Caribou and the Keeyask Generation Project

James A. Schaefer
Department of Biology
Trent University
Peterborough, Ontario K9J 7B8
Email: jschaefer@trentu.ca

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James Schaefer is Professor of Biology at Trent University where he teaches Conservation Biology, Ecology, Mammalogy, and Research Design & Data Analysis. Prior to his university appointment, he served for 4 years as Senior Wildlife Biologist with the provincial Wildlife Division in Newfoundland & Labrador. His caribou research began more than 25 years ago on the east side of Lake Winnipeg as graduate student at the University of Manitoba. Since then, he has studied caribou in Ontario, Newfoundland, and Quebec-Labrador, and published more than 50 peer-reviewed scientific articles, including 20 papers on the ecology and conservation of this species. He is currently a member of the Ontario Provincial Caribou Technical Committee and the International Boreal Conservation Science Panel.

This document represents a short review of caribou biology and the Environmental Impact Statement (EIS) pertaining to the proposed Keeyask Generation Project. My focus is largely on documents explicit to caribou (Terrestrial Environment Section 7; Response to EIS Guidelines Chapter 6; Responses to Information Requests, Round 1 & 2) but also those relevant to the fire regime and cumulative effects (Response to EIS Guidelines Chapters 6 & 7; Terrestrial Environment Section 2).

In short, my conclusions are that:

- The EIS provides a generally accurate depiction of caribou biology, but the assessment of the Project is hampered by two major uncertainties about summer resident caribou: (A) whether they represent boreal woodland caribou, a provincially and federally listed species; and (B) the extent of their population range, information that is valuable in evaluating habitat conditions and population persistence. While several lines of evidence imply that boreal caribou occupy the Project area, radio-telemetry tracking of female resident caribou would resolve those uncertainties.

- The key to conserving caribou is to add up all sources of habitat loss, both natural and human-caused, rather than considering each in isolation. The Project is planned to occur on an highly altered landscape with prospects for further disturbances from forest fires and other industrial projects. Although the EIS deems the Project impact as “small”, these disturbances in aggregate are likely to put the population of resident caribou at moderate to high risk.

1. Some essentials of caribou biology

The single most striking aspect of caribou ecology and conservation is space. Indeed, two ecotypes of caribou can be distinguished from how they use space, in particular, in the extent of movements and the distribution of females at calving time. Bergerud (1988) recognized the migratory ecotype (long distance movements, aggregation of females at calving) and sedentary ecotype (less extensive movements, dispersion of females at calving). In the EIS, these ecotypes appear equivalent to "barren-ground" (the Beverly Qamanirjuaq herd) or "coastal" caribou (the Cape Churchill and Pen Islands herds), and "summer resident" caribou, respectively.

While biologists generally accept these ecotypic designations, the nomenclature for caribou is variable, sometimes confusing. The sedentary ecotype is regularly referred to as "woodland", "forest-dwelling", or "boreal" caribou. The migratory ecotype is often called "barren-ground" or "forest-tundra" caribou. (Confusion can arise because "woodland" caribou also represents a subspecies which comprises both ecotypes.)

This distinction between sedentary and migratory caribou was a milestone in our scientific understanding. This is because these ecotypes differ strikingly in their population ecology, itself the foundation of conservation biology (Caughley & Gunn 1996). For sedentary caribou, typical population densities are low and invariant. The median density of sedentary caribou populations is 0.066 animals per square kilometre (Schaefer & Mahoney 2003) and Bergerud (1992) demonstrated that their numbers tended to stabilize at 0.06 animals per square kilometre. Rarely do sedentary caribou display substantial changes in abundance unless subject to overharvesting or habitat disruption by humans. This stands in contrast to their migratory counterparts where, in a few decades, herds may show 100-fold changes in abundance (Bergerud 1996, Couturier et al. 2010). There is growing evidence that fluctuations in migratory herds are driven by density-dependent changes in summer food (Messier et al. 1988, Mahoney & Schaefer 2002b, Couturier et al. 2010, Mahoney et al. 2011); climate may also play a role (Couturier et al. 2009, Mahoney et al. 2011, Bastille-Rousseau et al. 2013).

Virtually all caribou have immense requirements for space. Home ranges (the area traversed in 1 year) of sedentary ecotype tend to be in the hundreds or thousands of square kilometres (km^2) – for example, in northern Ontario, typically 3,600 - 5,300 km^2 for an adult female (Wilson 2013). Caribou also require old forests. Areas burned less than 40-50 years ago are unsuitable (Klein 1982, Schaefer & Pruitt 1991). Migratory caribou are renowned for their mobility. Home ranges of females are typically 23,000-98,000 km^2 for the Pen Island herd (Wilson 2013) and 160,000-208,000 km^2 for the Beverly-Qamanirjuaq herd (Nagy et al. 2011).

The behaviours of female caribou at calving time represent the defining features of the ecotypes. They are regarded as strategies to reduce the risk of predation on their calves (Bergerud 1996, Bergerud et al. 2008):

- Sedentary caribou space out. They disperse singly, typically onto islands, into forests, along shorelines, or into peatlands and give birth to their calves in solitude. This appears to a strategy by females, living in the midst of predators, to make themselves scarce, to reduce the search efficiency by wolves and bears and improve the prospects of calf survival.
- Migratory caribou space away. They typically travel north of treeline and increase the distance between themselves and their predators. These females aggregate in their thousands (or hundreds of thousands) on traditional calving grounds on the tundra.

These behaviours appear to permanent fixtures for an individual. To my knowledge, a switch between calving strategies has never been documented. Indeed, sedentary females display strong site fidelity to calving and post-calving locations, generally returning to them each year. Migratory caribou show slightly less site fidelity – an annual return to traditional calving grounds that may shift somewhat each year (Taillon et al. 2012). Both ecotypes show little fidelity to winter locations, which may be separated by hundreds of kilometres from one year to the next (Schaefer et al. 2000, Ferguson & Elkie 2004, Popp et al. 2011, Schaefer and Mahoney 2013). At the northern edge of the boreal forest during winter, the two ecotypes may intermingle (Schaefer et al. 1999, Wilson 2013).

