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Population Projections of Newfoundland Caribou Using Population Viability Analysis

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POPULATION PROJECTIONS OF INSULAR NEWFOUNDLAND CARIBOU USING POPULATION VIABILITY ANALYSIS.

Technical Bulletin No. 004

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EXECUTIVE SUMMARY

The Newfoundland woodland caribou (*Rangifer tarandus caribou*) population has declined by over 60% in the last decade. In 2008, the Government of Newfoundland and Labrador announced a five-year Caribou Strategy that would expand on the findings of earlier efforts to form an ecosystem-based analysis of local caribou population dynamics. The Strategy is research-intensive and focuses on caribou and predator ecology, predator-prey dynamics, predator-prey-habitat interactions, predator control methodologies, non-predation factors, and human dimensions.

To support the Caribou Strategy, population size projections for some major herds, as well as the total island population, were carried out to forecast the future demographic characteristics of the island caribou. These population projections were developed to improve the ability of wildlife managers to effectively and appropriately manage caribou on a sustainable basis. Simulations were performed using population viability analysis (PVA), a standard method used to estimate the probability that a population will persist for some arbitrarily chosen time into the future (Boyce 1992). *VORTEX* software was used to perform the PVA, which was parameterized with demographic data specific to Newfoundland caribou (Department of Environment and Conservation). The predictive accuracy of the model was tested and validated with known population census data, and was shown to capture the population trends well.

The intentions for this work were twofold. First, herd population size was projected from 2011 to 2030 using current demographic data, and secondly, various demographic parameters in the model were adjusted to test the likely effects of specific manipulations/scenarios on population performance. Resulting projections from these simulations gave an indication of the urgency for recovery efforts, and the manipulations identified processes that should be the focus of recovery efforts.

Three scenarios were considered:

1) Current conditions continue,

2) Elimination of legal harvest and,

3) Improved calf survival (herd-specific average survival rates from 1980-89, "pre-decline calf survival").

The PVA yielded the following results:

- All modeled herds, as well as the combined insular Newfoundland population, were projected to decline under current demographic conditions.

- While the elimination of legal harvest was not sufficient to halt or reverse the decline, it did slow the rate of decline for all herds, and the combined insular Newfoundland population.

- All herds, as well as the combined insular Newfoundland population were projected to have positive growth (an increased population size) when calf survival was increased to pre-decline rates.

- The minimum annual calf survival rate required to reverse the declining trend for the insular Newfoundland population lies between 40% and 45% (at these rates, the population is at or near stabilization). Similar rates were required for population stabilization of the individual herds.

Based on these projections, we can expect continued population decline for Newfoundland caribou unless rates of calf survival improve, through natural or human-induced reduction in predation on juvenile caribou.

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1. BACKGROUND

The Government of Newfoundland and Labrador has been researching its insular Newfoundland woodland caribou (*Rangifer tarandus caribou*) population since the 1950s. Comprehensive synthesis of these data (Mahoney 2000; Mahoney and Weir 2009) enabled identification of many important demographic and morphological trends in the population including the most recent population decline. The number of caribou on the island has dropped from over 95,000 animals in the late 1990s to approximately 36,000 at present. While the Newfoundland woodland caribou was the only population in North America listed as *Not at Risk* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2002, current population size and demographic trends are approaching the criteria for an *At Risk* assessment. An updated COSEWIC review will begin in 2012, and a redefinition of Newfoundland caribou status would have significant implications for recreational caribou harvest, the outfitting industry and resource extraction activities such as forestry, mining and energy development.

In an effort to better understand and describe the dynamics of woodland caribou in insular Newfoundland, the Government of Newfoundland and Labrador initiated the *Caribou Data Synthesis* in 1996 to systematically evaluate all available data and inform management decisions. Herd composition surveys, population censuses, radio-telemetry studies, investigations of body condition and diet, impacts of industrial activity, and hunting trends were all thoroughly examined. Through analysis and interpretation of these data, several significant trends emerged. In particular, the overall decline of the island population became apparent, as well as changes to population sex ratios, age structure and body size (Mahoney and Weir 2009; Mahoney et al. 2011). Calf recruitment also declined dramatically over time, from an average of 25-30% in the mid 1970s-1990s, to less than 10% in the early 2000s; levels insufficient to sustain a stable population. Ascertaining the potential causes of these low recruitment rates prompted initiation of a *Calf Mortality Study* in 2003. This study, which continued until 2007, was designed to determine the causes, rates and timing of calf mortality in three caribou herds. Results indicated that predation (primarily by black bear, lynx, coyote and bald eagle) was the main proximate cause of calf mortality, and over 80% of radio-collared calves died during the first six months of life (Trindade et al. 2011).

Prompted by these findings, the Government of Newfoundland and Labrador announced funding in February 2008 for a new five-year intensive research-based Caribou Strategy to address the population decline, obtain a better understanding of caribou-predator ecology, and provide a long-term management strategy for the island's caribou. This science-oriented program takes an ecosystem-based approach, encompassing predator-prey dynamics, habitat and socio-economic evaluations.

As part of this research and management effort, we used population modeling to predict numeric trends for woodland caribou on the island of Newfoundland. Morrison et al. (2012) used the Leslie-matrix modeling approach and projected continued decline for most Newfoundland herds by 2035; using this approach the island-wide caribou population was projected to decline by ninety percent. However, work completed by Lewis et al. (2011), subsequent to these Leslie-matrix analyses, indicated that prior methods used to calculate calf survival (iterative herd composition surveys and Heisey-Fuller estimates based on telemetry data assuming constant survival rates) may have modestly underestimated calf survival for many herds in Newfoundland, and use of these data may have resulted in the excessive rates of decline projected by the Leslie-matrix model (Morrison et al. 2012). More rigorous telemetry-based assessments of calf survival rates for the 2003-2010 period, which accounted for temporal variation in mortality rates, were performed in Program MARK (White and Burnham 1999) using the Nest Survival model. These models indicated that caribou calf survival rates (average 2007-2009, island-wide population) may have been closer to 30% (Lewis et al. 2011), rather than the ~20% used to parameterize the Leslie-matrix model developed by Morrison et al. (2012).

