Attachment A Kiggavik Project Effects: Energy-Protein and Population Modeling of the Qamanirjuaq Caribou Herd

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EXECUTIVE SUMMARY

The Kiggavik mine project has the potential to disturb caribou. Based on requests from the Beverly-Qamanirjuaq Caribou Management Board, AREVA agreed to provide a Project and cumulative effects assessment on caribou. To predict potential impacts, an individual-based energy-protein (E-P) model was linked to a population model. Those tools were used to provide analysis of the expected range of fall body weights of cows and calves due to the substantial variability observed in the individual caribou encounters with zones of influence (ZOI) within the Qamanirjuaq caribou range.

The key output indicators from the E-P model were the fall body weight of lactating cows and their calves. Those values provided inputs with respect to probability of pregnancy and over-winter calf mortality at the population scale. In "populating" both the energy-protein (E-P) model and the population model, the most appropriate and available data were used. For the E-P model, existing datasets on vegetation communities within the Qamanirjuaq's herd range were augmented with generic data from the CircumArctic Rangifer Monitoring and Assessment (CARMA) network to quantify forage quality/quantity and seasonal diet. Active/rest cycles were driven by known relationships between the proportion of day spent resting as dictated by latitude and day length, while the partition of the active cycle was primarily driven by climatic conditions developed for the Qamanirjuaq herd by CARMA. Collections of just under 1,000 caribou in the 1960s provided information of body weights, age and sex structure, pregnancy rates and mortality.

A number of development scenarios were used to accomplish six objectives:

1. Determine the individual and population level effects of the Kiggavik Project on the Qamanirjuaq herd.
2. Determine potential effects from other active and potential projects on the Qamanirjuaq herd.
3. Determine the added incremental impact of the Kiggavik project with respect to the total impact from development within the range of the Qamanirjuaq herd.
4. Predict variability of fall body condition of cows and calves within the herd by modeling a cross section of individual encounter rates.
5. Determine if the season of encounters with development effects fall body weights.
6. Determine harvest adjustments needed to offset development effects.

The primary dataset that used to quantify encounter rates that individuals of the Qamanirjuaq herd had with infrastructure ZOI was radio-collar data from 1993–2012. GIS analysis was used to determine the residency time that each collared caribou spent within ZOIs both for existing projects, likely projects and, separately, for a future Kiggavik mine. The scenarios were:

1. BASE scenario — no development, no encounters.
2. ASR —caribou were modeled based on a liberal assessment of encounter rates and residency time in the mine and <u>All-Season Road</u> (ASR) ZOI.
3. WR —caribou were modeled based on a liberal assessment of encounter rates and residency time in the mine and <u>Winter Road</u> (WR) ZOI.
4. CE —<u>Cumulative Effects</u> (CE) were modeled using the effects of disturbance on caribou encountering ZOIs within their range based on average seasonal residency for collars from 2005 to 2012.

5. CE+ASR — the incremental residency times in the ASR were added to the CE scenario to determine the total and incremental effects with the Kiggavik project.

Although not scenarios *per se,* the maximum residency time individual collars experienced in each season was determined, and modeled the quartile times (divided the dataset into quarters to provide an estimate of the variation in fall body weight of cows and calves that might be expected from the spectrum of total and seasonal exposures. As well, the importance of season (i.e. when they encounter a ZOI) in predicting disturbance effects was explored.

Results of running the scenarios through the E-P model were used as input for the population model through probability of pregnancy (fall body weight of cows) and over-winter survival of calves (fall body weight of calves). The Qamanirjuaq population was modeled over 26 years (2014–2040) and used the population size as the indicator of population effects. Further, the change in harvest (through lower annual harvest or through lower proportion of females in the harvest) possibly needed to offset the population effects of development was determined.

In 1,274 "opportunities," collared caribou only encountered the ASR 18 times and the WR 18 times for an encounter rate of 1.4%. Most of the encounters, as expected, were in the post-calving period (67% ASR and 72% WR). The major difference between the ASR and the WR was that the average residency time in the WR post-calving period was much lower (0.4 days) compared to the ASR (1.6 days). As well no encounters occurred in the late winter period in the WR compared to 1 encounter in the ASR.

The exposure to the ASR was modeled using average seasonal residency times recorded, and assumed all seasonal encounters occurred in the same year (total of 12 days resident in the ASR ZOI) and were experienced by the same individual — although encounters from collar data were interspersed from 2005–2012 and involved 12 different collars. In fact only 1 collar (that wintered near Kiggavik) spent 8 days associated with the ZOI, 2 collars spent 6 days and the remaining collars spent less than a day.

Compared to the base run, the modeled cows averaged 0.6 kg lower fall body weight and calves 0.46 kg lower body weight. Assuming a 1.4% encounter rate with the Kiggavik project, there was no difference (overlapping Standard Errors) in the final population size between the ASR scenario and the base scenario, even while keeping variability around the vital rate estimates extremely low. Given the lower residency days (compared to ASR) in the WR and the fact that 90% of the WR encounters were in post-calving and summer (when that road option is inactive), we didn't see the need to model the WR scenario given the more severe scenario (ASR) did not result in a population effect.

Results from the CE scenarios projected an average fall body weight decline of 0.8 kg and 0.62 kg for cows and calves. The CE+ASR predicted a decline of 0.8 kg and 0.68 kg decline for cows and calves respectively. Population size in 2040, based on E-P model output from these scenarios, and weighting by the percent of collars that interacted with the CE development projects (30% average across seasons), was projected an average 24,000 caribou decline from baseline population estimates. Again there was no significant difference between the CE and the CE+ASR estimates. For the CE scenario, the change in harvesting to offset the 24,000 decline was either a 5.1% reduced harvest or drop in the proportion of females in the harvest from 65% to 62%. Even though there was not a significant difference between the CE and the CE+ASR scenario population estimate, multiple runs of the stochastic model resulted in a slightly lower, through still not significant, average population size. Based on the average comparison from CE to CE+ASR, the harvest adjustment for CE+ASR compared to the CE estimate was 8 less caribou harvested per year or a drop in the proportion of cows from 62 % to 61.5 %. It is important to emphasize that the 24,000 drop in final population size was based on a very pessimistic (i.e., errs on the side of extreme precaution) disturbance scenario for caribou encountering ZOIs, especially with respect to the disturbance through the ZOI and the reduction in foraging time and eating intensity used in this analysis.

For individual collars, that maximum residency time in any year was tallied, resulting in a maximum annual residency time of 53 days. Dividing the individual collar results into quartiles, the fall body weights based on average time in each season for the 4 quartiles was modelled. Results indicated a steady decline in fall body weight for adult lactating cows from baseline conditions to high interactions (Q4: 100%). Body weight of adult cows ranged from a baseline of 78.9 kg to 76.3 kg for the worst case (the Q4: 100%) and calves from 53.41 to 52.68 kg. Interestingly the lowest calf weights were noted for the Q3: 75% scenario (52.62 kg).

The final analysis was to help determine the importance of season of ZOI exposure to fall body weight of cows and calves. This assumed that there would be on average 13 days of residency and that all the days would be in one of the seven seasons. Fall body weight of cows ranged from 78.9 to 77.3 kg and calves from 53.6 to 51.4 kg. The ecological reasons for the seasonal variability is discussed.

From our analysis we determined that the population level effects of the Kiggavik project will be not different from populations in the absence of the Kiggavik project. Any residual effects would be substantially masked by natural variability. While we were able to model ASR effects, based on current collared caribou movements, the WR option does not disturb the caribou to a scale that we could even develop an E-P model scenario.

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1 INTRODUCTION

This report is a component of the Kiggavik Project's project effects and cumulative effects assessment for caribou (Kiggavik Project Final Environmental Impact Statement [FEIS] submission to the Nunavut Impact Review Board, Volume 6, Section 13). This analysis was conducted to address the Beverly-Qamanirjuaq Caribou Management Board's (BQCMB) request to provide a caribou energetics effects assessment of the Kiggavik project. Further the BQCMB requested that AREVA also attempt to provide an assessment of cumulative effects of other projects within a broader cumulative effects study area.

The Kiggavik project is located on the periphery of five caribou herds identified in Nunavut's mainland region: the Beverly, Ahiak, Wager Bay, Lorillard, and Qamanirjuaq herds (Described in AREVA's FEIS submission, Volume 6, Appendix 6C — Wildlife Baseline). For this analysis, potential effects on the Qamanirjuaq herd, a herd that is relatively well-documented, has the most development within its range and is relevant to the mandate of the BQCMB, was modeled. Although a similar assessment approach could be attempted on all of the herds, the remaining herds are poorly understood and have less development within their ranges. We maintain however that the results from modeling the Qamanirjuaq herd could be applied to the other herds, and the potential effects on the Qamanirjuaq herd likely represent a "worst case" scenario.

The objectives of this analysis were to investigate the following issues:

1. Determine the potential individual and population level effects of the Kiggavik Project on the Qamanirjuaq herd.
2. Determine potential cumulative effects from other projects on individuals and the population of the Qamanirjuaq herd.
3. Determine the potential added incremental effect of the Kiggavik project with respect to the total effect from development within the range of the Qamanirjuaq herd.
4. Determine predicted variability of fall body condition of cows and calves within the herd by modeling a cross section of individual encounter rates.
5. Determine if there are seasonal differences in simulated effects on fall body condition of cows and their calves.
6. Determine harvest adjustments to offset potential development effects.

1.1 The Kiggavik Project

AREVA Resources Canada Inc. (AREVA) is proposing to construct, operate and decommission a uranium mine, called the Kiggavik Project (Project), in the Kivalliq Region of Nunavut. The Project is located approximately 80 km west of the community of Baker Lake. Four uranium ore deposits will be mined using open pit methods and one deposit will be mined using underground methods. All extracted ore from the mine sites will be processed through a mill. Some of the mined out pits will be used as tailings management facilities. The uranium product will then be packaged and transported using aircraft to southern transportation networks. The Project will be serviced by ship and barge and a winter access road. An all-season road between Baker Lake and the Project is a secondary option under consideration in case the winter road cannot adequately support the Project. Based on existing resources mine life is estimated at 14 years of operation with additional years for construction and decommissioning.

2 METHODS

To predict potential Project and cumulative effects on caribou energetics and populations, an individual-based energy-protein (E-P) model linked to a population model was used. Those tools were used to provide an analysis of the expected range of fall body weights of cows and calves due to substantial variability observed in the individual caribou encounters with infrastructure zones of influence (ZOI) within the Qamanirjuaq caribou range. The analyses of caribou encounter rates with possible disturbances is based on possible caribou movement and encounters with a variety of disturbances evaluated using satellite collar telemetry data provided by the Government of Nunavut.

2.1 Telemetry Data

Caribou satellite collar telemetry was used to evaluate potential caribou encounters with the Kiggavik Project and other potential disturbances within the Qamanirjuaq caribou range. Telemetry data included a minimum of 4 and maximum of 33 collars from 1993 to 2012 (Table 1). Collar data are described in "segments" or the distance and direction between collar reporting periods. Those segments are used to determine potential caribou encounters with disturbance activities across their range (described below). There was a general trend to more frequent locations and thus more segments available for analysis during the later years, and some of the analyses presented below was limited to data from 2005 onwards.

Table 1. Number of caribou collars, frequency of locations and mean segments used for analysis in this report.

Year	No. collars	Days between locations	Mean segment/collar
1993	4	4.0	66.8
1994	5	4.0	63.4
1995	8	4.2	45.3
1996	6	4.2	78.8
1997	10	4.9	23.2
1998	9	5.1	58.3
1999	7	4.7	79.1
2000	8	4.8	53.1
2001	8	5.1	50.6
2002	7	5.1	64.7
2003	6	5.1	72.5
2004	12	3.9	105.8
2005	9	3.1	188.3
2006	23	2.1	208.3
2007	23	2.2	180.4
2008	31	1.9	187.9
2009	27	2.4	198.9

Table 1. Number of caribou collars, frequency of locations and mean segments used for analysis in this report.

Year	No. collars	Days between locations	Mean segment/collar
2010	12	1.2	286.1
2011	33	1.1	214.8
2012	24	1.1	202.5

2.2 Caribou Seasons

Analyses of caribou encounters and potential effects on energetics were split by season. Seasonal date ranges were based on those identified by the BQCMB (Table 2). The spatial extent of the ranges were generated in a Geographic Information System (GIS) using the cumulative telemetry data and a simple kernel density analysis from caribou telemetry locations, constrained to the 95% use distribution. This commonly used method is an estimate of the geographic area likely to be used by at least the collared female component of the Qamanirjuaq herd on a seasonal basis. The seasonal ranges used in this assessment fall within the broader cumulative effects area described in the Project's FEIS Appendix 1E (Figure 1).

Table 2. Seasons in the annual movements of the Qamanirjuaq herd used in this report.

Qamanirjuaq Caribou Season*	Dates
Spring migration	Mar 16 – May 25
Calving	May 26 – Jun 25
Post-calving	Jun 26 – Jul 31
Summer dispersal	Aug 1 – Sep 15
Fall and Rut	Sep 16 – Oct 31
Early winter	Nov 1 – Dec 31
Late winter	Jan 1 – Mar 15
*based on BQCMB seasons for the Qamanirjuaq herd	

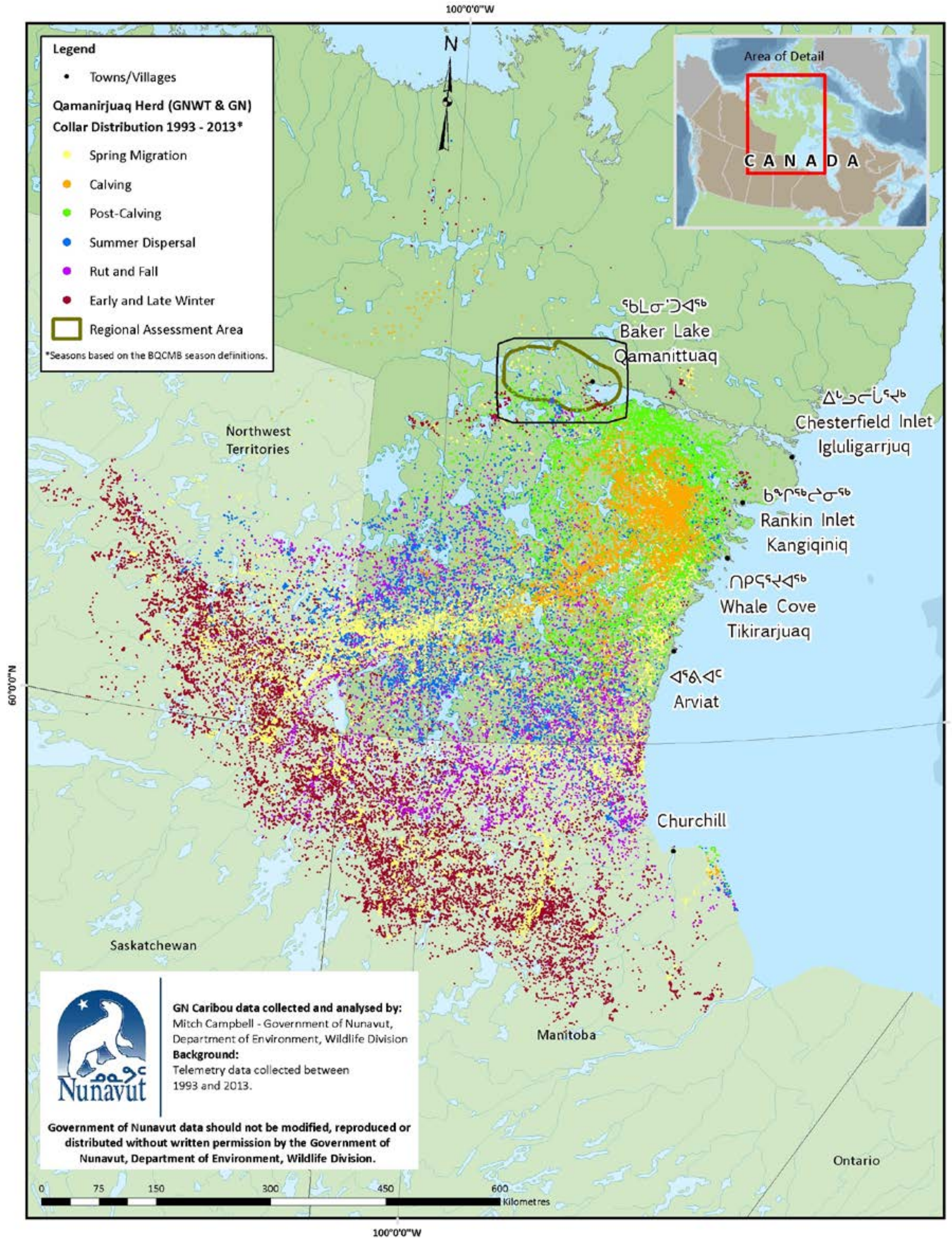

Figure 1. Qamanirjuaq herd collars by season, the information used to derive the 95% kernel density seasonal ranges that were used to derive habitat summaries for the energetics assessment.

