probability of pregnancy as the George River herd (Figure 15; Bergerud 2008). Figure 15 indicates that we have some confidence that the functional response applies to north Baffin Island caribou, allowing us therefore to use the functional response to predict probability of pregnancy (*ppreg)* from body weight (*BW*; kg) according to the formula:

$$ppreg = e^{(-10.029+0.134*BW)}/1 + (e^{(-10.029+0.134*BW)})$$

However, the range of body weights collected by Elkin (1992, 1993, and 1999) prevents us from determining whether Baffin Island caribou ever get big enough to result in the higher pregnancy rates observed in the George River herd.

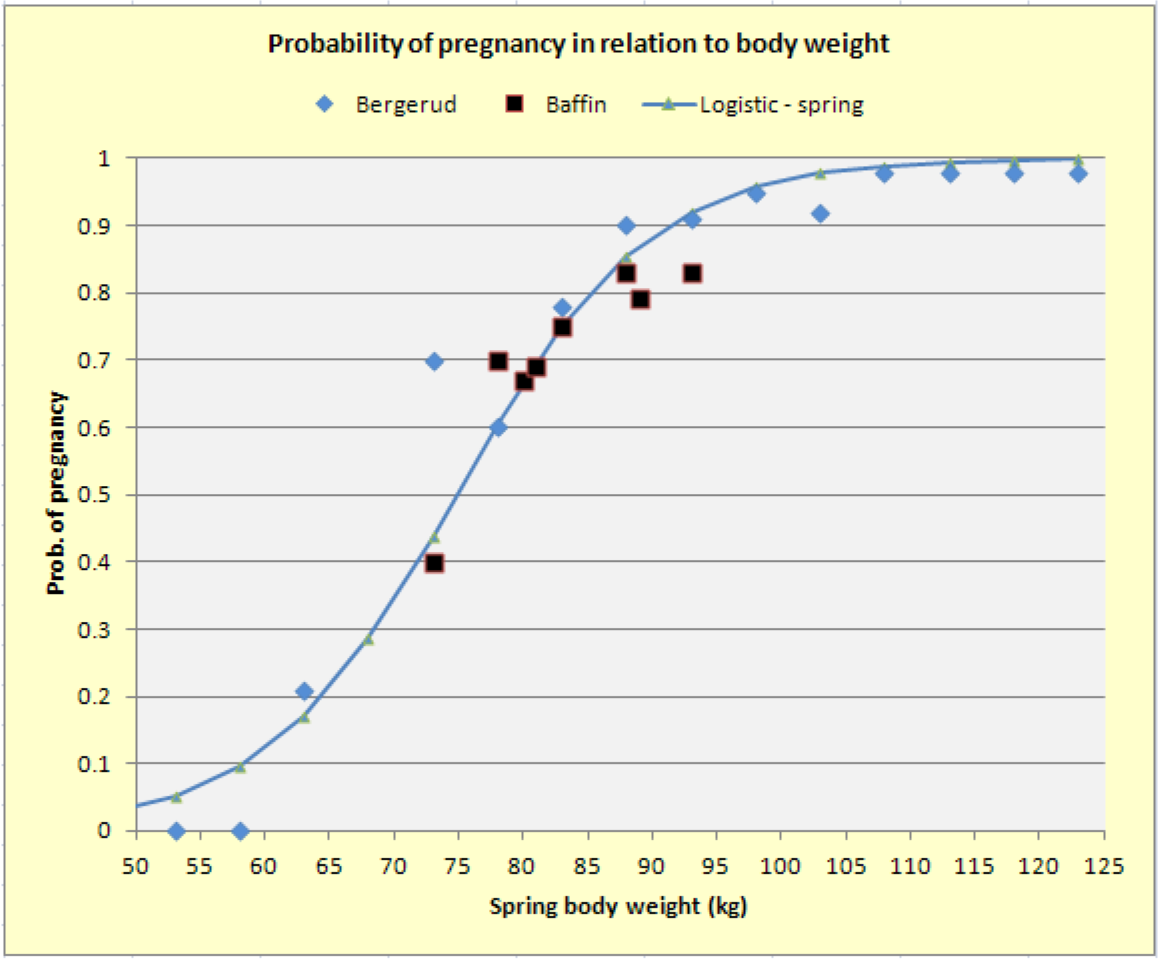

Figure 15. Functional response (blue line) from data compiled by Bergerud (2008) compared with data from Baffin Island caribou based on collections by Elkin in 1992, 1993, 1999 (Table 1), in addition to mean probability of pregnancy by weight class taken from Figure 14

2.2.11 Peak of calving

The energy-protein model requires a date for the peak of calving (median date of calving). Although a number of calving surveys noted dates when calves were observed, no estimate of peak of calving was presented. We used the movements of collared adult females as an indicator of calving date (Nagy 2011). Typically, caribou will be stationary for up to 3–4 days after giving birth, and the cessation of movement has been used as an indicator of calving date, and lack of cessation of movement as an indicator of lack of a viable calf or a barren cow. Based on this analysis, we were able to determine frequency of birth dates, peak of calving, and pregnancy rate from collared cows from 2009–2011 (Figure 16; Table 2).

These data indicate for 2009 and 2010 parturition rates were very similar (89% and 88%, respectively), with 2009 exhibiting a wider range of calving. Of nine collared cows in 2011, none appeared have given birth.

Table 2. Summary of dates, peak of calving, and parturition rate from sample of collared cows 2009-2011 for the North Baffin caribou

Year	earliest	latest	peak	#collars	# parturiant	parturition rate
2009	28-May	25-Jun	9-Jun	28	25	89
2010	28-May	16-Jun	9-Jun	16	14	88
2011	-	-	-	9	0	0

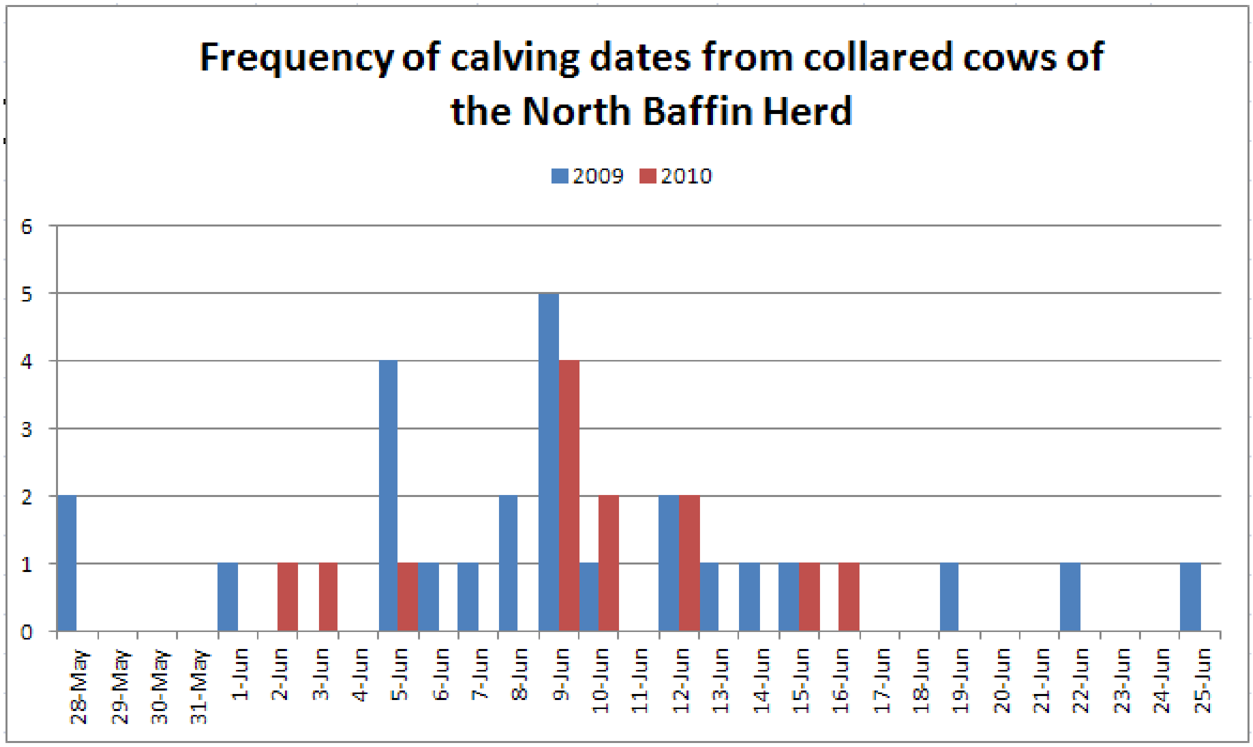

Figure 16. Frequency of calving dates for collared North Baffin caribou, 2009-2010, based on cessation of movement during and immediately after the parturition