Here we report on results of population projections based on another modeling approach - population viability analysis (PVA). PVA is widely used in conservation biology and wildlife management to evaluate threats faced by species, the probability of extinction or decline, and the chances for recovery based on alternative management options (Boyce 1992; Lacy 1993; Akçakaya and Sjögren-Gulve 2000; Brook et al. 2000). PVA also identifies key life stages or processes which should be the focus of management strategies or recovery efforts (Lacy 1993). This approach has been used to determine the fate of numerous taxa including avian, mammalian, reptilian, and fish species (Brook et al. 2000). PVA has been used to assess potential threats and to model the fate of caribou in North America (see examples in Hatter et al. 2004; Wittmer 2004; Decesare et al. 2010; Wittmer et al. 2010).

We used PVA to: (1) project population size with current demographic conditions, and (2) assess the likely impact of two potential variations from current conditions (elimination of legal harvest and improvement of calf survival) for three major insular Newfoundland herds and the combined island population. In contrast to Morrison et al. (2012), we used telemetry-based estimates of calf survival (calculated using Nest Survival models in Program MARK) and projected population size from 2011-2030.

2. METHODS

2.1 Population Viability Analysis

We used *VORTEX* v99.9b software (Lacy et al. 2003) to conduct the PVA. *VORTEX* is one of the most widely applied PVA packages being used extensively by the International Union for Conservation of Nature (IUCN), by wildlife agencies, and in university education and conservation programs (Lacy 1993). The *VORTEX* computer simulation model is essentially a Monte Carlo simulation exercise which iteratively (repeated executions of the input parameters and corresponding standard deviations) evaluates population influences by parameters that are too complex and variable for solution using basic equations. Monte Carlo simulations generate multiple random samples from user-defined probability distributions to simulate the process of sampling from an actual population. Results are repeatedly calculated, using a different set of values for each iteration, which in turn reveal a range of fates that the population might experience under a given set of circumstances.

B3VORTEX simulates a population by replicating a series of events that represent an annual cycle of a typical sexually reproducing diploid organism with low fecundity (reproductive rate). As such, the model requires specific input parameters about the species of interest, such as reproduction, survival rates, mate selection, population age demographics and hunter harvest. After running the model through a specified number of iterations, the program provides an average and range of outcomes for the population, including: measures of probability of extinction, mean population size, and mean population growth rate.

2.2 Model Parameterization- Assumptions and Justification

The PVA was parameterized with herd-specific data collected by the Department of Environment and Conservation, Government of Newfoundland and Labrador. Three major island caribou herds (**Fig. 1**) were modeled, as well as the combined insular Newfoundland population. These herds were chosen as they have the most comprehensive demographic data available.

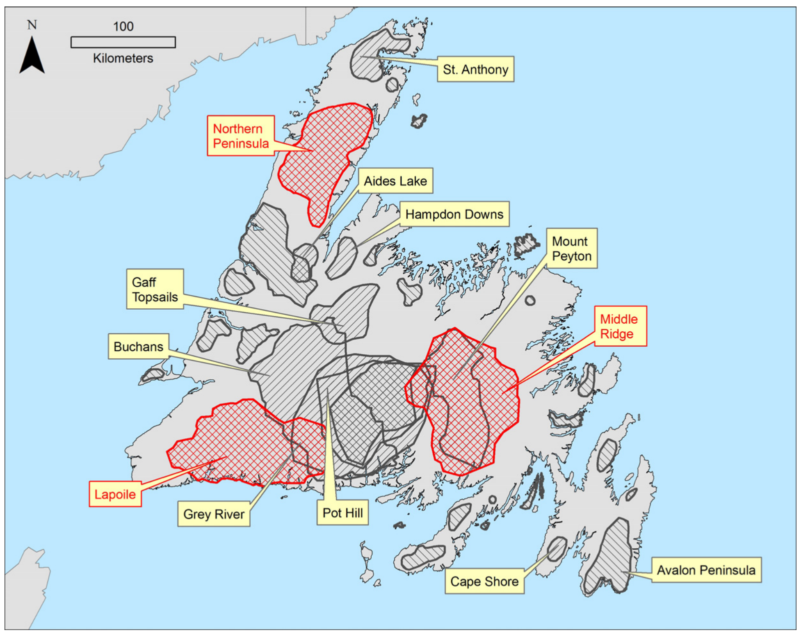

Figure 1. Map showing major woodland caribou herds on the island of Newfoundland. Herds modeled in this report are highlighted in red.

Required data for reproductive rates, survivorship, age structure, and harvest were obtained from herd composition surveys, radio-telemetry studies and harvest records. We used three-year averages for all parameters. If data were missing for a particular herd for any one of the three years, we used an average of the latest available three years (since 2006) for that herd to estimate the missing value. For the combined insular Newfoundland population, rates were calculated by pooling the means of the individual herds.

The following is a detailed account of *VORTEX* model options selected, assumptions made, and data used to parameterize the model:

1. A herd/population was considered extinct when only one sex remained.

2. The sex ratio of calves at birth was set at 50% males and 50% females.

3. The age of first offspring for females was set at 2 years to be consistent with productivity assessments collected through herd composition surveys, and the maximum age of reproduction was set at 12 years.

4. The ‘percentage of males in breeding pool’ was estimated based on the proportion of e of 4-9 year old males in the harvested population. We assumed this age distribution of harvest of caribou was representative of the total population for animals 2 years and older.

5. Productivity rate was defined as the proportion of parous females (adult females identified as pregnant, having given birth, or having a calf at heel during spring herd composition surveys) in the population.

6. Estimates of calf survival were determined based on 2007-2009 telemetry data and were performed in Program MARK (White and Burnham 1999) using the Nest Survival model.

7. Adult female survival rates for the La Poile and Northern Peninsula herds were calculated using radio-telemetry data (annual Heisey-Fuller estimates) from collars deployed on animals from the south coast herds (La Poile, Buchans, Grey River, Gaff Topsails and Pot Hill) and Northern Peninsula herds (St. Anthony, Gros Morne, Adies Lake, Hampden Downs and Northern Peninsula) since 2004 (n= 873 and 516 for south coast and Northern Peninsula herds respectively). We used average rates derived from 2008-2010 data. For Middle Ridge, the average survival rate for all collared adults was used as the estimated rate in 2008, and the 2009 and 2010 survival rates were derived from telemetry data on Middle Ridge.

