STATUS of WOODLAND CARIBOU (*Rangifer tarandus caribou*) in the JAMES BAY REGION of NORTHERN QUEBEC

PRESENTED TO THE
Ministère des Ressources naturelles et de la Faune du Québec
AND THE
Grand Council of the Crees (Eeyou Istchee)

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WOODLAND CARIBOU RECOVERY TASK FORCE
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EXECUTIVE SUMMARY

The boreal ecotype of forest-dwelling woodland caribou was designated as threatened in 2002 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In 2005 boreal caribou were recognized as vulnerable in Quebec, though a reassessment of this status is due. Whereas predation and hunting are deemed to be the proximate causes of population declines at present, the ultimate cause is attributed to landscape transformation. We analyzed 9 years of demographic and satellite telemetry data acquired from three local populations of boreal caribou in the James Bay region of northern Quebec (Eeyou Istchee). Our assessment of the situation is as follows:

1. Recruitment rates are declining across the region as a consequence of cumulative increases in range disturbance.
2. Overall adult (female) survival is also declining, and this condition is exacerbated by the subsistence harvest.
3. Current amounts of cumulative range disturbance are in excess of what is theoretically required in order to ensure population persistence (i.e. demographic tolerance thresholds).
4. At present all three populations (i.e. the Assinica, Nottaway and Temiscamie) are considered not self-sustaining (NSS) and current declines are predicted to worsen in the coming years as critical habitat is further eroded.
5. Road networks are strongly avoided by woodland caribou, which results in functional habitat loss. They also facilitate the deterioration of critical habitat, improving access to human and animal predators and paving the road to local extirpation. Proposed roads L-209 and extension 167 are predicted to substantially diminish functional landscape connectivity and therefore population resilience in addition to promoting conditions consistent with population decline.
6. To reinforce the existing protected areas network we recommend approval of the proposed Waswanipi and Nemaska protected areas in addition to the expansion of the Assinica Park Reserve.

7. To facilitate population recovery we recommend:

   a) Avoiding further development within areas known or presumed to be occupied by woodland caribou;
   b) Targeting net reductions in overall cumulative range disturbance;
   c) Encouraging an immediate halt to the subsistence harvest of woodland caribou; and
   d) Forming strategic alliances to ensure the proactive recovery of the James Bay metapopulation.

Lastly, we recommend an aerial census of the region in order to refine demographic estimates and more accurately assess population status and long-term viability. In light of recent findings we also recommend that the government of Quebec reevaluate the status of woodland caribou in the province. In closing we suggest a series of new research directions that may assist managers in evaluating risk with relation to forest management and caribou population persistence.

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DEFINITIONS

Critical Habitat: The habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species[1].

Local Population: A group of caribou occupying a defined area distinguished spatially from areas occupied by other groups of caribou. Local population dynamics are driven primarily by local factors affecting birth and death rates, rather than immigration or emigration among groups[2].

Functional Habitat Loss: Loss of habitat due to displacement from preferred habitats near human activity or infrastructure; also referred to as indirect habitat loss[3].

Metapopulation: A population of populations, or a system of local populations (demes) connected by movements of individuals (dispersal) among the population units[4].

Population Range: A geographic area occupied by a group of individuals that are subjected to the same influences affecting vital rates over a defined time frame[1].

Self-sustaining Population: A local population of boreal caribou that on average demonstrates stable or positive population growth over the short term (≤20 years), and is large enough to withstand stochastic events and persist over the long-term (≥50 years), without the need for ongoing active management intervention (e.g., predator management or transplants from other populations) [1].

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[1] Environment Canada 2012
[2] Environment Canada 2011
[3] Polfus *et al.* 2011
[4] Hilty *et al.* 2006

ABBREVIATIONS

COSEWIC: The Committee on the Status of Endangered Wildlife in Canada

FRI: Forest Resource Inventory

LEMV: Loi sur les espèces menacées ou vulnérables du Québec (2002)

JBR: James Bay region

MDDEP: Quebec Ministry of Sustainable Development, the Environment and Parks

NDQ: Nord-du-Québec region

PAIF: Annual Forest Management Plans

QMRNF: Quebec Ministry of Natural Resources and Wildlife

RAIF: Annual Forest Management Reports

RSF: Resource Selection Function

SARA: Federal Species-at-Risk Act (2002)

1. INTRODUCTION

1.1. Designated Status

All North American caribou and Eurasian reindeer are considered the same species, *Rangifer tarandus*. These can be further divided into five subspecies according to their morphological (Banfield 1961) and genetic differences (Roed 1992). Canada is considered to have three subspecies: the Peary caribou of the Arctic Islands (*Rangifer tarandus pearyi*), the barren-ground caribou (*Rangifer tarandus groenlandicus*) and the woodland caribou (*Rangifer tarandus caribou*) (Figure 1). For functional purposes, woodland caribou may be subdivided into ecotypes based on demographic and behavioural adaptations (Kelsall 1984). Forest-dwelling ecotypes of the subspecies caribou include the Northern and Southern Mountain populations of British Columbia, Washington and Idaho, the Newfoundland and Atlantic (Gaspésie) populations, and the Boreal population (Thomas & Gray 2002). The Boreal population, which includes the southern taiga populations of Ontario, Québec and Labrador, has been classified as Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2002) since 2000 (Thomas & Gray 2002), and are afforded protection under the Federal Species-at-Risk Act (S.C. 2002, c.29).

Boreal caribou in Quebec (hereafter referred to as woodland caribou) were recognized as vulnerable in 2005 under the *Loi sur les espèces menacées ou vulnérables* (LEMV), though this designation is likely in need of revisiting. The explicit objectives of the LEMV are as follows:

- To prevent the extinction of species in Quebec;
- To avoid reductions in the population size of species designated as vulnerable or threatened;
- To ensure the conservation of habitats for species-at-risk;
- To restore designated populations and their habitats; and lastly,
- To ensure no species becomes vulnerable or threatened.

In collaboration with the Grand Council of the Crees (GCC), and in recognition of their responsibilities under the LEMV, the Quebec Ministry of Natural Resources and Wildlife (QMRNF) has commissioned a study on the heretofore undocumented status of woodland caribou in the James Bay region (Eeyou Istchee). We hereby respectfully present the results of said study, which we trust will serve as an instrument of positive change for the conservation of this species-at-risk.

1.2. Background Information

In order to inform our responses to the questions outlined in **Section 1.3** we have endeavored to document both the 1) demographic and 2) behavioural responses of woodland caribou to changing habitat conditions in northern Quebec. In conducting this work we have greatly benefitted from the body of knowledge created by Environment Canada's boreal science committee, in addition to the insights and knowledge provided by our own research and that of our peers. **Sections 1.1** and **1.2** are intended as background information forming the conceptual framework upon which the work we have conducted is based.

1.2.1. Woodland Caribou on Managed Landscapes

Woodland caribou have existed in North America for thousands of years (Bergerud & Luttich 2003). During this time they have developed life history strategies permitting them to coexist with a diversity of other large mammal species on landscapes subject to various levels of disturbance by fire, windthrow and other natural phenomena. Since the mid-twentieth century, however, the rate and scale of human-induced landscape alteration have far exceeded the historic range of natural variation (Vors & Boyce 2009; Festa-Bianchet *et al.* 2011), and it is no coincidence that today the southern limit of semi-continuous woodland caribou occupancy contrasts sharply with the northern limit of industrial forest harvesting in Canada (Figure 1). Caribou are particularly adapted to landscapes dominated by mature coniferous forest and relatively low amounts of disturbance, yet it is precisely the inverse that is produced by forest management often in combination with other forms of resource extraction. Caribou require large tracts of mature forest in order to maintain low enough densities to satisfy their life-history requirements (e.g. foraging, rest, reproduction) without undue risk of predation. As core forest is gradually reduced to patches within a broader matrix of regenerating forest, once-preferred caribou habitats become environments to which other cervids (e.g. moose, white-tailed deer) and their predators (e.g. black bear, grey wolf) are better suited. As caribou are left with progressively less refuge habitat, they simultaneously face a higher risk of predation. Caribou calves in particular are highly susceptible to black bear predation in the first few weeks of life (Pinard *et al.* 2012), and inadequate calf recruitment inevitably triggers population decline. Greatly exacerbating the issue are correlated road networks, which allow both animal and human predators access into previously unexploited territories. When wolf populations respond positively to increases in the relative abundances of deer and moose in area and begin to prey opportunistically on both adult and juvenile caribou, this can rapidly lead to population decline and extirpation (Vors *et al.* 2007). An additive effect is produced when individual caribou are displaced into less optimal habitats simply to avoid predation; this results in **functional habitat loss** (Polfus *et al.* 2011) and may actually lead to reduced fitness due to sub-optimal nutrition and/or other proximate factors (Beauchesne 2012).

Harvesting incursions into areas actually occupied by caribou may have direct consequences for survival (Cumming & Beange 1993). In northern Quebec we have the example of a sizeable group of woodland caribou (est. 40) virtually trapped in an isolated remnant forest to the south of the Assinica range near Lac La Trève, a highly disturbed landscape where the risk of both animal and human predation is significant and the likelihood of persistence is virtually nil. Harvesting incursions into occupied caribou range can therefore invoke a flight response that may or may not lead to the desired outcome (e.g. displacement of caribou into alternate ranges).

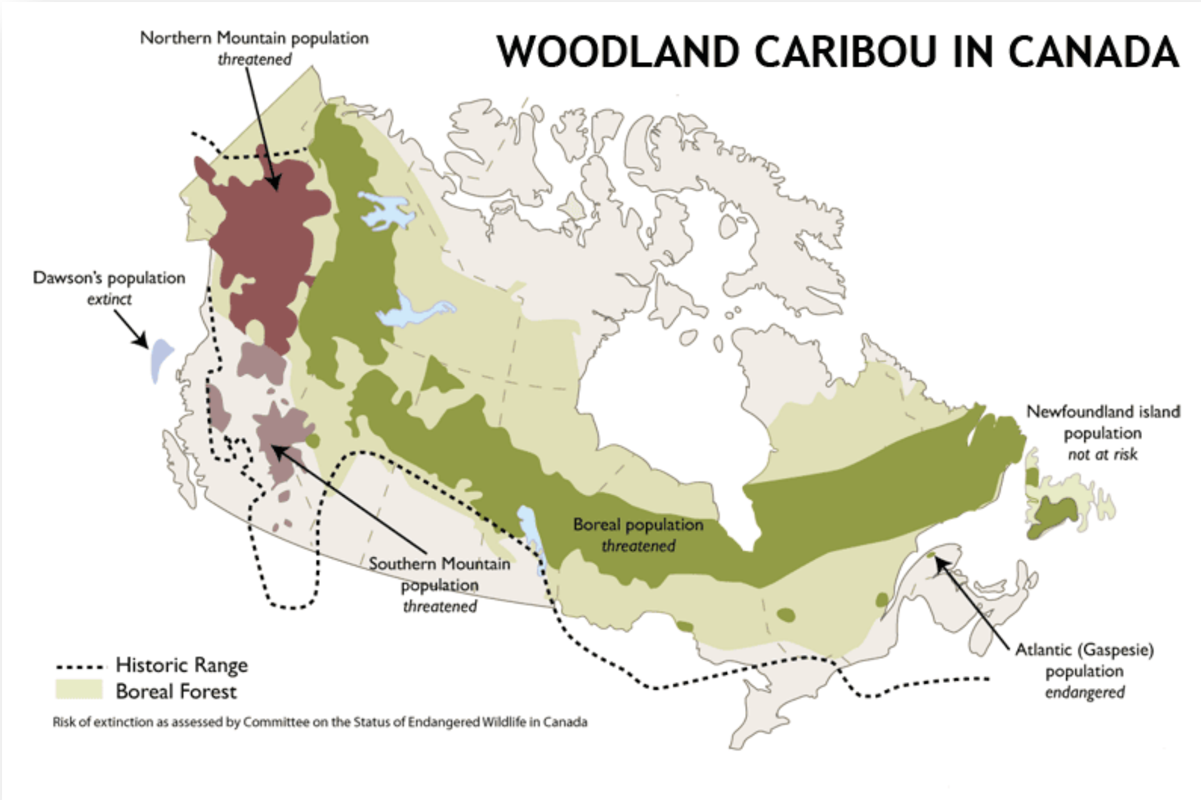

Figure 1: Woodland caribou (*Rangifer tarandus caribou*) ecotypes in Canada (COSEWIC 2002). The Assinica, Nottaway and Temiscamie herds belong to the threatened boreal population. The dotted line indicates the historic limit of continuous range occupancy.

1.2.2. The Disturbance-Recruitment Relationship

By pairing knowledge of habitat conditions with the demographic parameters of local populations of woodland caribou across Canada, Environment Canada (2008, 2011b) has demonstrated the negative linear relationship between range disturbance and population recruitment (Figure 2). Further modeling has led them to conclude that the total combination of non-overlapping fire (<= 40 yrs. old) and buffered (500m) anthropogenic disturbances (<= 50 yrs.) on a population's range is the most accurate predictor of juvenile recruitment (Environment Canada 2011).

Based on mean national estimates of adult sex ratio (63.9 males/100 females) and survival (S=0.852), it is estimated that an annual recruitment of 28.9 calves/100 females is required for a woodland caribou population to be self-sustaining. According to the recruitment-disturbance relationship, a population therefore has no more than a 50% chance of being stable when greater than or equal to 40% of its range consists of disturbed habitat. Environment Canada, in their draft *Recovery Strategy for the Woodland Caribou, Boreal Population, in Canada*, recommends maintaining a minimum of 65% undisturbed habitat within a local population's range in order to secure a measurable probability (60%) that the population will be self-sustaining (Environment Canada 2012).

Because caribou population dynamics (e.g. demographic parameters, persistence vs. extinction) are measured at the second-order, or landscape scale, this has been identified as the most relevant scale for recovery planning (Environment Canada 2008).

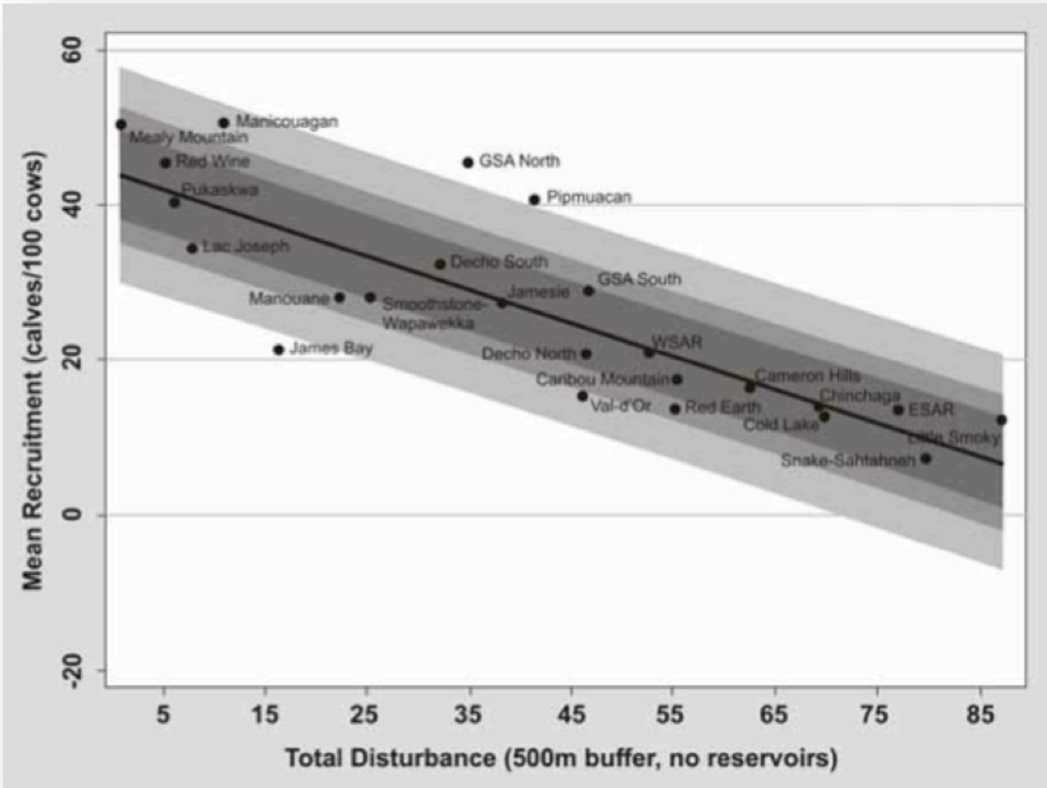

Figure 2: Empirical relationship between total range disturbance and mean recruitment rate using data from 24 boreal caribou populations across Canada (Environment Canada 2011).

1.3. Overview of Mandate

The goal of this report is to respond to the following questions:

Q1: What is the status of the woodland caribou population in the territory?

a) Determine the recruitment, mortality rate and the tendency of the populations

b) Determine the current status of the population by herd

Q2: What is the status of woodland caribou habitat?

a) Determine quality and critical habitat for woodland caribou during all phases of its annual cycle (calving, rutting, wintering)

b) Evaluate the condition of the habitat and the level of disturbance by herds

c) Determine the probability of persistence for each herd and the overall population with current habitat condition

Q3: Can each herd and the overall population support further disturbance and to what extent?

Q4: What is the impact of current and proposed road network and their related activities on the herds and their habitat?

a) Evaluate the cumulative impacts of roads and related activities on critical habitat

b) Evaluate the impact of proposed roads (L-209, 167, etc.) currently under Environmental Review

Q5: What is the contribution of actual protected areas and the territory above the northern commercial forestry limit for caribou conservation?

Q6: What role can the Waswanipi and Nemaska protected area proposal play to ensure recovery of the population?