3 THE CONCEPT OF SPACE USE, ABUNDANCE, AND CENTRE OF HABITATION IN CARIBOU

As defined by Skoog (1968), the centre of habitation of a caribou population is the area within the long-term annual range that offers the most secure area, with a diversity of seasonal resources, and which can be identified as the area occupied when the herd is at a population low. For most mainland herds, this area usually straddles treeline and includes a taiga and tundra component. As numbers increase from population lows, animals expand from the centre of habitation until they encounter marginal habitats and population growth declines (Bergerud, 2008). The small centres of habituation contain a mix of forage and weather to enable a limited number of caribou to persist until range recovers in the peripheral areas. As the population starts to expand, certain areas of the range are used on a more seasonal basis as herds optimize the seasonal attributes within their range.

3.1 Use of the RSA by caribou in relation to the Entire of North Baffin Caribou (NBC) Range

Caribou currently exist in the RSA in low densities following population highs in the late 1990s. In these low densities there is little evidence that they are acting like a migratory herd, rather collar information suggests that they stay within confined home ranges and obtain seasonal forage requirements within that home range, including calving. As the population recovers and densities increase there is ample historic information that major trail systems are established and that seasonal shifts emerge in order for the herd to better exploit the resources within their entire North Baffin range. From local knowledge, when caribou are abundant, calving appears more concentrated, surrounding and north and east of the mine site. Animals then expand westward and move north in fall and winter, returning to calving sites in the spring.

4 MODELING THE IMPACT OF THE MARY RIVER PROJECT ON NORTH BAFFIN CARIBOU

4.1 Modeling Approach

We designed the modeling process to assess five Scenarios which represent the baseline and four levels of impacts from the mine, infrastructure, and associated activity. We assumed that the herd initially was small, that the area acted as a center of habitation, and that the herd was rapidly increasing between each time step. Thus we modelled:

Scenario 1. The baseline condition, with no development but with an expanding and thus increasingly dense caribou population.

Scenario 2. The impact of caribou abandoning the ZOI completely. The negative effect of caribou abandoning the ZOI was an increased density on the rest of the range, thus reducing the effective biomass per individual.

Scenario 3. The impact of the potential for caribou to fail to cross the railway in key places, thus abandoning a portion of the RSA over and above the ZOI. In this scenario we assumed that the caribou would abandon 35% of the RSA which includes all of the ZOI (representing about 25% of the RSA) and an additional 25% of the RSA north and west of the development. We modeled the same source of impact: increased density outside the abandoned zone with a proportional decrease in biomass per individual.

Scenario 4. The same scenario as #3 above, except we assumed they would abandon the entire RSA north and west of the infrastructure, including the ZOI on the south and east side of the mine and railroad (65% of the RSA).

Scenario 5. The impact of caribou being in the Zone of Influence (ZOI) for the whole year. Impacts were modelled based on a reduction in foraging time and eating intensity (the proportion of the foraging time actually spent eating) and an increase in walking and running time (Murphy and Curatolo, 1987; Murphy et al 2000; Gunn et al 2011).

It is important to note that we employed these scenarios to demonstrate the "worst case" possibilities. Thus for Scenario 2 (abandonment of ZOI), although there will probably be a reduction of use within the ZOI close to human activity, we don't expect 100% abandonment of the entire ZOI. For Scenario 3 (abandon 35% of RSA), not only would we not expect animals to abandon the entire ZOI (Scenario 2), but they are unlikely to abandon significant portions of the RSA north and west of the infrastructure except perhaps temporarily in extreme weather conditions when crossing the railroad may prove difficult. Similarly, in Scenario 4 (abandon 65% of RSA) we only applied this extreme scenario to examine the energy-protein dynamics of the model and caribou response under extremely stressful conditions. For Scenario 5 (change in activity in ZOI) we test the impact on the population if a caribou spent the entire year in the ZOI. This is not likely as caribou do move constantly within their home range.

4.2 Herd growth

The objective of this exercise was to model the energy-protein relations of caribou encountering the mine site and infrastructure. Since there are direct links between some key body condition indicators and population vital rates (discussed below) we provide an assessment of not only the impacts on body condition, but also as an index of calf survival, weaning strategy, pregnancy rates, and adult cow survival. There is not sufficient data to model population dynamics for the North Baffin Herd, thus our treatment will simply relate to the vital rates and not population response.

Based on the data presented in the Mary River Project Wildlife Baseline Report (FEIS Appendix 6F), especially the analysis by Brody (1976), when the population was considerably higher than current, the model process assumes the RSA acts as a centre of habitation when the population is at a low and as the population grows, the range expands proportionally. As well, we assume the herd declines due to deteriorating range. Further, we assume the herd cycles every 65 years, is characterized by a slow initial recovery, rapid mid recovery, and rapid decline (Figure 17).

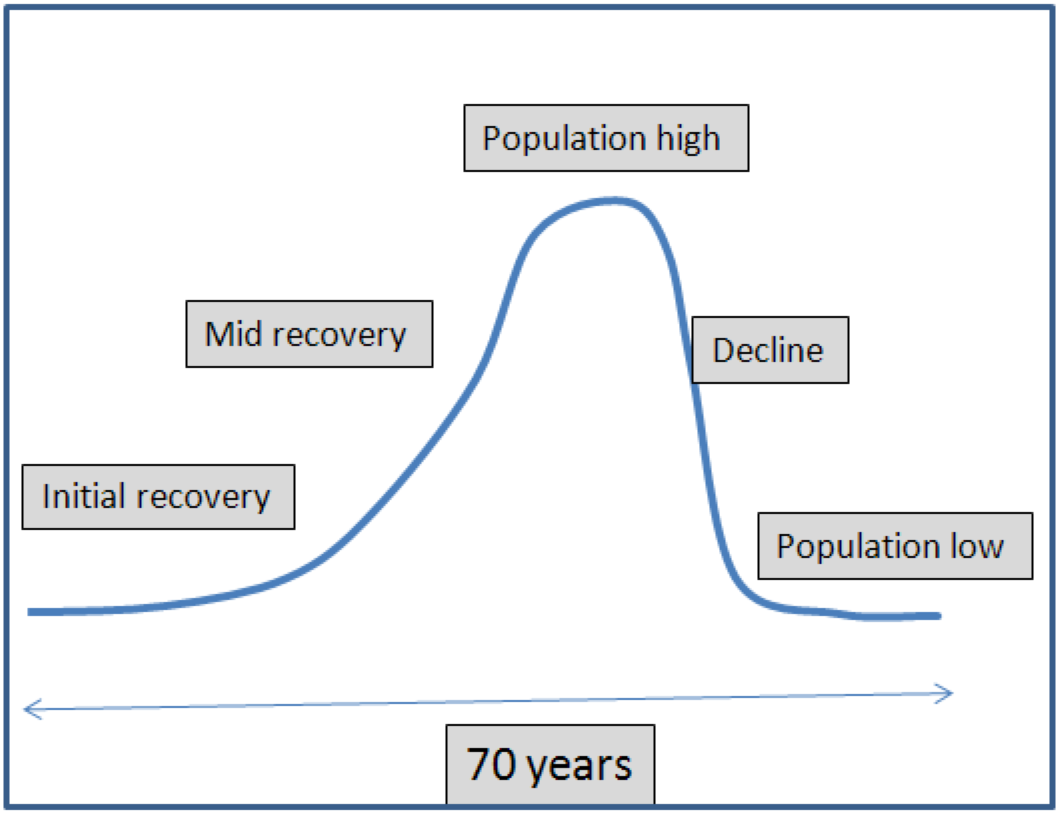

Figure 17. Assumed trajectory of the 65-year population cycle of the North Baffin caribou

If we assume that the general strategy of caribou throughout the abundance cycle is to maximize lifetime reproductive effort, then we can assume that a deteriorating range would first be noticed in adult body size, then pregnancy rates, then in calf survival, and finally in adult cow mortality (Crete and Huot, 1993; Russell et al 1997; Russell et al 1998; Russell and White 2000; Gerhart et al 1997). Also, we assume that when these herds are abundant, habitat is the main driver of these changes. In contrast, when range improves we would not necessarily detect that first in adult cow survival, rather in pregnancy rates. When populations are low, pregnancy rates can be high, while adult cow survival and calf survival remain low, not due to habitat, rather due to the combined effect of harvest and predation being able to hold populations down while range improves. Therefore, the length of the low density period would be dictated by the speed of the feedback between caribou density, harvest, predation, and the ability of the habitat to recover.