8. Adult male survival was assumed to be equal to adult female survival. A comparison of male and female survival rates island-wide from 1979-1998 (Mahoney 2000) revealed little difference between adult male and female survival rates based on radio telemetry data (hunting and poaching excluded: male = 93.3%; females = 90.2%, although sample sizes were low for males). Recent data were only available for adult females. Differences in hunting mortality of males and females were captured by harvest data (see #10 below).

9. We used the most recent mark-recapture census estimate as the initial population size for each herd individually, and for the combined island-wide population. This estimate was broken down into the number of animals in each age class from age 0 to 12+ years based on hunter harvest records. Age of all harvested animals was determined by cementum analysis (Matson’s Lab, Montana) of teeth extracted from jawbones submitted to the Department of Environment and Conservation. We used the age distribution derived from the 2006-2007 harvested samples for animals 2 years and older. Harvest data from individual herds were pooled to create an island-wide age distribution. This distribution was used as the starting age distribution for all herds and scenarios, because harvest sample sizes were too low to use herd-specific age distribution data.

Because the percentage of yearlings in the population was likely underestimated in the sample of harvested animals, we calculated percent yearlings by determining the number of calves surviving in the previous year (obtained from average annual calf survival rates from herd composition surveys). The *VORTEX* PVA model is a pre-breeding model and therefore the number of calves was calculated by productivity rates entered into the model, rather than being entered directly as a parameter.

10. We estimated the number of adult male and female caribou harvested from the hunter license returns. Yearling harvest was estimated at a rate of 5% of the total number of animals harvested (G. Luther, Wildlife Division, DEC). The 2011 harvest estimates were estimated based on the success rates from the 2010 license returns, as the 2011 data are not yet available (G. Luther, Wildlife Division, DEC). We used the estimated number of male and female animals harvested in 2011 for the 2011-2030 projections (i.e. harvest numbers for each year of the 19 year projections were held constant at 2011 levels).

11. The number of iterations per simulation was set at 1000.

Data used to parameterize the model for all three herds and island-wide are provided in Table 1.

Table 1: Input data (± SD) for the *PVA-VORTEX* model used to project insular Newfoundland caribou populations for the 2011-2030 period.

Herd	**Most recent census**	**Initial pop. Size**	**2011 pop. estimate[1]**	**% males in breeding pool**	**Productivity (%) (2009-11)**	**Historical calf survival (%) (1989-89)**	**Current survival (%)**		**Total harvest[3]**	
							Adult (2008-10)	**Calf (2007-09)[2]**	**Male**	**Female**
La Poile	2011	4200 ± 339	4200	58.2	83.8 ± 5.5	47.1	88.6 ± 3.2	33.4 ± 4.6	55	14
Middle Ridge	2010	8814 ± 463	8668	56.2	83.0 ± 5.1	49.4	91.2 ± 3.9	25.5 ± 6.1	82	17
Northern Peninsula	2008	5811 ± 346	6188	59.9	72.5 ± 3.9	46.3	91.1 ± 8.9	38.1 ± 6.4	102	14
Insular Newfoundland	2008	39,000	36,200	57.7	76.1 ± 4.4	48.7	89.8 ± 3.5	30.9 ± 5.2	477	100

[1] Determined by projecting population size forward from the most recent census to 2011 using PVA modeling.
[2] 2010 MARK estimate of calf survival was not used because of high rate of collar slippage which likely caused underestimated calf survival for this year; 2011 estimate was not available.
[3] Harvest numbers for 2011 were estimated based on reported harvest from 2010 hunter license returns. See bullet 10 on page 5 for a more detailed explanation of harvest input in the *VORTEX* model.

2.3 Model Validation

We tested the predictive accuracy of the *VORTEX* model to determine if it was a valid approach for projecting the abundance of insular Newfoundland caribou populations. Backcasting, we parameterized the model with average historical insular Newfoundland data (1979-1997 and 1994-2010) and compared the modeled population trajectories to known results based upon aerial population censuses.

We used mean island-wide (1979-1997 and 1994-2010) rates of calf survival, and productivity for these validation tests based on herd composition data. All adult survival rates were based on telemetry data. Estimates of calf survival were based on herd composition data for the validations, as the more rigorous telemetry based MARK estimates were not available for this historical time period. Calf survival was calculated from iterative spring (calving season) and fall/winter herd composition surveys according to:

$$\text{Calf survival} = \frac{\text{calves per 100 does (fall or winter)}}{\text{productivity rate (spring)}}$$

where calves per 100 does was determined from fall or winter herd composition surveys and productivity was determined from the previous spring herd composition surveys. Census data for all years (1979-1997 and 1994-2010) and all individual herds were used to calculate the insular Newfoundland population trajectory (field trajectory). Missing years were estimated using linear interpolation (G. Luther, unpublished data). Once the interpolation was completed for all individual herds, population estimates were summed across all herds to obtain yearly insular Newfoundland population estimates.

Two PVA-generated trajectories (calf survival calculated using fall or winter recruitment estimates) were compared graphically to the insular Newfoundland field trajectory (**Fig. 2**). Both simulated trajectories provided a reasonable fit to field data but a much better fit was obtained when winter recruitment estimates were used to calculate rates of calf survival in the 1979-1997 comparison **(Fig. 2a)**. Fall and winter recruitment rates produced comparable trajectories in the 1994-2010 simulation; both fit the census data very well. We concluded that the *VORTEX* model was a valid approach to assess the probable fate of Newfoundland caribou.