The GN-DOE did not provide the 95% kernel density-derived seasonal range boundaries that were used in this model to derive habitat summaries.

2.3 Human Activity and Corresponding ZOIs in the Qamanirjuaq Herd Range

The Zone of Influence (ZOI) of the Kiggavik Project is described in the Project's FEIS, Section 13. An illustration of the Project's potential ZOIs is presented in Figure 2. The effects of the mine and two road options (an all-season road [ASR] and a winter road [WR] are discussed in this assessment). Corresponding ZOIs are 15 km for the mine and 5 km for the road options.

A number of projects and human disturbances within the range of the Qamanirjuaq caribou were considered in the assessment of cumulative disturbances and effects on caribou. Those disturbances were selected from the broader Project Inclusion List (PIL) developed for the Kiggavik Project's Final Environmental Impact Statement FEIS (Appendix 1E — Cumulative and Transboundary Effects; AREVA's Kiggavik Project FEIS submission to the Nunavut Impact Review Board, 2014). The projects include active and deactivated mines, exploration projects, municipalities, transmission lines, energy projects, all season and winter roads in the Qamanirjuaq caribou herd range. Each project has a corresponding footprint that represents a direct loss of habitat. That cumulative direct loss of habitat was quantified in the Project's FEIS (Tier 2, Volume 6, Section 13.3 – Cumulative Effects Assessment for Caribou). This analyses focuses on caribou interactions with the potential broader Zones of Influence (ZOIs) associated with various disturbance activities. Those ZOIs are areas near development where due to sensory disturbances such as noise, caribou behaviour may change, or habitat may be affected to the point that caribou use habitat less effectively in areas within the hypothetical zones of disturbance. The various ZOIs potentially associated with those projects were used to determine the annual number of encounters and associated residency time in ZOIs for collared caribou. A summary and justification of the ZOIs used are in included in Table 3. The disturbances included mineral exploration, mines, energy corridors, all season roads, winter roads, and towns/municipalities. The hypothetical ZOIs were based primarily on what have been used in a number of caribou effects assessments for northern projects and from those published in the literature. The ZOIs include from a 14 km radius around mine sites, 15 kilometres around municipalities, five kilometres around exploration sites, and other sizes proportional to the hypothetical disturbances. The ZOIs err on the side of precaution in overestimating the likely areas of disturbance as discussed below. The resulting total areas of the ZOI are summarized by the Qamanirjuaq seasonal ranges (Table 2). The post-calving portion of the range experiences the greatest disturbance (6.0%), followed by spring migration and calving (2.7% each). By far, the greatest contributor by area covered by a ZOI is the municipalities in the post-calving range (accounting for 5.8% of the total 6% coverage, Table 4).

Analysis presented as a CE (cumulative effects) scenario includes a culmination of the 168 projects with spatial information, including exploration projects on file from 2003 to 2013 in the Project Inclusion List (FEIS Appendix 1E) plus the Kiggavik exploration project (Projects are described in the Project Inclusion List presented in Kiggavik's FEIS Appendix 1E — Cumulative and Transboundary Effects). The CE+ASR (CE plus all-season road) scenario and CE+WR (CE plus winter road) scenario were developed to examine the disturbance effects for the projects within the range of the Qamanirjuaq herd with and without the Kiggavik project. An additional scenario was developed which looked strictly at collared caribou that interacted with either mine and ASR or the mine and WR. Further, because there wasn't enough information on historical project activity to do a retrospective analysis, we assumed that the projects in the Project Inclusion List have been in existence since the start of collaring data. Thus, especially for exploration projects that fluctuate in activity on an annual basis, the analysis errs on the side of caution in assessing disturbance effects on caribou.

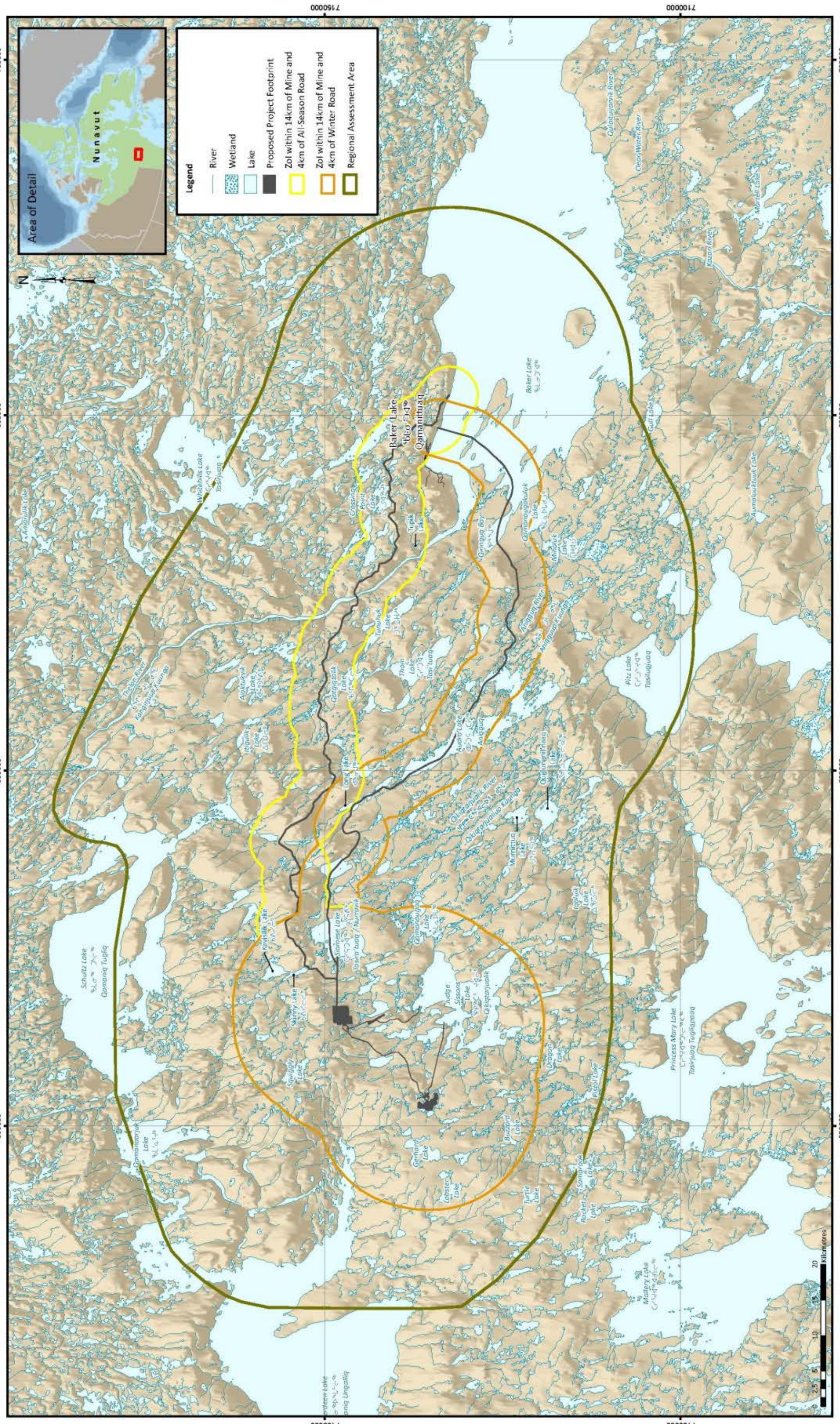

Figure 2. Regional study area and zones of influence of the Kiggavik Project (Source: AREVA Tier 2, Volume 6, Section 13).

Table 3. Hypothetical Zones of Influence for development activities in the cumulative effects assessment area.

Disturbance activity	ZOI (km)	References		Notes
		Published literature	Similar environmental assessments	
MU — Municipalities (Polygon)	15	Hypothetical **1,000 m** (Johnson et al. 2005), but no disturbance coefficients identified.	Meliadine FEIS (Golder Associates Ltd. 2014) and Gahcho Kué (De Beers Canada Inc. 2010) used a **15 km** extent with variable disturbance coefficients from 0.05 to 0.75	Presume community ZOI is extensive due to likely high harvest pressure and other land uses (e.g., traffic, noise). Use ZOI similar to other likely high disturbance activities; extend to 15 km, precedent set for Meliadine FEIS.
ASR — All Season Roads WR — Winter Road (Line)	4 (ASR) 0.2 (WR)	**4 km** (Vistnes and Nellemann 2001, Nellemann et al. 2003, Weir et al. 2007); Hypothetical 95% (i.e., DC = 0.05) reduction with **1 km** radius of operating mine road (Misery road, (Johnson et al. 2005); Abundance of calving caribou less than expected within **4 km** of a road (Cameron et al. 2005).	Hypothetical: All weather <u>construction</u>: **4 km** radius (Rescan 2013); All weather <u>operations</u>: **1.5 km** (Rescan 2013); Winter Road: **200 m** (Rescan 2013); ZOI extended to 5 km for the Meliadine Project (Golder Associates Ltd. 2014) and the Gahcho Kué project (De Beers Canada Inc. 2010) with variable disturbance coefficients from 0.05 to 0.75.	
EX — Exploration (Point)	5	Mineral exploration sites affected a *hypothetical* 50% reduction [i.e., DC = 0.5] in the value of habitats found within a 10 km radius of the assumed development site, and a 25% reduction [i.e., DC = 0.75] within a 5 km zone around that buffered area [**total 15 km**] (Johnson et al 2005, pg. 16).	For the Meliadine and Gahcho Kué Project assessments, exploration projects were assumed to have a **500 m** radius footprint (Golder Associates Ltd. 2014; De Beers Canada Inc. 2010b). Also for both projects, a **5 km** ZOI was applied to all active exploration permits for the entire five-year period, and over the entire year.	The CEA for the Back River Project did not include exploration projects as disturbance activities. A review conducted by Areva showed that exploration footprints likely to represent a 7.4 ha area (~154 m radius)
MI — Mining (Polygon or Point)	14	Observed lower probability of occurrence of caribou within **6–14 km** around combined mines and road (Boulanger et al. 2012). Hypothetical (not modelled) **15 km** ZOI (Johnson et al. 2005). Caribou numbers decreased within 6 km of mine centre in late winter through calving seasons (Weir et al. 2007).	The Back River Project considered two ZOIs at **4 km** and **14 km** (Rescan 2013). The Meliadine Project considered a three ZOI range with variable disturbance coefficients 0-1, 1 to 5, 5 to 14 based on Boulanger (2012) (Golder Associates Ltd. 2014). The Gacho Kué Project assumed a **15 km** ZOI was applied to all active mine sites regardless of the size of the footprint or the level of activity for each mine (De Beers Canada Inc. 2010).	
ERG — Energy corridors Point (plant); line(transmission)	4	Transmission lines: **4 km** ZOI (Vistnes and Nelleman 2001 and Nelleman et al 2003)	Meliadine (Golder Associates Ltd. 2014); Gacho Kué (De Beers Canada Inc. 2010) used a **500 m** radius footprint and a 1 km ZOI for power plants, and a **200 m** footprint for transmission lines. A ZOI ranged from **0** to **5 km** with variable disturbance coefficients from 0.05 to 0.75.	
TR — Tourism (e.g. guide and outfitting) Point	4	**4 km** ZOI (Vistnes and Nelleman 2001 and Vistnes et al 2003); 10% i.e., DC = 0.9) reduction in areas influenced by outfitters in a **500 m** buffer (Johnson et al. 2005).	Not considered in cumulative effects for Meliadine or Back River CEAs. Gahcho Kue used a **200 m** radius footprint and a **5 km** radius ZOI with a DC of 0.1 (De Beers Canada Inc. 2010).	Accounts for seasonality and presumed quota (i.e., managed) harvest around outfitter camps.
TR — Traditional Harvest and Land Use	na	Johnson et al. (2005) noted specifically that they did not consider responses to subsistence harvest.	Not considered in cumulative effects for Meliadine, Gacho Kué or Back River CEAs	Not a spatial reference, background conditions

Table 4. Disturbance area ZOI features in the seasonal ranges of the Qamanirjuaq caribou

	ZOI km²(% of range)		% of range covered by land use ZOI					
Seasonal Range[1]	**Base Case[2]**	**Project Case[2]**	**Municipality**	**All-season roads**	**Winter road**	**Mineral exploration**	**Mine**	**Energy corridor**
Spring migration	1,907 (2.7%)	1,907 (2.7%)	2.4	0.5	0.1	0.1	0.0	0.1
Calving	798 (2.7%)	798 (2.7%)	2.4	0.0	0.0	0.2	0.0	0.0
Post-calving	5,107 (6.0%)	5,190 (6.1%)	5.3	0.4	0.0	0.8	0.0	0.0
Summer dispersal	2,573 (2.4%)	2,581 (2.4%)	1.7	0.0	0.0	0.7	0.0	0.0
Fall and Rut	1,384 (0.9%)	1,386 (0.9%)	0.2	0.1	0.0	0.5	0.0	0.1
Early and Late winter	2,263 (1.7%)	2,263 (1.7%)	0.7	0.7	0.1	0.3	0.0	0.2

Notes:

[1]Seasonal ranges were generated using a kernel density analysis on caribou telemetry locations - density was constrained to the 95% utilization distribution.