Q7: Based on the results obtained, suggest potential solutions/actions that would ensure the survival of the herds in Eeyou Istchee?

1.4. Study Area

The area of interest broadly encompasses the coniferous boreal forest and taiga of northern Quebec from latitudes 49º to 53º N, and from longitudes 69º to 80ºW, principally including the Nord-du-Quebec (Region 10) and western portions of the Saguenay-Lac-St-Jean (Region 02) administrative regions (Figure 3). The zone extends west to the Ontario border and to portions of the territory beyond the current northern limit of commercial forestry. Three more-or-less distinct groups of woodland caribou have been identified here, known as (from west to east) the Nottaway, Assinica, and Temiscamie herds. The La Sarre herd, which occupies the transboundary region (QC/ON) south of the Nottaway, will not been addressed in this report.

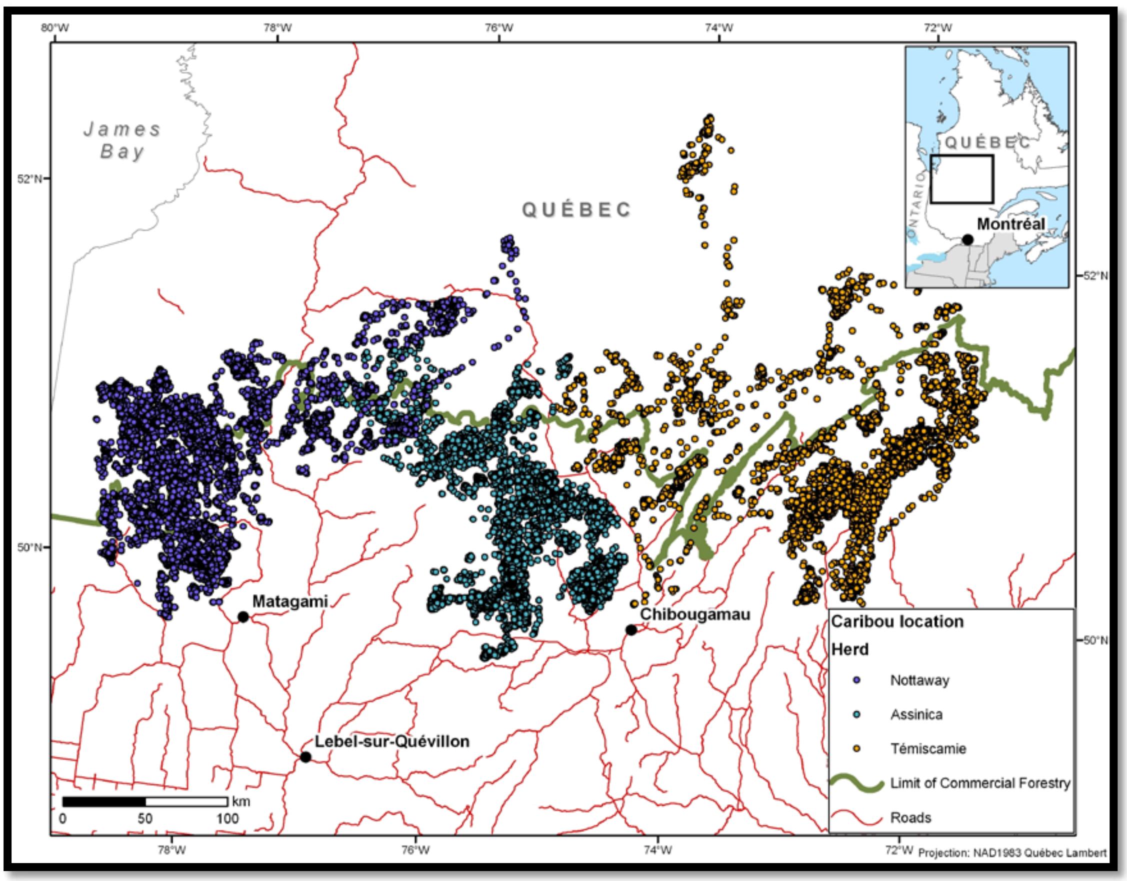

Figure 3: Overview of study area in the boreal forest of northern Quebec. Purple, blue and brown dots represent GPS locations transmitted between March 2004 and March 2007 from collared woodland caribou considered to belong to the Nottaway, Assinica, and Temiscamie herds (respectively).

2. METHODOLOGY

2.1. Data Sources & Preliminary Treatment

The primary sources of data used include a) GPS telemetry, b) geospatial land cover maps, and c) spring aerial surveys.

2.1.1. GPS Telemetry

GPS telemetry data were used a) to estimate local population ranges, b) to assign individual herd identities, and c) to model the relative probability of occurrence (habitat selection) on observed and predicted landscapes.

Data on caribou space use consisted primarily of satellite telemetry locations transmitted every 7 hours from GPS collars fitted to 45 different female woodland caribou captured between March 28, 2004 and April 02, 2011. Of the original ~163,285 records, 11 % consisted of identical duplicates and were removed. Where the necessary information was available (PDOP, or Positional Dilution of Precision), imprecise fixes were filtered out according to Dussault *et al*. (2001). GPS relocations were projected into Quebec Lambert Conformal Conic 1983 and later exported as an ESRI shapefile.

Inspection of caribou distributions revealed several outliers consisting of individuals dispersing far beyond the more-or-less clustered ranges of the woodland herds. Because this behavior was considered atypical of the boreal ecotype of woodland caribou, these individuals (n=4) were removed from the dataset prior to further analysis.

2.1.2. Geospatial Land Cover Maps

Geospatial land cover maps were used in combination with GPS telemetry data a) to evaluate critical habitat within local population ranges, and b) to model the relative probability of occurrence (habitat selection) on observed and predicted landscapes. The data came in several forms, including satellite imagery, Forest Resource Inventory (FRI) data, historic fire data, and point data associated with mining developments.

2.1.3. Satellite Imagery

Since a considerable portion of the study area lies north of the territory currently subjected to commercial forestry, we were unable to obtain an adequate coverage of accurate forest cover maps. For our environmental attribute data (i.e. land cover type), we therefore used a multi-spectral clear-sky composite satellite image of Canada obtained through NASA and classified at a 500-metre resolution by the Canada Centre for Remote Sensing (CCRS) (Trishchenko *et al.* 2007). The Moderate Resolution Imaging Spectroradiometer (MODIS) was conceived for ecological applications and is one of the most advanced sensors in operation. We subsequently resampled the image to 100-metre spatial resolution and reclassified it based on the observed response of woodland caribou to land cover classes with comparable habitat attributes (see Figure 5, APPENDIX 1*)*

2.1.4. Forest Resource Inventory (FRI)

The locations and dates of major disturbances (i.e. fires, insect outbreaks, windthrow, forest cutovers) and road segments produced in the territory were identified using Provincial FRI polygon and polyline data provided by the QMRNF. A semi-exhaustive verification was conducted by Francis Manka of the QMRNF in order to ensure that year of disturbance corroborated with evidence provided by satellite images taken between 2000 and 2011. Years were corrected where necessary and polygons and road segments were digitized or removed accordingly.

A complete coverage of Region 10 (management units 026, 085, 086 and 087) was available as of the operational period 2009/2010, and a complete coverage of Region 02 (management units 02451, 02452, 02551 and 02751) was available as of 2007/2008. Disturbance polygons were extracted from the original FRI coverage using the following criteria:

1) Young regenerating stands (<=50 yrs.) were identified where CL_AGE corresponded with any of the following categories: 10, 1010, 1030, 1070, 1090, 30, 3030, 3050, 3070, 3090, 30120.

2) Anthropogenic disturbances were identified where AN_ORIGINE was either null or greater or equal to 1960 and where ORIGINE was not null and corresponded to anything but the following: BR, CHT, DT, ES, VER.
3) Natural disturbances were identified where AN_ORIGINE was either null or greater or equal to 1970 and where ORIGINE was not null and corresponded to any of the following: BR, CHT, DT, ES, VER.
4) Polygons with non-null values for CO_TER that were anything but the following were considered anthropogenic disturbances: AL, EAU, DH, DS, ILE, INO, TNP.
5) Polygons with null values for all of ORIGINE, AN_ORIGINE, CO_TER and CL_AGE were considered unknown but later determined visually to be anthropogenic disturbances.

Cutovers and roads produced in operational periods subsequent to the most recent available coverages (i.e. 2008/2009 – 2010/2011 for Region 02; 2010/2011 for Region 10) were obtained from Annual Forest Management Reports (RAIF) provided by the QMRNF. Proposed cutovers and roads for the years 2011/2012 and 2012/2013 were obtained from Annual Forest Management Plans (PAIF) and roads subject to environmental assessment (“*routes assujetties*”)

2.1.5. Fire History

Polygons representing historic fires occurring north of the current limit of commercial forestry were obtained from the Canadian National Fire Database (Canadian Forest Service 2010). Fires occurring in 2011 were not available.

2.1.6. Mining Development

Point data associated with mining developments to 2011 were obtained from the QMRNF. All classes of mining developments were considered to be pertinent anthropogenic disturbances; these included active mines, developing mines (“en *développement*"), and mine improvements (“*mise en valeur*”).

2.1.7. Spring Aerial Surveys

To estimate demographic parameters we used both GPS telemetry and field data collected between 2002 and 2012 during spring aerial surveys of northern Quebec by members of the QMRNF, Chibougamau. Two types of assessments were conducted: 1) absolute density surveys (a.k.a. aerial censuses) and 2) herd composition surveys (Hatter & Bergerud 1991). The first consisted of systematic transects of the occupied territory followed by finer-scale classification of caribou groups; these took place in 2002 within a portion the Temiscamie range and in 2003 within a zone comprising overlapping portions of the Assinica and Nottaway ranges. Aerial surveys in subsequent years consisted exclusively of the second type, which involved localizing individuals via GPS tracking and counting wherever possible the number of males, females, calves and yearlings in each group. Documentation and capture of both known and previously unknown individuals also took place at this time. Herd composition surveys are far more affordable than absolute density surveys and are equally reliable for estimates of calf recruitment; however they cannot be used to derive reliable estimates of population size, density, adult sex ratios or individual detection probability.

2.2. Analytical Procedures

2.2.1. Population Delineation

The local population has been identified as the appropriate ecological unit for conservation and management of woodland caribou (Gaillard *et al.* 2000; Thomas & Gray 2002). Local populations are demographically distinct from other groups of caribou as determined by immigration and emigration rates. Dispersal rates <=10% may provide evidence for local population distinction (Hasting 1993; Environment Canada 2011), though this topic has received limited study (Waples & Gaggiotti 2006).

Woodland caribou of northern Quebec are considered a metapopulation within which some degree of interchange takes place between individuals of the Assinica, Nottaway, and Temiscamie herds. We used c-means fuzzy clustering of kernel-weighted centroids in order to assess the statistical evidence for identifying more than one local caribou population or herd (Schaefer & Wilson 2002; Courtois *et al.* 2007). We determined the optimal number of local populations by maximizing Dunn's (normalized) coefficient, and individuals were assigned to herds so as to maximize individual membership coefficients. C-means fuzzy clustering provided statistical evidence for the three distinct local populations depicted in Figure 3. The number of unique individuals per herd was as follows: Assinica, 22 (48.9%); Nottaway, 10 (22.2%); Temiscamie, 13 (28.9%).

2.2.2. Range Delineation

In order to delineate the current range of a local population, Environment Canada (2011) has recommended using a minimum of three years of high-quality data (e.g. GPS telemetry). However, due to temporal variation in range occupancy and lag effects produced by changes to the landscape, they consider twenty years of data to produce an accurate representation of population distribution. Using GPS telemetry data collected between 2004 and 2011, we employed a novel quantitative approach to defining population ranges by estimating a non-parametric kernel probability surface for each individual caribou using a grid common to each herd. The plug-in method was used in order to objectively choose the appropriate bandwidth, after which each cell was averaged in order to derive a weighted population kernel. Polygons delineating local population ranges were derived from the 100% probability contours of the kernel surface. Estimated range sizes are as follows:

Assinica	$\cong$ 27, 900 km^2
Nottaway	$\cong$ 36, 400 km^2
Temiscamie	$\cong$ 47, 500 km^2

The area of overlap between the Assinica and Nottaway ranges is approximately 6, 200 km^2.

2.2.3. Critical Habitat Exercise

Forest cutover polygons extracted from the FRI, RAIF, and PAIF datasets were merged together and converted to raster based on year of disturbance. Road segments were compiled in a similar manner, and the same was conducted for natural disturbances from the FRI and Canadian National Fire Databases. Where polygons overlapped, the minimum year was retained for anthropogenic disturbances, whereas the maximum was retained for coincidence points among natural disturbances. This procedure resulted in three spatially explicit raster maps representing the year of a) natural or b) anthropogenic disturbance and, finally, c) road construction at a 100-metre spatial resolution. In accordance with Environment Canada's metapopulation model, we added a 500-metre buffer to all anthropogenic disturbances including cutovers, roads, and mines. We report estimates of cumulative disturbance calculated from within the 100% probability contours of the weighted population kernels. Disturbed proportions were estimated using binary raster surfaces, thereby avoiding the confounding effect of overlapping polygons.

2.2.4. Demographic Parameters

Recruitment rate, which represents the proportion of new recruits or calves in the population at a specified time, was calculated for each year and herd as the number of calves per 100 adult females observed. All animals classified as adult females were considered to be sexually mature. Population recruitment was calculated as $R = CC / (100 + BC + CC)$, where CC is the number of calves per 100 adult females and BC is the number of adult males per 100 females. After Hatter & Bergerud (1991), we assumed an equal sex ratio in calves.

Adult female survival was estimated for each year using Pollock *et al.*'s (1989) staggered-entry modification to the Kaplan-Meier known-fate survivorship model (Kaplan & Meier 1958). To estimate adult mortality in the absence of hunting, we assumed harvested individuals would have otherwise survived the year in question and then removed them from subsequent years.

The ratio of males to 100 females was estimated using herd-wise count data (total males/total females) taken exclusively from 2002 and 2003 aerial censuses. We observed considerably more males than females in the JBR at this time than the recorded national average (Environment Canada 2008).

Approximate estimates of population density were derived from systematic transects (aerial censuses) flown in 2002 and 2003. Density was estimated as D = N / A, where N = the total number of caribou observed and A = the area (km^2) covered by the density survey that fell within the combined 100% weighted kernel polygons of the three herds. Thus if we consider the areas surveyed during aerial census surveys of 2002 (5,415 km^2) and 2003 (29,643 km^2 estimated to lie within occupied caribou range), and we estimate detection probability at 0.85 (Courtois *et al.* 2003), using total head counts (96 and 435, respectively) we derive density estimates of 2.04 caribou/100 km^2 for the Temiscamie herd and 1.69 caribou/100 km^2 for the Nottaway and Assinica herds.

Since 2002 and 2003 surveys were conducted prior to substantive knowledge of caribou distribution in the region, it is difficult to derive reliable estimates of population sizes at this time. At minimum we may conclude that the total population of woodland caribou in the study region 10 years ago was over 600 heads. Since then the landscape has been transformed considerably, and to estimate present population sizes we would really need to conduct a new census. In the meantime efforts can be made to model uncertainty in parameter estimates in order to produce more informed estimates of population size.

The recruitment-disturbance relationship was modeled for woodland caribou populations of northern Quebec using binomial logistic regression with a random intercept for herd. Observations were weighted based on the number of females contributing to independent estimates of the annual recruitment rate.

Adult female survival was modeled over time for the population-at-large (i.e. all herds combined) using simple logistic regression. Observations were weighted based on the number of animals alive at the start of each year. Annual periods began upon completion of spring aerial surveys and ended at the start of surveys the following year.

Lambda (λ), or finite annual rate of change, was calculated annually using the recruitment-mortality equation as described by Hatter & Bergerud (1991): $\lambda = (1\text{-}M)/(1\text{-}R)$, where M is adult female mortality and R is population recruitment.

2.2.5. Delineation of Seasonal Periods

Dates demarcating transitions between biological seasons were determined using a random effects-expectation maximization (RE-EM) regression tree (Rudolph & Drapeau 2012; Sela & Simonoff 2012). Daily distances travelled were smoothed using a 4-day moving window and then log-transformed to normalize distributions. The resulting metric became the dependent variable, which we modeled as function of Julian day using recursive partitioning with a random intercept for each id-year nested combination. Resulting seasonal periods were as follows:

Table 1: Time periods used to represent biological seasons for woodland caribou in northern Quebec.

Season	Start	End
Spring	April 07	May 20
Calving	May 21	June 12
Post-calving	June 13	July 26
Summer	July 27	October 11
Fall/Rut	Oct. 12	Dec. 16
Early Winter	Dec. 17	Jan. 28
Late Winter	Jan. 29	April 06

2.2.6. Resource Selection Modeling

2.2.6.1. Sampling approach

In order to assess the relative influence of different variables on woodland caribou occurrence in Northern Quebec, we compared habitat conditions at known (or "used") locations with conditions at random (or "available") locations within a boundary representing dilated individual 100% kernel polygons (Figure 4). Bandwidth was determined using the plug-in method. Two sampling designs were used: one to model global resource selection and another to model seasonal resource selection (i.e. spring, calving, post-calving, summer, fall/rut, early winter, and late winter). Kernel polygons were thus derived A) once for each individual over its lifetime, and B) numerous times repeated for each individual-season-year combination where >= 30 observations were available. In the first case, prior to random sampling kernel polygons were dilated by the 99% maximum daily distance traveled by the individual in question. In the second case, polygons were dilated by the 99% maximum daily distance traveled during three consecutive seasons centered on the season in question.

