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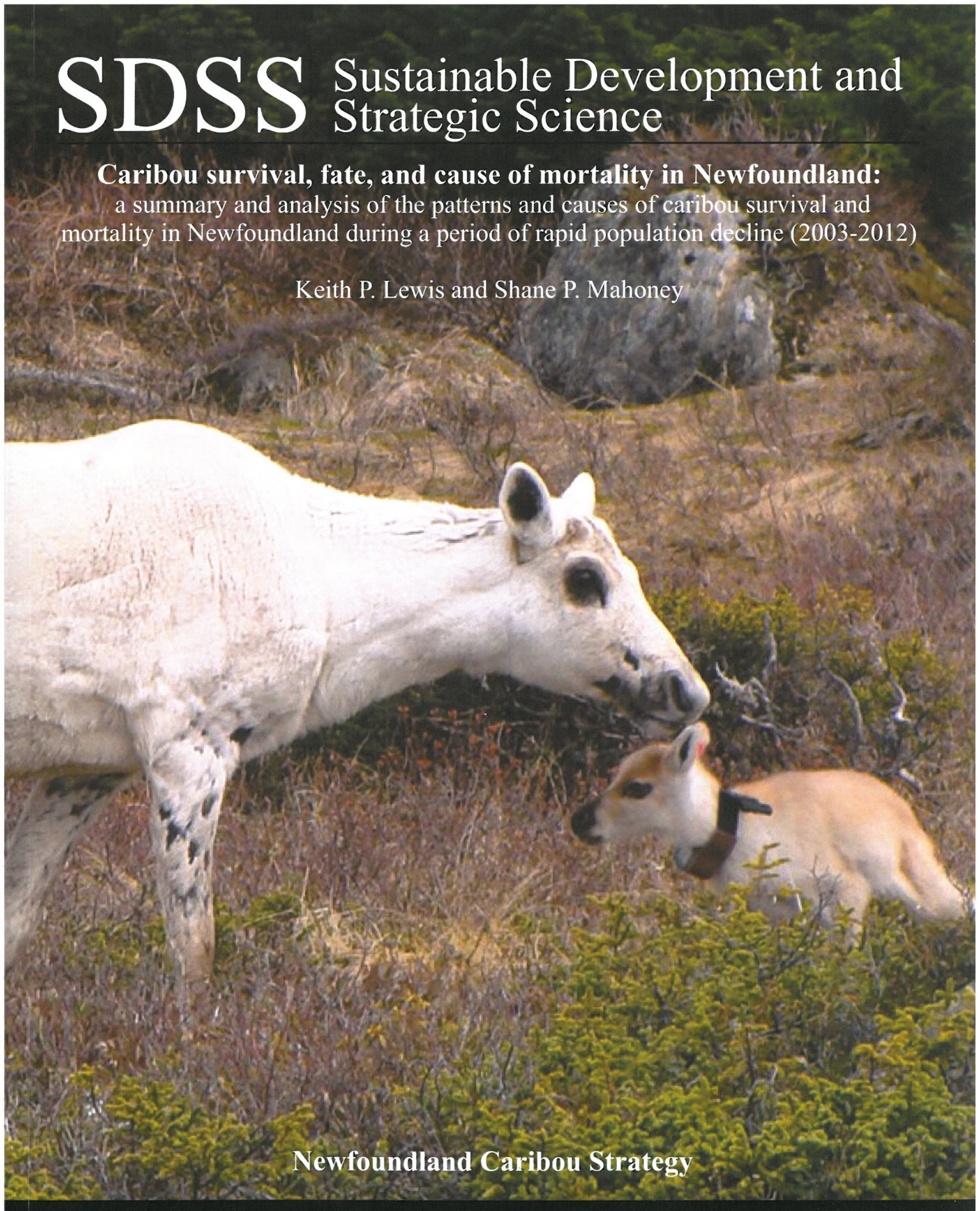
Caribou survival, fate, and cause of mortality in Newfoundland:

a summary and analysis of the patterns and causes of caribou survival and mortality in Newfoundland during a period of rapid population decline (2003-2012)

Keith P. Lewis and Shane P. Mahoney



Newfoundland Caribou Strategy

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Photo credits: June Swift (front) and Shane Mahoney (back)

Caribou Survival, Fate, and Cause of Mortality in Newfoundland

A summary and analysis of the patterns and causes of caribou mortality in Newfoundland during a period of rapid population decline (2003-2012)

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February 2014
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Executive Summary

Caribou (*Rangifer tarandus*) populations are declining globally, and all woodland caribou in Canada are designated as "At-Risk" except for the Newfoundland population. However, Newfoundland's caribou population has declined from nearly 94,000 animals in the late 1990s to just under 34,000 in 2012 and a change in the "At-Risk" status from the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is very possible.

The *Caribou Data Synthesis* and *Calf Mortality Study* showed that low calf survival rates were the main demographic cause of this decline. These studies form the foundations of the *Newfoundland Caribou Strategy,* a 5-year study that sought, in part, to determine factors underlying low calf survival rates and is the subject of this report.