In the model, we applied a growth rate for the herd through time to assess impacts at different levels of population abundance. After each iteration of the model, we recalculated the effective biomass per individual (proportional to the increasing density of caribou). Density of caribou increased by the combined effect of normal population growth and added caribou occupying range outside of the range abandoned in either the ZOI, 35% RSA, or 65% RSA, as described above. Figure 18 represents the model process to assess the development impacts at the population level.

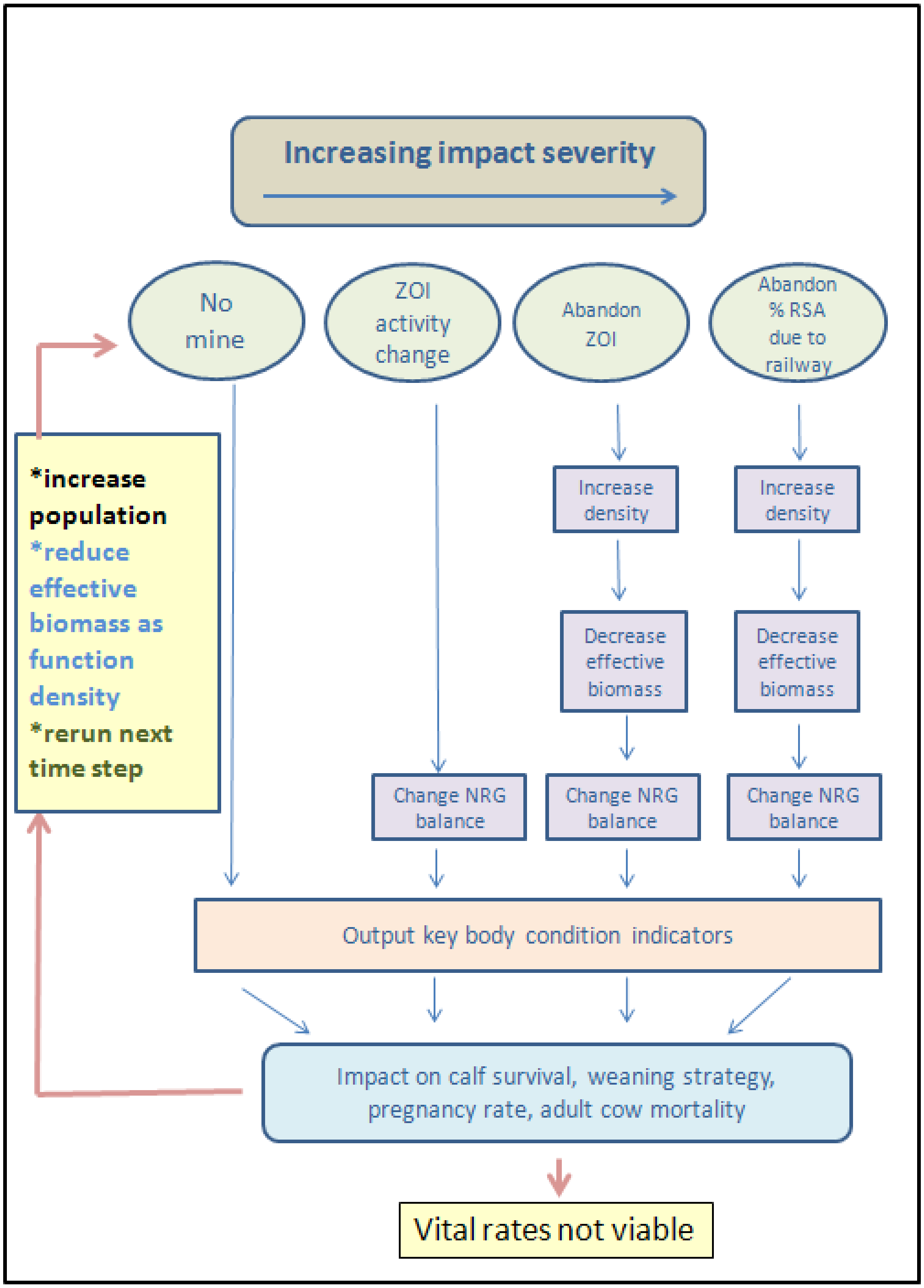

Figure 18. Steps in modeling the impact of the Mary River Project on the North Baffin caribou

For impact Scenario 1 (changing activity of caribou in ZOI), we made the following assumptions:

1. Caribou stayed in the ZOI all year;
2. The simulation was run with initial conditions representing the current condition where the caribou is not migratory and stays within a very small home range;
3. Activity change involved a reduction of 6% in daily foraging, 3% reduction in eating intensity, and 3% increase in both running and walking.

For the baseline run (Scenario 1), impact Scenario 2 (abandon ZOI), Scenario 3 (abandon 35% of RSA), and Scenario 4 (abandon 65% of RSA), we modeled over 5 year time steps. Table 3 presents the population size and the effective population size under Scenarios 2–4.

Table 3. Population size for the base run and effective population size based on 3 scenarios of range abandonment

		Area abandoned		
year	total pop	ZOI	35% RSA	65% RSA
1	1000	1040	1057	1111
5	1082	1125	1144	1202
10	1195	1242	1263	1327
15	1319	1372	1394	1466
20	1457	1514	1539	1618
25	1608	1672	1700	1786
30	1957	2034	2068	2174
35	2427	2523	2564	2695
40	3247	3376	3432	3607
45	4428	4603	4679	4918
50	6506	6763	6875	7226

Before each time step, we calculated the effective population size (EPS_{ZOI}) resulting from the abandonment of the ZOI by:

$$EPS_{ZOI} = POPN_t / 1 - (AREA_{ZOI} / AREA_{NBC})$$

where,
$POPN_t$ is the current population size of the herd at time t,
$AREA_{ZOI}$ is the area of the Zone of Influence, and
$AREA_{NBC}$ is the area of the North Baffin Caribou range.

Similarly we calculated the effective population size (EPS_{RSA}) after the abandonment of portions of the RSA as:

$$EPS_{RSA} = POP_{Nt} / 1 - (AREA_{RSA} / AREA_{NBC}) * AF$$

where,
$AREA_{RSA}$ is the area of the Regional Study Area, and
AF is the proportion of the RSA abandoned ("abandonment factor")

The calculation of the current biomass was calculated as:

$$BIO_t = BIO_1 / ((POPN_t - POPN_1) * REF + POPN_1) / POPN_1$$

where,
BIO_t is the current biomass used in the model (applied separately for all plant groups)
BIO_1 is the biomass all plant groups in year 1
$POPN_1$ is the starting population size in year 1, and
REF is the range expansion factor, i.e. a REF of 0.4 for example means that 40% of the additional caribou (from population growth and range abandonment) remained in the range, while 60% expanded to new range.

4.3 Key model indicators

Although the model tracks many indicators, for this application we summarize the results of the runs based on six key indicators. Most of the indicators relate to weaning strategy which has impacts on calf survival, pregnancy rate, age of first reproduction, and cow survival. Russell and White (2000) discuss the links between body condition and weaning strategy in caribou.