2.2.6.2. Habitat Classification

We extracted habitat classes from the 2005 MODIS classified satellite image using the spatial locations of each used and available point. Changes in landscape conditions over time due to anthropogenic and natural disturbances were accounted for using the specific year associated with each used GPS location.

The original MODIS image contained 39 distinct habitat categories, which were subsequently combined and reduced to 20 (APPENDIX 1). Habitat categories were combined based on attribute similarity and preference by woodland caribou. We assessed preference using Manly selection ratios for both global (Figure 5) and seasonal periods. Reference categories for resource selection models varied depending on the temporal period in question and were chosen based on two criteria: relative abundance on the landscape, and selection by caribou in proportion to relative availability on the landscape during the specified period.

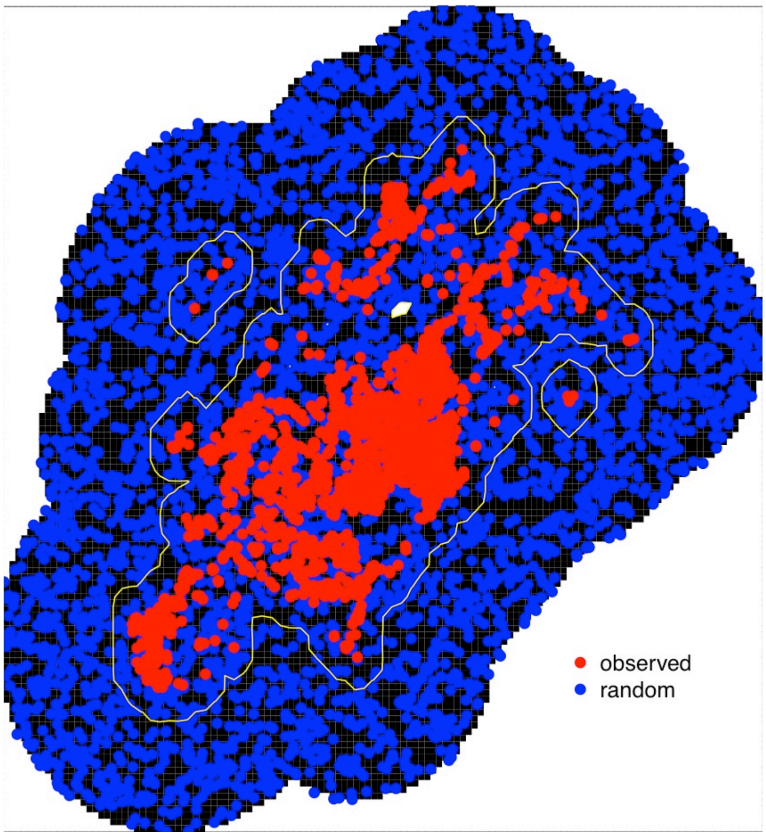

Figure 4: Example of random sampling for global habitat selection modeling. In red are observed ("used") GPS locations from one collared caribou (ID 2002007) and in blue are randomly generated ("available") points. Yellow lines encircle the 100% kernel probability contours, which were spatially dilated by 10.5 km, the 99% maximum daily distance traveled by this individual.

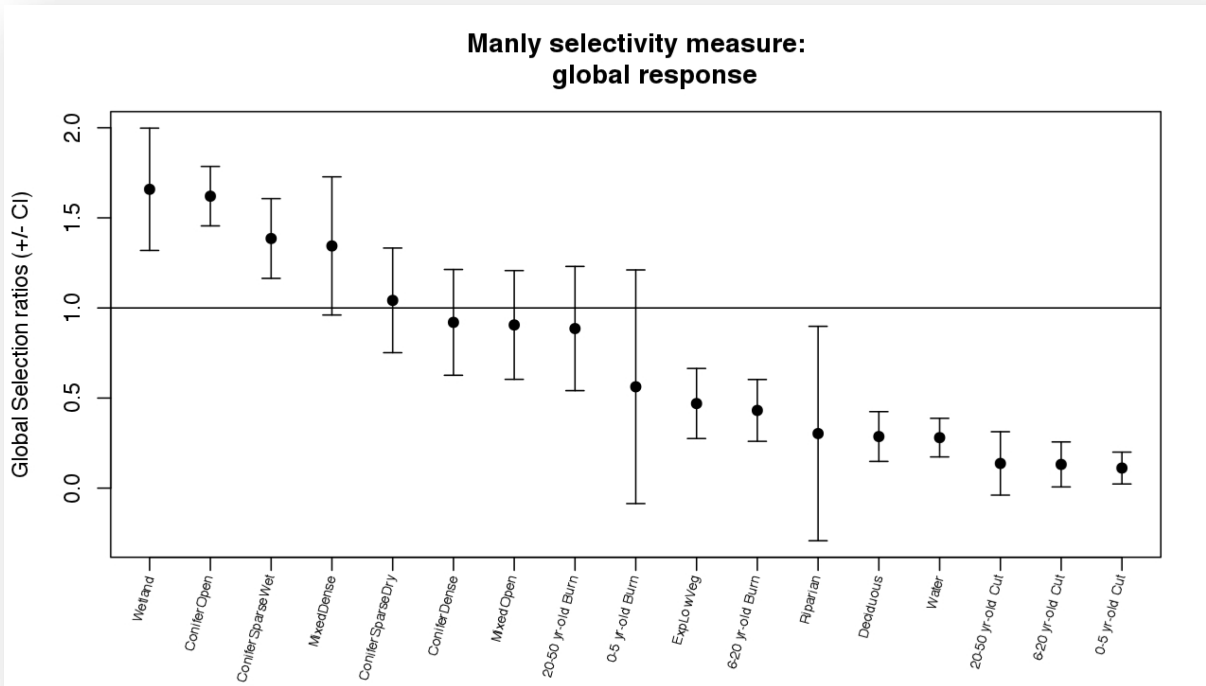

Figure 5: Manly selection ratios depicting relative global preference of different habitat types by woodland caribou based on a used-available design (**Section 2.2.6**). Where both upper and lower confidence intervals are free of 1 we infer significant selection (above) or avoidance (below) for the habitat type in question.

2.2.6.3. Resource Selection Functions (RSF)

We modeled the relative probability of woodland caribou occurrence as a function of habitat type and distance to nearest road using mixed conditional logistic regression (Duchesne *et al.* 2010). Observed and random points were paired within unique id-year strata and clusters were specified for each unique individual. Robust standard errors were used for statistical inference. Model predictions, when scaled between zero and one, represent an estimated Resource Selection Function or RSF. We did not distinguish between herds as the greatest source of variability was inter-individual.

Roads and other linear features may act as semi-permeable barriers to dispersal for woodland caribou (Dyer *et al.* 2002; Leblond *et al.* 2011; Rudolph 2011a; Whittington *et al.* 2011), which in general are known to avoid such features (Dyer *et al.* 2001) even when there is otherwise good-quality habitat nearby. This is known as functional habitat loss (Polfus *et al.* 2011). We modeled this avoidance behaviour using a negative exponential decay function that parameterizes a reduction in caribou avoidance behaviour with increasing distance from roads (Nielsen *et al.* 2002). We used Pan's (Pan 2001) QIC (quasi-likelihood under the independence model criterion) for generalized estimating equations to determine the optimal value of the decay constant alpha using the full global model (Table 2).

2.2.6.4. Model Selection & Cross-Validation

We tested a series of six competing models in order to determine the optimal combination of variables that could explain variation in the space-use behaviour of woodland caribou in northern Quebec. These candidate models are described as follows:

1. **Full (global) model**: All habitat types, disturbance types and road variable
2. **Anthropogenic disturbances**: only forest cutovers and road variable
3. **Natural disturbances**: only fires and other major natural disturbances
4. **Habitat**: road variable, natural and anthropogenic disturbance variables excluded
5. **Habitat and natural disturbances**: road variable and anthropogenic disturbances excluded
6. **Habitat and anthropogenic disturbances**: natural disturbances excluded

Table 2: Outcome of model selection procedure. The full candidate model (habitat plus natural and anthropogenic disturbances) was most parsimonious based on the QIC (quasi-likelihood under the independence model criterion).

Model	Description	QIC	ΔQIC
1	**Full**	**1663698**	**0**
6	Habitat + anthropogenic disturbances	1664197	499.11
2	Natural disturbance only	1676471	12772.77
5	Habitat + natural disturbances	1680543	16844.6
4	Habitat only	1684233	20534.9
3	Anthropogenic disturbance only	1697288	33589.88

The most parsimonious model based on QIC (Model 1) was subsequently cross-validated to determine predictive accuracy (Boyce *et al.* 2002). We employed two forms of k-fold cross-validation in order to test the ability of the model to predict caribou occurrence in both A) space and B) time. The spatial cross-validation consisted of removing one individual at a time (n=45), estimating the best model, and then seeing how well it predicted the spatial distribution of the individual that was removed. The temporal cross-validation was virtually identical except in this case we removed one year of data at a time (n=8) and tried to predict caribou occurrence during the missing year using the model estimated with all the other years combined. RSF values were binned and contrasted using a simple linear regression model (Howlin *et al.* 2004); the best predictive model was identified when the slope of the relationship between expected and observed selection was not significantly different from 1 and the regression line ran through the origin (i.e. Bo=0). When the slope was significantly greater than 1, there was significant positive correlation between predictions and actual use and the predictive abilities of the model were deemed acceptable.

Observed and expected counts were also contrasted using Spearman's rank correlation coefficient, in which case values above 0.6 generally indicate a decent level of predictive accuracy. Results were as follows:

Table 3: Results of spatial and temporal cross-validations of the most parsimonious candidate model (i.e. Model 1: habitat plus natural and anthropogenic disturbances). Values indicate that variation in the resource selection behaviour of individual caribou is substantially greater than variation in selection behaviour in different years.

Validation Model	**n**	**Lower 95**	**Beta**	**Upper 95**	**Spearman Correlation**
Temporal	8	0.967	1.116	1.264	0.944
Spatial	45	0.789	0.982	1.175	0.654

3. MANDATE

3.1. What is the status of the woodland caribou population in the territory?

3.1.1. Determine the recruitment, mortality rate and the tendency of the populations

Recruitment: Table 4 provides a summary of herd composition data obtained during aerial surveys conducted between 2002 and 2012. Weighted binomial logistic regression models indicate that recruitment rates (i.e. the number of calves per 100 adult females) are declining resoundingly within the Assinica ($p < 0.001$; Pearson $R2=0.95$) and Temiscamie ($p < 0.001$; Pearson $R2=0.91$) herds, and we observe a marginally significant decline within the Nottaway herd ($p < 0.08$; Pearson $R2=0.67$). The ratio of adult males to adult females, calculated for each herd from 2002 and 2003 absolute density surveys, was combined with recruitment rates to estimate population recruitment (R) for each survey year (see Methods pg. 9).

Survival of adult females appears to be declining for the study region overall (i.e. all herds combined; $p = 0.037$, Pearson $R2 = 0.71$) (Table 5). When mortality related to subsistence hunting is factored out, however, this relationship becomes marginally significant ($p = 0.076$; Pearson $R2 = 0.62$) (Figure 6).

In order for a population to be self-sustaining, adult mortality needs to be compensated by recruitment (e.g. if adult survival is 0.85, recruitment must be 0.15 or greater). In contrast with other ungulate species, female caribou generally do not bear young until the age of three, and once mature produce only one offspring per year (Bergerud 2000); adult female mortality therefore can have a significant negative impact on population growth rates, particularly in a context where recruitment is also declining. Causes of adult mortality are depicted in Error! Reference source not found..

Tendency: Figures 8-10 portray the estimated finite rate of population change (λ) for the three herds over the period of study using four different estimates of adult survival. In all but one scenario (i.e. absence of hunting mortality) the populations exhibit negative growth rates since approximately 2008.

Table 4: Demographic data compiled from two types of spring aerial surveys (aerial censuses (2002/2003) and herd composition surveys) conducted by members of the QMRNF, Chibougamau between 2002 and 2012. Recruitment (R) was estimated according to Hatter & Bergerud (1991) and herdwise adult sex ratios (Ratio Males:Females) were calculated from 2003/2003 aerial censuses.

Herd	Year	Effort (days)	# Males	# Females	# Calves	# Undetermined	Total	Calves/100 Females	Ratio Males: Females	R
Assinica	2003	4	107	89	47	55	298	52.81	1.2022	0.193
	2007	5	33	48	15	0	96	31.25		0.124
	2009	4	25	47	13	0	85	27.66		0.112
	2010	2	29	97	17	8	151	17.53		0.074
	2011	3	16	100	19	3	138	19		0.079
	2012	4	12	46	11	1	70	23.91		0.098
Nottaway	2003	1	47	46	18	26	137	39.13	1.0217	0.162
	2007	2	12	30	8	0	50	26.67		0.117
	2009	1	8	16	2	0	26	12.5		0.058
	2011	2	8	7	2	0	17	28.57		0.124
Temiscamie	2002	1	39	37	19	1	96	51.35	1.054	0.2
	2007	2	20	37	12	0	69	32.43		0.136
	2009	2	10	20	5	0	35	25		0.109
	2010	1	5	12	3	3	23	25		0.109
	2011	3	37	54	11	0	102	20.37		0.09
	2012	1	12	17	0	0	29	0		0

Table 5: Summary of collared caribou history in northern Quebec. "At risk" refers to the number of female caribou being tracked by GPS telemetry at the start of each new year (post-spring survey). Some of those that die each year (# Dead) have been harvested (# Harvested). Observed ($S_{Observed}$) and predicted ($S_{Predicted}$) adult survival rates are shown given two scenarios: 1) natural mortality only, and 2) natural plus hunting mortality. In both cases the model predicts declining adult survival over time; however in the true observed case (i.e. population subject to both natural and hunting mortality) the statistical relationship is strongest (p=0.037). This is equivalent to concluding that adult survival is declining given a 3.7% chance that in fact it is not (i.e. Type I error).

				Natural Mortality Only			**Natural + Hunting Mortality**		
Year	**# At Risk**	**# Dead**	**# Harvested**	**S (1-M)** Observed	**S (1-M)** Predicted	**S.E.**	**S (1-M)** Observed	**S (1-M)** Predicted	**S.E.**
2002	2	0	0	1.000	0.960	0.024	1.000	0.947	0.026
2003	14	0	0	1.000	0.953	0.024	1.000	0.938	0.026
2004	22	1	0	0.955	0.944	0.023	0.955	0.926	0.025
2005	25	4	1	0.880	0.935	0.022	0.840	0.913	0.024
2006	21	1	0	0.952	0.923	0.021	0.952	0.897	0.023
2007	28	4	2	0.929	0.910	0.020	0.857	0.880	0.022
2008	24	4	2	0.917	0.895	0.021	0.833	0.859	0.023
2009	28	7	0	0.750	0.877	0.026	0.750	0.836	0.028
2010	21	2	0	0.905	0.857	0.036	0.905	0.810	0.038
2011	26	5	2	0.885	0.835	0.050	0.808	0.780	0.052

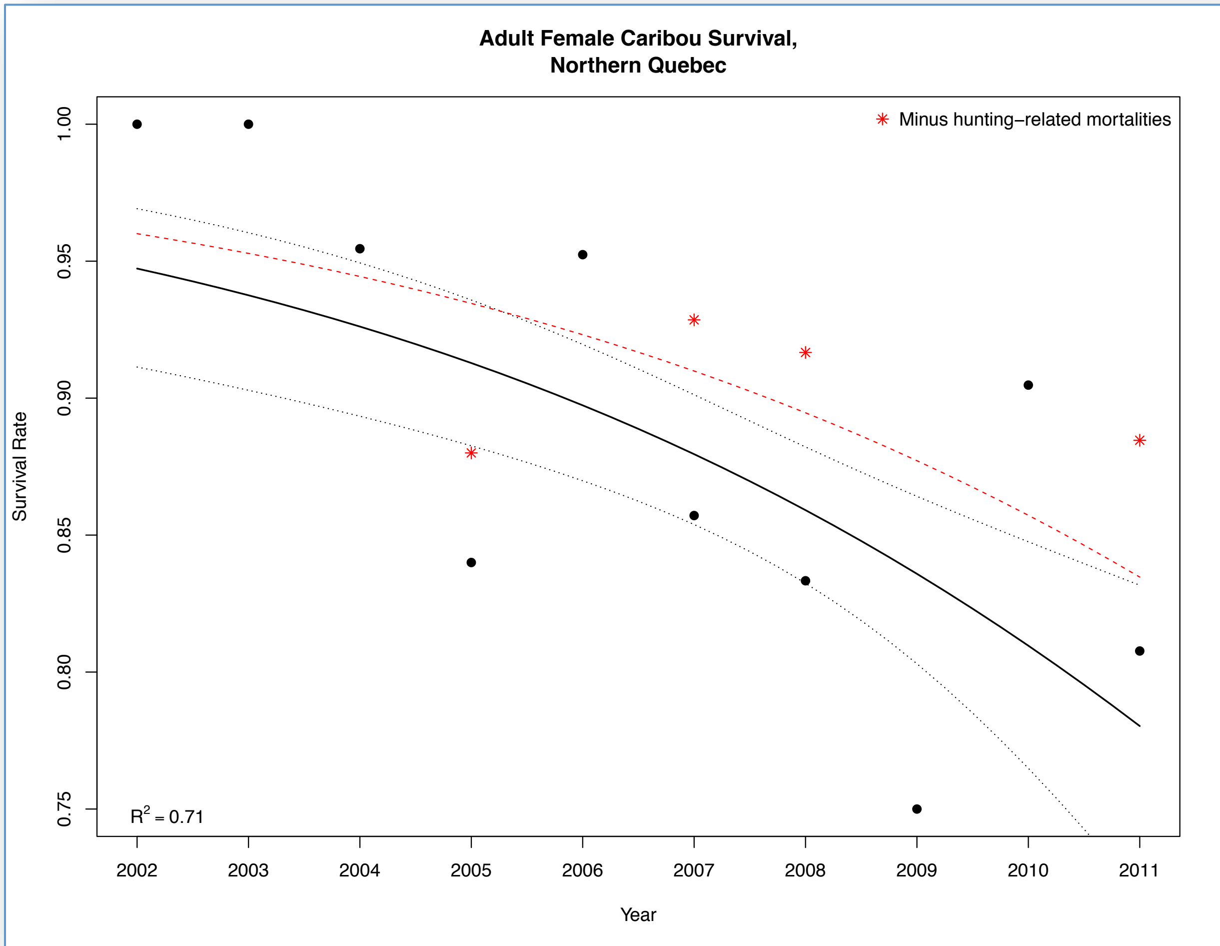

Figure 6: Estimated annual survival of adult female woodland caribou in northern Quebec from 2002 to 2011. The predicted curve and 95% confidence intervals were derived from the observed relationship as modeled with weighted binomial logistic regression.