There is a fine balance between gains and losses in caribou populations (Bergerud 1974). Recruitment[1], the addition of young-of-the-year to the adult population, is widely considered as an indicator of the direction of population growth (Bergerud et al. 2008, Environment Canada 2011).

[1] Recruitment is typically expressed as the percentage of calves (6-10 months old) in the whole population or as the ratio of calves per 100 females.

2. Trends in caribou populations

Woodland caribou are in trouble. In Canada, where the "boreal" population is listed as threatened, many local populations are in decline (Festa-Bianchet et al. 2011). This is the reiteration of a worldwide trend (Mallory & Hillis 1998, Vors & Boyce 2009). Callaghan et al. (2011), for instance, reported declines in nearly half of the populations (17/36) in Canada whose numerical trend was known. Range collapse – the loss of about one-half of their historic range – is another sign of the systematic demise of forest-dwelling caribou (Schaefer 2003, Laliberte & Ripple 2004, Festa-Bianchet et al. 2011).

Across the North, many herds of migratory caribou are declining, too (Vors & Boyce 2009, Gunn et al. 2011, Schaefer & Mahoney 2013), perhaps including the Beverly-Qamanirjuaq herd (EIS 7.5.2.3.3., Gunn et al. 2011). The Pen Islands herd has shifted its calving grounds to the east, although trends in population size are not conclusively known (EIS 7.5.2.3.3, Newton 2012).

Loss of habitat is widely acknowledged as the reason for the decline and disappearance of forest-dwelling caribou (Festa-Bianchet et al. 2011). Ultimately, the loss of caribou can be traced to heightened predation – a slow tumbling of dominoes that begins with the disturbance of old forests, more alternate prey (like deer and moose), more predators (like bears and wolves) and greater access by predators into caribou range. Woodland caribou may be one of the most sensitive mammal species to human disturbance (Laliberte & Ripple 2004). The flip side is that refugia from disturbances and from predation are key to their persistence (Bergerud and Page 1987, Bergerud 1996, Cumming et al. 1996, Stuart-Smith et al. 1997, Rettie and Messier 1998, Schaefer et al. 1999, Vors et al. 2007).

On the other hand, dramatic, long-term changes in the size of migratory herds are likely the norm (Gunn et al. 2011). These populations appear to be regulated by summer food (Messier et al. 1988, Couturier et al. 1990, 2010, Mahoney & Schaefer 2002b) and may exhibit cycles in abundance, perhaps on the order of a century or less (Morneau & Payette 2001).

3. Caribou and industrial developments

Wildlife conservation entails identifying and understanding limiting factors – variables which affect rate of population growth (Krebs 2002). These factors tend to differ between ecotypes.

For woodland caribou, the overriding limiting factor is predation. Citing more than a dozen studies, Callaghan et al. (2011) reported "wide agreement that the primary proximate limiting factor for boreal caribou populations is predation, driven by human-induced or natural landscape changes that favour early seral stages and higher densities of alternative prey."

In contrast, for barren-ground caribou (although wolf predation is important; Hearn et al. 1990, Bergerud 1996) food tends to be the principal limiting agent, especially at high densities (Messier et al. 1988, Couturier et al. 2010, Mahoney & Schaefer 2002b, 2013). If there are detrimental effects of the Project, they would most likely exacerbate these limiting factors – i.e., heightened predation on woodland caribou, and compromised energetics and nutrition for barren-ground caribou.

The most compelling signal of human-caused impact on wildlife is demographic – impairments to survival or reproduction. An important, recent achievement is the Environment Canada (2011) analysis linking woodland caribou population condition to habitat condition. Based on data assembled from 24 populations, this work related caribou recruitment to the proportion of the range disturbed by fire and human causes. Because recruitment is closely tied to population growth, and because recruitment of approximately 25 calves per female indicates a stable population (Bergerud & Elliot 1996), we can surmise that roughly one-third of a population range might be disturbed while still meeting conservation objectives. Environment Canada (2011) noted disturbance of the population range of 35-55% as Moderate risk, 55-75% as High risk, 75% or more as Very High risk.

A crucial point is that this disturbance includes all forms of habitat disruption in aggregate. It is computed as the proportion of a population range that has been subject to:

- Natural disturbances – areas burned within the past 40 years;
- Human disturbances – the summed total of features identifiable from aerial photographs (roads, dams, mines, pipelines, settlements, agricultural land, cut blocks, seismic lines, airstrips, power lines, railways), each "buffered" by 500 m.

On the other hand, because of their unparalleled mobility (Bergman et al. 2000), lower range fidelity (Schaefer et al. 2000), and large natural fluctuations in abundance and distribution (Messier et al. 1988, Mahoney & Schaefer 2002b), it has been more difficult to clarify human-caused effects on barren-ground caribou (cf., Cameron et al. 2005). Migratory caribou exhibit pronounced movements and changes in distribution – typical responses to natural variations in population size, summer food, insects, snowcover and snow melt.

There are many examples of avoidance by caribou, well beyond the precise bounds of landscape alterations. Diminished occupancy at distances of 1 km to 5 km from industrial developments is common (e.g., Mahoney & Schaefer 2002a, Weir et al. 2007, Boulanger et al. 2012, Newton 2012, Fortin et al. 2013). These patterns result, initially, from individuals moving away from the disturbed area (Fortin et al. 2013), but such habitat loss appears permanent (Mahoney & Schaefer 2002a), can lead to impaired survival (Courtois et al. 2007) and the systematic loss of populations (Schaefer 2003). Indeed, these distance thresholds are comparable to the critical distance (4 km from unimproved roads) predicting local extinction of woodland caribou in Ontario (Vors et al. 2007).