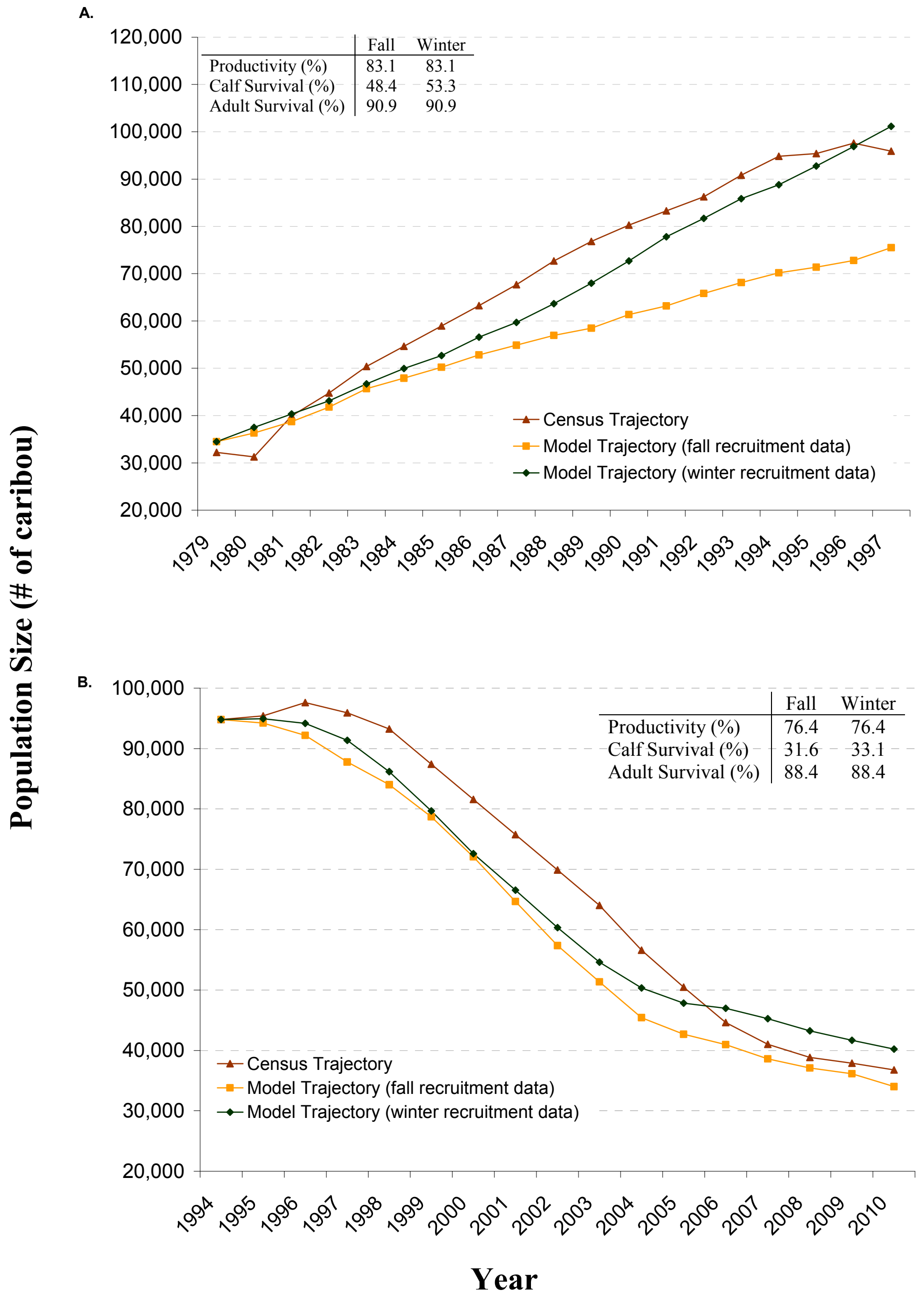

Figure 2: Comparison of VORTEX and census-based trajectories of the insular Newfoundland caribou population from a) 1979-1997 and b) 1994-2010 using calf survival calculated from both fall and winter recruitment data.

2.4 Model Simulation

2.4.1 Population Trajectories

Population surveys have been conducted for all major herds at least once since 2008. We projected each herd's population size from the year of its most recent survey to 2011 using PVA modeling in order to obtain a starting population estimate based on demographic data for 2011 onward. We then used these 2011 herd specific estimates to determine a total island population estimate for all Newfoundland herds for 2011. After obtaining a 2011 population estimate for all individual herds and for insular Newfoundland, we used the simulation model to project population dynamics under three different scenarios. All three scenarios were projected forward to year 2030.

The three scenarios were as follows:

- **Scenario 1- Current conditions continue.**
  The model was parameterized with current demographic and harvest rates and assumed these remained constant over the 2011-2030 simulation period.

- **Scenario 2- Elimination of legal harvest.**
  All demographic parameters remained the same as in Scenario 1, except the loss of individuals due to legal hunting was assumed to be zero.

- **Scenario 3- Improved calf survival.**
  All demographic and harvest parameters remained the same as in Scenario 1, except calf survival rates were increased using herd-specific average (Heisey-Fuller) survival rates (based on radio-telemetry) measured during the pre-decline population growth period (1980-89).

We compared trends in population size, population growth rate, and probability of extinction (time to extinction) between scenarios and among herds. *VORTEX* outputs data for each variable as the mean ± SD of the 1000 iterations run for each simulation. Probability of extinction was equivalent to the number of iterations that became extinct per total number of iterations. *VORTEX* calculated stochastic population growth as the exponential rate of increase (r). We converted r to lambda (λ) the annual rate of change, where $\lambda = e^r$.

When,

$\lambda=1$, the population is stable
$\lambda>1$, the population is increasing
$\lambda<1$, the population is decreasing.

2.4.2 Minimum Rates of Calf Survival Required for Population Stability

In addition to assessing the likely influence of improved calf survival (using historical pre-decline annual survival means) on population projections, we used PVA to determine the minimum rates of calf survival needed for population stability for each herd, and island-wide. To do so, we ran iterative simulations with varying rates of calf survival (25-55%) and assessed the impact on population growth rate (λ).

3. RESULTS

3.1 Population Size, Population Growth Rate (λ) and Probability of Extinction

<u>Insular Newfoundland</u>

Under current demographic conditions, the insular Newfoundland caribou population size was projected to decline from year 2011 to 2030 (**Fig. 3**) at an average rate of 5.1% per year (**Fig. 4**; λ=0.949 ± 0.012). The population size also declined, albeit at a slower rate (3.5%), when legal harvest was eliminated (**Fig. 4**; λ=0.965 ± 0.012). However, increased rates of calf survival (pre-decline average of 48.7% from 1980-89 data) resulted in an increase in population size from approximately 36,200 in 2011 to approximately 65,300 animals in 2030 (**Fig. 3**). For this scenario, population size increased at an average annual rate of 2.9% per year (**Fig. 4**; λ=1.029 ± 0.013). Probability of extinction by 2030 for the combined insular Newfoundland population was zero for all three scenarios.