Post-natal weaning occurs when biomass during the first week in June, and rate of plant growth over the next three weeks are insufficient to maintain growth rates in the calf. Upon weaning, the calf dies and the cow increases potential pregnancy rate in autumn (Griffith et al 2002).

Summer weaning occurs when cow protein reserves fail to be replenished due to extremely poor range, accidental injury, or disease. Calves weaned in midsummer are assumed to die.

Early autumn weaning occurs when the fat reserves of the cow are below a specified threshold primarily due to a combination of the factors listed above, as well as particularly bad insect years. As a result, although calves can be viable on their own by mid September, the survival rate of the calf declines (Russell et al 1991) and the age of first reproduction of the calf is likely increased. For the cow, this strategy enhances her survival through winter and increases her chance of getting pregnant.

Extended lactation is associated with poor physical condition of the calf during the normal weaning period (rut). As a consequence, the cow continues to nurse her calf, thereby reducing her probability of getting pregnant due to "lactational infertility" (Gerhart et al 1997), but ultimately increases the survival of her calf.

Normal weaning, which is initiated during the rut, results in higher pregnancy rates for the cow. In this latter case, both cow and calf have healthy levels of fat and protein reserves. Based on these relationships, the following indicators are summarized for this application of the model: 1) birth weight, 2) June calf growth rate, 3) midsummer protein gain of the cow, 4) late summer fat weight of the cow, 5) cow weight at the rut, 6) calf weight at the rut.

4.4 Scenarios 1 to 4 model results

4.4.1 Baseline result- diet

In the modeling process, the average biomass characteristic of a caribou population range is not necessarily indicative of the biomass caribou encounter during foraging. Intake rates in the model are calculated based on what is exactly in front of the animal's mouth, thus the model employs a biomass "multiplier" to account for the often clumped distribution of plants and microhabitats. For the Baffin range we needed to increase the biomass multiplier by a factor of 10 to result in typical fat and protein dynamics under above average climatic conditions. With the mix of habitat types and low biomass of green vegetation in the range of the North Baffin caribou herd, our modeled diets indicated that North Baffin Caribou consume a significant amount of less nutritious vegetation types (standing dead graminoids, evergreen shrubs, moss) compared to diets found in caribou from more productive habitats.

4.4.2 Baseline result – activity budgets

In partial compensation for the poorer diets, North Baffin caribou had relatively favourable snow conditions. Average snow depths were lower than other mainland herds, thus reducing the cost of cratering and increasing the eating intensity (amount of forage time actually spent ingesting food). In the summer, relatively cool windy conditions, typical of the range, meant that mosquitoes and oestrid fly harassment were normally low; especially oestrid harassment, as these flies are not active until temperatures were above 13^{o}C.

4.4.3 Indicators – birth weight

Simulated birth weight did not vary until after 35 years. This indicates that winter and spring conditions provided sufficient resources for caribou to allocate required energy and protein for foetal growth. The reduced forage conditions finally did result in lower birth rates after 35 years, and the decline was rapid until our simulation ended at 50 years (Figure 19). Reduced birth weight is associated with reduced calf survival. Bergerud (2008) found that among his sample of newborn calves, the average of those that died was 4.04 kg, while the average of those that survived was 5.08 kg. Once birth weight started to decline from 35-50 years, mean birth weight among all our scenarios varied from 4.7 kg (baseline) to 4.4 kg (65% RSA)

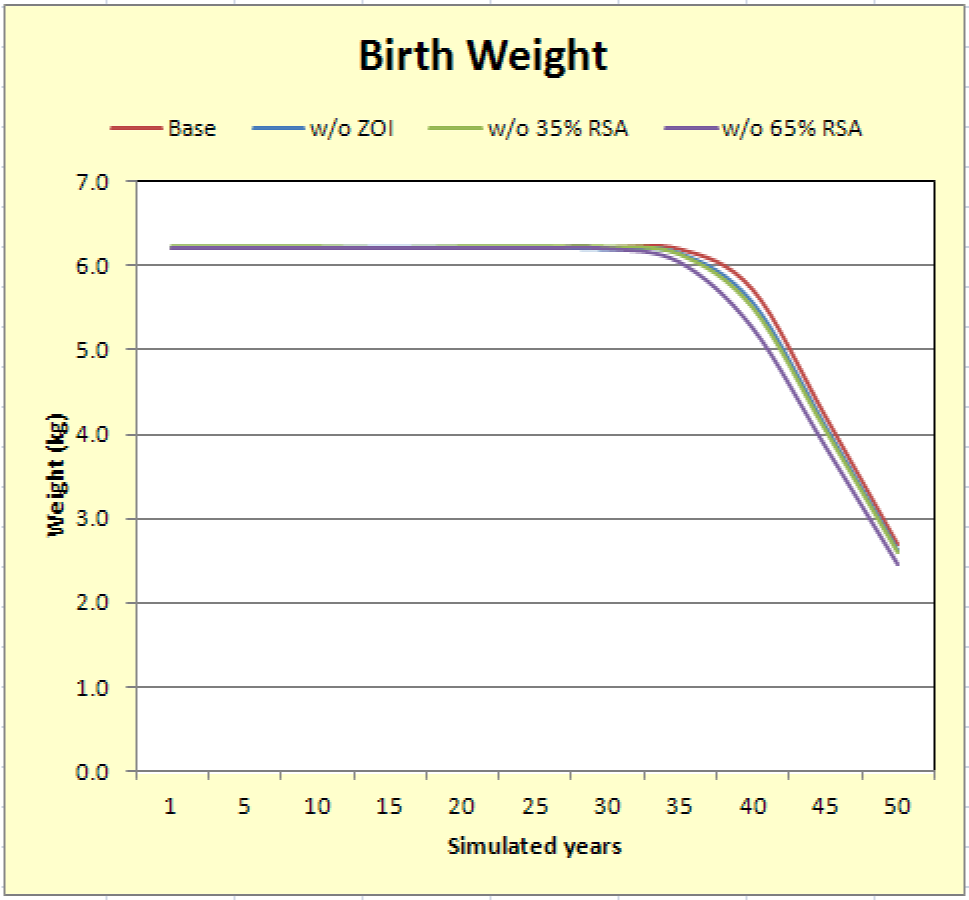

Figure 19. Simulated birth weight of North Baffin caribou under baseline and impact scenario conditions

4.4.4 Indicators – June calf weight gain

Late spring and early summer conditions resulted in high calf weight gains until 30 years into the simulation (5 years earlier than birth weight). All our impact scenarios found that a drop in weight gain could be detected between 20–25 years (Figure 20). For calves of the Porcupine herd, Russell and White (2000) estimated that cows would wean calves off if weight gain between 10 and 20 days after birth dropped below 200 g/day. If the same conditions occurred for the North Baffin herd, calves would be weaned, and the calf would die, between 40–45 years for the baseline simulation. All simulated impact scenarios resulted in the 200 g per day threshold being reached in the same 40–45 year timeframe.