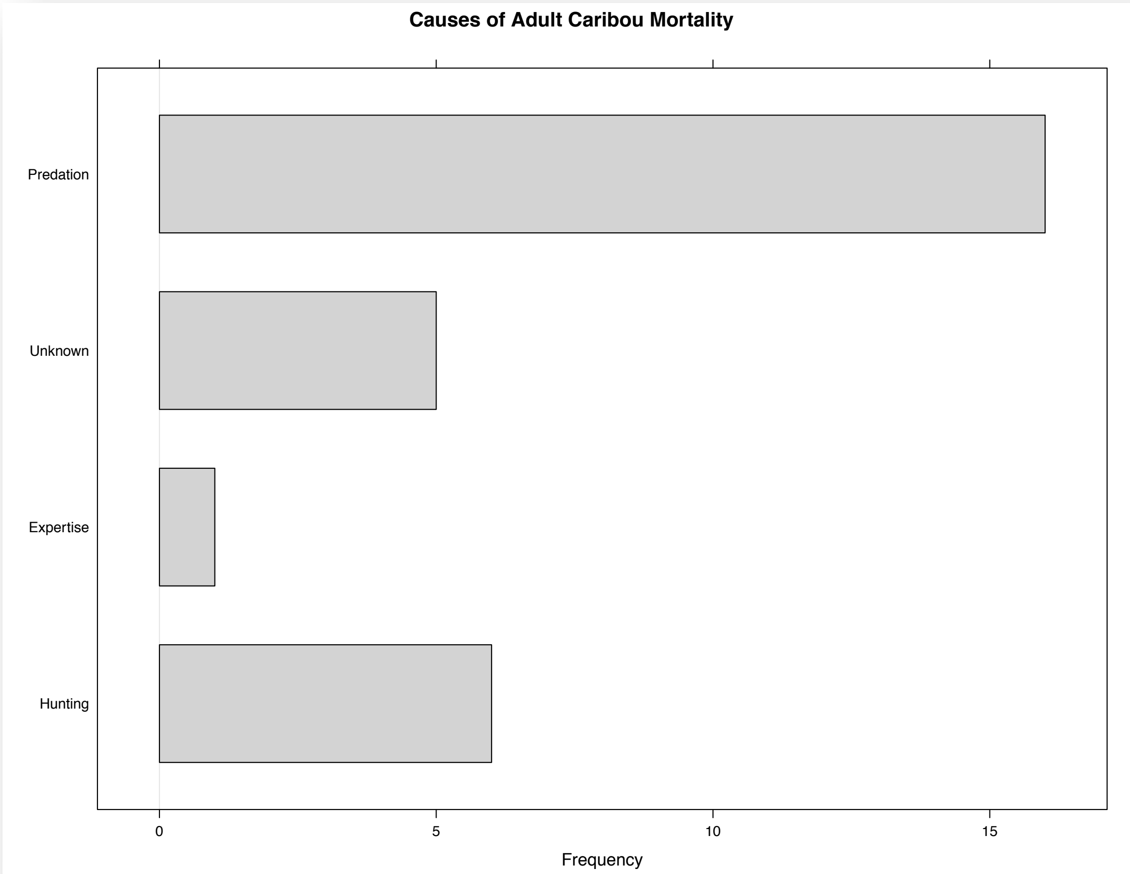

Figure 7: Causes of adult female woodland caribou mortality in northern Quebec between 2002 and 2012 based on the known fate of collared animals tracked using GPS telemetry (n=50).

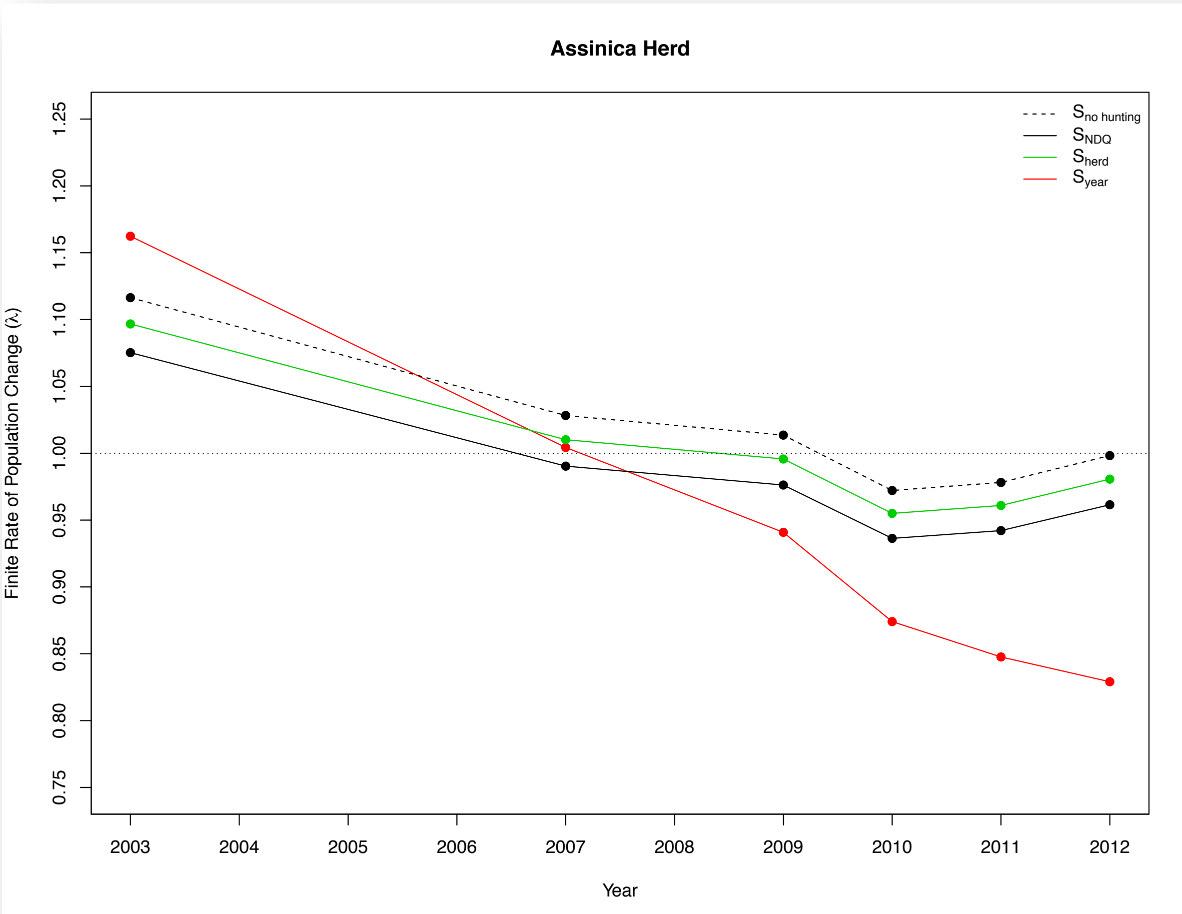

Figure 8: Observed population trajectories for the **Assinica** herd using herd-specific sex ratios and 4 different estimates of survival (**λ** = S/(1-R)). The first estimate (black dashed line) is the mean adult survival for the entire study region with hunting mortality factored out. The second estimate (in black) is identical but with hunting mortality included, and the third (in green) is mean adult survival observed for the Assinica herd alone. The first three estimates are constants, in which case lambda is mostly influenced by declines in recruitment rates. The fourth estimate (in red) varies over time as a model function of observed declines in adult mortality across the study region at large.

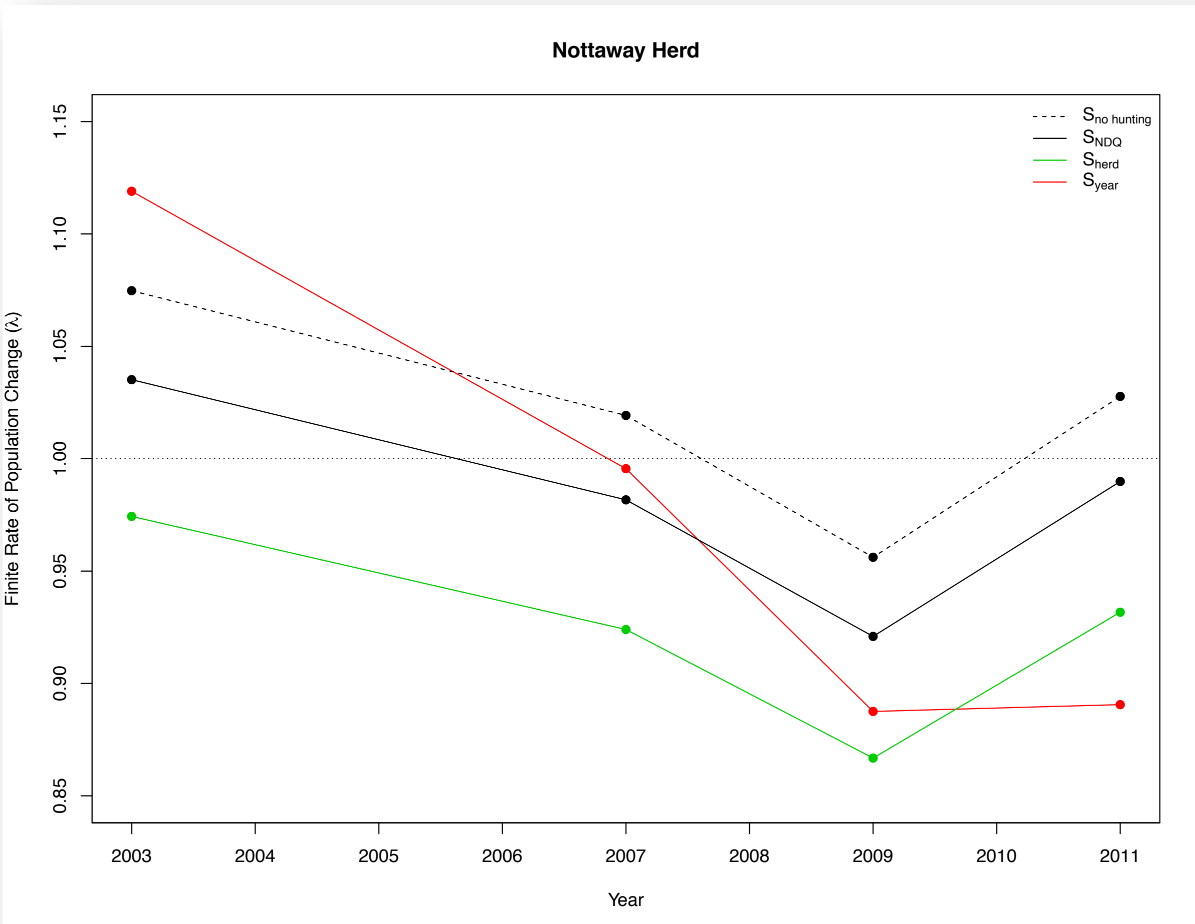

Figure 9: Observed population trajectories for the **Nottaway** herd using 4 different estimates of survival ($\lambda = S/(1-R)$). The first estimate (black dashed line) is the mean adult survival for the entire study region with hunting mortality factored out. The second estimate (in black) is identical but with hunting mortality included, and the third (in green) is mean adult survival observed for the Nottaway herd alone. The first three estimates are constants, in which case lambda is mostly influenced by declines in recruitment rates (note estimated adult survival was lowest within the Nottaway herd). The fourth estimate (in red) varies over time as a function of observed declines in adult mortality across the study region at large.

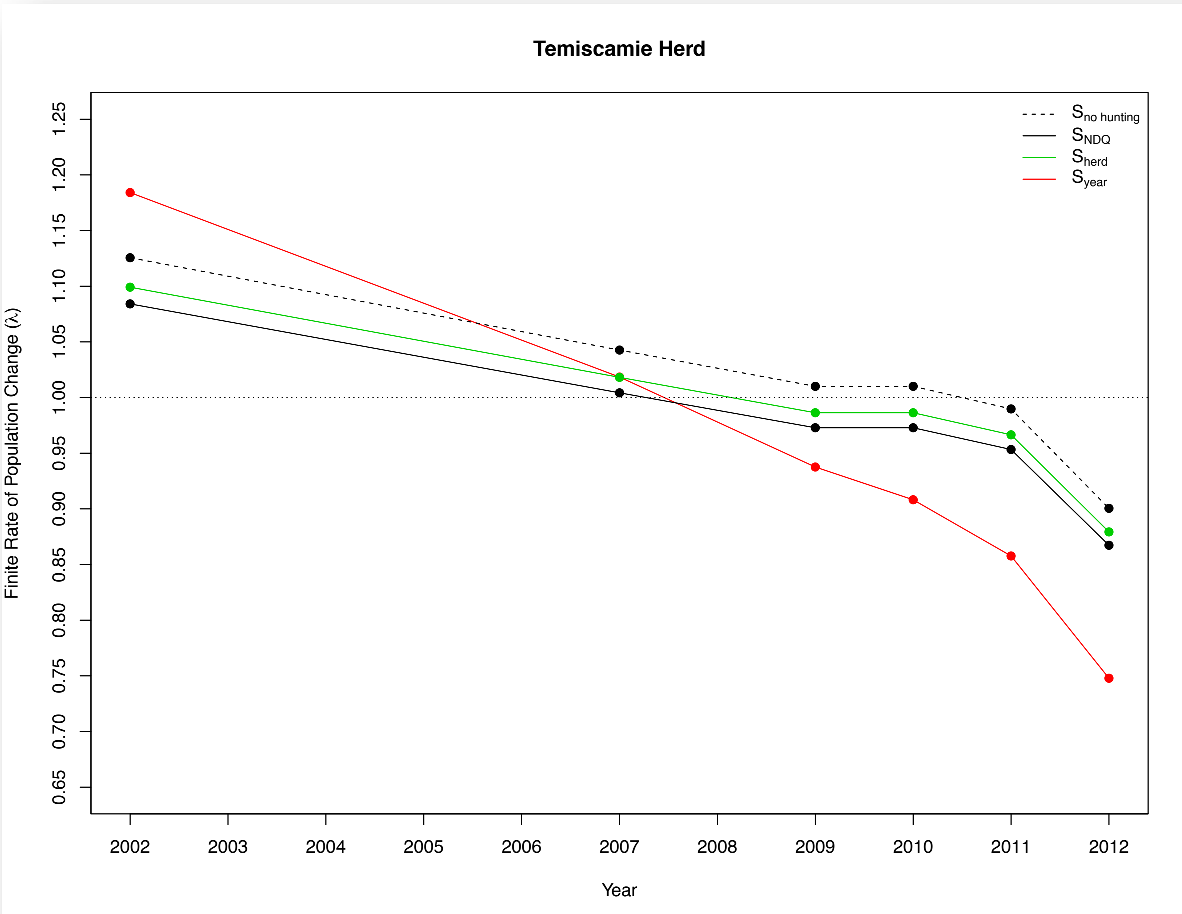

Figure 10: Observed population trajectories for the **Temiscamie** herd using 4 different estimates of survival (**λ** = S/(1-R)). The first estimate (black dashed line) is the mean adult survival for the entire study region with hunting mortality factored out. The second estimate (in black) is identical but with hunting mortality included, and the third (in green) is mean adult survival observed for the Temiscamie herd alone. The first three estimates are constants, in which case lambda is mostly influenced by declines in recruitment rates. The fourth estimate (in red) varies over time as a model function of observed declines in adult mortality across the study region at large.

3.1.2. Determine the current status of the population by herd

Based on significant declines in both recruitment and adult survival over the study period, at this stage we can conclude that all three populations are presently declining (i.e. **not self-sustaining** or **NSS**), the Assinica and Temiscamie herds definitively so, and the Nottaway more likely than not. If we ignore all evidence to the contrary and consider only weighted mean values (i.e. mean within-herd recruitment rates, mean adult sex ratio, and mean overall adult survival), even in the best-case scenario not one of the three herds could be considered self-sustaining (λ = 0.979, 0.986 and 0.978 for the Assinica, Nottaway and Temiscamie herds respectively). Lastly, if we were to consider a hypothetical scenario with no hunting mortality and no recruitment-disturbance relationship, all populations would be approximately stable at present despite progressive declines in recruitment rates.