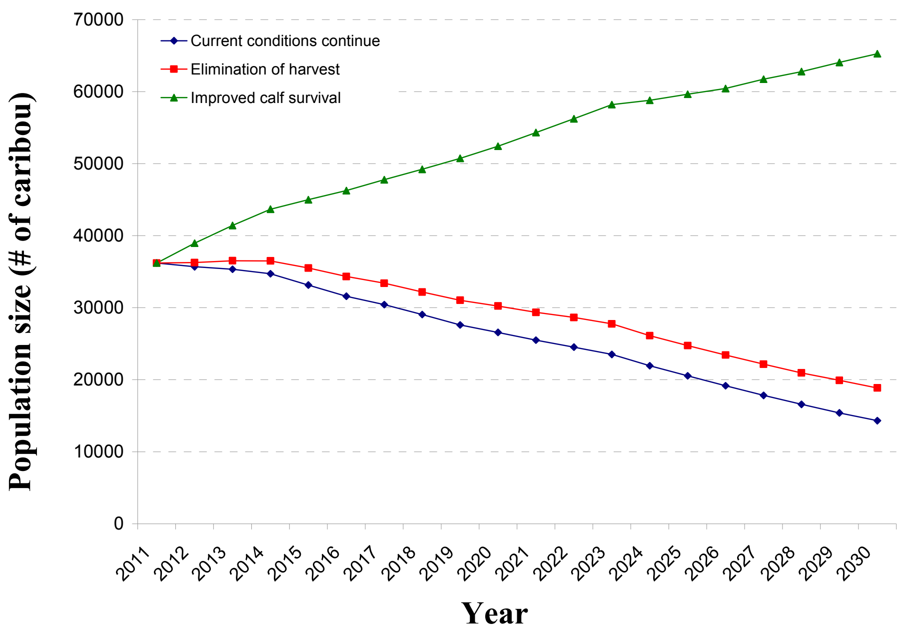

Figure 3. Projected population size for the insular Newfoundland caribou population based upon three prescribed scenarios.

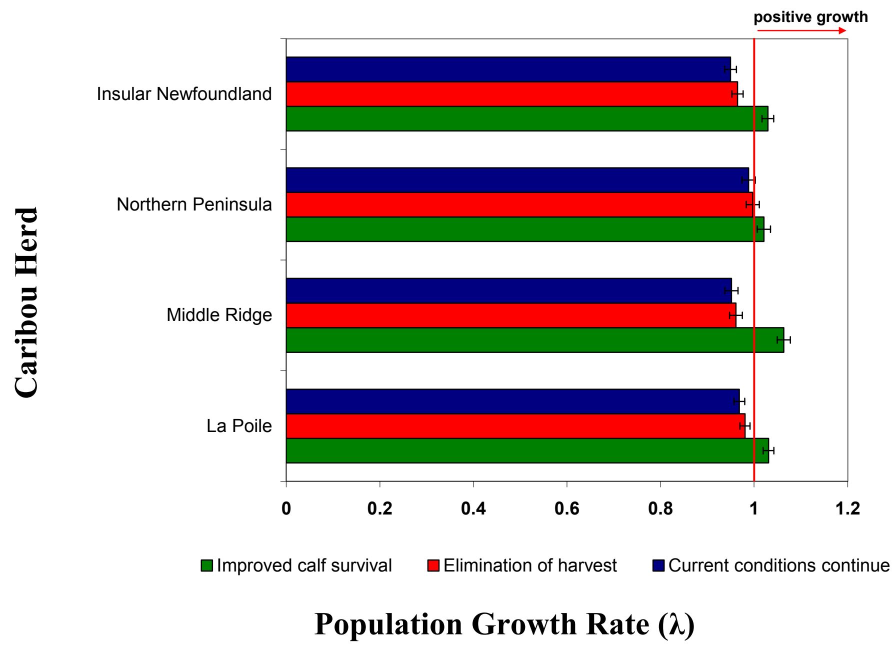

Figure 4. Projected population growth rates (λ ± 95% CI) for three major caribou herds and the combined insular Newfoundland population based upon three scenarios. All simulations were run from 2011-2030. Red vertical lines indicate population stability. Bars represent 95% confidence intervals for variation around the mean lambda value based upon 1000 iterations of the model.

Individual Herds

Population size of each herd declined under current conditions and with elimination of legal harvest, and population size of all herds increased with the improved calf survival rates (**Fig. 5**). Although general trends in population size (increase/decrease) within and between scenarios were comparable among the herds, their population growth rates varied (**Fig. 4**). Under Scenario 1, current conditions, only the Northern Peninsula herd was projected to have a population growth rate with confidence intervals which included the possibility of population stability by 2030 (**Fig. 4**; λ=0.988 ± 0.014). For La Poile and Middle Ridge, population size decreased at rates of 3.2% and 4.9% per year respectively between 2011 and 2030 (**Fig. 4**; La Poile λ=0.968 ± 0.011 and Middle Ridge λ =0.952 ± 0.014).

While the elimination of legal harvest (Scenario 2) was not sufficient to halt or reverse the projected decline for the herds (**Fig. 4**), it did slow the rate of decline for each herd. With harvest eliminated the population growth rates for the La Poile, Northern Peninsula, and Middle Ridge caribou herds increased by 1.2%, 0.9%, and 0.9% per year respectively compared to Scenario 1.

Increased rates of calf survival (Scenario 3, **Table 2**) were sufficient to increase population growth rate and population size for all herds (**Fig. 4**). The average annual rates of increase varied between 2.0% and 6.3%. The probability of extinction by 2030 was zero for all herds under all scenarios.