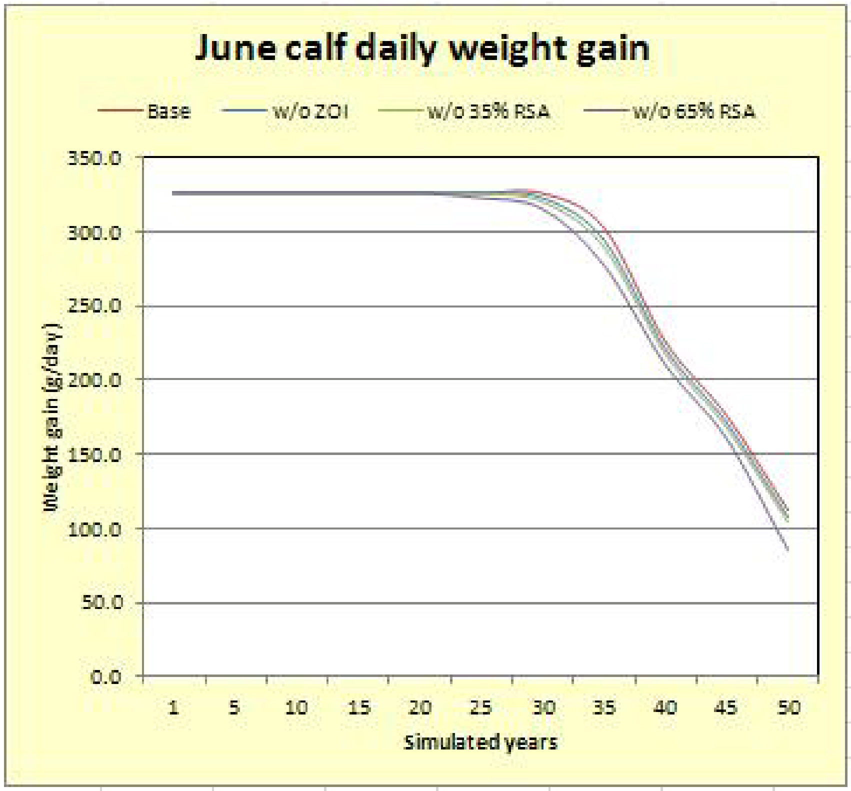

Figure 20. Simulated calf June weight gain per day of North Baffin caribou under baseline and impact scenario conditions

4.4.5 Indicators – summer cow protein gain

Russell and White (2000) argued that if the lactating cow could not replenish protein reserves in the summer, they would wean their calf in late July and August. Applying this same argument to the North Baffin caribou herd, we would expect summer weaning if protein gain dropped below a certain threshold. In the EP model, cows will give high priority to replenishing their protein reserve, even at the expense of milk production. Thus we impose a minimum protein gain per day during July, which has to be satisfied before additional milk production occurs. Therefore, for comparing protein gain and the potential for summer weaning, we used a 2 gram per day threshold for August protein gain, as there was no dynamics in July protein gain given the priority for protein gain in the Allocation sub-model. There was very little difference in the prediction of protein gain among the scenarios (Figure 21). The baseline protein gain at 25 years was 3.0 grams, dropping to 2.8 grams per day in the worst case scenario of 65% abandonment of the RSA.

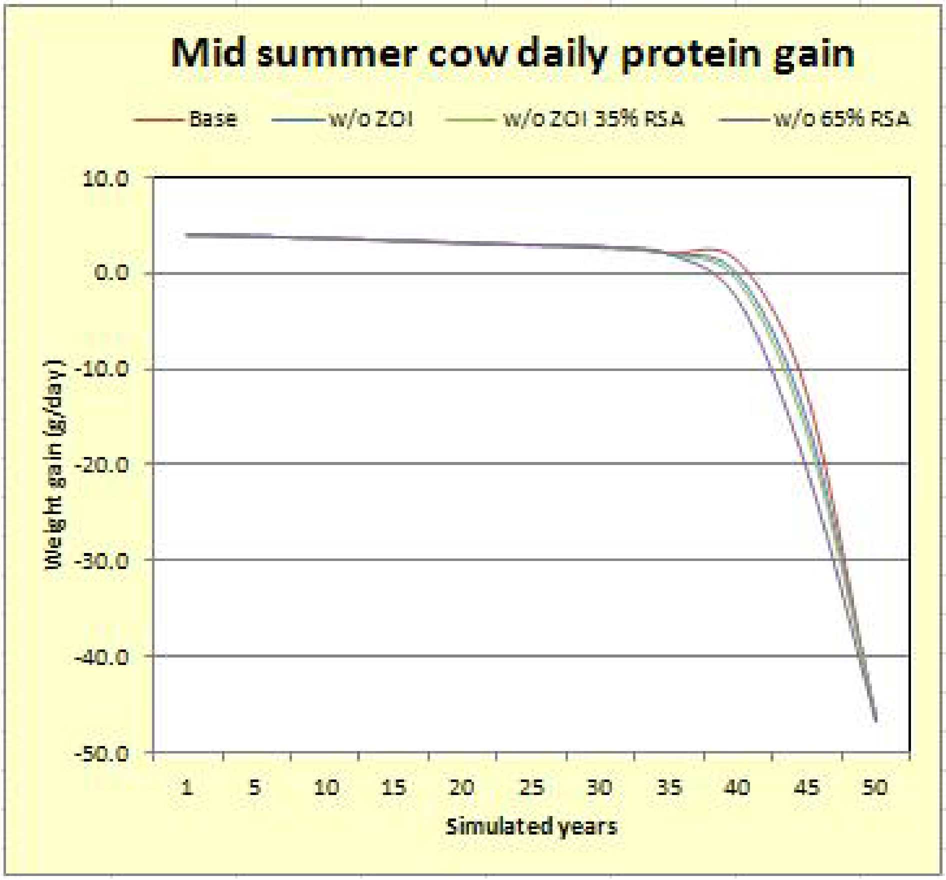

Figure 21. Simulated cow midsummer protein gain per day of North Baffin caribou under baseline and impact scenario conditions

4.4.6 Indicators – late summer cow fat weight

By mid September if cows are in relatively poor shape they can wean their calves off a little earlier than normal. These calves can survive, but with a reduced probability of survival (Russell et al 1991). In the Porcupine herd we only observed this strategy in one year that we were monitoring. In 1990 a high proportion of cows arrived on the rutting grounds with no milk in the udders, although often still accompanied by their calf. Russell and White (2000) set a threshold of 4.5 kg for early weaning for the Porcupine caribou herd. In our simulations, the decline in fall body condition was immediate as biomass was reduced (Figure 22). This response was consistent with data from Crete and Hout (1993) who maintained that maternal cows would buffer deteriorating environmental conditions by reducing body size before reducing reproductive output. The differences in fat weight among the development scenarios (a spread of about 1 kg of fat at the beginning of the simulation) are largely lost by the end of the simulation period. It appears that the subsequent reduction in calf size near the end of the simulation (see next indicator discussion) may serve to reduce the differences in cow body fat under very poor environmental conditions. The reduced fat weight due to development impacts, although not associated with weaning in the early years, may have a measureable effect on breeding pauses. Under average to below average conditions, cows annually lose body condition if they consistently give birth and raise a calf. Therefore, depending on the conditions, they will experience a breeding pause every 3-5 years (Cameron 1994). So, reduced fall body condition due to development may increase the frequency of breeding pauses and thus lower the long-term overall productivity of the herd.