Overall, Johnson et al. (2005, p.26) concluded that **"...** there is a large body of compelling evidence to support the assertion that caribou have a negative response to human disturbances." The sensitivity of caribou to human impact was one reason why northern Canada and Alaska (including the vicinity of the Project area) have been identified as a hotspot for latent extinction risk – one of 20 regions of the world where there is high potential for future species loss (Cardillo et al. 2006).

4. Keeyask Generation Project

Overall, I found that EIS to provide a largely accurate portrayal of caribou biology, in particular:

- The recognition of different groupings (populations or ecotypes) of caribou (TE 7.3.6.3);
- The acknowledged sensitivity of caribou to human disturbance (EIS 6.2.3.4.2);
- The importance of large, intact core areas (EIS 6.2.3.4.2);
- The importance of predation, especially for forest-dwelling caribou (TE 7.3.6.3).

With respect to migratory caribou, if we accept that calving and post-calving (in spring and summer) represent the most sensitive and limiting periods – the time when females and their calves are vulnerable to disturbances (Cameron et al. 2005, Schaefer & Mahoney 2007, Newton 2012) – the Project is likely to have small impact. There are still reasons to be vigilant regarding the potential for heightened mortality because of vehicle collisions (Brown et al.

2000), drowning (Messier et al. 1988), or overhunting (Bergerud 1974). I surmise that monitoring and mitigation measures (including firearms prohibitions, access management, roadside warnings; CEC Rd 1 CEC-0037b,c) will be sufficient to minimize the effect of the Project.

Nevertheless, regarding resident caribou, there are areas of uncertainty or inaccuracy in the EIS which have important implications for evaluating the Project regarding. Here, I focus on three questions.

A. Do boreal woodland caribou reside in the Project area?

Summer resident caribou are acknowledged to inhabit the Project area, but according to the EIS, the ecotype and herd association of these animals are uncertain (TE 7.3.6.3, EIS 6.2.3.4.7). The northernmost identified boreal caribou range, at present, is located some 100 km from Gull Lake and overlaps only marginally with the Regional Study Area (TAC Public Rd 2, EC-0032b). This designation is crucial, of course, given that boreal woodland caribou are listed as threatened. Although boreal woodland caribou "may or may not occur in the Keeyask area" (TE 7.4.7), I conclude that the evidence from the EIS and supporting documents is largely consistent with the Project area as part of boreal caribou range. This evidence includes:

i. The behavioural and demographic traits of summer resident caribou.– The EIS reports a isolated calving distribution, harem breeding, and low population density (typically ≤0.06 animals per square kilometre; *EIS Supplemental Filing #2*) of resident animals. These are some of the defining features of boreal caribou.

ii. Spring break-up and northern limits of the ecotype.– Bergerud et al. (2008) surmised that the northern extent of sedentary caribou coincided with the springtime availability of open water in large lakes (approximately June 15), hypothesized to represent escape habitat from predators. Indeed, the timing of open water in the vicinity of the Project (median date: May 26; Table 1) places the Keeyask area within this hypothesized range of boreal caribou. The distribution of woodland caribou in Manitoba depicted by Edmonds (1991) also locates the Project area virtually coincident with the northern range limits.

iii. The distribution of sedentary caribou in Ontario.– Recent telemetry tracking by the Ontario Ministry of Natural Resources provides additional indication of sedentary caribou occupancy.

Wilson (2013) found disjunction in the calving distribution between ecotypes, with sedentary females as far north as the approximate southern edge of the Hudson Bay Lowlands (Figure 1). Using the same data, Avgar et al. (2012) reported a breakpoint in rates of movement and home range locations at a latitude (53°32'N) which corresponds roughly to the same ecological line. If these geographic patterns apply in Manitoba, sedentary caribou likely inhabit the Project area.

iv. The size and morphology of antlers on resident male caribou.– The ratio of antler length to body length is another means to distinguish ecotypes. This proportion varies from roughly 0.25-0.53 for sedentary caribou, 0.45-0.63 for migratory caribou (Bergerud et al. 2008). I calculated this ratio for one resident male whose profile was captured by remote camera (Photo 2010-08-08). Although not unequivocal, the value (0.44) is within the expected distribution for the sedentary ecotype.

v. The Nelson-Hayes herd.– This population, an identified local boreal woodland caribou population which once resided in the Project area, appears to have "amalgamated" with the migratory Pen Islands herd (Manitoba 2005). Indeed, there are occasional, large influxes of migratory caribou into the Project area (EIS Supplemental Filing #2). This circumstance is reminiscent of the McPhadyen River and Red Wine Mountains herds in Quebec-Labrador (Brown et al. 1986, Schaefer et al. 1999, Bergerud et al. 2008), populations whose status also became uncertain or declined coincident with the seasonal ingress from the much larger, migratory George River herd. Despite the intermingling, sedentary female caribou tend to remain faithful to their range (Brown et al. 1986, Schaefer et al. 2000, Bergerud et al. 2008, Wilson 2013). The overlap with migratory caribou may cloud our ability to recognize the Nelson-Hayes herd, but the historic observations are consistent with the Project area as suitable for sedentary caribou.

vi. Local knowledge.– As noted in the EIS, some Keeyask Cree Nations distinguish a small number of local caribou (*mistikoskaw utikuk*) from migratory or coastal caribou (EIS 7.5.2.1.3, CEC Rd 1 KK-0012). This is also consistent with Innu in Labrador who, as I understand, recognize at least two types of caribou. These appear to correspond to scientists' designations of sedentary and migratory ecotypes.

Do boreal caribou inhabit the Keeyask area? The straight-line northern range limit, as currently depicted in the province (Manitoba 2005), highlights this gap in knowledge. Ecological boundaries rarely conform to such straight lines. The most compelling scientific evidence of sedentary caribou occupancy would be strong calving-site fidelity and a scattered distribution of females during calving and post-calving, determined by radio-telemetry. Such data do not exist. Nevertheless, it is important to remind ourselves that the absence of evidence does not constitute evidence of absence.