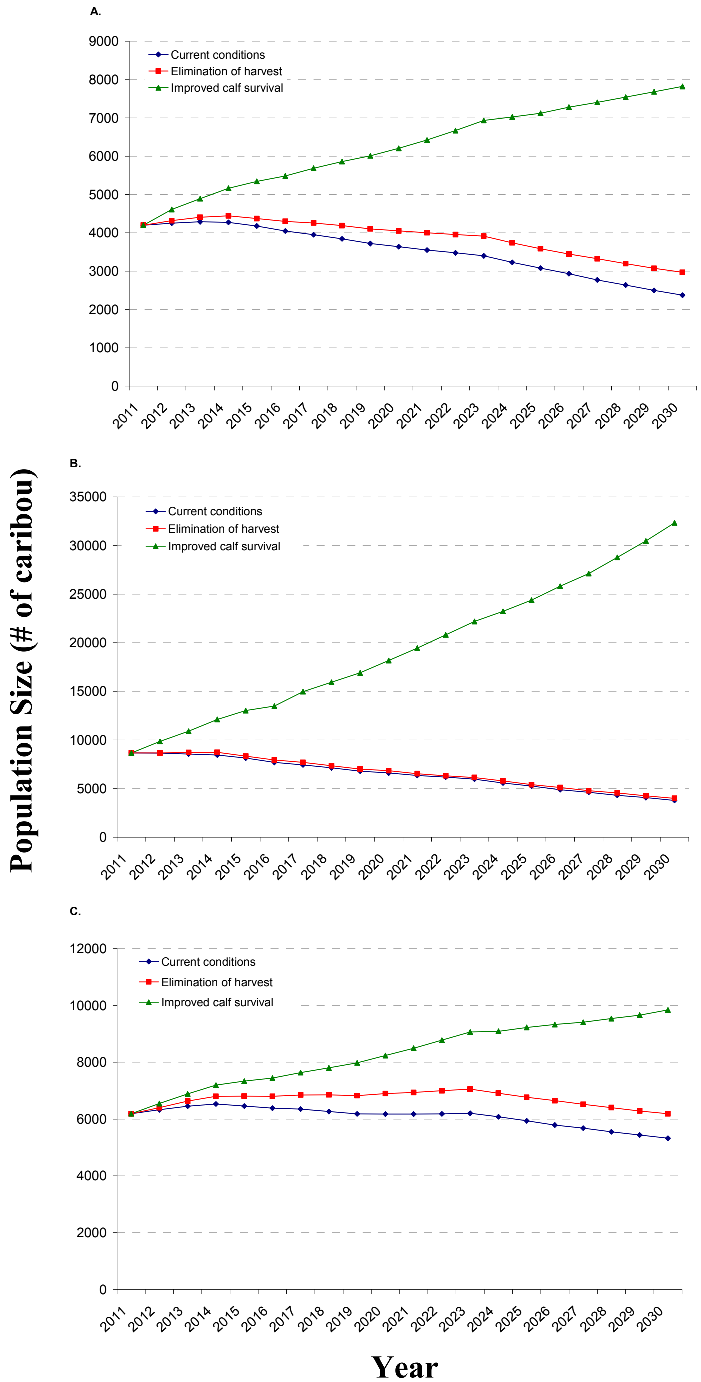

Figure 5. Projected population sizes[2] (2011-2030) for three Newfoundland caribou herds: (A) La Poile (B) Middle Ridge and (C) Northern Peninsula based upon three scenarios.

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[2] Note that in some cases the output for the improved calf survival scenario does not reasonably project the size of the herds, as the model assumes constant exponential growth up to the carrying capacity, which is set by the user. The upper limit for the size of each herd is not known at this time, thus it has not been incorporated into the simulations. As such, we provide projected populations without inclusion of a carrying capacity; and consequently there is no specified upper limit that truncates the numbers of individuals in the herd/population. Since natural populations do not increase indefinitely, the final output, in terms of population size, may be larger than can be supported by a particular herd. Nevertheless, the mean growth rates for the projections provide important information with regards to population viability.

3.2 Minimum Rates of Calf Survival Required for Population Stability

Our analyses indicated that pre-decline (historical) rates of calf survival were sufficient to halt and reverse the population declines projected under current conditions for each herd (Scenario 1). However, for management purposes we were interested in obtaining estimates of the *minimum* calf survival that would be needed to halt the decline and to stabilize caribou populations on the island (all other demographics being held at current levels). For the insular Newfoundland population as a whole, survival rates of 40-45% projected 95% confidence intervals that bounded λ=1, indicating that the population may stabilize at these rates (**Fig. 6**). Thus, the minimum calf survival rate required for population stabilization from 2011-2030 was in the range of 40-45%. The population size started to increase when calf survival exceeded 45% (95% confidence intervals no longer included, but exceeded λ=1).

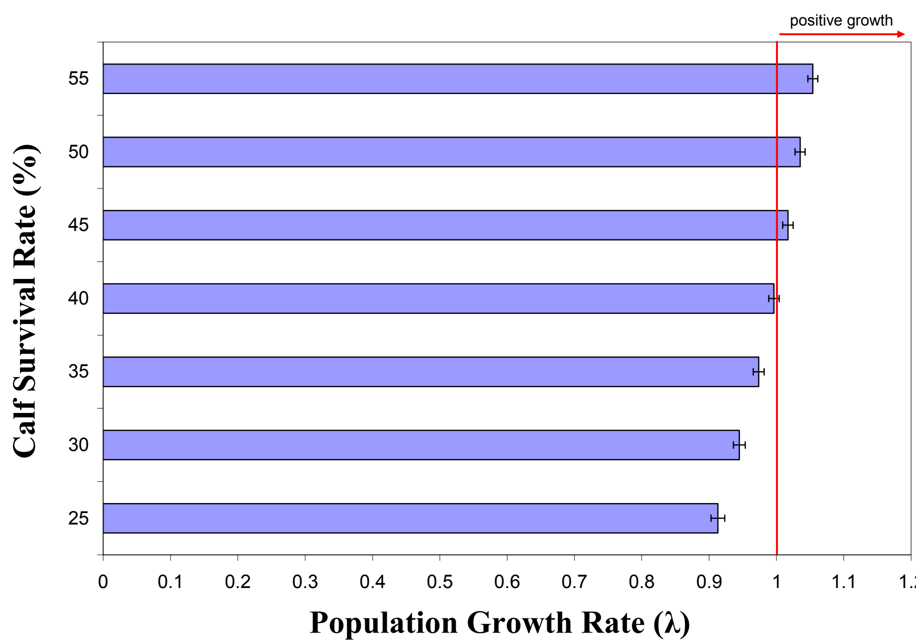

Figure 6. Relationship between calf survival and population growth rate (λ ± 95% CI) for the insular Newfoundland caribou population. Red vertical line indicates population stability. Bars represent 95% confidence intervals for variation around the mean lambda value based upon 1000 iterations of the model.