3.2. What is the status of woodland caribou habitat?

3.2.1. Determine quality and critical habitat for woodland caribou during all phases of its annual cycle.

The concept of critical habitat as defined by Environment Canada (2011b) is based on the relationship between recruitment rate and range disturbance at the scale of the local population. To be more explicit, "*if predator-prey dynamics are not conducive to caribou persistence at large spatial scales, more proximal factors will not be important*" (Environment Canada 2011). In terms of conservation planning, the availability and quality of habitat at finer scales (e.g. seasonal range) is therefore extraneous when compared to range conditions at broader scales (i.e. the landscape level). Above all things we must not lose sight of the fact that the ultimate factor driving caribou declines is the amount of disturbed habitat within the greater population range (landscape context)(Wittmer *et al.* 2007; St-Laurent & Dussault 2012).

In terms of the relative probability that a given area will be used by woodland caribou, Table 7 highlights the response of woodland caribou in northern Quebec (i.e. in terms of preference and avoidance) to different habitat types at different periods of its life cycle as determined via Resource Selection Function (RSF) modeling. Descriptions of habitat categories are found in APPENDIX 1. In general, caribou avoided disturbed, open, and broadleaf-dominated habitats and selected conifer-dominated and wetland habitats. Model coefficients are provided in Table 6.

Table 6: Output of a Cox proportional hazards logistic regression model displaying the influence of different habitat variables on the relative probability of caribou occurrence in northern Quebec. The RSF (or Resource Selection Function) column presents each variable on a linear scale in order of preference by woodland caribou.

Variable	β	Robust SE	RSF	Pr(>|z|)
Wetland	0.175	0.076	1.000	0.021
ConiferOpen	0.118	0.075	0.945	0.115
ConiferSparseWet	0.089	0.067	0.918	0.182
MixedDense	0.073	0.089	0.904	0.412
MixedOpen	-0.046	0.058	0.802	0.427
ConiferDense	-0.275	0.111	0.638	0.013
Burn2050	-0.306	0.118	0.619	0.009
Burn05	-0.436	0.299	0.543	0.145
Cut0620	-0.442	0.279	0.540	0.113
ExpLowVeg	-0.493	0.092	0.513	0.000
Cut2050	-0.656	0.395	0.436	0.096
Cut05	-0.696	0.190	0.419	0.000
Deciduous	-0.720	0.173	0.409	0.000
Burn0620	-0.814	0.135	0.372	0.000
Riparian	-1.252	0.578	0.240	0.030
Water	-1.266	0.135	0.237	0.000
I(exp(-0.0015 * rdist))	-2.248	0.262	0.089	0.000

Table 7: Behavioural response of woodland caribou in northern Quebec to the relative availability of different habitat types at different periods in their life cycle. Negative (-) implies a significant avoidance of a given habitat during the period or season indicated. Positive (+) indicates a significant preference (i.e. selection) for that variable. Plus or minus (+/-) indicates a non-significant effect, whether positive or negative. Categories shaded in black indicate reference levels chosen for RSF models for the period in question. The last variable (exp(-0.0015*rdist)) refers to the exponential avoidance of roads with increasing proximity.

Study Period / Habitat Type	Annual	Calving	Early Winter	Fall/Rut	Late Winter	Post-Calving	Spring	Summer
Burn05	+/-	+/-	+/-	-	+/-	+/-	+/-	+/-
Burn0620	-	-	-	-	-	-	-	-
Burn2050	-	-		+/-	-	-	+/-	+/-
ConiferDense	-	+/-	-	-	+	+/-	+/-	
ConiferOpen	+/-	+	+/-	+/-	+	+/-	+/-	+
ConiferSparseDry		+/-	+/-		+	+/-	+	+/-
ConiferSparseWet	+/-		+/-	+/-		+	+	+
Cut05	-	-	-	-	-	-	+/-	-
Cut0620	+/-	+/-	+/-	+/-	+/-	-	+/-	-
Cut2050	+/-	+/-	+/-	-	+/-	-	+/-	-
Deciduous	-	-	+/-	-	+/-	+/-	+/-	+/-
ExpLowVeg	-	-	+/-	-	+/-	+/-	+/-	+/-
MixedDense	+/-	+/-	+/-	+/-	+/-			+
MixedOpen	+/-	+/-	+/-	+/-	+/-	+/-	+	+/-
Riparian	-	-	-	-	+/-	+/-	-	+/-
Water	-	-	-	-	-	-	-	-
Wetland	+	+/-	+/-	+/-	+	+	+	+
exp(-0.0015*rdist)	-	-	-	-	-	-	-	-

3.2.2. Evaluate the condition of the habitat and the level of disturbance by herd

Critical habitat is inversely proportional to range disturbance, measured as the cumulative proportion of natural (<= 40 years) and anthropogenic disturbances (<= 50 years, buffered by 500m) located within a population's range. We calculated range disturbance within the 100% weighted kernel contours of the Assinica, Nottaway and Temiscamie populations for each year between 2002 and 2013 (projected; Figure 11). Under theoretical conditions, the national meta-population model predicts negative growth rates for the Assinica and Temiscamie herds and positive to stable growth rates for the Nottaway herd. However the metapopulation model is based on mean recruitment rates and is fitted to data of inconsistent quality from a wide array of sources.

We used our own empirical data to model recruitment rates as a function of cumulative range disturbance observed over the study period (Sorensen *et al.* 2008). Mixed logistic regression indicated that range disturbance is a strong predictor of recruitment rates in northern Quebec ($p < 0.001$) with important differences in origin for each population (Figure 12). Results indicate that tolerance to disturbance may vary from one population to another, with threshold levels considerably lower for the Nottaway herd (31.4%) than for the Temiscamie (40.4%) and Assinica herds (46.9%).

Unfortunately, the critical value of 28.9 calves/100 females assumes an adult survival equivalent to the national average ($S = 0.852$) and a ratio of 63.9 males to 100 females. In northern Quebec we have observed a regional average of 121.8 males to 100 females and a mean adult survival of 0.867. In actual fact, for a population to remain stable under these conditions would require recruitment rates above 34 calves/100 females. In this case (using herd-specific sex ratios), critical disturbance thresholds are estimated to be considerably lower at 30.6% for the Nottaway, 39.4% for the Temiscamie, and 45.1% for the Assinica.

Lastly, in a theoretical situation where the effect of hunting mortality was removed, adult survival would be estimated at 0.9 and the population would only require 24.6 calves/100 females in order to be self-sustaining.

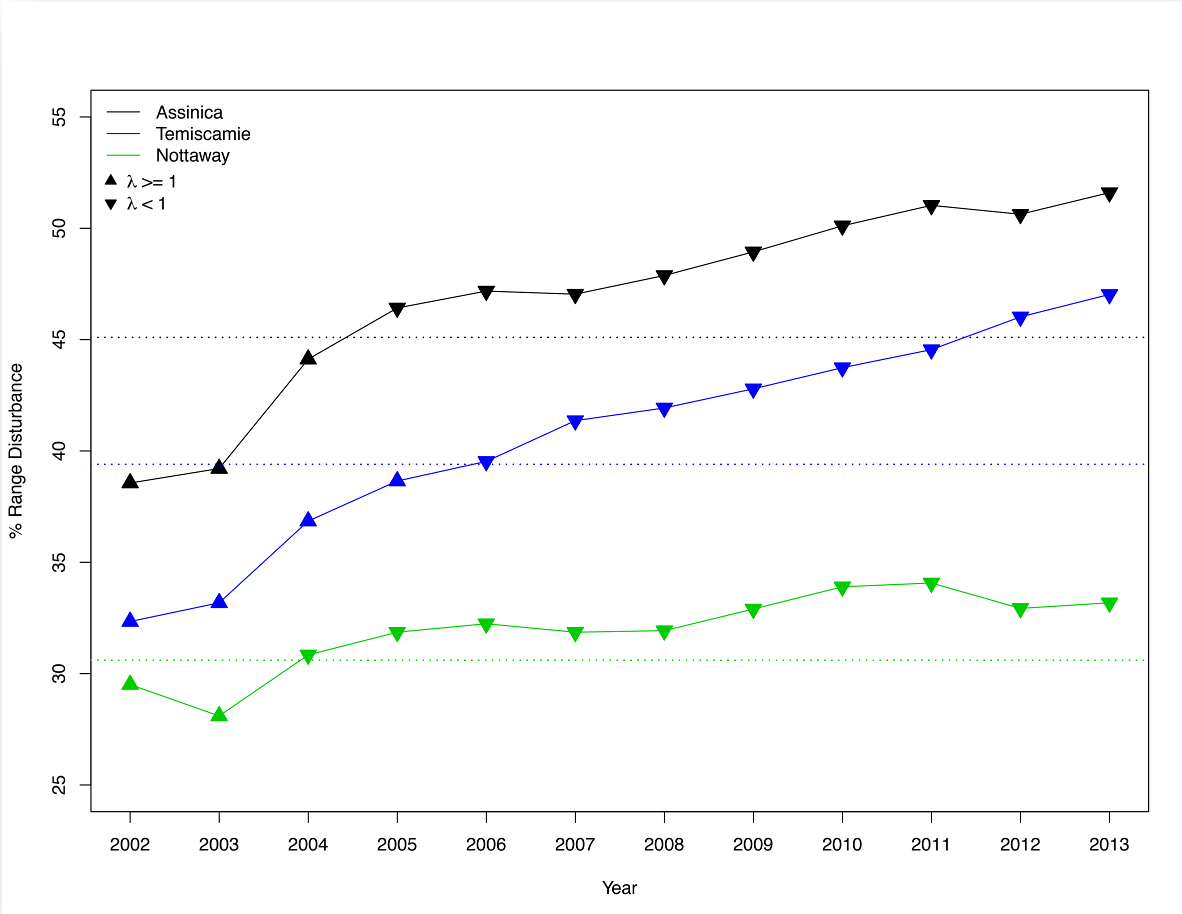

Figure 11: Cumulative disturbances measured within the 100% weighted kernel home range polygons of the Assinica, Nottaway and Temiscamie herds between 2002 and 2013 (projected). Considered were natural disturbances (e.g. fire, insect outbreak, windthrow) <= 40 years old and anthropogenic disturbances (e.g. forest harvesting, roads, mines) <= 50 years old with 500-metre buffer added (Environment Canada 2011). Dotted lines indicate herd-specific disturbance levels beyond which population growth rate is predicted to be negative based on empirical modeling of the recruitment-disturbance relationship. Lambda estimates were derived using the regional weighted mean for adult survival (S_{NDQ}=0.867) and herd-specific sex ratios.

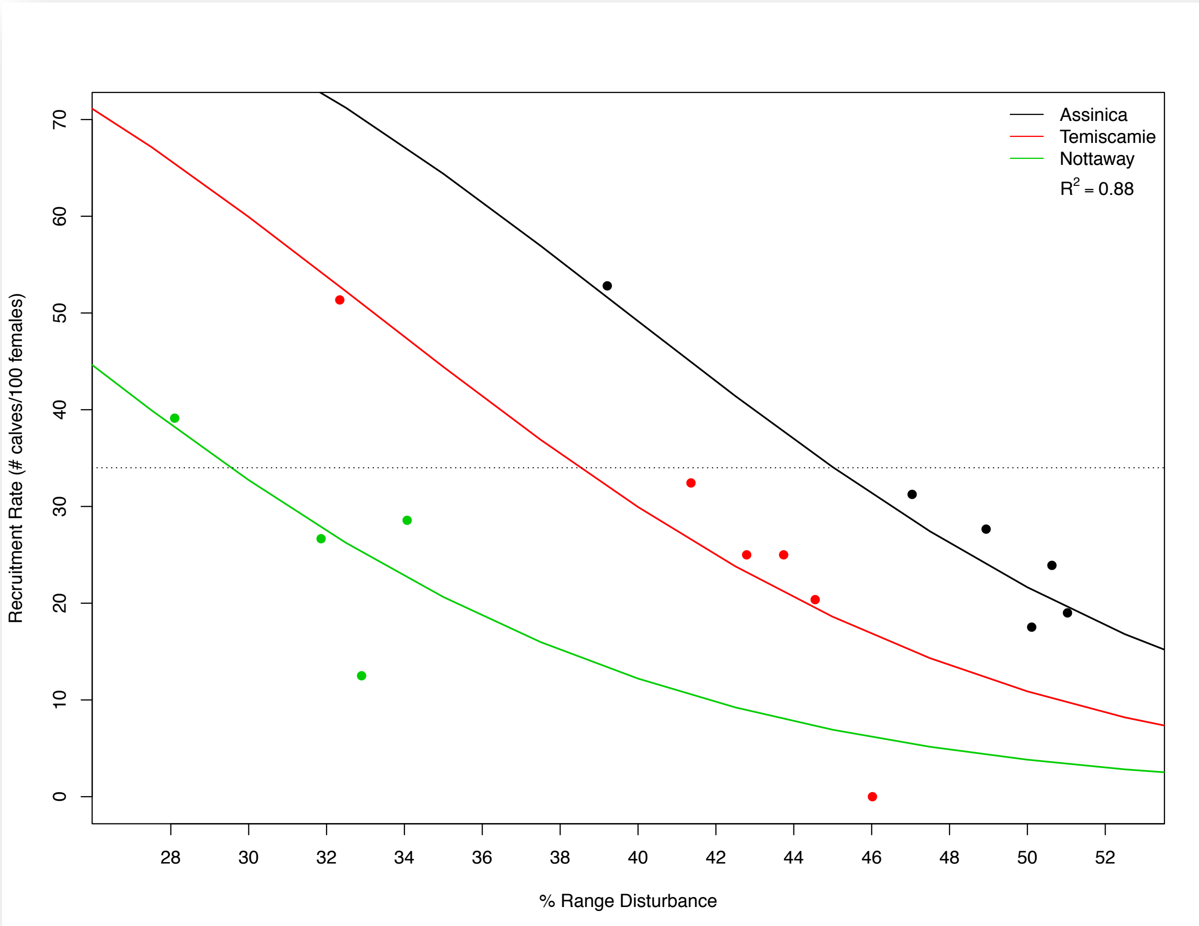

Figure 12: Relationship between calf recruitment and cumulative range disturbance for three woodland caribou populations in northern Quebec. Predicted curves were obtained using logistic regression with a random intercept for each herd. Results indicate that populations have different levels of tolerance to disturbance. Given a mean sex ratio of 1.21 males to females (from 2002 & 2003 absolute density surveys) and the mean annual adult survival (S_{NDQw}=0.867) observed for caribou in northern Quebec, these populations would actually need to recruit 34 calves/100 females in order to remain stable (as indicated by the dotted line).

3.2.3. Determine the probability of persistence for each herd and the overall population with current habitat condition

The probability of persistence has been defined by Environment Canada (2011) as the probability that a population would remain above the quasi-extinction threshold (n=10 adult females) over a 50-year time horizon given current range and demographic conditions. Unfortunately in order to properly estimate the probability of persistence, whether potential or projected, we would require improved recent estimates of population size and age-class structure, a somewhat better understanding of immigration and emigration rates (metapopulation dynamics), and substantially more time to conduct population viability analyses. However the data we have acquired and analyzed thus far will go far to seeing that this is possible. In the meantime, we may wish to consider a crude example.

Let us suppose for argument's sake that there are 200 caribou in the Temiscamie herd. In our first example (Table 8) we ignore the recruitment-disturbance relationship and settle on the mean observed recruitment rate for this population (28.25 calves/100 females). We also presume that adult survival is stable at 0.867 (S_{NDQw}), which is superior to the national average. Given an adult sex ratio of 1.05 males per female, this produces a negative growth rate of 0.978, which, if held constant, would lead to quasi-extinction in 140 years. In example two we use the 2012 predicted recruitment rate of 16.7 calves/100 females (based on projected habitat conditions) but we leave the other two parameters as before. This produces a lambda estimate of 0.933, in which case the population would be reduced to 10 individuals within 45 years. Finally we consider a third example where recruitment rate holds steady at 16.7, but in which adult mortality drops to 0.748 by 2012 in line with a model predicting declines in adult survival over time. In this case assuming lambda was held constant at 0.805, the population of 200 individuals would reach quasi-extinction within 15 years.

Table 8: Time to quasi-extinction (N <= 10) given an initial population of 200 and a constant growth rate (**λ**). Survival and sex ratio parameters are derived from the Temiscamie herd given three scenarios; 1) average observed conditions (no decline), 2) predicted recruitment rate given 2012 disturbance conditions (decline in recruitment), and 3) predicted recruitment and adult survival estimates for 2012 (decline in both recruitment and adult survival).

Scenario	Recruitment Rate (Calves/100 Females)	Adult Survival S	Sex Ratio (Males:Females)	Lambda λ	Time to Quasi-extinction (Years)
1: Optimistic	28.25	0.867	1.054	0.978	140
2: Moderate	16.7	0.867	1.054	0.933	45
3: Pessimistic	16.7	0.748	1.054	0.805	15

Following absolute density surveys 10 years ago, the total population of woodland caribou in northern Quebec was roughly estimated to be 700. Since that time recruitment rates have declined steadily, and possibly adult survival as well. Given anecdotal information supported by records provided by the Cree Trappers' Association (St-Pierre *et al.* 2006), the number of adults harvested annually for subsistence purposes between 1988 and today is likely higher than what the population has been able to sustain. This may be particularly true when we consider that animals are seldom harvested in isolation but in multiples, in which case our own estimates of adult mortality (based on the history of collared individuals alone) may be underestimated.

Environment Canada (2008) conducted a non-spatial population viability analysis using demographic parameters gleaned from various caribou populations across Canada. Among their findings was that "*populations of boreal caribou with poor demographic conditions (e.g. low calf survival and moderate adult female survival) face a high risk of quasi-extinction regardless of population size*" (Environment Canada 2008). Considering that we have observed similar conditions in northern Quebec, this imparts a certain urgency to act with respect to the restoration and conservation of the James Bay populations, which are unlikely to rebound without decisive action.