I conclude that, <u>more likely than not</u>, boreal caribou occupy the Project area. This implies that caution is warranted. In addition, I believe it appropriate to assess the degree of habitat loss using the Environment Canada (2011) approach that links disturbance and recruitment. (See below: *What are the future prospects for caribou?*)

B. Is caribou habitat underutilized?

Habitat loss is widely recognized as the principal agent of decline of forest-dwelling caribou (Vors et al. 2007, Festa-Bianchet et al. 2011). This understanding is founded on a <u>definition of habitat</u> in its broad sense – not merely vegetation, topography, and other easily mappable features, but predators and their alternate prey (Rettie & Messier 2000, Bergerud et al. 2008, Festa-Bianchet et al. 2011, Callaghan et al. 2011). For the persistence of forest-dwelling caribou, refugia from predation is pivotal (Bergerud 1996, Cumming et al. 1996, Rettie & Messier 1998, 2000).

This broad habitat perspective is not fully conveyed in the EIS. Habitat is denoted as "the place where an organism or population lives" (EIS 6.5.8.1.1), but a more exact definition includes the <u>resources and conditions</u> that govern the presence, survival, and reproduction of a population (Caughley & Gunn 1996). In this regard, habitat is closely tied to population limiting factors which, in turn, represent the centrepiece of biological conservation (Krebs 2002).

Perhaps because of this restrictive definition, the EIS infers repeatedly that habitat for resident caribou "does not appear to be limiting to summer cows and calves"and "appears to be underutilized" (EIS 6.2.3.4.7; 7.5.2.2.3); that more habitat is likely available than being used; accordingly , if displaced, "caribou ... will most likely find suitable habitat elsewhere" (EIS 6.5.8.1.1; CEC Rd 1, CEC-0037a). This conclusion seems to originate from the observation that just 5-10% of lake islands and of peatland islands were inhabited (TE 7.3.6.3). Thus, concludes the EIS, "not all suitable calving islands are occupied" (CEC Rd 1, CEC-0037a).

I believe this conclusion is incorrect. It ignores the importance of space *per se* as habitat for forest-dwelling caribou. Low density, especially during calving and post-calving, appears pivotal to calf survival. Indeed, Bergerud (1992; Bergerud et al. 2008) argued that a density of 0.06 caribou per square kilometre represented a stabilizing density above which sedentary caribou populations decline. If this threshold density is exceeded, the space between females and their calves likely diminishes; this may result in improved search efficiency by wolves and hence reduced calf survival (Bergerud et al. 2008). The population declines.

Space, therefore, is critical to sedentary caribou. The loss of undisturbed space represents a loss of habitat. As such, projections for resident caribou in the vicinity to the Project seem optimistic.

C. What are the future prospects for caribou?

One of the lessons to be gleaned from the decline of forest-dwelling caribou is that piecemeal approaches to resource development are inadequate for conservation (Suffling et al. 2008). The first step in conserving caribou is to ensure that all forms of disturbance, both human-caused and natural, are considered in aggregate. This is the crux of the Environment Canada (2011) model that links the proportion of disturbance on caribou range to calf recruitment and population persistence.

While the long-term viability of caribou in the Keeyask region is uncertain (EIS 6.5.8.1.1), it does not follow that all outcomes are equally likely. Indeed, in this “greatly altered region” (EIS 7.3.1) “where intactness is already low” (EIS 6.5.3.3.5) from past and present human developments, wildfire is an important, recurrent, additional form of disturbance (CEC Rd 2 CEC-0102c). The fire regime – a comparatively short rotation period with few fires constituting the majority of area burned – attests to the Project area as a fire-prone ecosystem. Indeed, seven years (in descending order: 1989, 1992, 1998, 1994, 1981, 1995, 2003) account for two-thirds of the area burned in the RSA in the past 30 years (Figure 2). This kind of fire distribution is typical in the boreal forest (Johnson et al. 2001). For example, in the Project area prior to fire suppression, 3% of fires accounted for 98% of the area burned (TE SV 2.5.3.1).

This dynamism needs to be incorporated in the assessment of the Project and the prospects for forest-dwelling caribou. Indeed, although there is “unavoidable uncertainty” (TE SV 2.5.4.4) with respect to the occurrence of a large fire, such a hazard needs to be modelled, not just monitored. Wise boreal forest management means buffering for uncertainties. Forest fires will occur; their consequences to caribou habitat will be long-term. Precaution is needed to avoid foreclosing on future options.

The three major fires in Keeyask area in 2013 (CEC Rd 2 CAC-0159) underscore this uncertainty. As noted in a supporting document (TE SV 2.5.4.5), "A single large and/or severe fire could substantially alter habitat composition over the long term, which could alter many of the terrestrial environment predictions."

I agree. To provide an indication of future habitat conditions, I developed a simple stochastic (probabilistic) model incorporating fire occurrence and forest regeneration, based on recent fire history in the Keeyask region (TE Table 2D; *Appendix 1*, below). I projected the model 40 years into the future, starting in 2009 (the last year of fire occurrence data), and estimated probabilities of risk to caribou based on 1000 model runs. I used the Environment Canada (2011) definition of disturbance (<40 years old) and categories of risk : Very Low (<10% disturbed), Low (10-35% disturbed), Moderate (35-45% disturbed), High (45-75% disturbed), and Very High (>75% disturbed). The degree of disturbance in Year 0 was set at 33.9% (Zone 6; CEC Rd 1, CEC-0037a; CEC Rd 2,Table 3).

The output from model implies some risk of decline in caribou habitat suitability in the next few decades (Figure 3). In particular, the model demonstrated that:

- After 20 years, there is roughly 50% chance of Moderate risk (Range uncertain), 10% chance of High risk (Range not self-sustaining);
- After 40 years, there is approximately 33% chance of Moderate risk, 40% likelihood of High risk, and 27% likelihood of Low risk (Range self-sustaining).