[2]Total disturbance cases do not include duplication of overlapping disturbance ZOIs (i.e., the sum of the land use proportions add up to more than the corresponding cumulative ZOI proportion).

2.4 Encounter Rates and Residency Time in ZOIs

A GIS-based walk-line approach was developed to estimate the time spent by collared female caribou in the ZOI of development infrastructure. Walk-lines (defined as a straight line connecting two telemetry point locations) were generated from telemetry point locations and overlaid on a ZOI to determine the spatial relationship of the ZOI between the two locations. Walk-lines were attributed with duration of time (both within and outside a ZOI) using the proportion of line length in combination with re-location interval. For example, Figure 3 displays two walk-lines within a ZOI: one walk-line entirely within the ZOI, and one walk-line that was split when intersected with the ZOI. Although they have similar line lengths within the ZOI (8.9 vs. 8.8 km), they represent two very different durations within the ZOI (24 hours vs. 7.8 hours, respectively), resulting in a more accurate residency estimate compared with using simple line lengths; i.e., accounting for duration increases the influence of lines that were always fully contained within the assessment area because they represent a full day of occupancy.

All walk-line durations (hours) within a ZOI area were summed and divided by the total duration of all walk-lines (within and outside of a ZOI) to estimate residency time as a proportion of total collar duty cycle time (time between two consecutive locations).

Determination of encounter rates and residency time is based on the following assumptions:

1. The animals collared were accurately identified as members of a particular herd; i.e., they move and live with what is generally accepted as a particular herd.
2. The animals collared accurately represent a cross-section of a herd; i.e., as a subset, they sufficiently reflect the annual or seasonal home range (or extent) of an entire herd.

3. The encounter rates are based on the assumption that an animal is exposed to one disturbance event each time it enters a ZOI.
4. The residency values represent an estimate of the range/proportion of time that any one caribou herd spends in a ZOI.

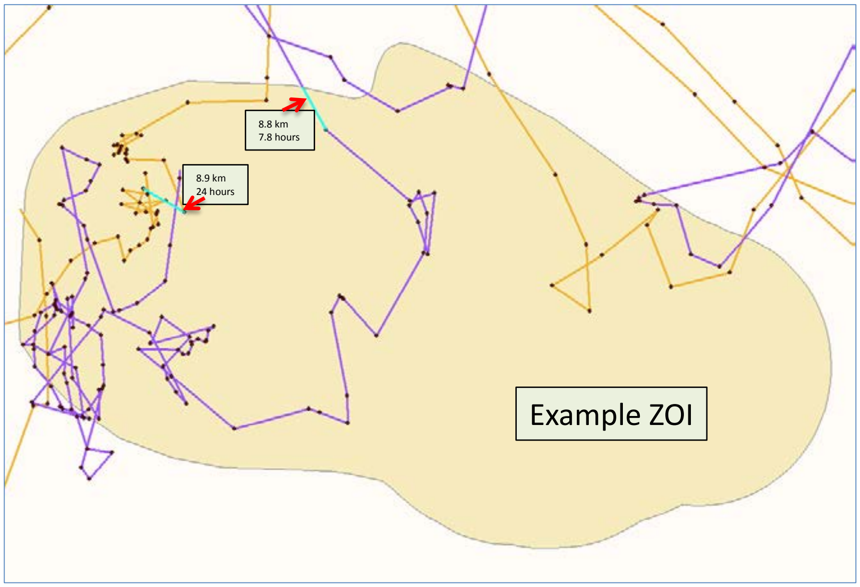

Figure 3. Example Calculation of "Walk-lines" in a Hypothetical ZOI.

2.5 The Energy-Protein Model

The energy-protein (E-P) model (White *et al* (in press)) has been applied recently in the assessment of the proposed Mary River mine on Baffin Island (Russell 2012, 2014). In brief, the E-P 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 and protein 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, 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.

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 CARMA Network's climate database (Russell et al 2013a). These data combined with vegetation and biomass attributes specific to a particular region are used to generate seasonal forage quantity, quality, activity, and diet.

Recent improvements to the model enable it to be applied to assessing effects of environments (either anthropogenic or natural) to the population level. These changes include:

1. The model will determine weaning strategy, thus lactating caribou can now wean calves early to ensure they are in better fall physical shape to ensure their winter survival.
5. Up to 1,000 animals are run through the model simultaneously to better represent impacts at the population level (i.e. impacts on a cross section of the population rather than a single individual), and
6. Model output can be used to drive a population model to assess project effects at the population scale.

2.6 Energy-Protein Model Input Data

2.6.1 Biomass

Vegetation classes: Vegetation types from Circa 2000 Landsat ETM+ Land Cover Mosaic (Olthof et al 2009) of Northern Canada were downloaded. Vegetation classes (Table 5) followed the Federal Geographic Data Committee (FGDC) standards (Wulder and Nelson 2003). To determine the annual availability of vegetation classes, the Olthof classifications were collapsed into classes greater than 5% in the caribou seasonal ranges (Figure 4).

There are no applicable studies relating biomass to community types within the range of the Qamanirjuaq herd. Therefore we applied values derived for similar vegetation types on the range of the Bathurst caribou herd, east of the study areas. Chen et al (in press) combined the FGDC vegetation classes into three classes (lichen, herb-shrub and shrub) for the range of the Bathurst caribou herd. Similarly, the classes from Figure 4 were collapsed into shrub, herb-shrub and lichen classes (Figure 5).

Table 5. Vegetation classes from the Circa 2000 Landsat ETM+ mosaic for northern Canada

Code	Dominant vegetation type
1	Evergreen forest (> 75% cover) – old
3	Deciduous forest (> 75% cover)
4	Mixed coniferous (50 – 75% coniferous) – old
6	Mixed deciduous (25 – 50% coniferous)
7	Evergreen open canopy (40 – 60% cover) – moss-shrub understory
8	Evergreen open canopy (40 – 60% cover) – lichen-shrub understory
9	Evergreen open canopy (25 – 40% cover) – shrub-moss understory
10	Evergreen open canopy (25 – 40% cover) – shrub-moss understory
13	Mixed evergreen-deciduous open canopy (25 – 60% cover)
14	Mixed deciduous (25 – 50% coniferous trees; 25 – 60% cover)
15	Low regenerating to young mixed cover
16	Deciduous shrubland (> 75% cover)
18	Herb-shrub-bare cover, mostly after perturbations

Table 5. Vegetation classes from the Circa 2000 Landsat ETM+ mosaic for northern Canada

Code	Dominant vegetation type
19	Open forest, shrub-herb-lichen-bare
20	Wetlands
21	Sparse coniferous (density 10 – 25%), shrub-herb-lichens cover
22	Sparse coniferous (density 10 – 25%), herb-shrub cover
23	Herb-shrub
24	Shrub-herb-lichen-bare
26	Lichen-shrubs-herb, bare soil or rock outcrop
28	Low vegetation cover (bare soil, rock outcrop)
35	Lichen barren
36	Lichen-shrub-herb-bare
37	Sparse coniferous (density 10 – 25%), lichens-shrub-herb cover
38	Rock outcrop, low vegetation cover
39	Recent burns
41	Low vegetation cover
43	Water bodies
45	Snow/ice
Source: Olthof et al 2009.	

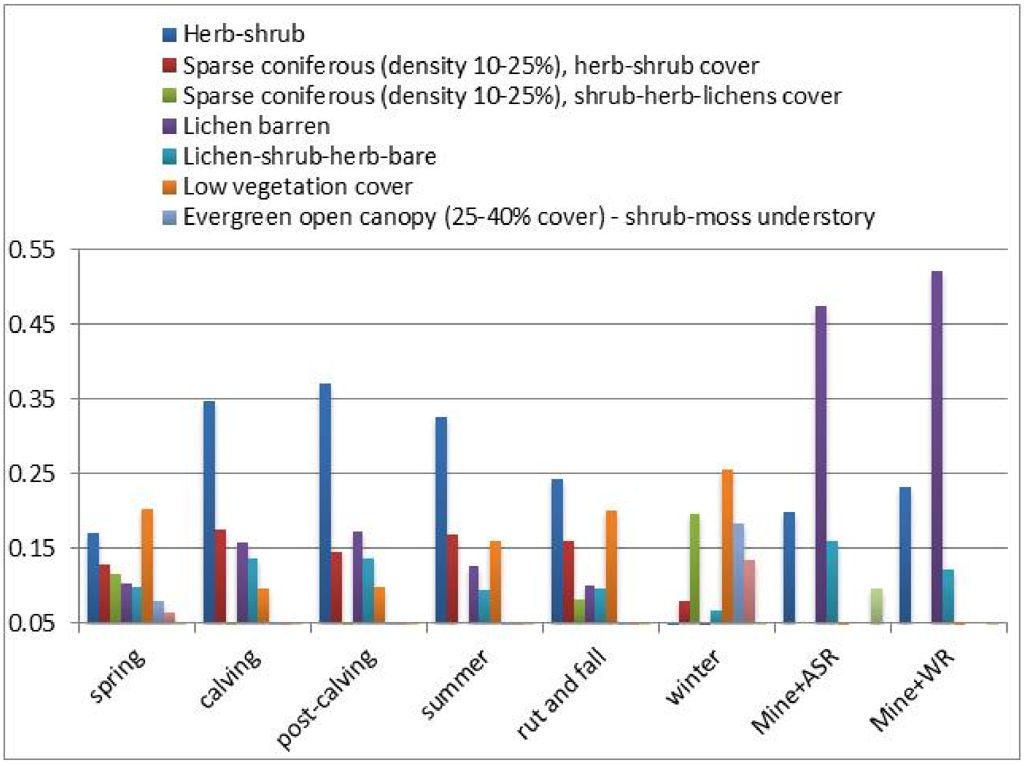

Figure 4. Vegetation classes within the Qamanirjuaq caribou herd seasonal ranges and the Kiggavik Project Zones of Influence (ASR- all season road; WR-winter road).

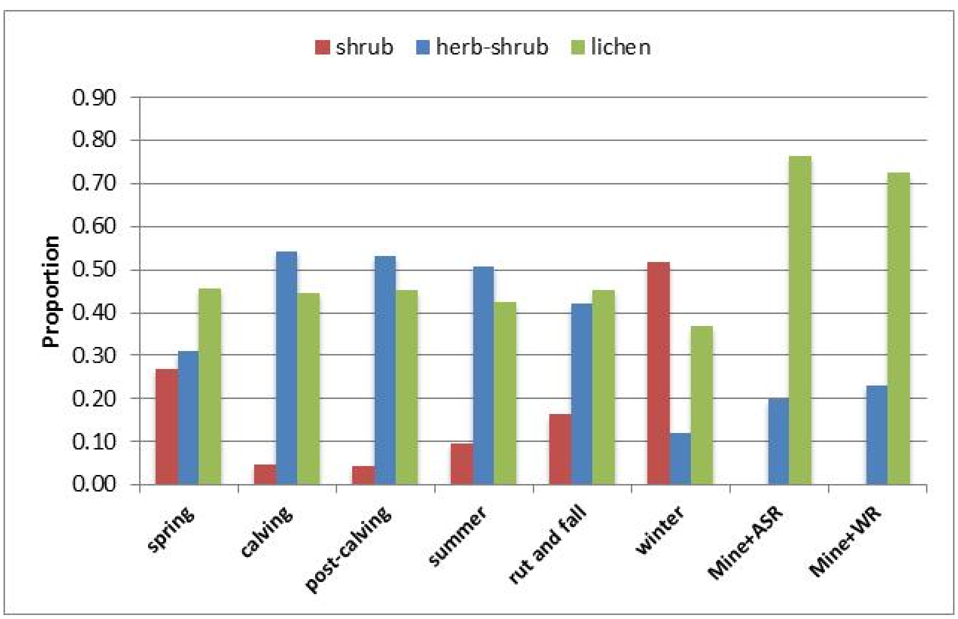

Figure 5. Relative proportion of three vegetation classes in the Qamanirjuaq caribou herd's seasonal ranges and the Kiggavik Project's ZOI (ASR- all season road; WR-winter road).

2.6.2 Cover type biomass

Because no data are available for the range of the Qamanirjuaq herd, we obtained leaf biomass data for Bathurst summer range from the Canada Center for Remote Sensing (Chen et al, in press). The data, derived 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. 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 2011 at 10-day intervals between May 5 and October 26 for the shrub, herb-shrub and lichen vegetation classes. Average plant biomass for most types peaked in the 1–10 August time period (Figure 6).

Because the modeling is being projected in the future, an examination of trends in biomass was conducted. Although there is substantial annual variability among years, by plotting the 3-year running average of cumulative annual biomass (sum of biomass in every time period from May 1 to November 10; Figure 7) a significant increasing trend was apparent for all three cover types. Due to these trends, therefore, biomass input values more representative of the post- 2000 era were used, assuming that the trends continue into the future.