Survival rates can be influenced by many different factors or combinations of these factors, such as the size or density of the population. A higher population density often attracts more predators, increases rates of disease, and decreases the amount of food per individual. When a demographic rate (e.g., survival) changes with population density, it is termed density dependent. Conversely, climatic factors such as a harsh winter can influence survival independent of density. Both density-dependent and density-independent factors can differentially influence a population depending on its phase, i.e., whether the population is increasing or decreasing, and are termed phase dependent.

This study expands upon previous work and is one of the largest of its kind in the world in terms of the numbers of animals collared, reflecting the long-term commitment of the Government of Newfoundland and Labrador to caribou management and conservation. The following conclusions are based on data gathered from 2003 to 2012 in five different study areas in Newfoundland as part of the *Calf Mortality Study* and the *Newfoundland Caribou Strategy*:

1. Caribou survival was relatively constant from 1980 to 1997 during the population increase (ca. 66%). After a gap in telemetry studies from 1998 to 2002, calf survival rates were extremely low (ca. 7%). From 2003 to 2012, calf survival generally increased, but the survival rate never reached the levels of the 1979 to 1997 period and the population continues to decline, albeit at a considerably lessened rate (hereafter, results are for 2003–2012 unless noted otherwise).

2. Calf survival decreased as population size (density) increased, i.e., a density-dependent relationship. Given the relatively constant survival during the population increase, this suggests a phase-dependent influence on survival rates, i.e., that population size must exceed some threshold before it influences calf survival. Further, most calves collared as neonates die within the first 3 months, and especially the first 5–6 weeks. Heavier calves had a higher probability of surviving than lighter calves.

3. Climate had little influence on caribou calf survival. This is perhaps not surprising given that Newfoundland is a relatively mild climate for caribou and there are no over-winter predators of significance, i.e., caribou are not likely to die from extreme winter events and there are no wolves (*Canis lupis*) or other predators that hunt more efficiently as snow depth increases.

4. Survival was high and relatively constant for over-winter calves (calves approximately 6 months to 1 year old), as well as yearlings (12–24 months), 2-year-olds (24–36 months), and adults (> 36 months). Changes in the survival rates of these older cohorts must be carefully monitored as they can have more profound population-level influences than changes in calf survival rates.

5. Predation was the main cause of calf mortality (ca. 90%). A greater percentage of calves suffered predation during the population decrease than during the increase.

6. Predation was less important as a cause of mortality for older cohorts. Of the few animals that died, roughly half of the older calves died because of predation and one-quarter of the adults did.
7. Black bear (*Ursus americanus*) and coyote (*Canis latrans*) were the dominant predators. Predation by lynx (*Lynx canadensis*) and Bald Eagles (*Haliaeetus leucocephalus*) was much less common. Low calf predation by lynx is a departure from earlier findings.
8. Although coyote are a common predator, it is difficult to determine whether they are simply killing calves that other predators might have taken anyway. Therefore, it is difficult to determine their role in the population decline. However, it is clear that there is little evidence to support anecdotal reports of high levels of predation on older caribou, especially, during the winter.
9. Caribou calf survival has not yet reached the level where the caribou population will stabilize. This may mean a change to "At-Risk" under COSEWIC and have implications for development in the province.
10. The conclusions of this study could not have been realized without the *Caribou Data Synthesis*, the *Calf Mortality Study*, and the *Newfoundland Caribou Strategy* and underscores the importance of long-term data (1979–2012) to research and management.

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Introduction

Survival rate is a critical demographic variable that often varies by species and amongst age classes. Variation in juvenile survival plays a predominant role in the population dynamics of large herbivores, and juvenile survival tends to be more sensitive to density-dependent (intrinsic) factors than adult survival (Gaillard et al., 1998). However, extrinsic factors, such as climate, have been shown to explain variation in the recruitment of caribou calves in a predator-limited system (Hegel et al., 2010) where density-dependent factors have a relatively weak influence compared to the systems without large predators (Wang et al., 2009). The interaction between density dependence and large-scale climatic phenomena (e.g., the North Atlantic Oscillation - NAO) has also been shown to simultaneously influence phenotypic and demographic traits of northern ungulates (Post and Stenseth, 1998, Post et al., 1999, Post and Stenseth, 1999). Mechanistically, this interaction is driven by snow depth that is correlated with the NAO. Increased snow depth improves hunting efficiency by wolves (*Canis lupis*) which are the main predator of most northern ungulates (Post et al., 1999).

However, caribou (*Rangifer tarandus caribou*) in Newfoundland do not have a year-round, large predator; wolves were eliminated from the island almost 100 years ago, and low juvenile survival of caribou has been shown to be the main demographic factor underlying an approximately 15-year-long population decline (ca. 96,000 to 33,000; Weir et al., 2013). Low juvenile survival is largely due to predation by black bears (*Ursus americanus*) and non-native coyotes (*Canis latrans*) in the first few months of a calf's life (Mahoney and Weir, 2009, Trindade et al., 2011).