While these values should not be taken literally, they do suggest the Project may occur in the midst of a more disturbed landscape than described in the EIS, with negative repercussions for caribou. Rather than adverse residual effects that are small in magnitude (EIS 6.5.8.1.3), the model implies that the Project will take place in a context where the risk to resident (boreal) caribou is moderate, perhaps even high (Figure 3). The Keeyask Generation Project will only exacerbate that habitat disruption (CEC Rd 2, Table 3).

There are additional reasons for caution. The possible increased hazard from wildfire, as implied by the model, could be underestimated or exacerbated. This is because of:

- A shifting fire regime under climate change – i.e., more frequent and larger fires (TE 2.5.3.1);
- Corridors and other forms of habitat loss associated with the Keeyask Transmission Project (EIS 7.5.2.3.3) and other hydroelectric developments (Bipole III, Gillam Redevelopment; CEC Rd 2, Table 3; EIS 6.5.8.1.5);
- A larger moose population, growing at 2.9% per year in 17 years (TE 7.4.9.1), which represents a doubling of the moose population every 25 years – more alternate prey for wolves. Experience from elsewhere suggests that, if moose density exceeds 0.10 animals per square kilometre, caribou may be extirpated (Bergerud et al. 2008).

5. Conclusions

The EIS (6.5.8.1.5) concludes that the residual effects of the Project on caribou are anticipated to be "adverse``, ``small`` to ``medium`` in extent, ``long term`` in duration, and ``small`` in magnitude. Moreover, these assessments are considered to have "a moderate to high degree of certainty", even ``high confidence`` with respect to habitat availability, core areas, and regional intactness.

I am not fully convinced, however, by these conclusions, nor by their certainty. I sum up my conclusions with two points:

- The Project is being assessed in the face of <u>two major uncertainties</u>. The first is the ecotypic designation of summer resident caribou. Although the evidence at-hand suggests that, more likely than not, boreal caribou occupy the Project area, confirmatory observations are needed. Radio-telemetry tracking of female resident caribou (e.g., 2 years of observations) will not only provide those useful observations, it will also help resolve the second major uncertainty, the extent of the population range of resident caribou (CEC Rd 2, CEC-0105). Indeed, it is difficult to assess the condition of a population range without knowing the extent of that range.

- The Project is planned to occur on an <u>highly altered landscape</u> that may be disturbed further in near future from additional industrial projects and forest fires. The EIS acknowledges some habitat loss for caribou – estimated at 0.5% of the RSA (CEC Rd 2, Table 3). Although the Project contribution may be "small", these disturbances in aggregate may propel the caribou population into the Moderate or High risk categories. Whether such risk is acceptable is a societal decision. Nonetheless, it is worth underscoring that piecemeal approaches to boreal forest management in the past have represented a failure to conserve caribou.

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Table 1. Dates of known open water in the vicinity of the Keeyask Generation Project. Data from *Responses to Information Requests, CEC, Round 1 (CAC-0001)*.

Year	Keeyask Area	Stephens Lake
2001	May 25	May 25
2002	Jun 13	Jun 23
2003	May 29	May 26
2004	Jun 11	Jun 6
2005	May 29	May 18
2006	May 12	May 7
2007	May 26	May 19
2008	Jun 9	May 31
2009	Jun 2	Jun 8
2010	May 7	May 15
2011	May 26	May 26
2012	May 14	May 22
2013	May 25	May 29