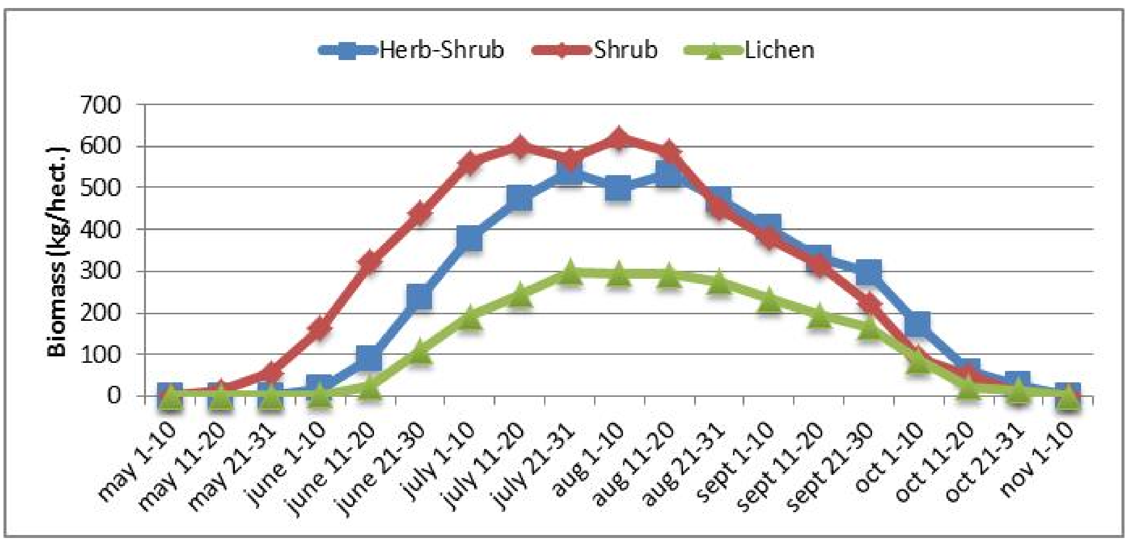

Figure 6. Average above ground green biomass for the Bathurst caribou summer range, 1985–2011 (W. Chen, unpublished data, CCRS)

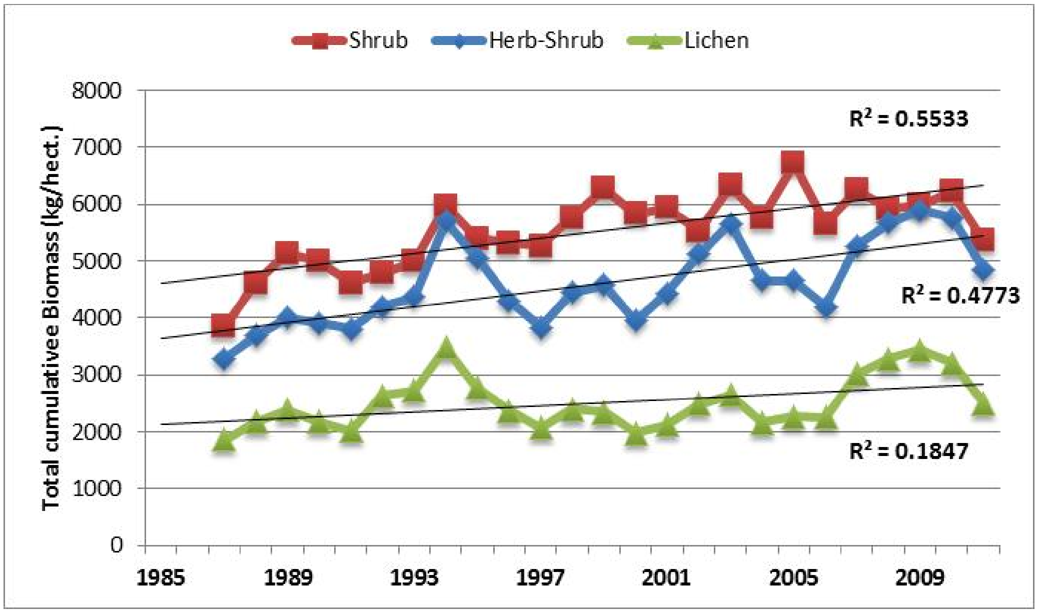

Figure 7. Cumulative annual biomass from 1 May to November 10 for three vegetation classes on the summer range of the Bathurst caribou herd (data from W. Chen, CCRS)

2.6.3 Plant group quantity

The E-P model tracks 10 plant groups that are eaten by caribou:

2. Moss
7. Lichens
8. Mushrooms
9. Horsetails
10. Deciduous shrubs
11. Evergreen shrubs
12. Forbs
13. Graminoids
14. Standing dead graminoids
15. Cotton grass heads

Thomas and Killian (1998) provided a detailed breakdown of plant group biomass on the Saskatchewan winter range of the adjacent Beverly caribou herd. The relative abundance of plant groups from that study as representative of winter plant group biomass was used for this analyses. The most comprehensive vegetation sampling on the spring to fall seasons is from Campbell et al (2012). They provide percent cover for most plant groups within 12 Ecozones. Two of the Ecozones, the Kazan River Upland and the Maguse River Upland, encompasses the non-winter seasons of the Qamanirjuaq herd. Based on the dominant plant groups identified among the eight vegetation classes described, classes were lumped into the three used by Chen et al (in press), namely shrub, herb-shrub and lichen dominated classes. Figure 8 provided the relative abundance of shrub, herb and lichen abundance in the three classes. Biomass estimates were then assigned for specific cover classes for all plant groups to derive the annual availability of major plant groups for the Qamanirjuaq herd (Figure 9).

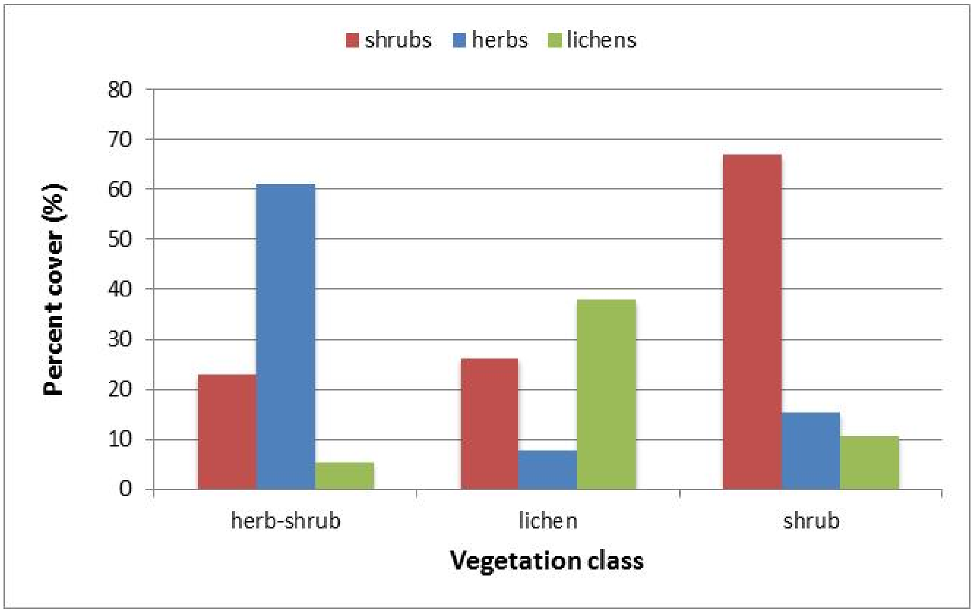

Figure 8. **The percent cover of shrubs, herbs (including graminoids), and lichens derived from vegetation classes described by Campbell et al (2012).**

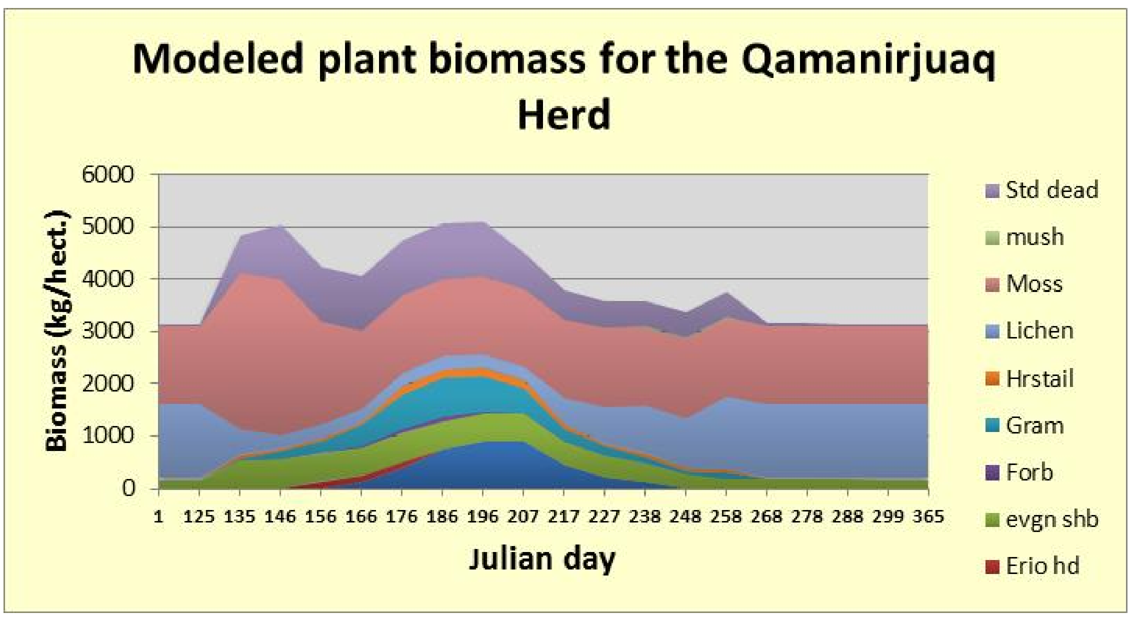

Figure 9. **Modeled plant biomass for the Qamanirjuaq caribou herd**

2.6.4 Plant group quality

The E-P model requires seasonal values by plant group for 1) nitrogen concentration, 2) Neutral Detergent Fibre (NDF), 3) Acid Detergent Fibre (ADF), and 4) secondary compounds of shrubs (BSA). A "Scenario Builder" spreadsheet was developed to generate model inputs. That spreadsheet used existing published data (Johnstone et al 2002; Finstad 2005) to associate plant nutrients with phenological stage, primarily dictated by growing-degree-days and biomass.

2.6.5 Climate variables

Climate data for the seasonal ranges of the Qamanirjuaq herd 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 CircumArctic *Rangifer* Monitoring and Assessment (CARMA) Network's climate database (Russell et al 2013a). Figure 10 illustrates the region-specific variables used by the Scenario Builder spreadsheet to generate input data for the E-P model.

HERD	VARIABLE	JULIAN	VALUE
QAM	Snow depth	1	36.5
QAM	Snow depth	32	43.2
QAM	Snow depth	72	51.5
QAM	Snow depth	106	47.9
QAM	Snow depth	130	17.7
QAM	Snow depth	146	6.0
QAM	Snow depth	0	0.0
QAM	Snow depth	0	0.0
QAM	Snow depth	273	25.6
QAM	Snow depth	293	22.9
QAM	Snow depth	320	12.4
QAM	Snow depth	356	21.7
QAM	GDD	146	14.8
QAM	GDD	156	20.9
QAM	GDD	167	90.5
QAM	GDD	177	138.5
QAM	GDD	190	342.7
QAM	GDD	208	548.5
QAM	Eriophorum index	208	222.3
QAM	Mosq index	190	4.2
QAM	Oest index	208	3.6
QAM	Mushroom index	260	51.7

- Snow depth
- Date first and last snow
- Energy costs walking, cratering
- Foraging time, food intake

- Plant growth
- Plant quality
- Diet

- Cottongrass flowers year t+1

- Activity budget, forage intake

- Mushroom biomass

Figure 10. Climate variables used in the Scenario Builder to generate data input for Energy-Protein model.

In this example the average climate conditions are depicted for the Qamanirjuaq herd.

2.6.6 Diet

In the model, unless specific data are available, a likely diet based on known nutrient requirements, forage biomass, and forage quality was generated. An algorithm (White et al 1999) was applied in this case and any available diet determinations (e.g. Thomas and Killian 1987) were used as validation data for late winter. A typical output for seasonal use of the 10 major plant types tracked in the model is illustrated in Figure 11.

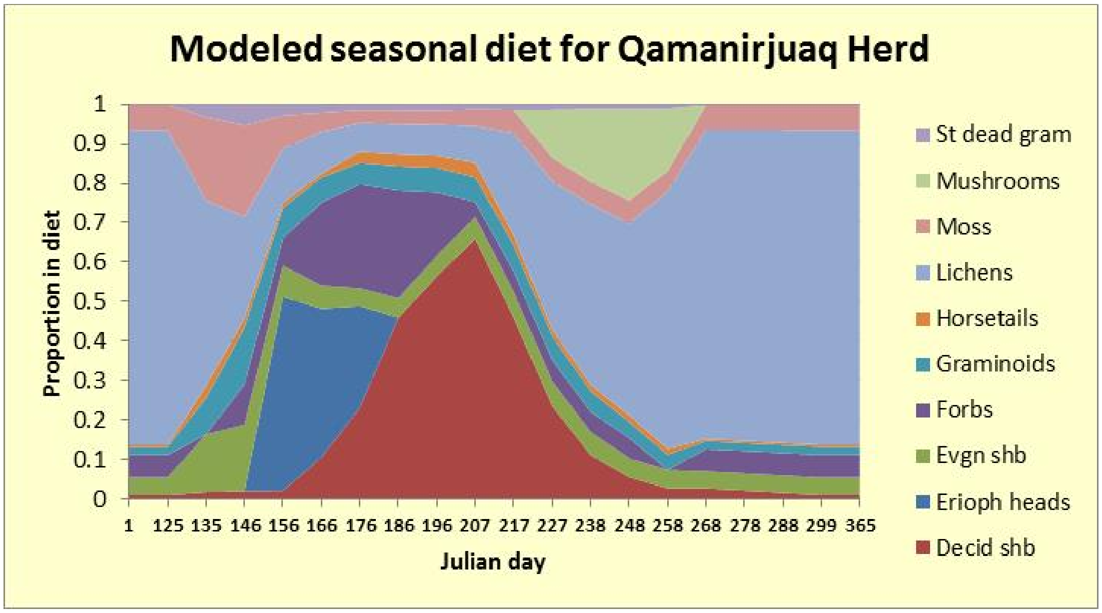

Figure 11. Modeled seasonal diet of the Qamanirjuaq herd

2.6.7 Activity budgets

There have not been any studies to document the seasonal activity budgets of the Qamanirjuaq herd. Van Oort et al (2005) documented the seasonal pattern of active/rest cycles for wild reindeer at similar latitudes as the Qamanirjuaq herd (62^{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):

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

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). Activity budgets generated by the model for average weather conditions on the Qamanirjuaq range are illustrated in Figure 12.

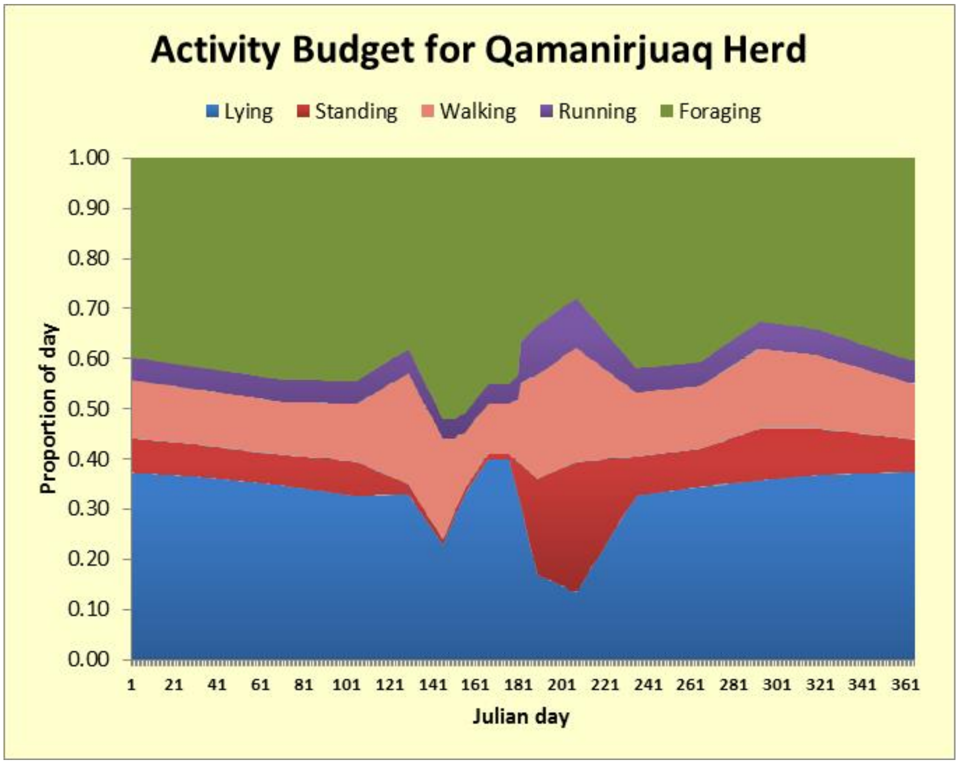

Figure 12. Activity budgets generated by the Energy-Protein model under average weather conditions for the Qamanirjuaq herd.