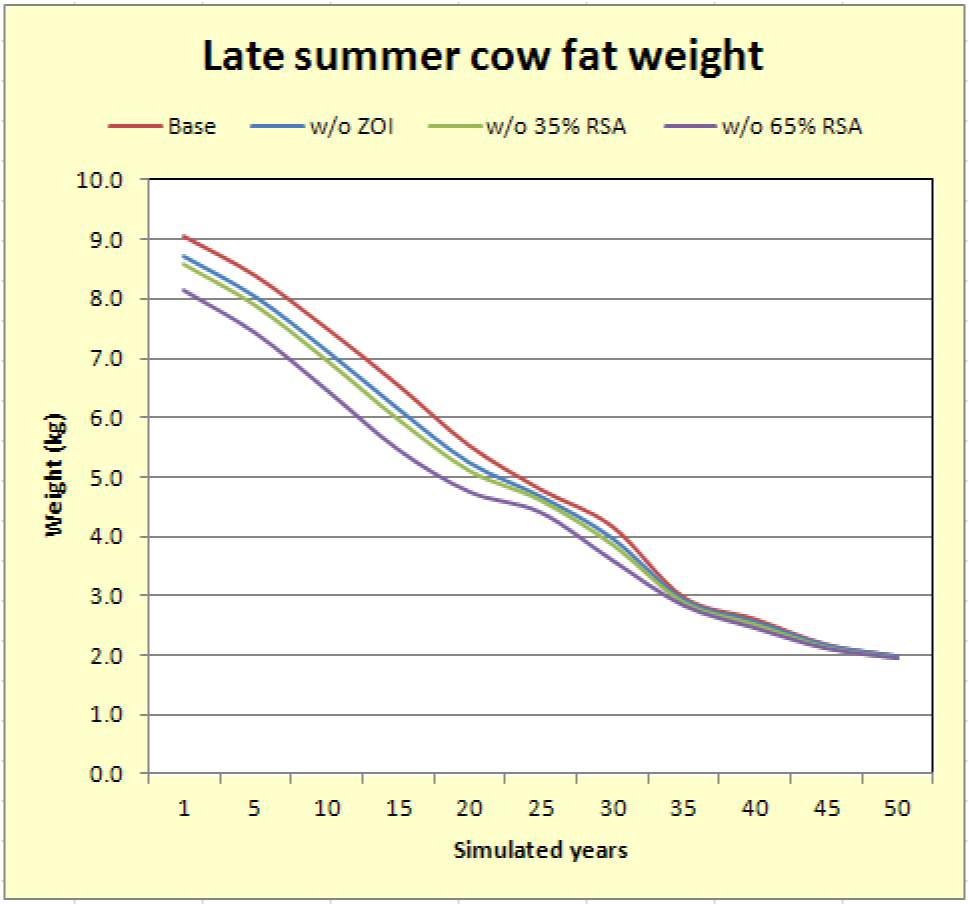

Figure 22. Simulated late summer fat weight of cows for North Baffin caribou under baseline and impact scenario conditions

4.4.7 Indicators –cow weight at rut

In the model, we forced cows to be pregnant and successfully raise a calf to the rut to examine the "worst case" relationships between habitat and development. Cow body weight at rut dropped from 88 kg at the beginning of the simulation to 63 kg after 50 years (Figure 23). Similar to late summer fat weight the difference among development scenarios was more pronounced at the beginning of the simulation and differences converged near the end. This could be explained by caribou strategy to initially reduce body condition during poor environmental conditions but to ensure their own survival in very poor conditions at the expense of their foetus or calf.

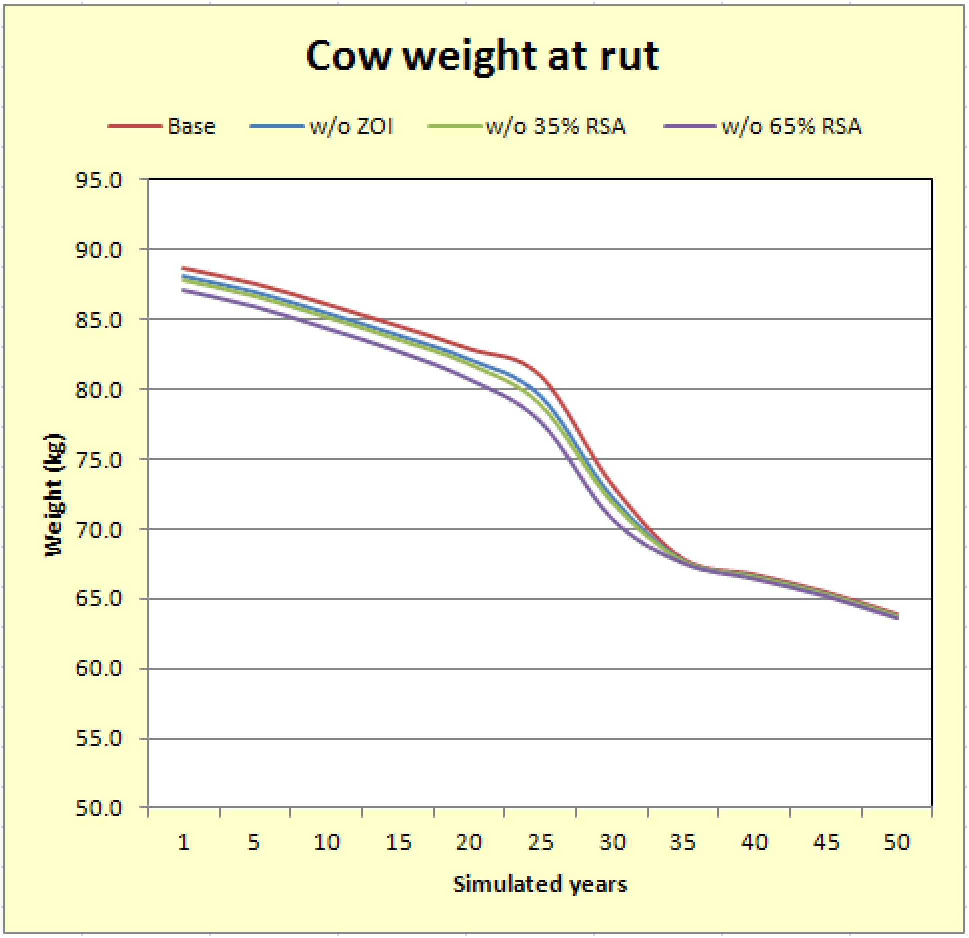

Figure 23. Simulated cow weight at rut for North Baffin caribou under baseline and impact scenario conditions

Female condition during the breeding period has been shown in a number of studies to accurately predict the probability of pregnancy (Cameron and Ver Hoof 1994, Thomas and Barry 1990, Bergerud 2008). Using the equation presented earlier in this report, we calculated pregnancy rates for all scenarios (Figure 24). The greatest drop from the baseline conditions was at 25 years where a 10% difference between baseline (70%) and the 65% RSA scenario (60%). The magnitude of the difference is due to body weights falling on the steep part of the logistic curve where small differences in body weight (3.3 kg) translate into large differences in predicted pregnancy rates.

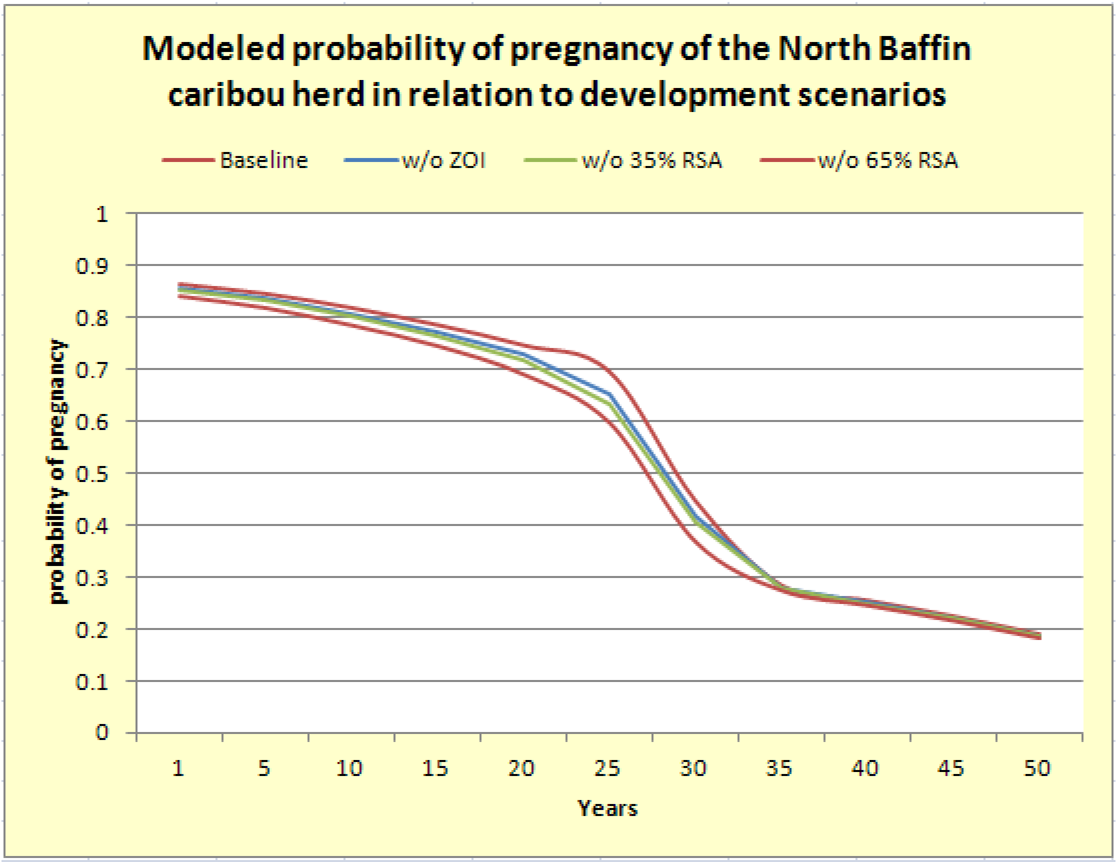

Figure 24. Modeled probability of pregnancy for North Baffin caribou under baseline and impact scenario conditions

4.4.8 Indicators – calf weight at rut

The weight of the calf going into winter effects the future age of first reproduction, weaning strategy (extended lactation if calf small), pregnancy rates (lactational infertility) and calf survival. Calves did not start to lose weight until 25 years but dropped dramatically at that point (Figure 25). The greatest difference in calf weight among scenarios was ~ 2 kg on the steepest part of the decline. Although the correlations have been made, there are no published functional response curves to be able to assign a change in vital rates in relation to calf weight at rut.