3.3. Can each herd and the overall population support further disturbance and to what extent?

The short and conclusive answer to this is negative, the reasoning for which is sound. To begin with, disturbance levels within the estimated range boundaries of all three populations already meet or exceed the limits recommended by federal experts in the recovery strategy for boreal caribou (Environment Canada 2011). Their minimum recommendation of 65% undisturbed habitat (disturbance management threshold) is meant to afford a measurable probability (~60%) that the population will be self-sustaining (Environment Canada 2011). However, they also address the pertinence of establishing range-specific thresholds, which they recognize may vary around theoretical intervals (Environment Canada 2012). Accordingly, given demographic conditions observed in the study region, we now know that an even somewhat higher amount of undisturbed habitat would be theoretically necessary in order to obtain the same likelihood of success, at the least in the case of the Nottaway and Temiscamie herds. While we are not equipped to speak in terms of probability until we have conducted demographic simulations, we can state that based on the results of empirical modeling of the recruitment-disturbance relationship in northern Quebec, all three populations are currently subject to disturbance levels in excess of those deemed necessary to ensure even net stability (Table 9).

Table 9: Differences between critical values theoretically required to ensure stable population conditions ($\lambda >= 1$) and those observed with respect to recruitment rates and range disturbance for three woodland caribou populations in northern Quebec. Critical recruitment rates were estimated based on mean regional adult survival (S=0.867) and herd-specific adult sex ratios (# males/100 females).

	RECRUITMENT RATE (# calves/100 females)		**RANGE DISTURBANCE (%)**	
HERD	Critical Threshold	Observed ($\overline{X}_w$)	Critical Threshold	Observed (actual)
Assinica	33.7	28.6	45.1	51.0
Nottaway	31.0	30.3	30.6	34.1
Temiscamie	31.5	28.2	39.4	46.0

3.4. What is the impact of current and proposed road network and their related activities on the herds and their habitat?

3.4.1. Evaluate the cumulative impacts of roads and related activities on critical habitat

The importance of road networks in determining the space use and demographic dynamics of woodland caribou cannot be understated (St-Laurent *et al.* 2012). Not only do roads contribute enormously to landscape fragmentation and habitat loss by accommodating industrial resource development, they also facilitate improved access to previously unexploited habitats for both animal and human predators (James & Stuart-Smith 2000). Expansion of road networks may therefore profoundly compromise the viability of woodland caribou populations, as the recruitment-disturbance relationship demonstrates.

Roads may act as semi-permeable barriers to caribou dispersal (Dyer *et al.* 2002). For example, a recent study in northern Quebec demonstrates that female caribou in proximity to highly roaded areas may be constrained in their search for predator-free space during the critical calving period (Rudolph 2011a). For many reasons, individual caribou typically avoid roads, in large part to reduce the risk of encountering predators (James & Stuart-Smith 2000), and this avoidance behaviour can result in the functional loss of otherwise good quality habitat, displacing animals into and less familiar and/or less favorable areas (Nellemann & Cameron 1998; Faille *et al.* 2010) and ultimately compromising individual fitness. As a case in point, we modeled the space-use behaviour of woodland caribou in northern Quebec and determined that the single most important factor influencing the relative probability of caribou occurrence was the proximity of the road network. To be specific, caribou strongly avoided all areas next to roads, an effect which dissipated exponentially with increasing distance, yet which was still discernible at a distance of 2 kilometers (Figure 13). This is a classic example of functional habitat loss, and when combined with the cumulative influence of widespread changes in forest cover, serves to explain in large part the northward recession of woodland caribou populations since the early part of the 20th century (Figure 14).

The functional loss of habitat due to avoidance behavior may be as important as habitat alteration itself (Weclaw & Hudson 2004). We used a 500-metre buffer to quantify the impact of roads and other disturbances on caribou populations because this distance was determined to be strongly correlated with recruitment rates throughout Canada (Environment Canada 2011). In terms of other negative influences, however, 500 metres is likely quite conservative in terms of a distance threshold, as our model demonstrates. This is supported by Leblond *et al*. (2011), who found that caribou avoided tertiary forest roads by up to 750 m, primary roads by up to 1.25 km, and highways by up to 5 km. Woodland caribou in northern Quebec have been shown to exhibit an aversion to road networks measured at distances of up to 10 km (Rudolph 2011a).

Evidently, whereas concentrating forest harvesting activities within areas that are already disturbed is likely to result in minimal net functional habitat loss, new road incursions into previously undisturbed territories will only exacerbate the deterioration of critical habitat.

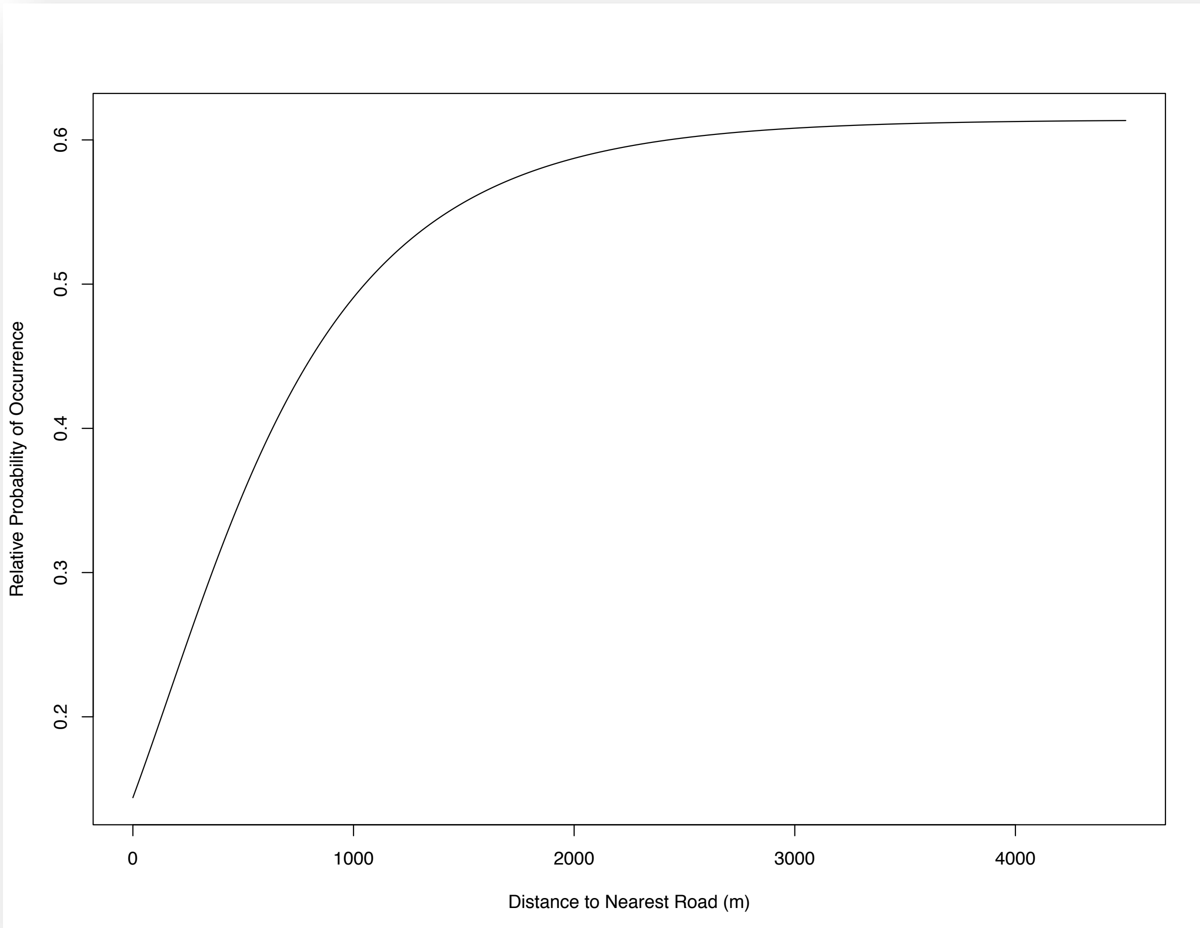

Figure 13: Predicted response of woodland caribou to roads in northern Quebec. The relative probability of caribou occurrence, as derived from RSF modeling, increases exponentially with increasing distance from roads. However mild, this avoidance effect is still discernible at distances beyond 2 kilometers.

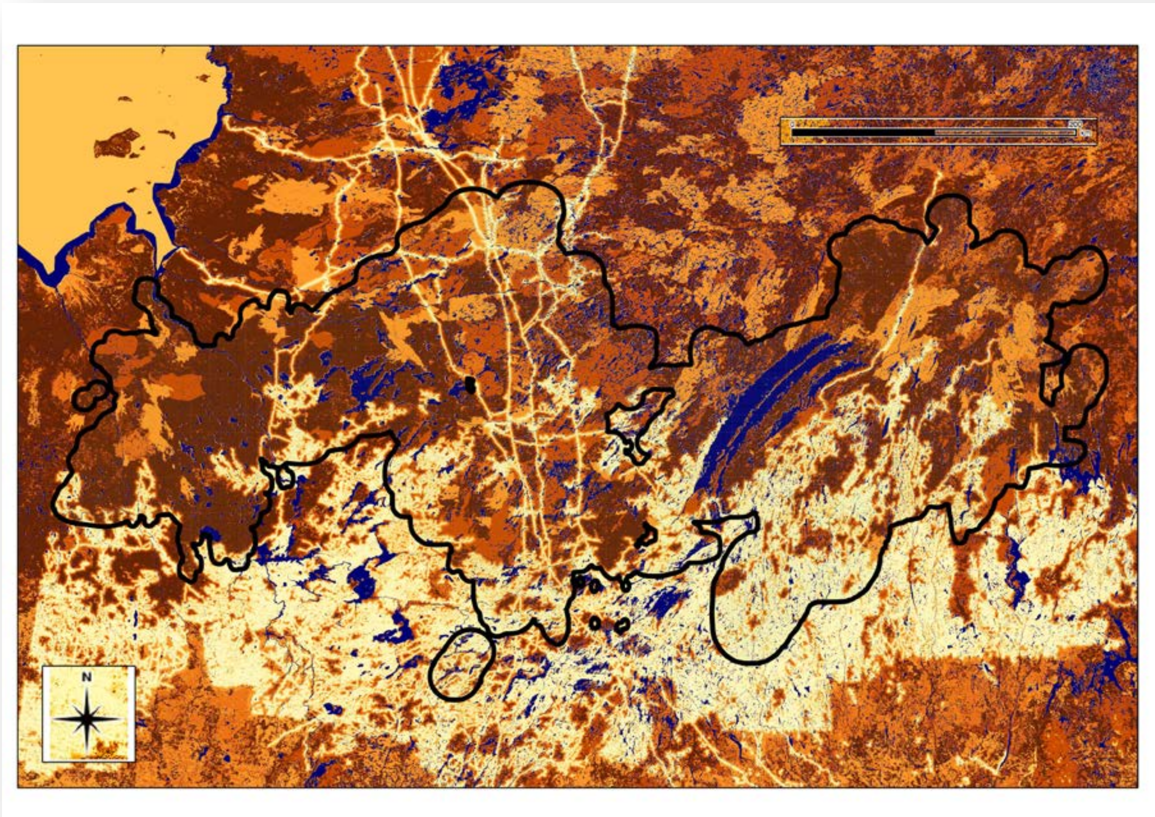

Figure 14: Map of the study area depicting the relative probability of woodland caribou occurrence as determined by conditional logistic regression (darker colours indicate higher relative probabilities). The relative probability of encountering caribou decreases exponentially with increasing proximity to roads (lightest shade), the single most influential variable in the model. Expansion of the road network from south to north is clearly strongly linked with caribou range recession.

Based on the relationship depicted in Figure 13, if we were to place a conservative 1 km buffer around all the roads in Eeyou Istchee as of today, the cumulative impact of roads on caribou habitat availability (i.e. functional habitat loss) could be quantified as follows:

Table 10: Amount of functional habitat loss attributed to roads within the 100% weighted kernel polygons of three local caribou populations in northern Quebec. The use of a 1-km buffer was deemed conservative given documented avoidance of roads by caribou at sufficiently greater distances. Reported are confirmed conditions in 2011, projected conditions in 2013, and projected conditions in 2013 with roads under environmental assessment included (2013+).

HERD	YEAR	AREA (km^2)	PROPORTION (%)
Assinica	2011	9, 653	35.55
	2013	10, 312	37.98
	2013 +	10, 684	39.35
Nottaway	2011	5, 659	15.64
	2013	5, 869	16.22
	2013 +	6, 106	16.88
Temiscamie	2011	15, 125	32.27
	2013	16, 534	35.28
	2013 +	16, 572	35.36

3.4.2. Evaluate the impact of proposed roads (L-209, 167, etc.) currently under Environmental Review

There are many new roads scheduled for construction in the current operational year and numerous cutover areas in parallel. While we will specifically address the two roads explicitly identified within the mandate, all roads scheduled for construction within woodland caribou ranges deserve to be carefully weighed with respect to their potential negative impact on the likelihood of population persistence.

Roads subject to environmental review are generally conceived to support wide gravel surfaces and sustain traffic speeds of 70 km/hr. These developments are therefore perennial in nature and likely to open relatively vast unexploited territories to resource extraction with far-reaching negative impacts on already-declining caribou populations, not the least of which include habitat loss (both actual and functional) and fragmentation in concert with important shifts in predator- and human-prey dynamics that inevitably trigger the decline and extirpation of caribou from the surrounding area. For these reasons it is appropriate that such infrastructures be subjected to an environmental assessment.

While the amount of functional habitat lost in the creation of roads L-209 and 167 is expected to be moderate relative to the quantity and distribution of roads already approved and/or under construction in the region, a much bigger concern is the rupture of connectivity between caribou groups that this is bound to entail. Research has shown that perennial road infrastructures which support moderate to high amounts of traffic are considerably more likely to form a semi-permeable barrier to dispersal than would a smaller temporary road and are more likely to preclude a greater degree of functional habitat loss (Dyer *et al.* 2002; Nellemann *et al.* 2003; Leblond *et al.* 2012). In general, and given the current state of our knowledge, to approve developments of this kind would therefore be counterproductive to the goal of woodland caribou population recovery.

In the absence of all other related developments, the proposed extension of road 167 would traverse the vast unexploited portion of the Temiscamie range to the east and north of Lac Mistassini and effectively divide the herd into eastern and western bands (Figure 15). This would presumably create a barrier to east-west dispersal and make exchanges between the Assinica and Temiscamie herds (which have been observed to occur along the eastern and western portions of Lac Mistassini) problematic. The road would disrupt caribou currently residing in the area (as evidenced by collared animals) and provide access to a vast stretch of high-quality caribou habitat that is likely of interest for timber harvesting. Doing so would also improve access between the Mistissini territory and that of the Nitassinan of the Innus of Mashteuiatsh, which is likely to create subsistence hunting opportunities that will further jeopardize adult survival. For these reasons and in recognition of the precarious status of the Temiscamie population, we do not recommend approval of the proposed 167 extension. If such a development were to go forward, however, we would highly recommend it serve exclusively as a transportation corridor, with controlled access and absolutely no lateral incursions into previously undisturbed portions of the Temiscamie range. Traffic should be regulated and ideally minimized during the critical spring dispersal, calving and post-calving periods (i.e. approximately from early April until late June). Furthermore, the spatial probability surface derived from RSF modeling could be used to ensure that roads do not pass through areas with a high likelihood of caribou occurrence.

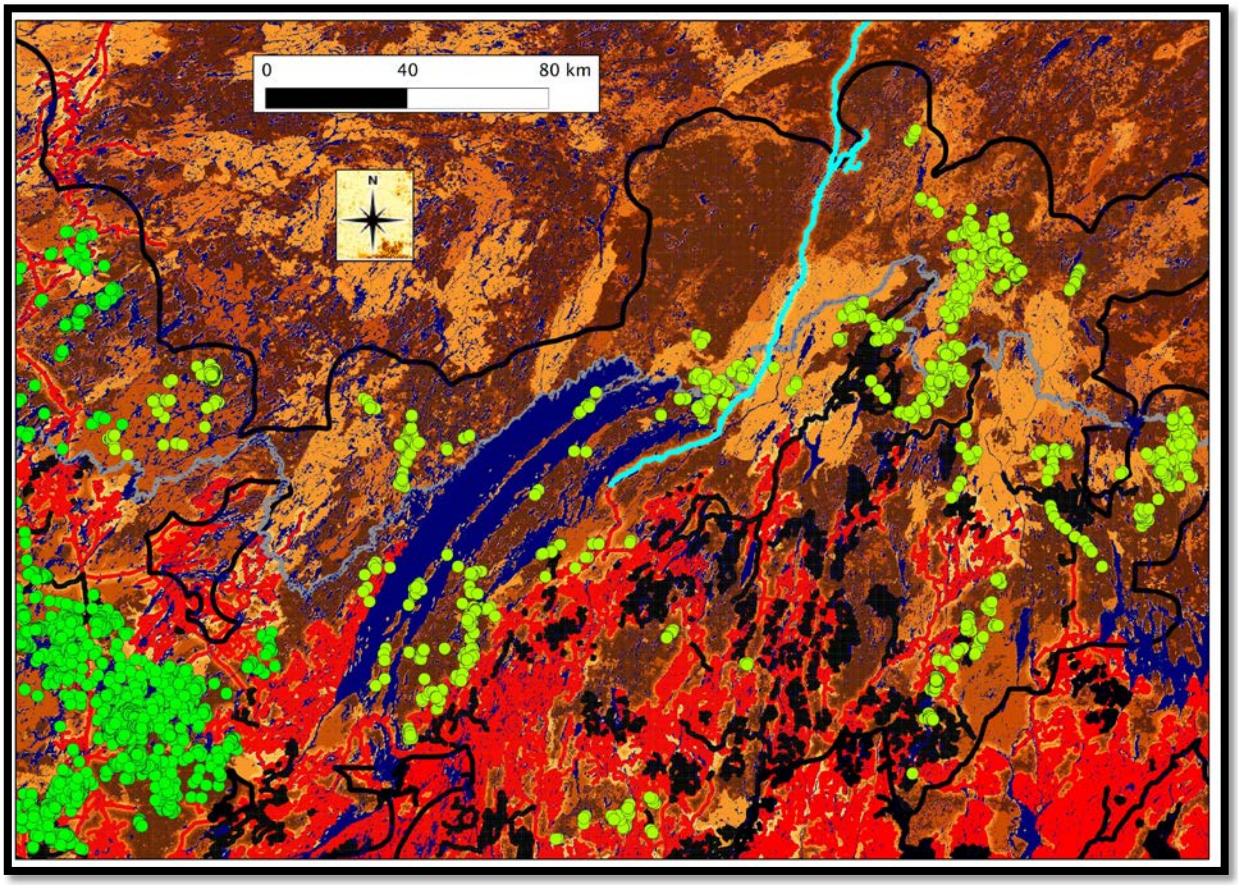

Figure 15: Inset view of the Temiscamie range (as of 2011) and the proposed extension of road 167 under environmental assessment (light blue). Existing roads are depicted in red, planned roads (PAIF) are depicted in black, and shades of yellow/brown represent the relative probability of caribou occurrence, with darker colours associated with higher probabilities. Points represent 2011 & 2012 GPS locations of collared female caribou of the Temiscamie (yellow) and Assinica (green) ranges. The grey line indicates the northern limit of commercial forestry, and the black outline represents the unified boundary of the three 100% weighted population kernels.