2.6.8 Animal condition

It is important to have an understanding of "normal" caribou body 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. groenlandicus)* considerable variation exists in mean body size and seasonal fat and protein levels. Using the CARMA body condition database, the age-specific body weights (±sd; Figure 13) and sex and age structure (Figure 14) of the Qamanirjuaq herd based on collections in the 1960s by Dauphine (1976) was determined.

To generate random animals to run simultaneously through the E-P model, we based the age sex structure on the collections described in Dauphine (1976). Miller (1974) acknowledged that the younger age classes, bulls and the 1962 cohort (collections 1966–1968) were not well represented in the sample and therefore argued for an adjusted herd age structure. Table 6 was the adjusted age and sex structure used in our modeling.

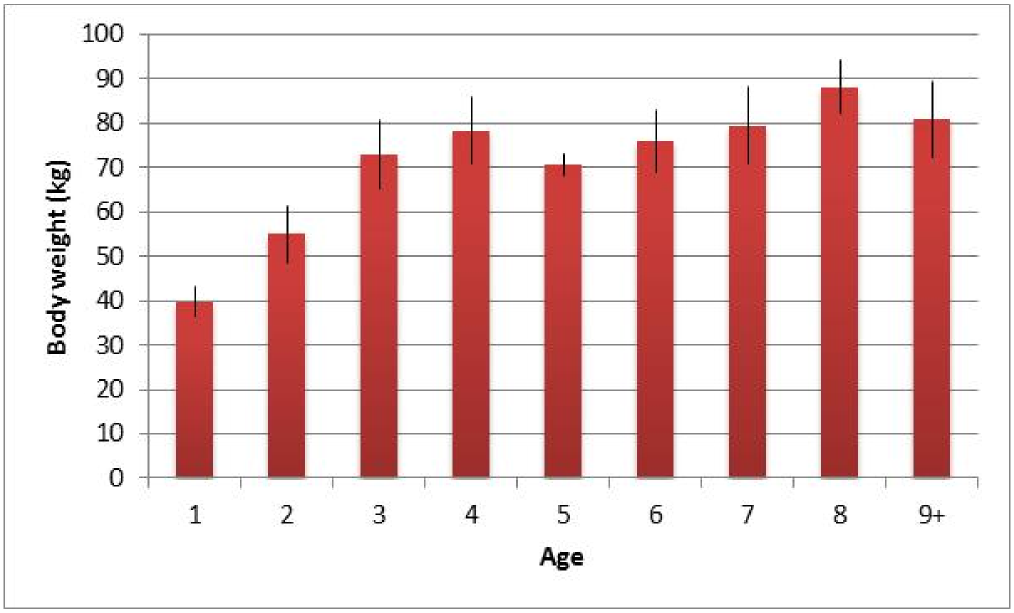

Figure 13. Female age-specific body weights (±SD) in the Qamanirjuaq Herd from collections by Dauphine (1976)

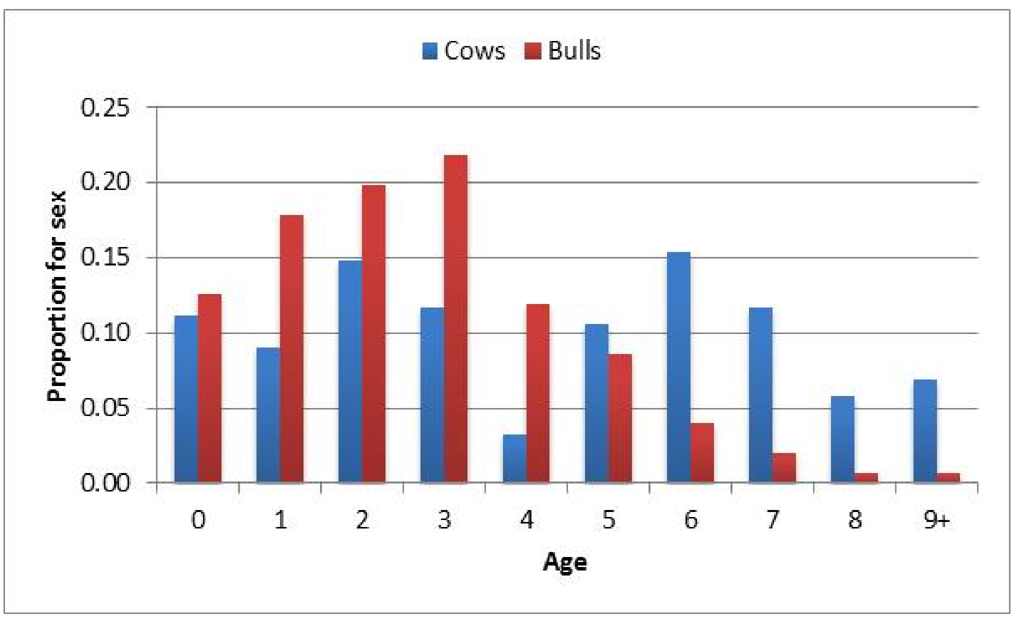

Figure 14. Sex-specific Age structure of the Qamanirjuaq herd based on collections from Dauphine (1976).

Table 6. Proportion of age and sex classes in the Qamanirjuaq Herd used to initiate the population model

Age	Females	Males
0	0.127	0.127
1	0.075	0.071
2	0.070	0.063
3	0.052	0.052
4	0.047	0.042
5	0.033	0.024
6	0.049	0.020
7	0.049	0.016
8	0.031	0.002
9	0.024	0.004
10	0.010	0.001
11	0.007	0.001
12	0.003	0.000

2.6.9 Peak of calving

The E-P model requires a date for the peak of calving (median date of calving). Nagy (2011) used the slower movement rates of parturient caribou to determine peak of calving as the mean calving date of 12 June (±4 days).

2.7 The Population Model

The population was developed under DG-Sim, a software framework suitable for developing demographic simulation models of caribou (*Rangifer tarandus caribou*) populations. The software allows users to simulate population numbers, age structure and sex ratios forward in time under alternative “what-if” scenarios. The framework is general enough that it can easily be configured for any caribou population. Model inputs include initial population size, age structure, sex ratio, recruitment rates, mortality rates, harvest rates and, and for retrospective analyses, past population census data. DG-Sim uses a Monte Carlo simulation approach whereby input parameters are optionally sampled stochastically from user-defined probability distributions. Model results include confidence estimates for population projections based on the uncertainty in input parameters and the degree of agreement of future projections with past census data. Figure 15 illustrates the model algorithm used to model populations.

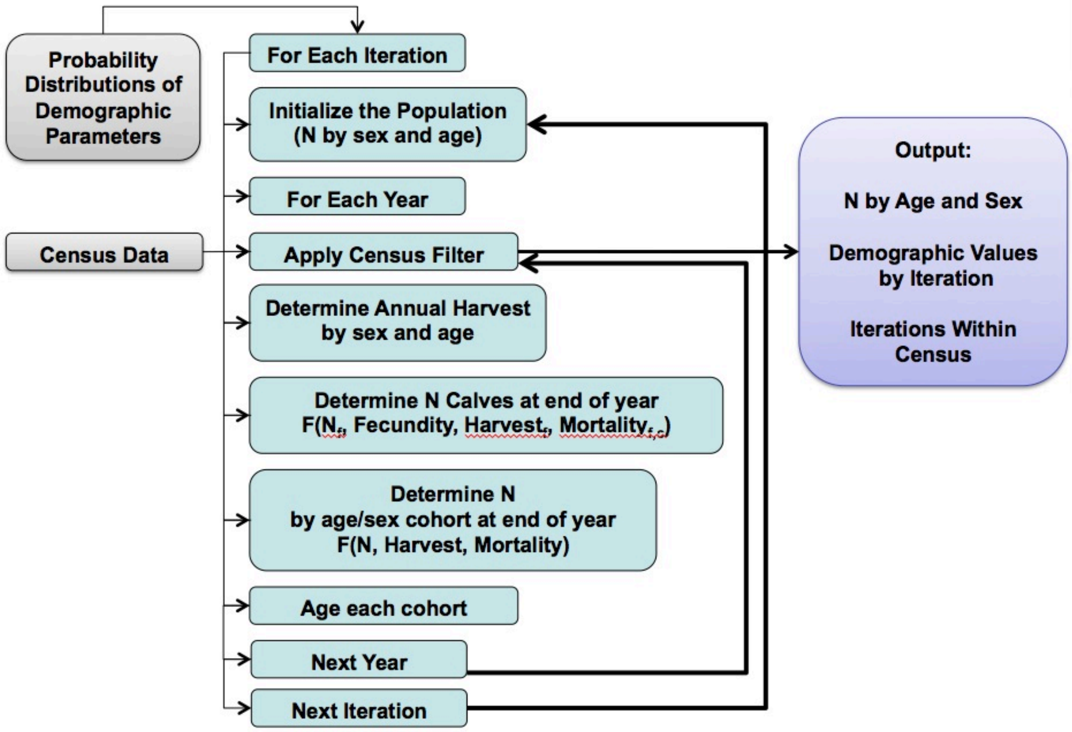

Figure 15. Algorithm modeled in the DG-Sim population model

2.8 Population Model Input Data

Pregnancy rates were reported by Dauphine (1976) from 999 caribou collected in the 1960s. Based on that collections and raw data obtained from the collections we determined age-specific pregnancy rates (Table 7). Even though these data were based on collections over 50 years ago, they still remain the most comprehensive dataset on the body condition, age structure and reproductive status of the Qamanirjuaq caribou herd.

Based on life table analysis, Miller (1974), estimated adult mortality rates for 3+ year-old females is 0.17 and for males (4+ years) is 0.38. Because these values are based on life tables, estimates include harvest. Bergerud (1980) and others have pointed out the problem of unequal cohort groups as a problem with mortality rates from life table analysis. Further, as Miller (1974) indicates, it was very difficult to collect from unsegregated groups to adequately reflect the population. Based on these estimates and our best guess for younger age groups, Table 7 presents the mortality rates of age sex groups used in the population model.

It was not an objective to model historical harvest estimates, rather it was to use the population model to assess effects of development on a harvested population. Thus the estimate for average total Qamanirjuaq harvest (10,300 caribou per year) reported by Intergroup Consultants Ltd (2008) was used. Further a typical, largely Inuit, harvest of 65% females (Priest and Usher, 2004) was used, and apportioned the harvest in proportion to the age and sex structure of the herd (Table 7).

Table 7. Pregnancy rate, mortality rate and harvest for age and sex classes as modelled in the population model for the Qamanirjuaq herd

Sex	Age class	Pregnancy rate[1]	Mortality rate	Harvest[2]
female	calves	0.00	0.44	0
female	Yearlings	0.00	0.07	1,115
female	2 yr olds	0.02	0.11	1,041
female	3 yr olds	0.48	0.11	773
female	3-8 yr olds	0.90	0.11	3,109
female	9+ yr olds	0.89	0.21	654
male	calves	n/a	0.47	0
male	Yearlings	n/a	0.12	865
male	2 yr olds	n/a	0.12	768
male	3 yr olds	n/a	0.21	634
male	3-8 yr olds	n/a	0.21	1,267
male	9+ yr olds	n/a	0.41	74

[1] based on their birthday — for example the rate for yearlings is for females reaching one year of age during the calving season.

[2] represents the number harvested if using a total annual harvest of 10,300 caribou and 65% female harvest.

2.9 Modeling Approach

2.9.1 Energy-Protein modelling

Analysis was limited to the disturbance within a ZOI, primarily because Kiggavik lies on the periphery of the Qamanirjuaq herd and encounter rates with the ZOI is very low (see Results section). Russell (2014) provided an assessment of displacement effects as well as disturbance. Displacement was not modelled for the Kiggavik assessment because:

- Kiggavik is located on the periphery of the Qamanirjuaq annual range and does not bisect any migration routes and use of the area (encounter rates with Kiggavik infrastructure is very low)
- To place effects of Kiggavik in context of other infrastructure within the Qamanirjuaq home range, the area, timing and path of every encounter in the last 20 years, would need to be known to model displacement effects. That information was not available
- The assessment of the effects of displacement is through reduced forage availability as density of caribou increases and, as is presented in this report, the modeled population growth is not significant in respect to increased density over the next 25 years, beyond the time frame of the proposed Kiggavik mine operation
- From experience with the Mary River project assessment (Russell 2014), energetic effects on caribou is primarily through disturbance over a wide range of herd densities.

Literature and opinion varies on if there are measureable differences in activity due to disturbance within a ZOI. However for those studies that do measure a difference, the distance caribou are affected are generally no more than 500 m from the source of disturbance. In this analysis it was assumed that caribou are disturbed throughout the ZOI, as far as 15 km for some type of development (summarized in Table 3). While in any ZOI, caribou are assumed to respond as follows:

- reduce foraging time 6 % (Russell 2014);
- increase walking and running by 3 %; and
- due to vigilance in the presence of human activity, reduce eating intensity by 3 % (i.e., reducing the percent of the foraging period spent actually ingesting food).

To assess potential effects of the Kiggavik project at the population level, the average annual residency (number of days) across all years among all collars for each of the seven seasons was determined. It was then assumed an animal would experience those maximum number of encounters in one year. Thus the simulated animals would exhibit a much higher interaction with the project than occurred for any of the individual collared animals in the analysis.

In assessing the effects of the cumulative infrastructure, the average seasonal residency in any year for each collar (between 2006 and 2012) was calculated. It was then assumed the modelled animals would experience that level of interaction in one simulated year. In setting up the modelling run it was assumed the seasonal encounters were on consecutive days within a season. Figure 16 provides an example of high exposure to infrastructure over the annual cycle on an individual as applied to the E-P model.

A potentially important consideration is the timing of the exposure to infrastructure. To compare the relative importance of different seasons in affecting fall adult cow body weight (and probability of pregnancy) and calf weight, the energy-protein model was run while exposing the mean annual exposure (13 days) separately in each season.