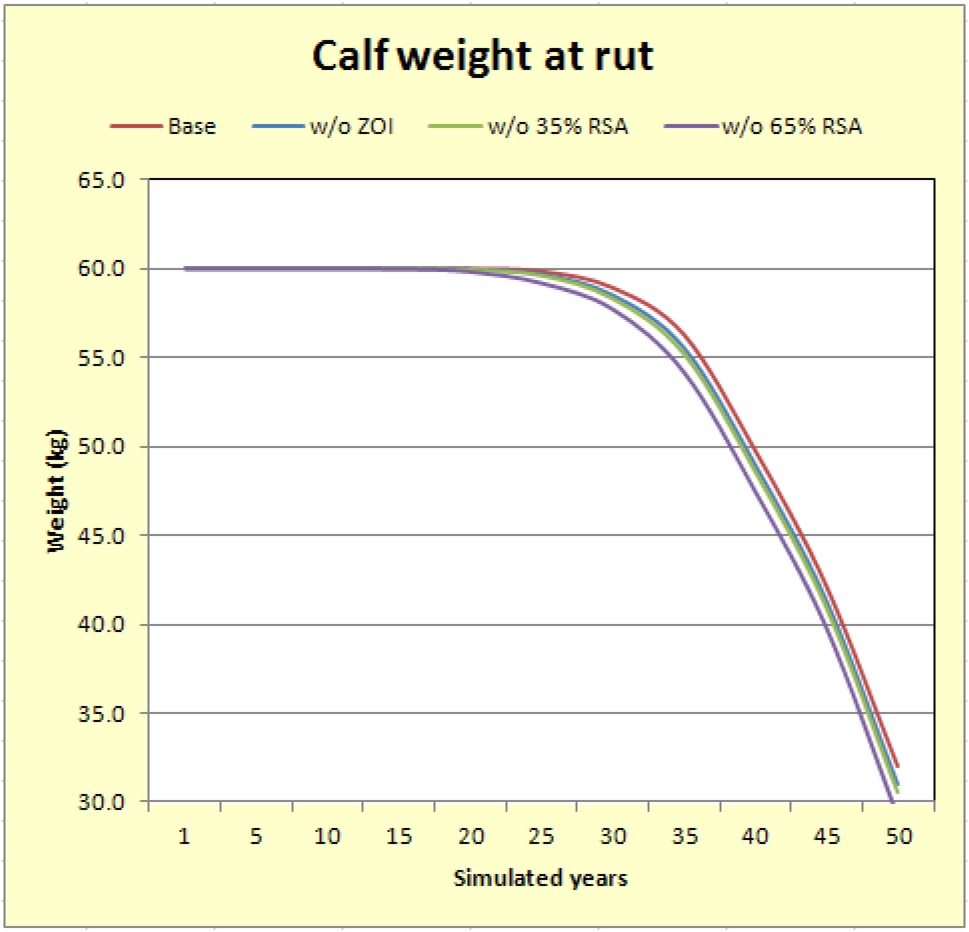

Figure 25. Simulated calf weight at rut for North Baffin caribou under baseline and impact scenario conditions

4.5 Scenario 5 model results

As expected, forcing caribou in the ZOI all year and changing their activity as described above resulted in a significant reduction in the key indicators. The results were similar to comparing the year 1 results in the baseline with approximately the year 35 baseline run. However, the impact on the population, considering only 3.8% of the population would expect to be in the ZOI (or less if they avoided the zone), resulted in small reductions in our key indicators (Table 4). At the population level, birth weight declined by 1 gram, June weight gain by 2.2 grams per day, summer protein by 1.3 g per day, September cow fat by 0.3 kg, cow weight at rut by 0.8 kg, calf weight at rut 0.4 kg, and pregnancy rate by 2.3%.

Table 4. Summary of results for Scenario 5

	Birth wt (kg)	June wt gain (g/day)	Summer protein gain (g/day)	Sept cow fat (kg)	Rut cow wt (kg)	Rut calf wt (kg)	Pregnancy rate
Baseline run	6.218	326.4	4.1	9.046	88.6	60.0	0.86
ZOI activity change	5.900	269.0	-31.0	2.200	67.3	49.0	0.27
Weighted for population	6.206	324.2	2.8	8.786	87.8	59.6	0.84
Change from baseline	0.012	2.181	1.333	0.260	0.810	0.417	0.023

5 OVERALL CONCLUSIONS

The model results provide estimates of how declining biomass may impact the expanding, and thus increasingly dense, population of North Baffin Caribou. As well the Scenarios that we modeled provide a relative assessment of the role of an increasingly pessimistic impact potential during this expansion phase. In all runs cows did better with no devleopment, with the ZOI abandoned, 35% of the RSA and 65% of the RSA getting progressively worse with respect to percent change from baseline conditions of the key variables (Figure 26).