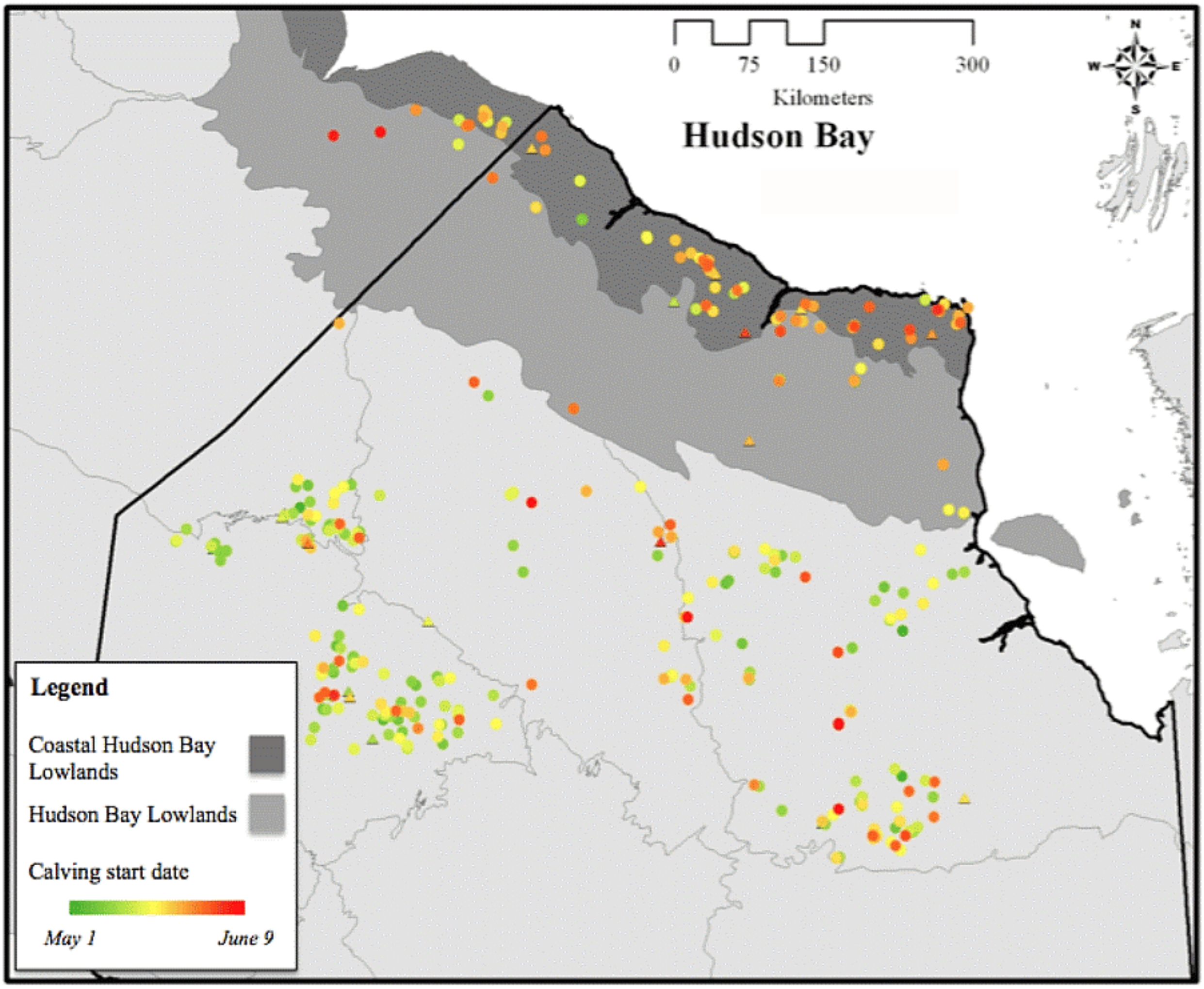

Figure 1. Calving distribution of 131 radio-collared female caribou in northern Ontario, 2009, 2010, and 2011 (from Wilson 2013).

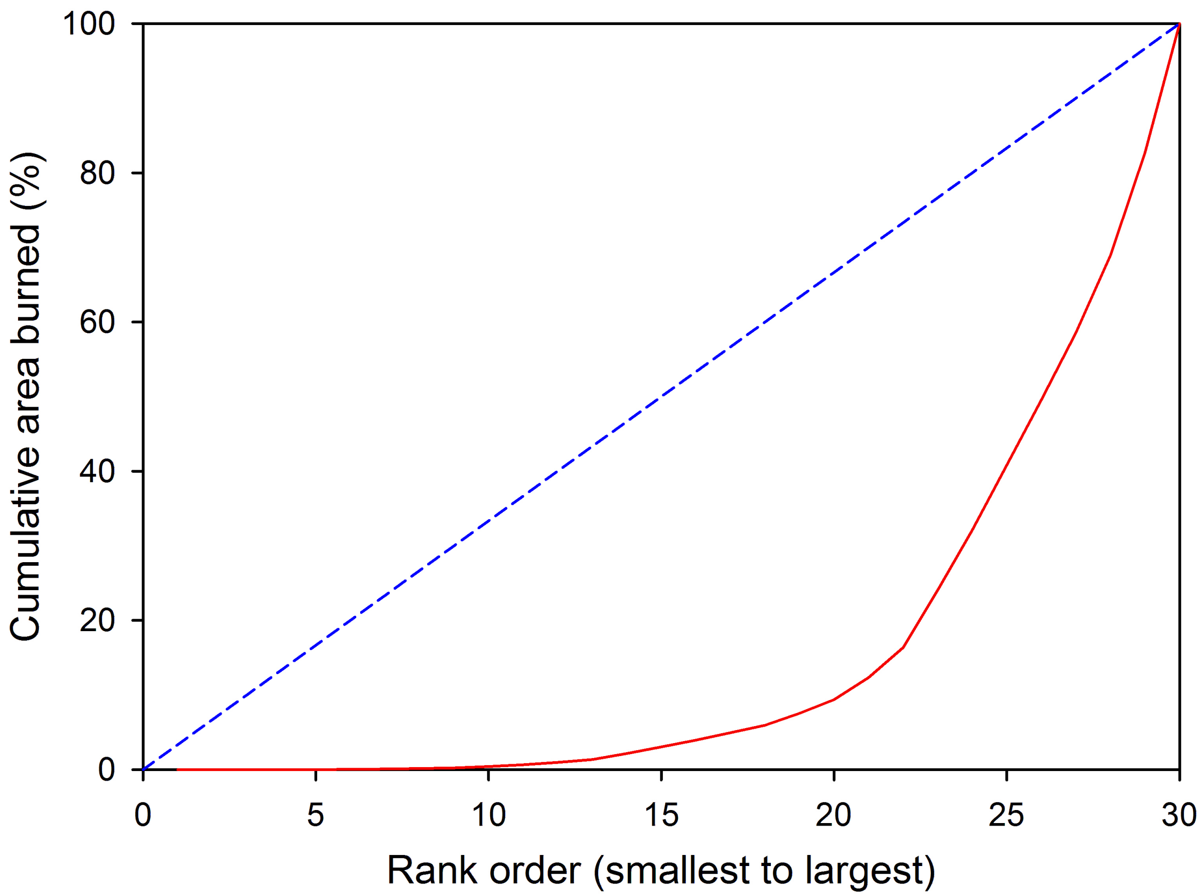

Figure 2. Rank order of annual area burned (solid line) in the Keeyask study area, 1979-2009. The dashed line represents the expected distribution if the area burned was equal each year. Data are from *Terrestrial Environment, Supporting Volume, Section 2, Table 2D-3.*