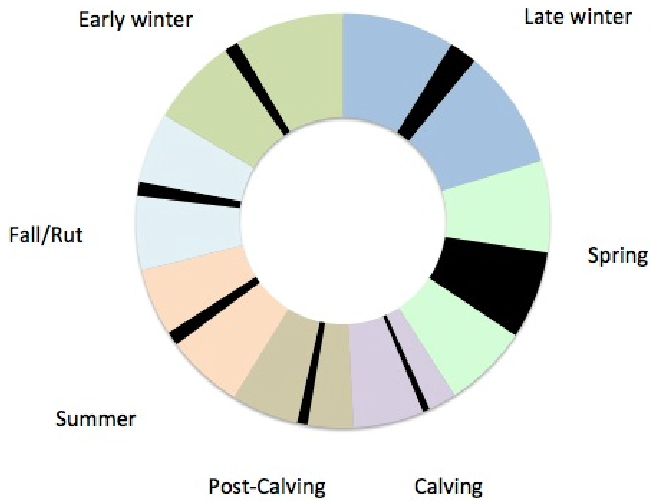

Figure 16. Modelled encounters associated with a high level of exposure. Days of encounters with infrastructure are in black.

2.9.2 Population modelling

The Qamanirjuaq herd was modeled over a 26-year time span (2014 to 2040). Changes in body size due to ZOI disturbance were lined to population effects through changes in pregnancy rates and calf mortality. 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 used was the probability of the cow getting pregnant in the fall. Russell et al (in prep.) analyzed multi-herd data to calculate herd-specific pregnancy rates based on relative body weights (*RBW)* of individuals (weight relative to the 95th percentile for each herd). For the Qamanirjuaq herd the 95th percentile was 91.8 kg. Based on logistic analysis, the probability (*ppreg)* of a Qamanirjuaq cow becoming pregnant is:

$$ppreg = e^{(-11.2471+15.988*RBW)}/1 + (e^{(-11.2471+15.988*RBW)})$$

The pregnancy rate change associated with the change in relative body size of adult cows under our development scenarios was calculated. This change was then applied to annual pregnancy rates in the population model throughout the simulation. As a starting population in the E-P model, average fall body weight for lactating cows was 78.9 kg, which sits on a relatively steep portion of the probability of pregnancy versus body weight curve (Figure 17).

Increased calf mortality is proportional to weight change compared to the baseline weight and the mortality estimates in the model (no development scenario). In the absence of any studies that provide appropriate data, a 1 kg change on calf fall body weight was assumed to be equivalent to a 2% increase in overwinter mortality. In the final assessment of the Mary River project (Russell 2014), interveners agreed that a 1kg weight change associated with a 2% increase in overwinter mortality was appropriate.

Finally after determining the final population size for the development scenarios, it was determined how a reduction in annual harvest or a reduction in the female component of the harvest would be necessary to offset the effects of development.

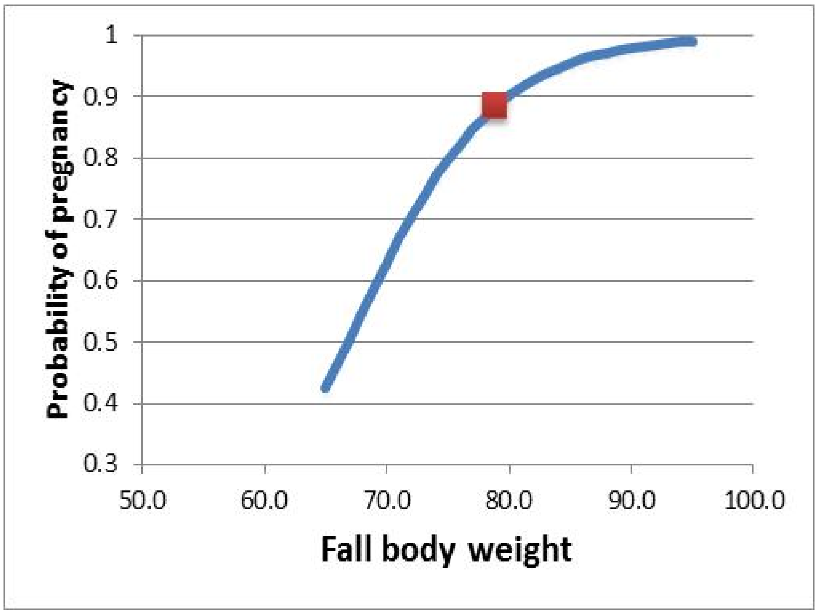

Figure 17. The relationship between fall body weight and probability of pregnancy in the Qamanirjuaq herd.

The red square represents the average fall body weight for baseline scenarios used in this analysis.

3 RESULTS

3.1 Kiggavik Project Encounter Rates and Residency Time

An index of the Qamanirjuaq caribou that entered the ZOI of the mine and all-season road (ASR) or the mine and winter road (WR) (Figure 18) and the average residency time (Figure 19) were determined from a collared sample of adult cows. Between 1993 and 2012, Qamanirjuaq caribou collars did not enter the ZOI of mine, ASR or WR in 14 of the 20 years (75%) and in only 2 years (2010, 2011) did more than one collar enter the project ZOI. The highest number of collars in the ZOI was during post-calving in 2010 with 7 of 33 (22%) collars were in the ZOI for an average residency time of 23 hours. The analysis was confined to collar data between 2005 and 2012 as 2005 was the first year collared animals entered the ASR and WR and in those years collar samples were larger (see Table 1). A total of 365 “collar years” were monitored. Over the seven seasons, collared caribou only entered the ASR and WR on 18 occasions for an encounter rate of 1.4% (18 encounters / 182 collars*7 seasons). Most of the encounters were in the post-calving period when 12 and 13 encounters were recorded in the ASR and WR ZOIs respectively. No collared caribou were in either ZOI during the spring and calving periods and not in the WR in late winter.

Even though most of the encounters occurred in the post-calving period, the length of the encounter (residency time) was short relative to the later seasons (Figure 19). Based on Figure 18 and Figure 19, it is difficult to model realistic encounter rates. For example the highest probability that a collar will interact with the ZOIs is during the post-calving season, calculated at only 3.3% probability (12 encounters/364 collars-years*100). As well, if encountering the ASR, the residency time is about 1.5 days of disturbance. For modelling potential project effects, a worst case scenario was taken and assumed that an individual would encounter the ASR during post-calving, summer fall/rut and winter (Figure 20). Because similar encounter rates occurred in the WR ZOI, only one scenario (ASR) was run, as the results could conservatively be applied to the WR given the collared caribou associated with the WR recorded lower residency times in the post-calving period (0.4 days) when the winter road is inactive, and no encounters in late winter when the road would be active.

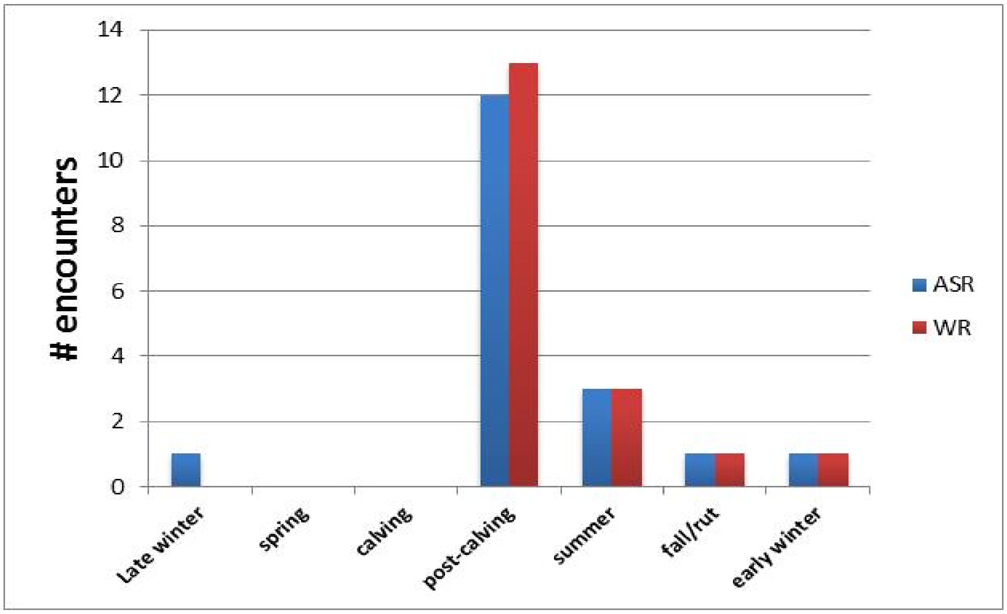

Figure 18. The number of encounters by collared Qamanirjuaq caribou with the ASR and WR ZOI between 2005 and 2012.

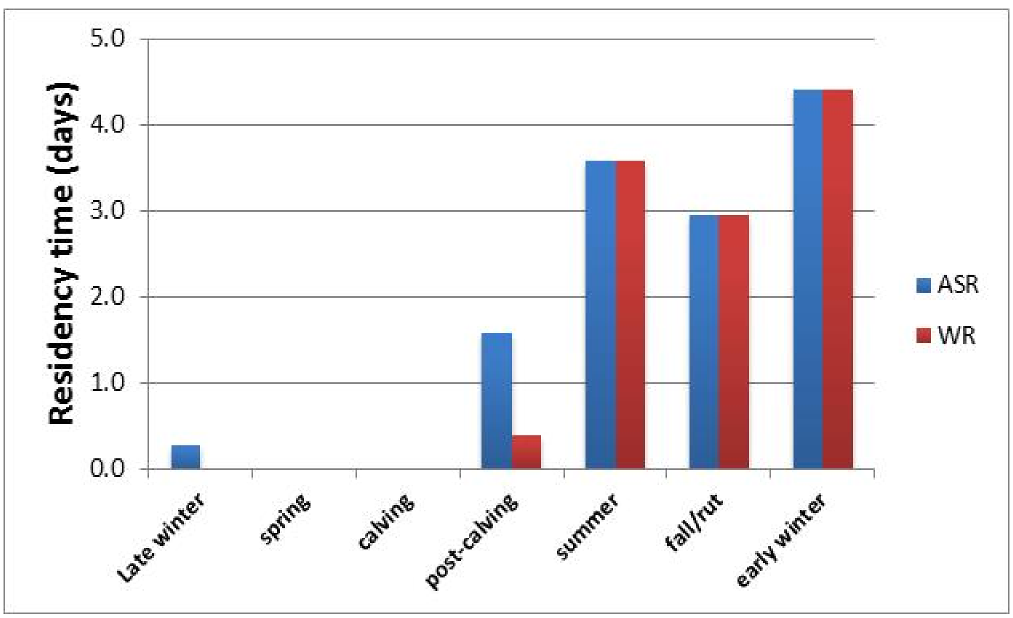

Figure 19. Average seasonally specific residency time per encounter for the Qamanirjuaq collared caribou.

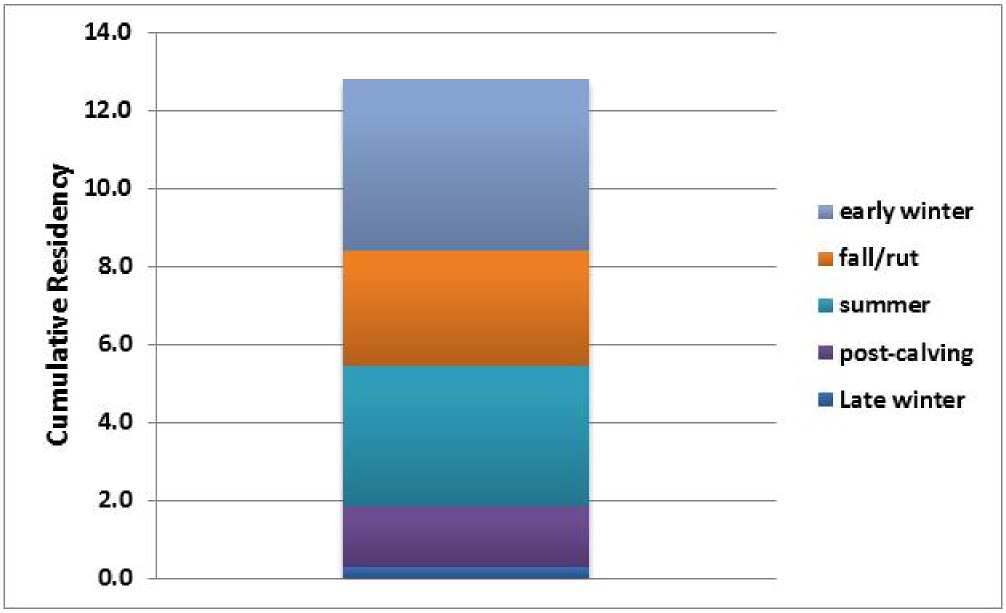

Figure 20. Cumulative residency time (days) used in the E-P model for caribou that entered the ZOI of Kiggavik ASR and mine ZOI.

3.2 Cumulative Encounter Rates and Residency Time

Similar to the treatment of the Kiggavik project, analysis was restricted to 2005–2012 for range wide encounters with development ZOIs. Across seasons, an average of 30% of the collars interacted with infrastructure between 2005 and 2012. However there was considerable seasonable variability (Figure 21). During the calving period the fewest percent of collars were associated with ZOIs (16%), whereas the following season, post-calving, recorded the highest association (60% of collars).

For those collars that were associated with ZOIs, there was considerable seasonal variability in the average length of time caribou were associated with infrastructure (Figure 22). The average seasonal residency time (days) for collars encountering infrastructure ranged from 1.1 days for the fall/rut and early winter period 4.4 days per year in the summer. As well Figure 22 illustrates the added contribution to average residency time of the Kiggavik project for the ASR and WR ZOIs. For the E-P model runs, it was assumed that one animal experienced the average seasonal residency time (from Figure 20) in a single year.

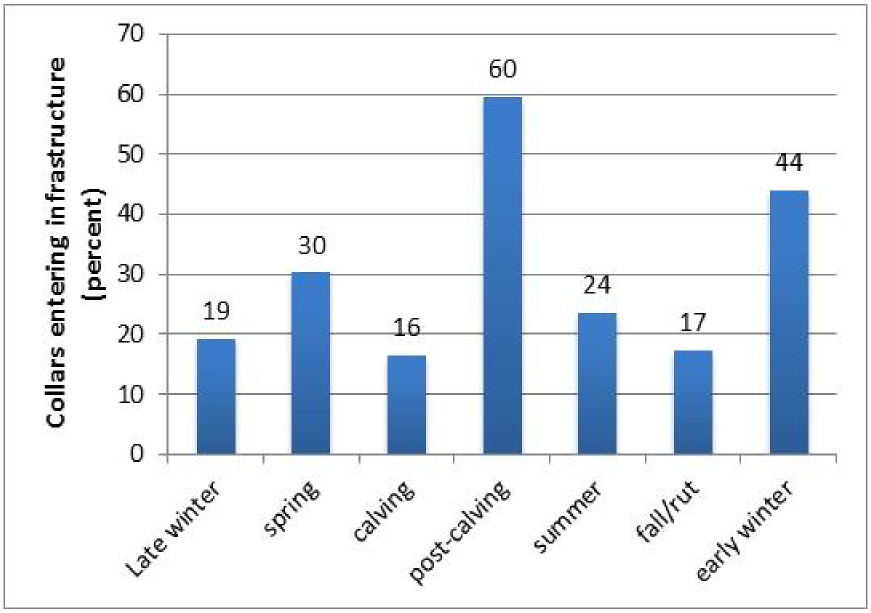

Figure 21. Average percent of Qamanirjuaq herd collars that encountered ZOIs by season (2005–2012).