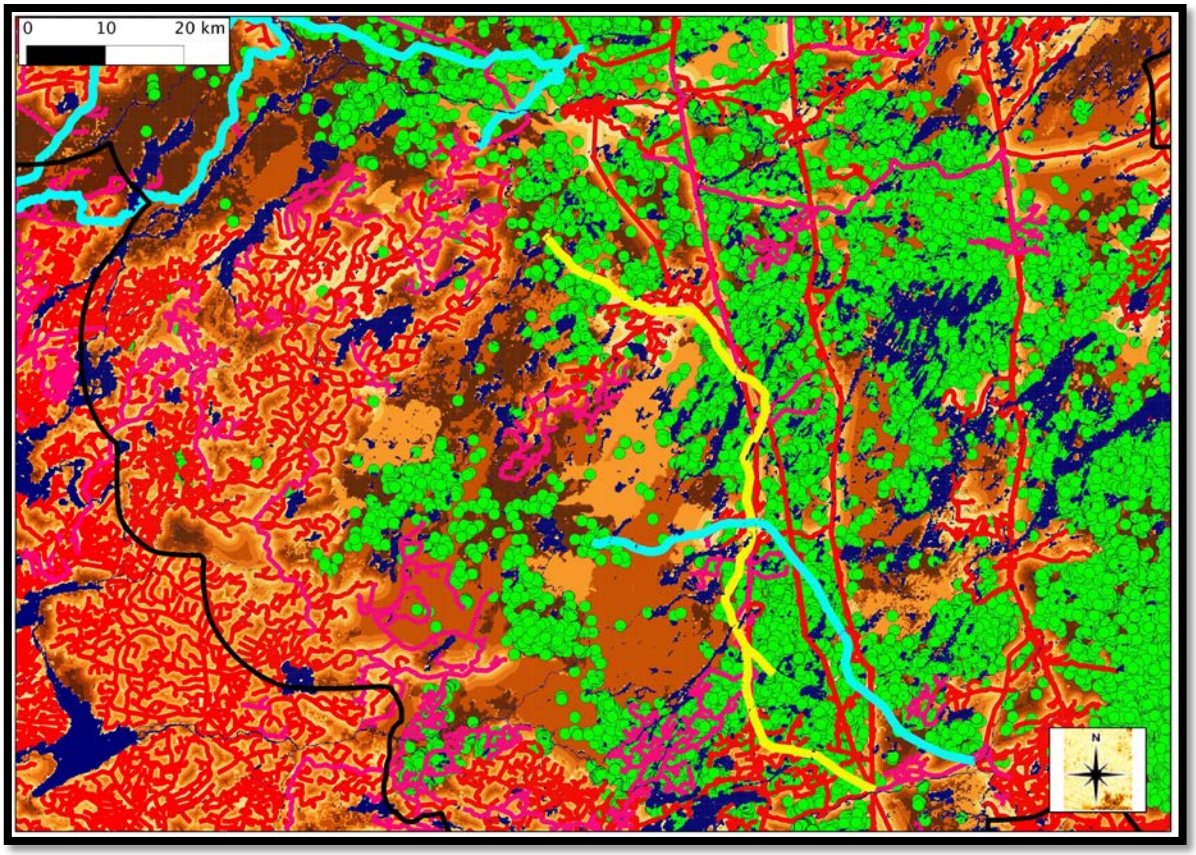

Figure 16: Map of the Assinica range with the proposed road 209 under environmental assessment (yellow line). Existing roads are depicted in red, currently planned roads in pink, and other roads also subject to environmental assessment in blue (e.g. road "I" to the immediate north and west). Shades of yellow/brown represent the relative probability of caribou occurrence (darker colours associated with higher probabilities). Points represent collared caribou locations recorded since 2004, since which time about a dozen collared individuals have used the west-central zone as a summering area.

With respect to the L-209 we are confronted with similar issues as raised previously. The proposed road would skirt the south-central portion of the Assinica range and eventually connect with road I (UAF86-65), linking the Oujé-Bougoumou territory with the northeastern traplines of Waswanipi and providing all-weather access to the sector south of the Broadback River (Figure 16). The less-disturbed pocket immediately to the west of L-209, portions of which are presently slated for harvesting, has been used as a summering area by about a dozen collared caribou since 2004 and is therefore of particular conservation interest. It is also one of the last unroaded portions in the southern stronghold of the Assinica range, the most threatened herd in the region. To approve the L-209 at this juncture would virtually ensure their extirpation in the southwest and effectively pave the way to the progressive deterioration of critical habitat to the north and west, a sector with high potential for connectivity with the Nottaway herd. From a conservation standpoint, we would therefore strongly advise against both road L-209 and road « I ». In fact, continued incursions into previously unroaded portions of all three caribou ranges would risk to further jeopardize the viability of these populations.

3.5. What are the contributions of existing protected areas and the territory above the northern commercial forestry limit for caribou conservation?

The conservation of wide-ranging animals like caribou requires progressive strategic planning at regional scales. Unfortunately the creation of protected areas intended for their conservation usually only takes place once the majority of the territory has been allocated for resource extraction, and this tends to result in piecemeal solutions that may or may not serve the originally intended purpose. Lesmerises (2011), for example, demonstrated that the likelihood of caribou occurrence was only high when core forests were greater than 1000 km^2 in size and not surrounded by a dense network of roads, cutovers and cabin developments. These conditions would be difficult to attain within the study area, so in order to secure the greatest chance of population recovery, we strongly recommend that current developments cease within areas under review for protection until such time as their official status has been determined. Furthermore, it bears repeating at this time that the single biggest factor influencing caribou population persistence is the amount of disturbed habitat within the larger home range. The creation of parks will therefore do little to stem population declines if the relative amount of critical habitat continues to depreciate on the surrounding landscape.

It goes without saying that any protected areas designed to benefit woodland caribou should receive the highest form of wilderness protection possible (i.e. minimal to no infrastructure and strictly controlled access).

During the strategic planning process there are numerous criteria that may be used to evaluate an area's potential for supporting woodland caribou conservation. These include the following:

1. Is there evidence of current or historic occupation of the area by woodland caribou?
    - Aerial census
    - GPS telemetry data
    - Traditional Ecological Knowledge
    - Anecdotal evidence

2. Does the area demonstrate a high probability of being used by woodland caribou?
    - Habitat selection modeling
    - Potential to satisfy diverse life history requirements (e.g. forage quality and availability, refuge habitat, calving locations, aggregation with conspecifics)

3. Are the landscape conditions within which the area is situated conducive to population viability?
    - Amount of critical habitat at larger scales: below tolerance thresholds?
    - Connectivity with other protected areas and/or local populations?
    - Adjacency and configuration of road network and infrastructure?
    - Latitude (opportunities to bolster range occupancy to the south?)

4. Is the area large enough to provide meaningful protection for woodland caribou?
    - Consider variation in annual and seasonal home range size
    - Room to space out at low densities (anti-predator strategy)?
    - Adequate protection from human and animal predators?
    - Sufficiently low levels of disturbance?

While we will comment on some of the protected areas currently in place in the James Bay region, we cannot conduct a sufficiently in-depth analysis of this question within the scope of the present mandate. In future we welcome the opportunity to be more meaningfully involved in the protected areas planning process.

The information we have indicates that there are four main areas currently approved for full protection within the region of interest: 1) an agglomeration of parcels near the Nottaway River (Collines de Muskuchii, Plains of the Missisicabi, the Turgeon River; Harricana River), 2) two parcels west and north of Lac Evans (Tourbières-boisées-du-Chiwakamu, Lac Dana), 3) the Assinica/Broadback River, and 4) the Albanel-Témiscamie-Otish.

In terms of caribou occupancy, all parcels (except for the northwest portion of the Harricana) are located within the 100% probability contours of the regional metapopulation (based on GPS telemetry of over 50 individuals since 2004). The first (1) is situated at the western extreme of the occupied territory and therefore may have lower long-term probabilities of being used by caribou, though they are associated with relatively high probabilities of selection (Table 11). Collared animals of the Temiscamie have tended to use the southeastern shore of Lac Mistassini much more than the northeast, and much of the Albanel-Témiscamie-Otish has been used relatively little in the last 10 years, presumably because it traverses a regenerating burn (1996/2002) which they have learned to avoid. In fact, the Albanel-Temiscamie-Otish projects the lowest observed probability of being used by caribou. The entire eastern shore of Lac Mistassini is of interest for caribou conservation, however, so long as it remains occupied by animals of this herd. The Assinica park reserve, while somewhat fragmented by linear infrastructure and partially composed of post-fire regeneration, captures an area consistently frequented by collared caribou of the Assinica herd. This is presumably in part attributed to range fidelity, for it is not necessarily the highest quality habitat. Notwithstanding, the park may contribute to buffering northward range recession provided it is not overly conducive to alternate prey and their predators (Courbin *et al.* 2009). This being said, it must necessarily be expanded beyond proposed boundaries in order to encompass the highest quality habitats remaining to the southeast.

The areas around Lac Evans demonstrate a high potential for use by caribou, they have been recognized as important by the Crees (Dion *et al.* 2010), and they are part of the zone of overlap between the Assinica and Nottaway herds and therefore strategic for connectivity when taken together with the Assinica park and other proposals.

Table 11: Protected areas within the study region and the relative probability of caribou occurrence within each. Values (mean and standard deviation) were derived from the spatial predictions of the global Resource Selection Function (RSF) model given landscape conditions as of 2011.

ID1	ID2	NAME	STATUS	DESCRIPTION	AREA (km²)	$MEAN_{RSF}$	SD_{RSF}
70	3	Les Tourbières-Boisées-du-Chiwakamu	Decreed	Biodiversity Reserve	156.3	**0.905**	0.134
92	29	Lac Dana	Decreed	Biodiversity Reserve	342.8	**0.738**	0.283
118	57	Collines de Muskuchii	Decreed	Biodiversity Reserve	791.4	**0.698**	0.272
0	0	Nemaska	Proposed	Protected Area	3,466.4	**0.687**	0.303
122	61	Plaine de la Missisicabi	Decreed	Biodiversity Reserve	751.1	**0.658**	0.241
0	0	Mishagamish (Waswanipi)	Proposed	Protected Area	4,535.5	**0.602**	0.300
678	1	Assinica (Noyau dur)	Announced	National Park Reserve	3,149.1	**0.534**	0.290
141	80	Albanel-Témiscamie-Otish	Decreed	Biodiversity Reserve	11,874.1	**0.459**	0.269

The significant negative impact of cumulative forest harvesting on woodland caribou habitat in the JBR is evident in the fact that 70.2% of the area considered to exhibit a high probability of caribou occurrence (scaled RSF value >= 0.99) occurs north of the practicable limit of commercial forestry (Figure 17). In fact, only 8.7% of the very highest quality habitats (scaled RSF value = 1) are found south of this boundary. Not surprisingly, the relative probability of occurrence is higher on average (mean=0.65) and less variable (sd=0.27) in the unexploited territory north of the limit of commercial wood allocation than it is in the highly managed landscape to the south (mean=0.44; sd=0.31). Furthermore, core forests consisting of high quality woodland caribou habitat are substantially larger and more plentiful in the northern portion of the territory, are considerably less fragmented, and comprise a greater proportion of the landscape overall. In the interest of caribou conservation, therefore, we do not recommend that the practicable limit of commercial forestry be expanded further north.

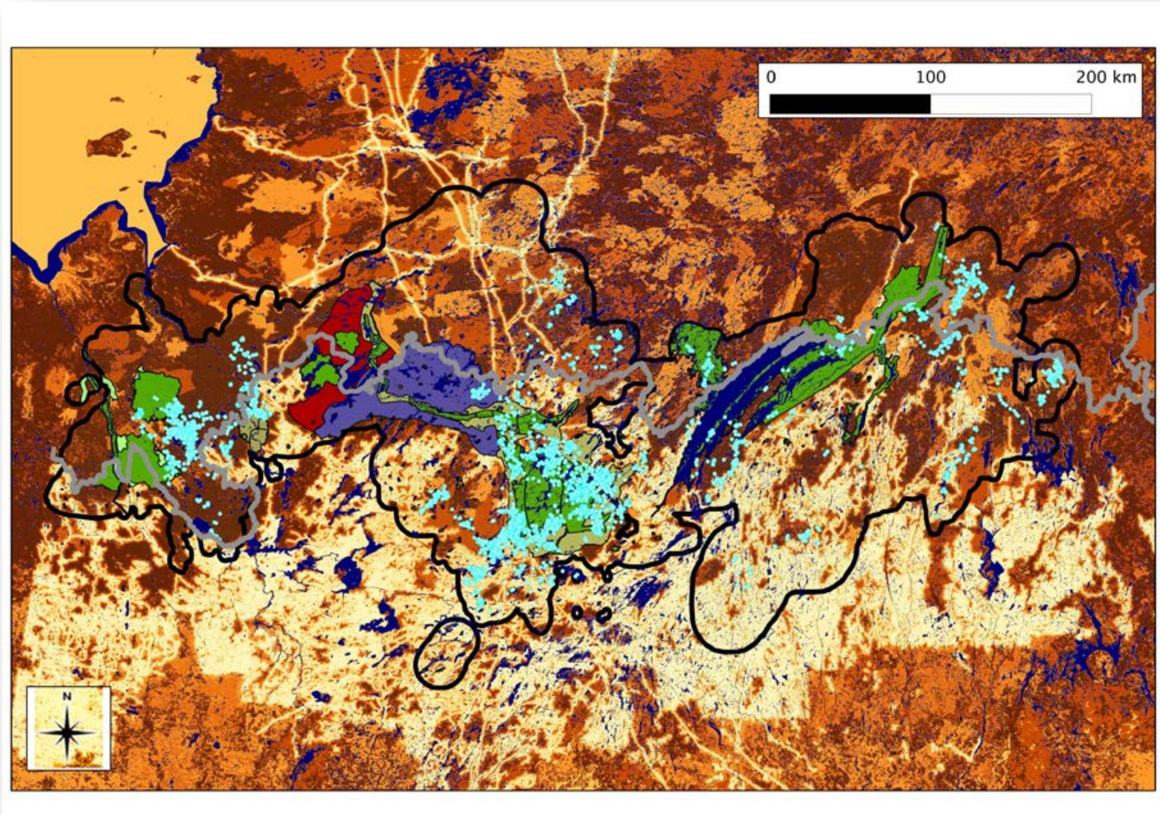

Figure 17: Existing protected areas (green polygons) within the unified 100% probability contours of the regional caribou metapopulation (black outline). The Nemaska (red) & Waswanipi (purple) protected areas are also shown. Shades of yellow/brown represent the relative probability of caribou occurrence (darker shades reflect higher probabilities). GPS point locations from collared caribou in recent years (2011-2012) are depicted in blue and the grey line indicates the northern limit of commercial forestry.

3.6. What role can the Waswanipi and Nemaska protected area proposals play to ensure recovery of the population?

Cree knowledge of caribou distribution and habits is considered a valuable resource in the process of identifying important areas for woodland caribou and should be integrated wherever possible within the protected areas planning process (e.g. *see* Dion *et al.* 2010). First Nations communities take pride in environmental conservation and have a strong sense of connection to the land; they therefore have the capacity to play an important role in the protection and stewardship of their traditional territories.

We consider that the proposed Waswanipi (also known as the Mesikamis Virgin forest) and Nemaska protected areas would be valuable complements to the Assinica park and Chiwakamu/Lac Dana biodiversity reserves. The importance of the overall sector is evident given converging support from parallel nominations by Nature Quebec (2007) and the Canadian Parks & Wilderness Society. Not only would doing so serve to protect a significant portion of the highest quality habitat remaining south of the current limit of commercial forestry, but it would facilitate exchanges between the Nottaway and Assinica herds, and connectivity between local populations is essential in achieving a secure conservation status for woodland caribou (Environment Canada 2011). However this will only be possible if access to the territory is strictly controlled (i.e. minimal human disturbance) and if communities are prepared to forgo the harvesting of woodland caribou until populations show signs of recovery. We therefore endorse the Waswanipi and Nemaska nominations with certain reservations.