Minimum calf survival rates needed for projected population stability from 2011-2030 were similar for the three individual herds. The upper limits of these minimum rates were lower than the historical averages for all herds **(Table 2)**.

Table 2. A comparison of the minimum average calf survival rates (%) required to attain population stability (λ=1) (based on 20 year PVA projections) and the rates of calf survival observed historically (1980-89) for three major insular Newfoundland caribou herds.

Herd	Minimum Calf Survival Rate Required for Population Stability (λ=1)	Historical Average (1980-89) Calf Survival Rate
La Poile	40-45%	47.1%
Middle Ridge	35-40%	49.4%
Northern Peninsula	40-45%	46.3%

4. DISCUSSION

Woodland caribou populations throughout North America have declined over many decades, a pattern that has likely increased in recent years (Bergerud 1974; Gray 1999; Vors et al. 2007; Vors and Boyce 2009). The most recent COSEWIC assessment for woodland caribou (COSEWIC 2002) designated four of five populations in Canada as Endangered, Threatened or Special Concern. While the Newfoundland population's status was designated as *Not at Risk* in 2002, we now know that many of the island herds were actually declining at that time, and have declined further and dramatically since then. These demographic trends may result in the insular Newfoundland populations being designated *At Risk* during the next COSEWIC review, scheduled for completion by 2013. Should this occur, there will be significant implications with respect to natural resource development, sustainable use of the caribou resource, and recreational access to areas occupied by these herds.

We used population viability analysis (PVA) to predict the fate of Newfoundland woodland caribou over the next 20 years. PVA indicated that the caribou herds modeled will continue to decline *if current demographic conditions persist* (Scenario 1). Under this scenario, herd projections to the year 2030 indicate declines ranging from 1.2% to 4.8% annually (λ=0.988-0.952). The combined insular Newfoundland population was also projected to decline under this scenario (λ=0.949; 5.1% annual decline). Furthermore, even when hunting mortality was eliminated in the model, the island population and each individual herd continued to decline, albeit at slower rates.

Overall, rates of decline projected by PVA (under current conditions) are consistent with those estimated from recent population censuses (~3% average annual decrease in the combined insular Newfoundland population since 2008; G. Luther, unpublished data). The projected decline under current conditions is supported by data from the 2011 population census conducted on the south coast of Newfoundland, which indicated a 10.7% overall rate of decline for the combined south coast herds over three years from 2007-2011, an average annual rate of 2.8% (G.

Luther, unpublished data). The population census planned for the Northern Peninsula herd in winter 2012 will provide an additional test of these projections.

The PVA-projected annual rate of decline for the Middle Ridge herd under current conditions (4.8 ± 1.4%) was inconsistent with recent population census results for this herd which suggested the population may have stabilized from 2006-2010 (2006 = 8748 ± 331; 2010= 8814 ±761). While we caution against concluding the population decline in the Middle Ridge herd has halted based on a single census estimate, recent herd composition surveys on the Middle Ridge herd have indicated an improvement in calf recruitment in this population. However, current recruitment rates (2009-2011 average percent calves= 10.8 ± 4.3) remain significantly lower that those observed in the 1980's (1980-1990 average percent calves = 22.0 ± 3.0) when the population was expanding and are likely insufficient to sustain the population at current levels. That being said, it is possible that overall rates of calf survival for the Middle Ridge herd used in the PVA (and estimated from radio-collared animals) may be biased by the extremely low rate of survival of calves from the southern calving ground of the Middle Ridge herd (S. P. Mahoney, unpublished data). In 2011, we increased our sample size of collared calves on both the northern and southern calving grounds of Middle Ridge, in part, to improve the precision of our estimates of calf survival for this herd. Results are not yet available.

Assuming that current rates of productivity, adult survival and harvest remain constant, PVA revealed that minimum calf survival rates between 40% and 45% are needed to attain population stability. These projected rates are comparable to those observed during a period of population growth for Newfoundland caribou (Mahoney 2000) when rates of increase averaged about 8% per annum over a greater than 30 year period and therefore are probably reasonable management targets.

Model Limitations

Prudent interpretation of these *VORTEX* PVA results must be applied. Many factors can influence population fluctuations, including environmental and genetic variation, catastrophic events, the chance results of probabilistic events (such as sex determination, location of mates, breeding success and survival), habitat loss and human disturbance, and interactions among theses factors (Gilpin and Soulé 1986). Because many of these factors were not explicitly incorporated within the model applied here, it is obviously a simplistic representation of a more complex natural system. That being said, the *VORTEX* model effectively captured Newfoundland caribou population trends when compared with census data during periods of population growth (1979-1997) and decline (1994–2010). Still, the demographic conditions applied in the model will not remain constant to 2030, and therefore, the calculated population growth rates can only be considered best approximations. Nevertheless, these population projections do provide a framework which can be improved as new information becomes available and which can be used to test management options going forward.

Conclusions

Both the current PVA and Leslie-matrix models (Morrison et al. 2011) project continued, though reduced, rates of decline for Newfoundland caribou assuming current demographic trends continue. The most effective means to assist the island caribou populations would be to improve calf survival to a minimum of 40-45%, and possibly suspend or reduce harvest for some herds. While closure of harvest alone, currently set at less than 2% for most herds, will not be sufficient to stabilize populations, it would slow the rate of decline and thus provide some further enhancement to herds already showing improved calf survival. Regardless, further increases in rates of calf survival will be required to halt or reverse the current decline. It is uncertain whether or not calf survival can be brought up to the levels that were seen in the 1970s and 1980s; however, this demographic must be improved if the population is to recover.

Poor recruitment has been considered the proximate cause of caribou decline on the island (Mahoney and Weir 2009). High rates of calf mortality, resulting principally from predation by bears, coyotes, lynx and eagles in the first two months of life, is the mechanism responsible for low recruitment (Trindade et al. 2011). Therefore, any action which appreciably reduces predation pressure on calves will assist in population recovery.