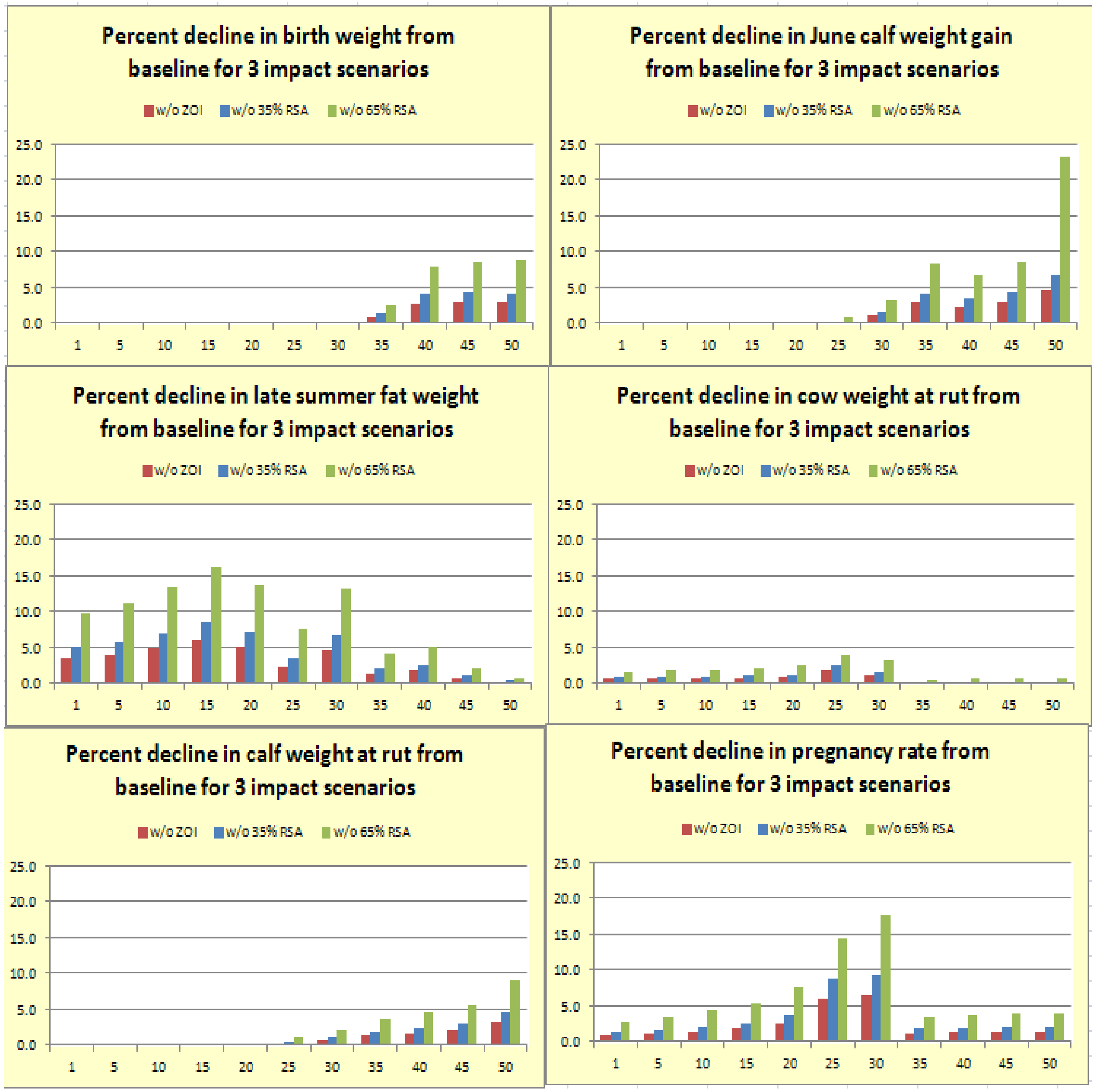

Figure 26. Percent change of key variable from baseline conditions for impact Scenarios 2–4.

In general terms, with increasing density, birth weight remained high for 35 years then dropped, June weight gain stayed high 25 years before dropping, summer protein gain dropped after 30 years, September fat weight and cow weight at rut declined immediately, while calf weight at rut declined after 15 years. The additional impact for Scenarios 2, 3, and 4 varied through time and among Scenarios. We feel that the least severe impact modeled (Scenario 2), abandoning the entire ZOI, is not likely to occur. For that Scenario, the changes to the key variables from baseline values at the highest densities were:

Variables	Change from baseline
Birth weight	-2.9%
June calf weight gain	-4.7%
Summer protein gain	-4.8%
September fat weight	-5.9%
Rut cow weight	-1.7%
Rut calf weight	-3.2%
Pregnancy rate	-6.4%

Differences of all Scenarios at low densities never exceeded -3.5%. Scenario 4 (abandoning all areas of the RSA north and west of the infrastructure), imposed in the most severe stress on the animals, resulting in up to a 17.7% decline in pregnancy rate in the years just prior to the declines in birth weights, calf growth, summer protein loss, and fall calf weight. In those years (25–30 years into the simulation), the model predicted that the cow would sacrifice her own condition to ensure the survival of her calf, but only until it increased the probability of her not surviving. At that point the survival of the calf suffered with reduced birth weights and growth rates.

This analysis allows us to better understand the impacts of human activity on the energy-protein relations of caribou. When new North Baffin specifc data become available, more monitoring of impacts on activity and distribution is conducted, and a better understanding of the popualtion dynamics of this population is achieved, we can use this modeling approach to reassess impacts of this development and others that may occur in the future. As well, this modeling did not assess the role of climate in exacerbating or ameliorating the projected impacts of development.

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Appendix A: Scenario model results

Scenario 1. Results of modeling baseline conditions of expanding caribou population

Year	Population	Birth weight (kg)	June calf weight gain (g/day)	Summer protein gain (g/day)	Sept. cow fat (kg)	Rut cow weight (kg)	Rut calf weight (kg)	Pregnancy rate
1	1000	6.2	326.4	4.1	9.0	88.6	60.0	0.86
5	1082	6.2	326.4	3.9	8.4	87.5	60.0	0.85
10	1195	6.2	326.4	3.7	7.5	86.1	60.0	0.82
15	1319	6.2	326.4	3.5	6.5	84.5	60.0	0.79
20	1457	6.2	326.4	3.3	5.5	82.9	60.0	0.75
25	1608	6.2	326.4	3.0	4.8	81.0	59.8	0.69
30	1957	6.2	326.4	2.9	4.2	73.2	58.9	0.45
35	2427	6.2	303.4	2.2	3.0	67.9	56.3	0.28
40	3247	5.7	226.3	1.3	2.6	66.8	49.8	0.25
45	4428	4.2	176.3	-12.6	2.2	65.5	42.1	0.22
50	6506	2.7	112.2	-46.7	2.0	63.9	32.0	0.19

Scenario 2. Results of modeling abandonment of the ZOI

Year	Population	Birth weight (kg)	June calf weight gain (g/day)	Summer protein gain (g/day)	Sept. cow fat (kg)	Rut cow weight (kg)	Rut calf weight (kg)	Pregnancy rate
1	1039.5	6.2	326.4	4.0	8.7	88.1	60.0	0.86
5	1125	6.2	326.4	3.9	8.0	87.0	60.0	0.84
10	1242	6.2	326.4	3.7	7.1	85.5	60.0	0.81
15	1372	6.2	326.4	3.4	6.2	83.9	60.0	0.77
20	1514	6.2	326.4	3.2	5.2	82.2	59.9	0.73
25	1672	6.2	326.4	2.9	4.7	79.6	59.7	0.65
30	2034	6.2	322.6	2.8	4.0	72.3	58.5	0.42
35	2523	6.1	294.4	2.1	2.9	67.8	55.5	0.28
40	3376	5.6	220.8	-0.2	2.6	66.7	48.9	0.25
45	4603	4.1	170.9	-15.5	2.2	65.4	41.3	0.22
50	6763	2.6	107.0	-46.3	2.0	63.8	31.0	0.19

Scenario 3. Results of modeling abandonment of 35% of Regional Study Area

Year	Population	Birth weight (kg)	June calf weight gain (g/day)	Summer protein gain (g/day)	Sept. cow fat (kg)	Rut cow weight (kg)	Rut calf weight (kg)	Pregnancy rate
1	1057	6.2	326.4	4.0	8.6	87.9	60.0	0.85
5	1144	6.2	326.4	3.8	7.9	86.7	60.0	0.83
10	1263	6.2	326.4	3.6	7.0	85.2	60.0	0.80
15	1394	6.2	326.4	3.4	6.0	83.6	60.0	0.76
20	1539	6.2	326.4	3.1	5.1	81.8	59.9	0.72
25	1700	6.2	326.4	2.9	4.6	78.9	59.6	0.63
30	2068	6.2	321.0	2.7	3.9	72.0	58.3	0.40
35	2564	6.1	290.5	2.0	2.9	67.7	55.2	0.28
40	3432	5.5	218.5	-0.9	2.5	66.6	48.6	0.25
45	4679	4.0	168.5	-16.7	2.1	65.3	40.9	0.22
50	6875	2.6	104.7	-46.1	2.0	63.8	30.6	0.18

Scenario 4. Results of modeling abandonment of 65% of Regional Study Area

Year	Population	Birth weight (kg)	June calf weight gain (g/day)	Summer protein gain (g/day)	Sept. cow fat (kg)	Rut cow weight (kg)	Rut calf weight (kg)	Pregnanc y rate
1	1111	6.2	326.4	3.9	8.2	87.2	60.0	0.84
5	1202	6.2	326.4	3.7	7.4	86.0	60.0	0.82
10	1327	6.2	326.4	3.5	6.5	84.4	60.0	0.78
15	1466	6.2	326.4	3.3	5.5	82.8	60.0	0.74
20	1618	6.2	326.4	3.0	4.8	80.8	59.8	0.69
25	1786	6.2	323.2	2.8	4.4	77.7	59.2	0.60
30	2174	6.2	315.8	2.5	3.6	70.8	57.7	0.37
35	2695	6.0	278.2	1.9	2.9	67.5	54.1	0.27
40	3607	5.3	211.0	-2.9	2.5	66.4	47.4	0.24
45	4918	3.9	161.2	-20.6	2.1	65.2	39.8	0.21
50	7226	2.5	86.2	-46.7	2.0	63.6	29.2	0.18