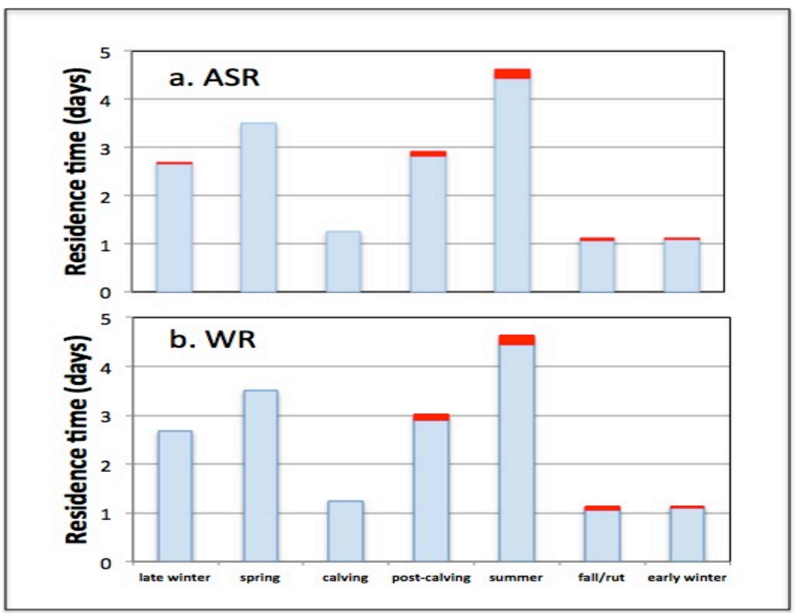

Figure 22. Average residency time (days) in infrastructure ZOI of the Qamanirjuaq herd 2005–2012.
The contribution of the Kiggavik project in the a) ASR and b) WR are in red

3.3 Effects of Exposure to Infrastructure and Season

Given there was both individual variability and seasonal variability in the amount of time individual collars spent within ZOIs, a number of scenarios were established to provide an assessment of how individual variability in seasonal encounter rates may be reflected in caribou fall body condition. To determine disturbance effects on a range of encounters, the maximum residency in any year across all seasons for individual collars was summed and assumed that a particular individual would experience those encounters in one year. Using this criteria, it was determined that individual collared caribou annually encountered ZOIs from no days to 53 days (Figure 23). To model the effect on a range of encounter rates, the values in Figure 23 were divided into quartiles. Thus Q1 represents the highest residency days for the lowest 25% of collars, Q2 represents the highest residency times for 50% of the collars, etc. To determine a representative partition of days for the seasonal periods, seasonal residency for four collars surrounding each quartile was averaged (Figure 23). The red bars in Figure 23 represent collars used to determine the residency times by season for the 4 quartiles. The average number of days was 13 days and the median number of days was 8 (Figure 23).

We used the results of seasonal residency for each quartile (Figure 24) as scenarios in the E-P model runs. Comparing the quartiles, a substantial amount of variability was noted in the proportional representation of seasons of total annual residency days (Figure 24). For example, spring residency was the highest in the Q4: 100% scenario, while post-calving was the highest proportion in the Q3: 75% scenario and summer in the Q2: 50% scenario (Figure 24). To determine how important the season of residency was to model output, six additional scenarios representing seasons were run. The model was run for the average residency time (13 days) assuming that all 13 days occurred in one season.

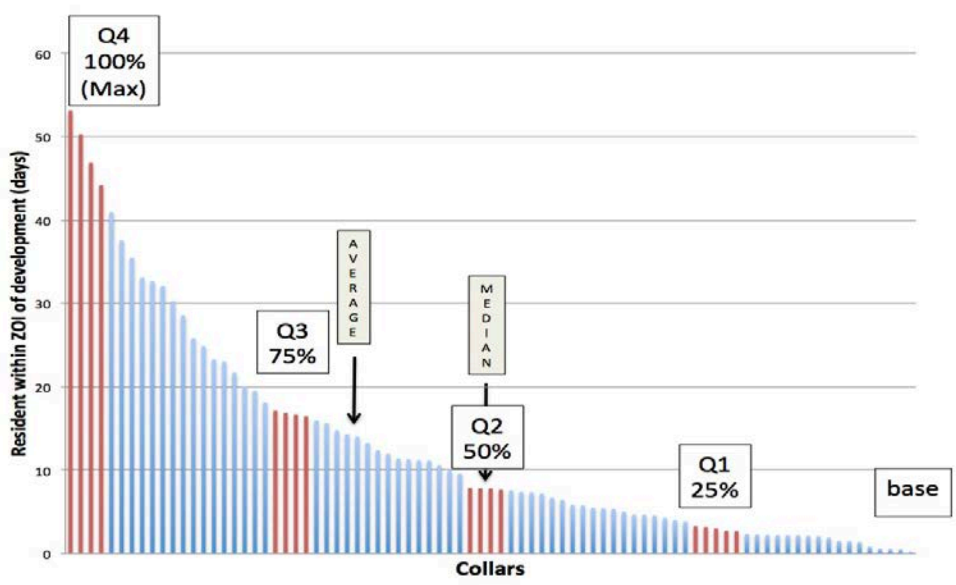

Figure 23. The sum of maximum residency across all seven seasons for individual collars of the Qamanirjuaq herd from 1993–2012.

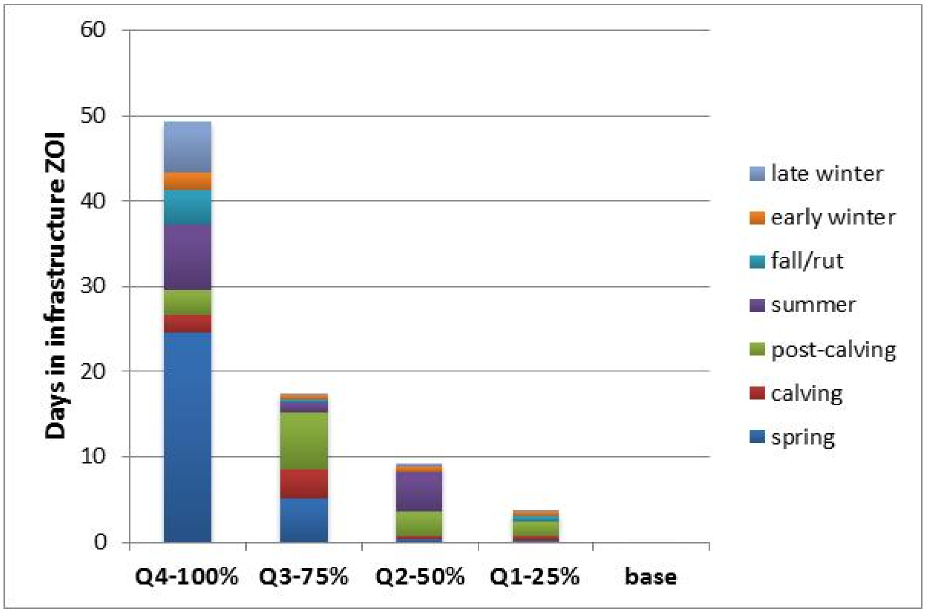

Figure 24. Breakdown of the number of days of residency for four levels of exposure to ZOIs for the Qamanirjuaq herd.

3.4 Energy-Protein and Population Modelling

3.4.1 Kiggavik Project Effects

All scenarios resulted in a decline in fall body weight of cows and calves compared to the baseline (no disturbance) conditions (Table 8). Although given the worst case ASR scenario resulted in cow body weights 0.6 kg below base and calf weights 0.46 kg below baseline, when applied to the population scale the declines are not detectable. As reported earlier, less than 1 % of collar-years were affected by the Kiggavik project's ASR ZOI.

Using seasonal average residency days associated with infrastructure ZOIs between 2005 and 2012, and given the assumptions regarding disturbance in ZOIs, it was determined that fall cow weight and calf weight respectively declined by 0.8 and 0.52 kg, which translated into 0.2kg and 0.15 kg at the population scale (based on the percent of collars associated with development).

Based on the scenarios testing a wide range of caribou interactions with ZOIs using the quartiles determined through individual collars (from Figure 23), there is a steady decline in fall body weight for adult lactating cows from baseline conditions to high interactions (Q4: 100%). Body weight of adult cows ranged from a baseline of 78.9 kg to 76.3 for the worst case (the Q4: 100%) and calves from 53.41 to 52.68 kg. Interestingly the lowest calf weights were noted for the Q3: 75% scenario (52.62 kg). As explained below, the difference is likely related to the time (season) of interaction with ZOIs.

Fall body weights of cows and calves may not have been only affected by residency days, as how those days were distributed among the seasons may also have been important. For example it was possible that 5 days of disturbance in late winter is not the same as 5 days of disturbance in post-calving. From

Figure 27 and Figure 28, it was determined that encounters during the summer period had the most effect on fall calf weight but not adult cow weight. Conversely encounters during fall had less of an effect on calves and more of an effect of their mothers.

Table 8. Results of E-P model simulations, the proportion of collars effected and the cow and calf body weight values used to calculate calf mortality and pregnancy rate in the Qamanirjuaq population model

Scenario	E-P model output		Proportion collars effected	Population model input	
	Fall cow weight (kg)	Fall calf weigh (kg)t		Fall cow weight (kg)	Fall calf weight (kg)
Base	78.9	53.41	1	78.9	53.41
ASR	78.3	52.95	0.01	78.9	53.41
CE	78.1	52.89	0.3	78.7	53.26
CE+ASR	78.1	52.73	0.3	78.7	53.21
Q1: 25%	78.7	53.27	1	78.7	53.27
Q2: 50%	78.6	52.62	1	78.6	52.62
Q3: 75%	78.0	53.25	1	78.0	53.25
Q4: 100%	76.3	52.68	1	76.3	52.68

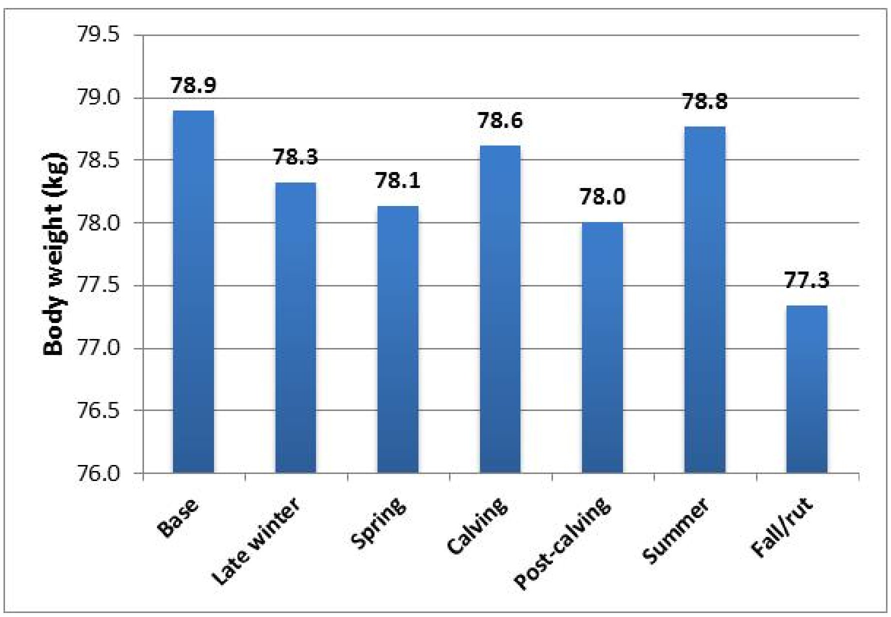

Figure 25. Qamanirjuaq caribou fall adult body weight of lactating cows seasonally exposed to 13 days within ZOIs.

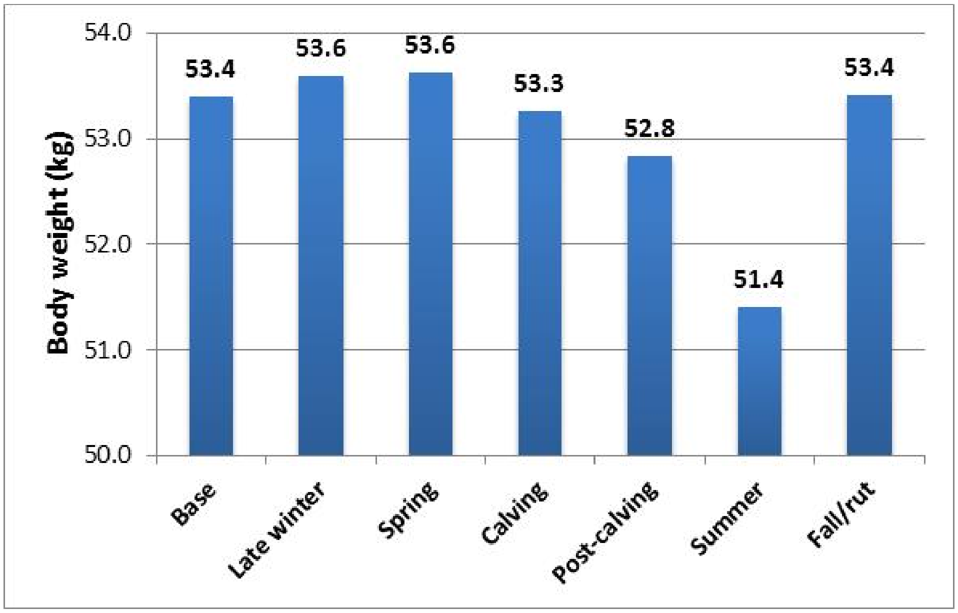

Figure 26. Qamanirjuaq caribou fall body weight of calves seasonally exposed to 13 days within ZOIs.

3.5 Population Model

Based on the output from the E-P model runs, the population through to 2040 for baseline conditions (no development within the range), a CE and a CE+ASR scenario models were run. From a starting population of 350,000 the population size in 2040 increased to 410,483 ± 5,023(SE), a 17% increase from the starting population. Even though the variance around the vital rate input data was minimized to better compare differences in scenarios, many of the scenarios overlapped. There was very little difference in the Base results and the ASR results. Outputs from the CE and CE+ASR, assuming the extreme response to ZOIs note above, resulted in 385,511 ± 5,056(SE) and 384,034± 4,506(SE) caribou at the end of the simulation period (Figure 27).

The population simulations reported in Figure 27 assumes a constant annual harvest of 10,300 caribou with 65% females in the harvest. For the scenarios it was then determined either the reduction in annual harvest or the reduction in the percent of females in the harvest (without reducing total harvest level) that would need to be implemented to offset the decline in population due to development effects (Table 9). For the ASR alone the model could not identify a required reduction because final population size was too similar. A reduction of 5% (519 animals) of total harvest or reducing females in the harvest from 65 % to 62 % could offset the CE scenario. Similarly a reduction of 5.1 % (527 animals) or reducing females in the harvest from 65 % to 61.5 % could offset the CE+ASR scenario. The difference in harvest offsets between CE and CE+ASR was 8 caribou or 0.5% reduction in the percent of females in the harvest.