However, the ultimate mechanisms underlying the Newfoundland caribou population decline, and the increased vulnerability of calves to predation in recent years, are not fully understood. Acquiring this knowledge is a major focus of the Caribou Strategy (2008-2013). Density-dependent responses in caribou body size and vigor, including decreased adult female body size, decreased birth weight, and decreased male antler size have been observed and may be linked to forage competition and/or a decline in forage quality (Mahoney et al. 2011; Mahoney and Weir 2009). Certainly, decreased birth rates may have predisposed calves to higher predation rates (Bergerud et al. 2008). If so, the greater than 60% decrease in abundance of caribou over the past decade may lead to improvements in caribou body size and condition through reduced forage competition. Indeed, such improvements may already be occurring and may well be related to the increase observed in rates of calf survival since 2007 (data presented in Lewis et al. 2011). If so, we might anticipate continued upward trends in recruitment leading to populations stabilizing and then increasing. However, the timeframe required for these “natural” dynamics to run their course may exceed the limits of social acceptance, in which case management action to reduce or manipulate predators may be required. Furthermore, there is no guarantee that observed improvements in calf survivorship will continue. What is certain is that without improvement in calf survival by natural dynamics or management intervention to manipulate predators, Newfoundland caribou face an uncertain future.

5. LITERATURE CITED

Akçakaya, H. R. and Sjögren-Gulve, P. (2000). Population viability analysis in conservation planning: an overview. *Ecological Bulletins*, 48, 9-21.

Bergerud, A.T. (1974). Decline of caribou in North America following settlement. *Journal of Wildlife Management*, 38, 757-770.

Bergerud, A.T., Luttich, S. N., and Camps, L. (2008). The Return of Caribou to Ungava. Montreal, Quebec. McGill-Queens University Press.

Brook, B. W., O'Grady, J. J., Chapman, A. P., Burgman, M. A., Akçakaya, H. R., and Frankham, R. (2000). Predictive accuracy of population viability analysis in conservation biology. *Nature*, 404, 385-387.

Boyce, M.S. (1992). Population viability analysis. *Annual Review of Ecology and Systematics,* 23, 481-497.

COSEWIC (2002). COSEWIC assessment and update status report on the woodland caribou *Rangifer tarandus caribou* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 98 pp.

Decesare, N. J., Whittington, J., Hebblewhite, M., Robinson, H., Bradley, M., Neufield, L. and Musiani, M. (2010). The role of translocation in recovery of Woodland Caribou populations. *Conservation Biology*, 25, 365-373.

Gilpin, M. E. and Soulé, M.E. (1986). Minimum viable populations: processes of species extinction. In M. E. Soulé (Ed), *Conservation biology: the science of scarcity and diversity* (pp. 19-34). Sunderland MA: Sinauer Associates.

Gray, D. R. (1999). Updated status report on the woodland caribou in Canada. Prepared for the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) by Grayhound Information Services, Metcalf, Ontario, Canada.

Hatter, I. W., Quayle, J., and Ramsay, L. R. (2004). A conservation status assessment of the Mountain Caribou ecotype based on IUCN Red List criteria. Proceedings of the Species at Risk 2004 Pathways to Recovery Conference. Victoria, B.C.

Lacy, R. C. (1993). *VORTEX*: a computer simulation model for population viability analysis. *Wildlife Research,* 20, 45-65.

Lacy, R. C., Borbat, M., and Pollak, J. P. (2003). *VORTEX*: A stochastic simulation of the extinction process, Version 9.50. Chicago Zoological Society, Brookfield, Illinois.

Lewis, K. P., Weir. J. N., Luther, G., Mahoney, S. P., Morrison, S., Randell, H., and Soulliere, C. (2011). Woodland caribou population monitoring: resolving population surveys, population monitoring, and demographic metrics. Poster presented at the 2011 Arctic Ungulate Conference, Yellowknife, N.W.T (August 2011).

Mahoney, S. P. 2000. A synthesis and interpretation of the biology of woodland caribou on the island of Newfoundland. Department of Environment and Conservation, Government of Newfoundland and Labrador, St. John's, NL.

Mahoney, S. P. and Weir, J. N. (2009). Caribou data synthesis- progress report. Overview of the status of woodland caribou in insular Newfoundland: Research methodology, results, interpretations and future projections. Sustainable Development and Strategic Science Government of Newfoundland and Labrador, St. John's, NL. Technical Bulletin No. 001.

Mahoney, S. P., Weir, J. N., Luther, G., Schaefer, J. A. and Morrison, S. F. (2011). Morphological change in Newfoundland caribou: Effects of abundance and climate. *Rangifer*, 31, 21-34.

Morrison, S., Weir, J. N., Mahoney, S. P., and Luther, J. G. (2012). Projection of woodland caribou populations in Newfoundland. An application of Leslie-matrix population models to predict the future of Newfoundland caribou herds. Sustainable Development and Strategic Science, Government of Newfoundland and Labrador, St. John's, NL.

Trindade, M., Norman, F., Lewis, K. P., Mahoney, S. P., Weir, J. N, and Soulliere, C. (2011). Caribou calf mortality study. A summary and analysis of the patterns and causes of caribou calf mortality in Newfoundland during a period of rapid population decline: 2003-2007. Sustainable Development and Strategic Science, Government of Newfoundland and Labrador, St. John's, NL. Technical Bulletin No. 002.

Vors, L., and Boyce, M. (2009). Global declines of caribou and reindeer. *Global Change Biology,* 15, 2626-2633.

Vors, L., Schaefer, J. A., Pond, B. A., Rodgers, A. R., and Patterson, B. R. (2007). Woodland caribou extirpation and anthropogenic landscape disturbance in Ontario. *Journal of Wildlife Management,* 71, 1249-1256.

White, G. C. and K. P. Burnham. (1999). Program MARK: Survival estimation from populations of marked animals. *Bird Study*, 46 (Supplement), 120-138.

Wittmer, H. U. (2004). Mechansims underlying the decline of Mountain Caribou (*Rangifer tarandus caribou*) in British Columbia. PhD thesis. Univ. of B.C. 104 pp.

Wittmer, H. U., Ahrens, R. N. M., and McLellan, B. N. (2010). Viability of mountain caribou in British Columbia, Canada: effects of habitat change and population density. *Biological Conservation*, 143, 86-93.

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