4. RECOMMENDATIONS

Based on the results obtained, suggest potential solutions/actions that would ensure the survival of the herds in Eeyou Istchee?

We have modeled the direct link between cumulative range disturbance and population viability (as estimated via recruitment rates) in northern Quebec, and the evidence we have gathered thus far indicates that in order to ensure a reasonable likelihood of success at this juncture, the best course of action would be habitat restoration. This is particularly true for the Assinica and Temiscamie herds, but is likewise recommended for the Nottaway. Existing levels of disturbance are considered to be in excess of herd-specific tolerance thresholds, and further landscape disturbance will likely perpetuate the downward spiral of these populations. Options for further interventions within delimited ranges are thus limited. Our recommendations, effective immediately, are as follows:

> **Recommendation # 1 a)**: Prevent (or at the very least strictly minimize) further development within areas known or presumed to be occupied by woodland caribou.

As a minimum requirement this should apply to areas demonstrating a high likelihood of present or recent caribou occupancy as determined by a combination of knowledge on the recent distribution of collared animals, information from past and recent aerial surveys, and RSF modeling.

> **Recommendation # 1 b)**: Target net reductions in the relative amount of disturbance within local population ranges.

In principle, all remaining undisturbed habitat should be placed on reserve until adequate habitat renewal has taken place and sustainable levels of critical habitat become newly available on the landscape. In practice, opportunities for development within remaining undisturbed habitat should be carefully considered in terms of the impact they may have on the likelihood of population persistence. This precautionary principle should be applied until populations are determined to be stable or growing, of adequate size, and their ranges within acceptable limits of disturbance. As recommended by Environment Canada (2011b, pg. 92), this approach can be situated within an adaptive management framework wherein the notion of critical habitat is reassessed and refined over time as new knowledge becomes available.

Perhaps unwittingly, the modalities of forest management entrenched in the *Paix des Braves* treaty (i.e. dispersed, multiple-pass mosaic cutting) have created habitat conditions favorable for moose to the evident detriment of woodland caribou (via indirect competition for predator-free space). It must therefore be acknowledged that in order for caribou conservation efforts to succeed, forest management must henceforth be done differently in the James Bay region. To begin with, we must be prepared to accept reductions in the Annual Allowable Cut. Secondly, portions of the landscape managed in a way that optimizes moose habitat must be spaced sufficiently apart from woodland caribou range and at sufficiently large scales to avoid attracting moose and their predators into these areas. Where forest management does take place it should occur in zones of less intensive use by caribou subject to mitigation measures elaborated by Rudolph (2011b) and in keeping with the principles of ecosystem management (Drapeau 2008). Emphasis should go toward the creation of conditions that minimize predator-prey encounters (e.g. avoiding the creation of "hard" forest edges) and that preserve functional connectivity between herds. Lastly, it stands to reason that given the high quality habitat found in the northern portion of the Jamésie (JBR) range, in the interest of conservation we do not recommend that the practicable limit of commercial forestry be expanded further north.

With respect to access, efforts to stem population declines cannot be effective if we continue to expand the road network into previously undisturbed portions of caribou range. Preventing new incursions and strictly controlling access may serve to buffer the longer-term changes in predator-prey dynamics that can lead to population extirpation. The goal at present should be no net increase in road surface area, with an emphasis on the deactivation and rehabilitation of unused forest access roads. Where roads are considered necessary they should be small, temporary, and removed and restored after use (see Nellemann *et al.* 2010 for a successful example of *Rangifer* habitat restoration following cabin and road removal). Where harvesting is deemed necessary it should be concentrated in existing disturbed areas to the south where the probability of caribou occurrence is low (e.g. second-growth or residual forests, timber directly adjacent to roads). Since small forest blocks within 500 metres of recent cutovers or roads are already considered to be functionally lost to woodland caribou, further forestry operations could be concentrated in these areas with minimal net loss to critical habitat as defined by Environment Canada (2011b). As proposed by caribou biologists elsewhere in Quebec (MRNF 2011), we likewise recommend that no cabin development be approved in the region until populations have shown evidence of recovery.

Recommendation # 2: Encourage an immediate halt to all subsistence harvesting of woodland caribou in the James Bay region.

In 2006, St-Pierre *et al*. (2006) concluded that the aboriginal harvest of woodland caribou in Eeyou Istchee was likely sustainable provided natural mortalities were low. This was based on current estimates of population size and relatively high recruitment rates observed during 2002 & 2003 aerial censuses. While in retrospect their conclusion seems reasonable, we now recognize the negative impact that cumulative landscape disturbances have had on population recruitment over the past 10 years. In parallel we also recognize that expansion of the road network tends to be correlated with improved hunting success. While we are not equipped at present to quantify the impact of subsistence hunting on population size, we have demonstrated its impact on adult survival and population trend overall. Furthermore, given that hunters typically harvest multiple animals at a time, survival estimates based on the fate of random individuals (i.e. collared caribou) may be overly optimistic.

When adult mortality is low and calf recruitment is minimal, populations will decline only gradually as a function of senescence. However when adult mortality is high or even moderate in the absence of significant recruitment, populations decline rapidly (Environment Canada 2008). We maintain that until such time as calf recruitment improves and/or a recent census provides evidence of recovery, caribou populations in the JBR cannot withstand further preventable reductions in adult numbers. The implementation of this recommendation is therefore considered to be of the utmost priority.

While ensuring the sustainability of caribou populations as a traditional food source and vital ecosystem component is clearly in the best interests of the Cree people, we do recognize the difficulty of the present situation, and we extend our support at this time in hopes of promoting a solution through education and stewardship. As a source of inspiration we cite the Algonquin people of Kitcisakik, Lac Simon and Long Point, who in recognition of the perilous state of lake sturgeon populations on their communities' traditional territories elected to voluntarily abstain from harvesting this species in 2009. A similar agreement was recently reached with respect to the endangered Val d'Or caribou herd (Jonathan Leclair, pers. comm. 2012). Such a collective consensus may too be obtained among the Cree people given the present troubled state of woodland caribou in Eeyou Istchee. In the meantime, in order to inform our assessment of current population status we would benefit substantially from recent estimates of the number of woodland caribou harvested for subsistence purposes in the region since approximately 2005.

Recommendation #3: Include the proposed Waswanipi and Nemaska parks in Quebec's network of protected areas and expand the Assinica Park Reserve.

As mentioned previously, we consider that the proposed Waswanipi (also known as the Mesikamis Virgin forest) and Nemaska protected areas would be valuable complements to the Québec government's current network of protected areas in the James Bay region. Doing so would protect a significant portion of the highest quality habitat of woodland caribou remaining south of the current limit of commercial forestry. Moreover, it would also facilitate exchanges between the Nottaway and Assinica herds, and, thus maintain connectivity between these local populations, which is an essential step toward the effective conservation of woodland caribou (Environment Canada 2011). In addition, as it presently stands the Assinica Park reserve fails to protect the highest quality habitat remaining at the southern range of this rapidly declining population. In order to maximize the probability of successful conservation, it is therefore recommended that the Assinica park reserve be expanded to capture the remaining portion of high quality habitat located immediately southeast of its current boundaries.

Recommendation # 4: Develop strategic collaborations in proactive attempts to find management solutions that will benefit woodland caribou.

Without stronger inter-jurisdictional collaboration it will be exceptionally difficult to find effective solutions to the challenges that lay ahead. We therefore recommend that MRNFQ managers of both Region 10 and Region 02 cooperate actively to ensure the effective recovery of the Temiscamie population. The same applies further south with respect to the La Sarre herd, which thus far has received inadequate attention and yet is strongly deserving of its own critical habitat assessment. To resume collaborative efforts between the QMRNW and the Ontario Ministry of Natural Resources would facilitate the assessment of this herd's current status and prospects of recovery. Furthermore, in order to ensure that the findings of this study are considered in the planning and creation of the region's protected areas network, the creation of a working group comprising members of the scientific task force and the MDDEP would be advisable. In addition there may be other agencies and/or stakeholder groups with the potential to make positive contributions to the process.

Finally, the Cree Nation's role as stewards in the management and conservation of woodland caribou is crucial. As this issue plays out on their traditional territory, they have the interest, the knowledge and the capacity to play an active part in the recovery effort. We therefore encourage the continued development of a collaborative relationship between the Grand Council of the Crees, the QMRNF, and other relevant parties with an interest in the successful conservation of woodland caribou in the region. To that effect, we as scientists are prepared to continue working with all parties in order to ensure that this takes place.

Recommendation # 5: Conduct a systematic aerial census of the territory in order to obtain recent estimates of population size, density, age class structure and adult sex ratios.

Although there is clearly an immediate need for the conservation and restoration of critical woodland caribou habitat in the JBR, we would have a much better sense of the prospects of woodland caribou recovery once we had obtained a contemporary reference point. This will allow us to assess how populations have fared since 2002/2003, and to project how they are likely to fare in the coming years given different management projections, allowing for environmental stochasticity and demographic variation. Updated estimates of adult sex ratios may also alter our current assessment to some degree with respect to the recruitment rates that are necessary to infer population stability ($\lambda>=1$).

Recommendation # 6: Improve research and monitoring program.

The cost of conserving caribou populations is expected to rise as we increase development pressures on the landscape. For example, declining recruitment rates are now a major threat to population viability, yet we have little to no information on the abundance and distribution of predators (i.e. black bear, grey wolf) and alternate prey species (i.e. moose, white-tailed deer) in the region. Acquiring such information will require financial commitments in order to commission surveys and deploy technologies to track, study, and if necessary control these other wildlife species of interest. Regarding the controversial practice of predator control, while it may be of some interest in the short term as habitat restoration occurs, it also both costly and relatively ineffective, and therefore should not be considered a solution in and of itself. Acquiring information on predator distributions and abundances in the region, and that of their prey, is considered to one of the research areas in most need of attention in the coming years.

At the same time there are innumerous yet pertinent facets of woodland caribou ecology that we have yet to uncover in the James Bay region. For example, is there enough forage of adequate quality remaining to satisfy the life history requirements of individual caribou at critical times of the year? What landscape and/or habitat attributes are influencing the likelihood of calf survival at finer scales (e.g. calving site selection)? What is the relationship between road development and adult mortality? How is climate change expected to influence the probability of successful population recovery? These are but a few issues considered worthy of further investigation.

With respect to the status of woodland caribou populations in northern Quebec, one essential exercise we have not yet conducted is an estimation of current population size given a) 2002/2003 estimates of population size and density, b) demographic rates we have estimated using GPS telemetry and aerial survey counts over the past 10 years (e.g. mortality rates, juvenile recruitment), and c) annual estimates of the subsistence harvest dating to 1988. By modeling uncertainty in demographic estimates we can derive a probabilistic measure of current population size that can be validated upon completion of the next aerial census.

Moving forward, something we have not yet measured is the degree to which the eventual recruitment of critical habitat may aid recovery efforts. Given the random contribution of fire, which we are not at liberty to control, how quickly can we expect the different caribou ranges to recover from current disturbance levels under various forest management scenarios? For example, a) total protection with active restoration (best chance of recovery), b) spatially deferred intensive management (e.g. concentrated activity along roadways and in buffered moose management areas to the south), and c) business-as-usual (no change to current practices). An exercise blending wood supply modeling with population viability analysis would allow us to evaluate the impact of various conservation scenarios on the allowable harvest volume, and on the viability of caribou populations over a given time horizon (e.g. McKenney *et al.* 1998; Weclaw & Hudson 2004).

Another aspect of interest is the way in which we characterize range occupancy. For the purposes of this exercise we measured range disturbance within static polygons representing the 7-year cumulative space use patterns of each herd; however by allowing our characterization of space use to vary over time we may come to a more refined definition of the disturbance-recruitment relationship and thus to a better understanding of how different planning scenarios are likely to affect the probability of population persistence. Given time to conduct population viability analysis, this could lead to more refined range-specific indicators of risk that may help direct future management efforts.

Given the range-specific variation we have observed in demographic responses to cumulative disturbance, we do not exclude the possibility that herds are responding in a synchronous manner at a scale larger than what we have explicitly measured (i.e. metapopulation). To that effect, relatively little is actually known about metapopulation dynamics in the JBR and the degree to which the Nottaway, Assinica, and Temiscamie herds are related via immigration and emigration. However maintaining and improving functional linkages between these herds is essential if we are to ensure their long-term survival. Given future uncertainty, ensuring the resilience of the regional metapopulation would be advantageous in terms of increasing the likelihood of success of its recovery. One possible solution is to use modeling techniques to prioritize conservation efforts with a view to optimizing landscape connectivity, thereby improving demographic resilience to natural and anthropogenic disturbances. Increasingly, genetic techniques are also being used to reveal valuable insights into population condition, genetic diversity, and landscape connectivity.

Recommendation # 7: Reevaluate the status of woodland caribou in Quebec.

Given available evidence from this body of work and that gleaned from ongoing research being conducted elsewhere in Québec, there is now adequate cause to believe that the majority of woodland caribou populations in the province are currently subject to disturbance levels exceeding what is theoretically required to ensure their persistence. This suggests that their current designation as provincially vulnerable is optimistic and that the status of woodland caribou in Québec is in need of revisiting. The fact that boreal populations of woodland caribou have been designated as threatened in Canada since 2000 (i.e. implying a greater degree or incurred risk) lends additional credence to this notion. We therefore recommend that the QMRNF undertake a new exercise as soon as possible to reevaluate the status of woodland caribou in Québec, thereby taking into account the abundance of new scientific work that has been conducted on the subject since 2005. This re-evaluation will likely have an important impact on the federal recovery strategy for woodland caribou, which considers the James Bay area to support but one unique and self-sustaining population (Environment Canada 2012). Our findings clearly demonstrate that there are three local populations in the James Bay region, all of which are currently declining. Furthermore, because the Nottaway, Assinica and Témiscamie herds form part of the semi-continuous Canadian boreal population (n = 12), they are bound to be of higher conservation priority than those herds considered to be declining and isolated (n = 28, Environment Canada 2011).

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APPENDIX 1: Reclassification schema showing the original 43 habitat categories of the Canadian Center for Remote Sensing's 2005 MODIS classified satellite image and the 20 new category groupings based on behavioural preferences by caribou (determined via examination of Manly's selection ratios).

DESCRIPTION 1	CLASS 1	DESCRIPTION 2	CLASS 2
Sparse Vegetation: Recent Burn	34	Burn05	1
Mixed Evergreen-Deciduous Forest: Mature – Young Closed	4	Burn0620	2
Mixed Deciduous: Closed Canopy	5	Burn0620	2
Sparse Vegetation: Old Burn	35	Burn0620	2
NA	40	Burn2050	3
Temperate Needleleaved EG: Closed Canopy	1	ConiferDense	4
Temperate Needleleaved EG: Moss/Shrub U.S. – Open Canopy/med. Crown den	6	ConiferOpen	5
Temperate Needleleaved EG: Lichen/Shrub U.S. – Open Canopy/med. Crown den	7	ConiferSparseDry	6
Temperate Needleleaved EG: Moss/Shrub U.S. – Open Canopy/low crown den	8	ConiferSparseDry	6
Temperate Needleleaved EG: Poorly Drained – Open Canopy/low crown den	10	ConiferSparseWet	7
NA	41	Cut05	8
NA	42	Cut0620	9
NA	43	Cut2050	10
Cold Deciduous Broadleaf Forest	2	Deciduous	11

APPENDIX 1 (CONT'D):

Deciduous Broadleaved: Low to Medium Density	11	Deciduous	11
Deciduous Broadleaved: Young Regenerating	12	Deciduous	11
Mixed Deciduous: Low to Medium Density	14	Deciduous	11
Temperate Needleleaved EG: Lichen/Rock U.S. – Open Canopy/low crown den	9	ExpLowVeg	12
Deciduous High: Low Shrub Dominated	16	ExpLowVeg	12
Herbaceous: Grassland in Prairie Region	17	ExpLowVeg	12
Herbaceous: Herb-Shrub-Bare Cover	18	ExpLowVeg	12
Herbaceous: Evergreen Shrub-Herb Moss Cover	20	ExpLowVeg	12
Polar Grassland: Herb-Shrub	21	ExpLowVeg	12
Polar Grassland: Shrub-Herb-Lichen-Bare	22	ExpLowVeg	12
Polar Grassland: Herb-Shrub poorly drained	23	ExpLowVeg	12
Polar Grassland: Lichen-Shrub-Herb-Bare Soil	24	ExpLowVeg	12
Polar Grassland: Low vegetation cover	25	ExpLowVeg	12
Lichen: Barren	30	ExpLowVeg	12
Lichen: Sedge-Moss-Low Shrub Wetland	31	ExpLowVeg	12
Sparse Vegetation: Rock Outcrop	33	ExpLowVeg	12

APPENDIX 1 (CONT'D):

Herbaceous: Cropland-Woodland	26	HerbCropland	13
Herbaceous: Cropland	27	HerbCropland	13
Herbaceous: Cropland	28	HerbCropland	13
Herbaceous: Cropland	29	HerbCropland	13
Mixed Evergreen-Deciduous Forest: Mature – Old, Closed Canopy	3	MixedDense	14
Mixed Evergreen Forest: Low to Medium Density	13	MixedOpen	15
Mixed Deciduous: Low Regenerating Young Mixed Cover	15	MixedOpen	15
Non-Vegetated: Mixes of Water and Land	38	Riparian	16
Non-Vegetated: Snow and Ice	39	SnowIce	17
Non-Vegetated: Urban and Built-Up	36	Urban	18
Non-Vegetated: Water Bodies	37	Water	19
Herbaceous: Wetlands	19	Wetland	20
Lichen: Spruce bog	32	Wetland	20