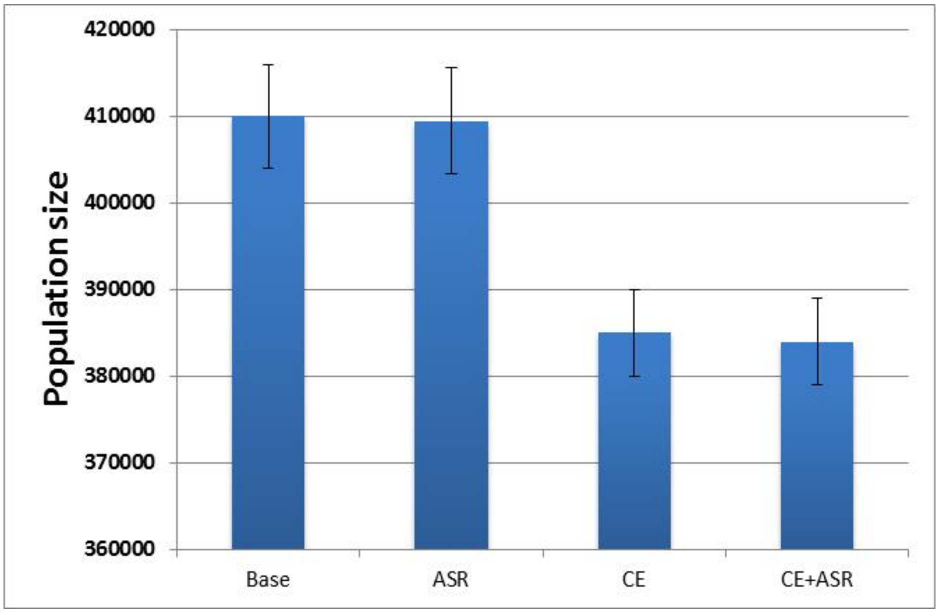

Figure 27. Final population size (±SE) of the Qamanirjuaq caribou herd based on a starting population of 350,000 caribou, a 26-year model run and applied to different development scenarios.

Table 9. Harvest change required to offset effects of development scenarios with respect to reducing overall harvest or reducing the percent of females in the harvest

Scenario	% Females in harvest	Reduced harvest
Base	65	0
ASR	65	0
CE	62	5%
CE+ASR	61.5	5.10%

5 DISCUSSION

5.1 Kiggavik Project Effects

For a number of reasons, the analysis tested worst-case (i.e., erring on the side of extreme precaution) scenarios with respect to the Kiggavik project. Wolfe et al (2000) maintain that cumulative costs will be a function of the intensity and frequency of disturbance effects, the proportion of the population that is exposed to disturbance, the location and temporal persistence of disturbance and the suite of disturbances that impinge on individuals across seasonal ranges. Ideally, clear cause and effect relationships between disturbance and caribou performance should be established. Reliance on robust correlations and off site experimental testing of key cause-effect mechanisms will be required.

In the model, when animals were anywhere in a ZOI, we assumed that they would reduce the percentage of the day they spent foraging (searching and eating) by 6 % and increase their time walking and running by 3 % each. Further we reduced the eating intensity (percent of the foraging activity spent ingesting food) by 3 % to reflect higher vigilance activity. Thus this reaction would apply to animals as far as 15 km from mines and town-sites, and lesser distances from other types of infrastructure (see Table 3). Based on available research, we contend that this is an overly pessimistic (errs on the side of caution) scenario.

White (1983) contends that even a small reduction in food intake or food quality has a greatly enhanced, or multiplied, effect on an animal's condition. Few studies have compared paired observations near the infrastructure and away from the infrastructure. Fancy (1983) found no difference between movement rates and activity for caribou near two active drilling sites compared to caribou at controlled sites. As well, Russell and Martell (1985) found no difference in activity during winter from caribou adjacent the Dempster Highway compared to groups at least 10 km from the highway. Murphy and Curatolo (1987) found that when insects were absent, caribou within 600 m of an elevated pipeline and road with traffic, and within 300 m of a pipeline and road without traffic, had significantly different activity budgets than undisturbed caribou further from the source of disturbance — disturbance effects were significantly greater in the site with traffic. Time spent lying and running and movement rates were the best indicators of oilfield disturbance, whereas time spent feeding was not affected. Thus they conclude that insect harassment, but not oil field development, reduced the time caribou spent foraging.

Erring on the side of precaution was built into the model the following ways:

- We assumed that caribou would be behaviourally disturbed throughout the 15 km ZOI around the mine and 5 km along each of the transportation options, the all-season road (ASR) and the winter road (WR). Although redistribution has been observed in proportion to distance from infrastructure for as far as 14 km (Boulanger et al 2012), changes in activity budget, if related to distance from disturbance, seldom is detectable beyond 500 m.
- We assumed that disturbance would occur throughout the year in both the WR and ASR. Although this is probably the case in the ASR, for the winter road (WR) ZOI, disturbance would likely only occur when the winter road was established on an annual basis. No encounters were recorded in late winter (Jan1 to March 15) in the WR ZOI, a period when most WR-related activity would occur.
- We determined residency times based on the average time in each season when encounters occurred from when collars first encountered the Kiggavik ZOIs (2006 to 2012). However as noted earlier, Qamanirjuaq caribou did not even enter the ASR and WR ZOIs in 14 of the 20 years that collars have been on the herd (i.e. since 1993).

- Finally, we assumed that the average residency time in each season all occurred in one year (the simulation duration of the E-P model) and were all experienced by one individual, although the encounters were recorded over 8 years and involved 12 collared caribou. Our ASR scenario exposed caribou for 12 days although of all the collars that encountered the Kiggavik ZOI: 1 was exposed for 8 days (wintered in the area), 2 exposed for 6 days and the remaining 9 collars were exposed for less than a day.

Based on these considerations, the modeled caribou, when exposed to the Kiggavik project, resulted in lower fall body weights of cows and calves equivalent to decline in pregnancy rate of 1.0% and an increase in overwinter mortality of calves of 0.93%. These estimates were 100 times lower when applied to the population model because Qamanirjuaq caribou had a 1.4% encounter rate with the Kiggavik project ZOI.

When applied to the population model, the run presented indicated that final population size of the Kiggavik project was statistically similar to the baseline project (based on overlapping Standard Errors (SE), but on average resulted in less than 1% fewer caribou based on the ASR option. The major difference between the ASR and the WR was that the average residency time in the WR post-calving period was much lower (0.4 days) compared to the ASR (1.6 days). As well, no encounters occurred in the late winter period in the WR compared to 1 encounter in the ASR. Given the lower residency days (compared to ASR) in the WR and the fact that 90% of the WR encounters were in post-calving and summer, when the WR would not be operating, we didn’t see the need to model the WR scenario given the much more severe scenario (ASR) did not result in a population effect.

Thus individual caribou, if they reacted as we have assumed in our modeling and if they occupied the ZOI as often and as long as we modeled, the Kiggavik mine and ASR road option could affect body condition of a cow and the growth of her calf in some years. However at the population level, assuming that caribou continue to interact with the ZOI with the same encounter rates into the future as they do now, the population modeling shows that final population estimates are indistinguishable from baseline conditions. Moreover, for the WR option, the encounter rates when the road may be operable were not even frequent enough to run a scenario and thus we conclude that the WR options would not even have energetic effects, never mind population scale effects.

5.2 Cumulative Effects

For a number of reasons, similar to those described in the Kiggavik section above, it is likely that the CE assessment presents a current worst case (i.e., erring on the side of precaution) scenario. Analysis presented as a CE (cumulative effects) scenario, includes 168 projects plus the existing Kiggavik exploration project. The CE+ASR (CE plus all-season road) scenario and CE+WR (CE plus winter road) scenario were developed to examine the disturbance effects for the projects within the range of the Qamanirjuaq herd with and without the Kiggavik project. Given there wasn’t enough information to do a retrospective analysis, it was assumed that the projects in the list have been in existence since the start of collaring data. Thus, especially for exploration projects, the analysis errs on the side of caution in assessing disturbance effects on caribou.

Results from the CE scenarios projected an average fall body weight decline of 0.8 kg and 0.62 kg for cows and calves. The CE+ASR recorded a decline of 0.8 kg and 0.68 kg for cows and calves respectively. Projected population size in 2040, based on the E-P model output from these scenarios, and weighting by the percent of collars that interacted with the CE ZOIs (30 % average across seasons), we projected an average 24,000 decline from baseline population estimates. Again there was no significant difference between the CE and the CE+ASR estimates. For the CE scenario, the change in harvesting to offset the 24,000 decline was either a 5.1% reduced harvest or drop in the proportion of females in the harvest from 65% to 62%. Even though there was no significant difference between the CE and the CE+ASR scenario population estimate, multiple runs of the stochastic model resulted in a slightly lower, through still not significant, average population size. Assuming that, average harvest adjustment compared to the CE estimate was 8 less caribou harvested per year, or a drop in the proportion of cows from 62% to 61.5%.

5.3 Effects on a Range of Exposure

To provide some insight into the variability that may be encountered in the Qamanirjuaq population with respect to exposure to development, we focused on the exposure of individual collars to the cumulative projects within their range. For individual collars, we then tallied the maximum residency time in any year for each season. The maximum annual residency time from this procedure was 53 days. Dividing the individual collar results into quartiles, we modeled the fall body weights based on average time in each season for the 4 quartiles. Results indicated a steady decline in fall body weight for adult lactating cows from baseline conditions to high interactions (Q4: 100%). Body weight of adult cows ranged from a baseline of 78.9 kg to 76.3 kg for the worst case (the Q4: 100%) and calves from 53.41 to 52.68 kg. Interestingly the lowest calf weights were noted for the Q3: 75% scenario (52.62 kg).

Although we did not then take these results and run them through the population model, we did take the opportunity to calculate, for the most exposed animals, how much annual variability existed. For example, for the eight collars with the highest residency times, the modeled average residency time was 42.3 days of exposure to ZOIs. However for these eight collars the highest residency time they actually experienced in any single year was 28.3 days (Figure 28). Further for these eight collars, the second highest year they were exposed was for only 5.6 days (Figure 28).

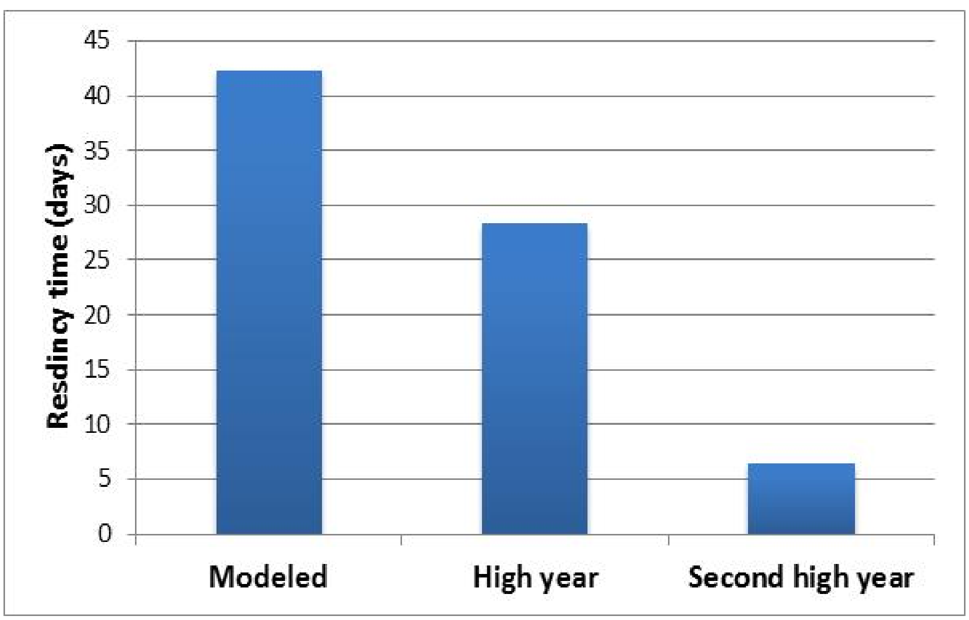

Figure 28. Modeled and actual highest and second highest year for the eight collars experiencing the highest interaction with ZOIs in the Qamanirjuaq herd range.

5.4 Seasonal Effects

The season that caribou encounter ZOIs appears to affect the body condition of cows and their calves in the fall period. We modeled the possibility that all contact with ZOIs occurred in one season. Thus we modeled 13 days (from Figure 20) of residency applied to each season in separate simulations and compared fall cow and calf weights to base conditions (no contact with ZOIs). Results from late winter and spring indicate that although fall cow weights drop by 0.6 kg (late winter) and 0.8 kg (spring) relative to baseline, calf weights are actually 0.2 kg higher than baseline. Late winter and spring are typically energetically and protein stressful for caribou and disturbance would affect cow weight going into the calving period. However if protein reserves were high, birth weight of the calves would not be affected. Thus we speculate that cows entering the growing season lighter would have lower energy and protein demands to satisfy their maintenance requirements and would thus allocate more energy and protein to milk production, resulting in high growth rates for calves. Some research indicates that this phenomenon occurs naturally, when cows going into the winter that are in very good condition will lose more weight than lighter cows, suggesting an ideal spring weight entering the calving season. The demographic impact however would be that although calf survival may be higher in the subsequent winter, probability of pregnancy would be reduced corresponding to a lower fall body weight of the cows.

There is a strong selection for cows with newborns to space away from human activity in the calving period. However in our modeling we “forced” them to stay associated with a ZOI and experience alteration in activity patterns. Based on that scenario, cows did slightly better and calves slightly worse compared to the results of the late winter and spring analysis. The residency period spanned the parturition period when energy demands due to lactation dramatically increases. However peak energy and protein demands due to lactation is not until about 10 days post-calving so the impact might not have been as severe as later in the summer.

During post-calving, forage biomass is rapidly growing and digestible, mosquitoes and parasitic flies are just beginning to harass the caribou, but generally this is a period focussed on regaining fat and protein reserves and milk production. During the summer period, insect harassment peaks, biomass peaks and nutritive quality begins to decline. As a consequence, in nutritionally stressful summers, cows employ a “selfish cow” strategy, whereby they will reduce milk production and or wean altogether to ensure their own survival. Thus in our modelled output, cows appeared to employ the selfish cow strategy as encounters reduced their access to food and her calf attained the lowest comparative body weight in fall. The demographic effect is higher calf mortality, but higher probability of pregnancy.

By fall cows are primarily on a lichen diet as shrub and graminoids have lignified and are low in digestibility, nitrogen (except in mushroom years) is scarce, and milk production is low. From our analysis, cows did the poorest when subjected to disturbance, although calves were comparable to baseline conditions.

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