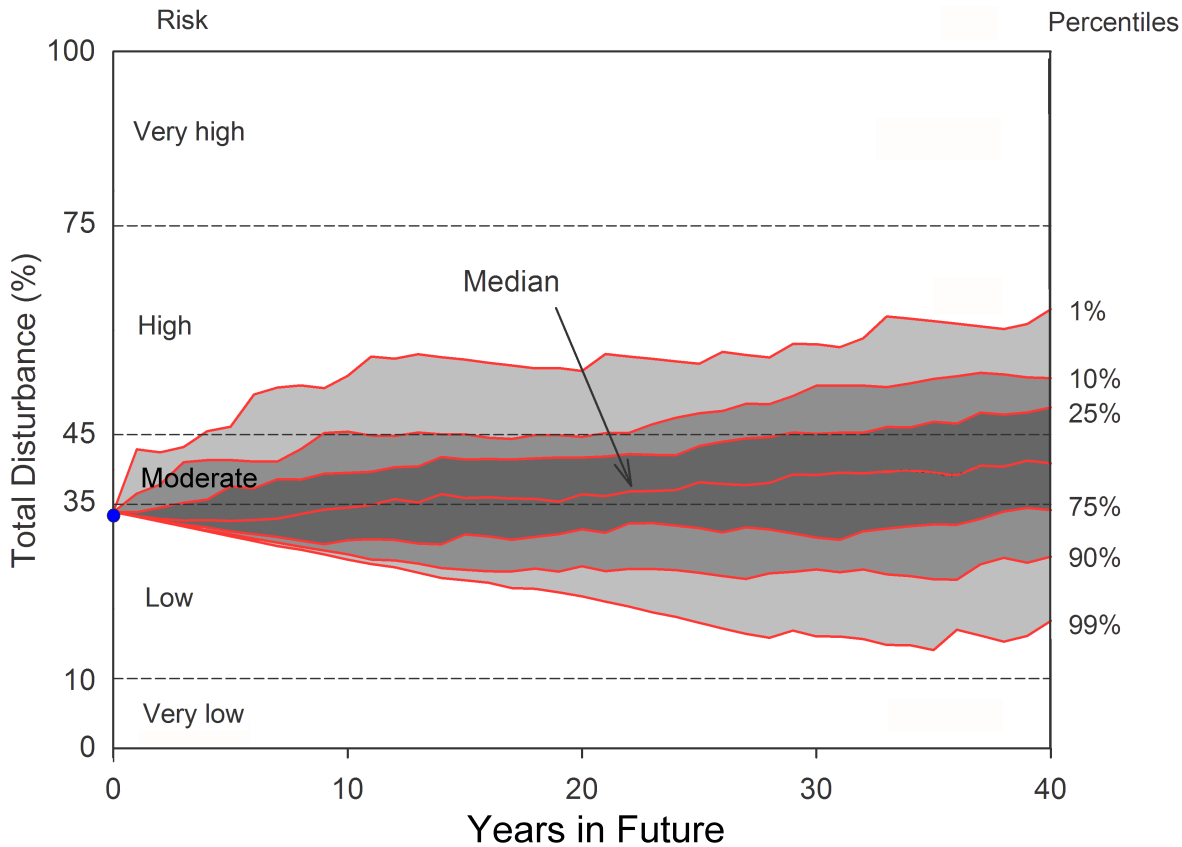

Figure 3. Proportion of the Project area disturbed, projected 40 years into the future, based on a stochastic model of fire occurrence in Keeyask study area (Appendix 1). Risk categories to caribou are from Environment Canada (2011).

7. Appendix 1 – Stochastic model of fire occurrence

I developed a simple stochastic model of future habitat condition based on fire history in the Keeyask region, 1979-2009 (Terrestrial Environment, Supporting Volume, Section 2, Table 2D-3). Following Armstrong (1999), I fit a lognormal distribution to the annual burn rate:

$$Y = 45 * \text{Lognorm}(X, -1.3710654, 4.63616058)$$

where Y is the percentage of the area burned, and the two other parameters represent the mean and variance, respectively.

I wrote the model in Basic (Table A1) to conduct a random draw each year for 40 years to simulate the annual area burned. I set an upper limit to the percentage burned at 17%, equivalent to the largest burn year, 1989. Each new burn was distributed equally across all age classes, consistent with a constant fire hazard in the boreal forest, irrespective of stand age (Johnson et al. 1995). To mimic succession, the age of each age class was incremented by one each year.

The model was run for 40 years from year 0 (Year 2009). I set the starting landscape age class distribution as 66.1% undisturbed (≥40 years old) and distributed the remaining proportion of the range (33.9% disturbed, <40 years old) was evenly according a constant annual burn rate in the region (i.e., 1.03% per year). This was reasonably close to the reported rate of 1.29% per year (Terrestrial Environment, Supporting Volume, 2.5.3.1).

I ran the model 1000 times and determined the distribution of the proportion of the area disturbed (<40 years old) as percentiles: 1%, 10%, 25%, median, 75%, 90%, and 99%.

The model is admittedly simple. On one hand, the landscape did not distinguish lakes (not subject to disturbance), which likely means the degree of disturbance is overestimated. On the other hand, it did not consider human disturbances (not subject to succession), which likely means the degree of disturbance is underestimated. The model was also aspatial in fire occurrence.

Table A1. QB64 Basic program to conduct stochastic modelling of annaul fire occurrence in the Keeyask region.

```
OPEN "C:OUTPUT.TXT" FOR OUTPUT AS #1
PRINT #1, "Z YEAR DISTURBED INTACT BURN"
RANDOMIZE (TIMER)
DIM AGE(40)
'Perform multiple simulations
FOR Z = 1 TO 1000
'The starting age distribution
AGE(40) = 66.100        '<- AGE 40 YEARS OR MORE
AGE(0) = 1.030 :  AGE(1) = 1.019 :  AGE(2) = 1.009 :  AGE(3) = 0.998 :  AGE(4) = 0.988 :  AGE(5) = 0.978 :  AGE(6) =
0.968 :  AGE(7) = 0.958 :  AGE(8) = 0.948 :  AGE(9) = 0.938 :  AGE(10) = 0.929 :  AGE(11) = 0.919 :  AGE(12) = 0.910 :
AGE(13) = 0.900 :  AGE(14) = 0.891 :  AGE(15) = 0.882 :  AGE(16) = 0.873 :  AGE(17) = 0.864 :  AGE(18) = 0.855 :
AGE(19) = 0.846 :  AGE(20) = 0.837 :  AGE(21) = 0.829 :  AGE(22) = 0.820 :  AGE(23) = 0.812 :  AGE(24) = 0.803 :
AGE(25) = 0.795 :  AGE(26) = 0.787 :  AGE(27) = 0.779 :  AGE(28) = 0.771 :  AGE(29) = 0.763 :  AGE(30) = 0.755 :
AGE(31) = 0.747 :  AGE(32) = 0.740 :  AGE(33) = 0.732 :  AGE(34) = 0.724 :  AGE(35) = 0.717 :  AGE(36) = 0.710 :
AGE(37) = 0.702 :  AGE(38) = 0.695 :  AGE(39) = 0.688
'Simulate for 40 years
FOR YEAR = 0 TO 40
'Random draw: Probability distribution of percentage of range burned from lognormal distribution
 REPICK:
 PICK = RND * 100
 IF PICK > 0 AND PICK < 10 THEN BURN = 0.0003
 IF PICK > 10.00 AND PICK < 20.00 THEN BURN = 0.0029
 IF PICK > 20.00 AND PICK < 30.00 THEN BURN = 0.0137
 IF PICK > 30.00 AND PICK < 40.00 THEN BURN = 0.0504
 IF PICK > 40.00 AND PICK < 50.01 THEN BURN = 0.1662
 IF PICK > 50.01 AND PICK < 55.00 THEN BURN = 0.3543
 IF PICK > 55.00 AND PICK < 58.00 THEN BURN = 0.5509
 IF PICK > 58.00 AND PICK < 61.63 THEN BURN = 0.8236
 IF PICK > 61.63 AND PICK < 67.19 THEN BURN = 1
 IF PICK > 67.19 AND PICK < 70.29 THEN BURN = 2
 IF PICK > 70.29 AND PICK < 72.40 THEN BURN = 3
 IF PICK > 72.40 AND PICK < 73.98 THEN BURN = 4
 IF PICK > 73.98 AND PICK < 75.24 THEN BURN = 5
 IF PICK > 75.24 AND PICK < 76.28 THEN BURN = 6
 IF PICK > 76.28 AND PICK < 77.16 THEN BURN = 7
 IF PICK > 77.16 AND PICK < 77.93 THEN BURN = 8
```

```
 IF PICK > 77.93 AND PICK < 78.59 THEN BURN = 9
 IF PICK > 78.59 AND PICK < 79.19 THEN BURN = 10
 IF PICK > 79.19 AND PICK < 79.72 THEN BURN = 11
 IF PICK > 79.72 AND PICK < 80.21 THEN BURN = 12
 IF PICK > 80.21 AND PICK < 80.65 THEN BURN = 13
 IF PICK > 80.65 AND PICK < 81.05 THEN BURN = 14
 IF PICK > 81.05 AND PICK < 81.43 THEN BURN = 15
 IF PICK > 81.43 AND PICK < 81.78 THEN BURN = 16
 IF PICK > 81.78 AND PICK < 82.10 THEN BURN = 17
 IF PICK > 82.1 THEN GOTO REPICK
 FOR A = 0 TO 39        '<- Tally the age classes under 40 (= Disturbed %)
 DISTURBED = DISTURBED + AGE(A)
 NEXT A
 PRINT USING " ### #### ##.## ##.## ##.###"; Z; YEAR; DISTURBED; AGE(40); BURN
 PRINT #1, Z; YEAR; DISTURBED; AGE(40); BURN
 DISTURBED = 0
 LOSS = 1 - (BURN / 100)   '<- LOSS DUE TO BURN EQUALLY DISTRIBUTED IN EACH AGE CLASS
 'Increment each age class by 1 year
AGE(40) = (AGE(40) + AGE(39)) * LOSS:  AGE(39) = AGE(38) * LOSS:  AGE(38) = AGE(37) * LOSS:  AGE(37) = AGE(36) *
LOSS:  AGE(36) = AGE(35) * LOSS:  AGE(35) = AGE(34) * LOSS:  AGE(34) = AGE(33) * LOSS:  AGE(33) = AGE(32) *
LOSS:  AGE(32) = AGE(31) * LOSS:  AGE(31) = AGE(30) * LOSS:  AGE(30) = AGE(29) * LOSS:  AGE(29) = AGE(28) *
LOSS:  AGE(28) = AGE(27) * LOSS:  AGE(27) = AGE(26) * LOSS:  AGE(26) = AGE(25) * LOSS:  AGE(25) = AGE(24) *
LOSS:  AGE(24) = AGE(23) * LOSS:  AGE(23) = AGE(22) * LOSS:  AGE(22) = AGE(21) * LOSS:  AGE(21) = AGE(20) *
LOSS:  AGE(20) = AGE(19) * LOSS:  AGE(19) = AGE(18) * LOSS:  AGE(18) = AGE(17) * LOSS:  AGE(17) = AGE(16) *
LOSS:  AGE(16) = AGE(15) * LOSS:  AGE(15) = AGE(14) * LOSS:  AGE(14) = AGE(13) * LOSS:  AGE(13) = AGE(12) *
LOSS:  AGE(12) = AGE(11) * LOSS:  AGE(11) = AGE(10) * LOSS:  AGE(10) = AGE(9) * LOSS:  AGE(9) = AGE(8) * LOSS:
AGE(8) = AGE(7) * LOSS:  AGE(7) = AGE(6) * LOSS:  AGE(6) = AGE(5) * LOSS:  AGE(5) = AGE(4) * LOSS:  AGE(4) =
AGE(3) * LOSS:  AGE(3) = AGE(2) * LOSS:  AGE(2) = AGE(1) * LOSS:  AGE(1) = AGE(0) * LOSS:  AGE(0) = BURN
 NEXT YEAR
NEXT Z
CLOSE
```