A number of factors associated with the caribou population decline indicate a density-dependent response including morphology (Mahoney et al., 2011), changing diet (unpublish. data), and increased tooth wear (Weir et al., 2013). However, while calf survival was consistently high from 1979 to 1997, a period of sustained population growth before the decline, a density-dependent response of juvenile calf survival has not been analytically demonstrated nor have other hypotheses been tested (Table 1). Seasonal climate could influence calf survival through a variety of mechanisms. Severe winter weather or poor growing conditions in the spring could influence female body condition and subsequent birth weights. Alternatively, seasonal climate leading to poor foraging conditions after birth could result in poor calf development and survival (peak lactation period; Hegel et al., 2010) or insect harassment during the summer could lead to low calf survival (Weladji et al., 2003, Hegel et al., 2010). Plant phenology, as measured by the Normalized Difference Vegetation Index (NDVI), has been shown to predict caribou calf body mass (Pettorelli et al., 2005a,b), which in turn, can influence survival (Jenkins and Barten, 2005).

In response to the declining caribou population, the Government of Newfoundland and Labrador announced $15.3 million in funding for a 5-year *Caribou Strategy* in February 2008. The *Caribou Strategy* was a comprehensive program to inform caribou management in Newfoundland by improving ecosystem-level knowledge and involved collaring and subsequently monitoring newborn (neonates) and 6-month-old calves (to understand over-winter survival and mortality; termed over-winter calves hereafter), as well as adult caribou (> 36 months). In addition, calves that survived were monitored opportunistically as yearlings (12–24 months) and 2-year-olds (24–36 months). This document provides an examination of multiple mechanisms underlying low neonatal survival from 2003 to 2012 (Table 1). Survival rates for older cohorts were not examined mechanistically because they are fairly constant over time. This document is part of a continuum of studies of calf survival and mortality that began over half a century ago with Thomas Bergerud (Bergerud, 1971, 1983) and were continued in 1979 with the initiation of radio-telemetry studies (Mahoney et al., 1990, Mahoney and Weir, 2009, Mahoney et al., in prep). As well, this document also updates the survival and fate of all age classes of caribou from the *Caribou Data Synthesis* (Mahoney, 2000), which includes a compilation of the survival and fate of all calves collared in Newfoundland between 1979 and 1997 and the *Calf Mortality*

Report (Trindade et al., 2011), the precursor to the *Caribou Strategy* (2003–2007). However, this work considerably expands upon these studies by documenting the survival rates and fates of older age-classes, i.e. yearlings, 2-year-olds, and adults. This work is primarily focused on the time period from 2003 to 2012, but some analyses include data from the 1979–1997 (*Caribou Data Synthesis*) period for comparison and context.

Methods

Study areas

This study was conducted on the Gaff Topsails (2003 and 2004), Mount Peyton (2003), Middle Ridge (2003–2012), La Poile (2007–2012), and the Northern Peninsula (2008–2012) caribou herds on the island of Newfoundland (Fig. 1) as part of a series of caribou research projects, i.e. the *Calf Mortality Study* and the *Caribou Strategy*. Middle Ridge, La Poile, and the Northern Peninsula are considered the main study areas while Gaff Topsails and Mount Peyton are secondary and are included as part of the survival analyses but not herd-specific summaries of calf fate (for details on these herds, see Trindade et al., 2011). Further, as the research progressed, a secondary calving ground was identified in the southern region of Middle Ridge. This calving area, Middle Ridge South, was the focus of a predator manipulation study (Gullage et al., 2014), effectively becoming a fourth main study area, and is treated as such for neonate calves. However, it is impossible to tell where an uncollared calf comes from after it leaves the calving grounds, and therefore, this designation is only meaningful for neonate calves collared on the calving grounds. In addition, this work relies on an enormous collaring effort of adult caribou by the Newfoundland and Labrador Wildlife Division on the south and west coasts and the Northern Peninsula.

Gaff Topsails

The Gaff Topsails herd range is within the Long Range Barrens Ecoregion (Fig. 2; Daaman, 1983). The region is dominated by bogs, fens, and barrens, but also includes patches of black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*) forest, commonly found in sheltered valleys (Daaman, 1983, Soulliere, 2008). The dominant shrub is sheep laurel (*Kalmia angustifolia*) but rhodora (*Rhododendron canadense*) is also common. The calving grounds are on a high plateau dominated by shrub barrens. Forestry has been prevalent in this ecoregion and overlaps the caribou summer range. Human disturbance is confined mostly to the logging roads, e.g., ATV use and cabin development.

The Gaff Topsails herd increased from a count of 720 animals in 1969 to 5,980 ± 891 animals (90% CI) in 1989, but fell to 1,893 ± 244 animals (90% CI) in 2011 (G. Luther, pers. comm.).

La Poile

The La Poile study area (11,251 km^2) overlaps three ecoregions: the Long Range Mountains Ecoregion, the Western Newfoundland Forest Ecoregion, and the Maritime Barrens Ecoregion (Fig. 2). The Long Range Mountains Ecoregion is mostly covered by heath and moss barrens, rock outcrops, with some sparse forest patches. To the west is a small band of the Western Newfoundland Forest Ecoregion, characterized by balsam fir forest with black spruce and larch (*Larix laricina*) on the wetter sites (Meades, 1990). Forestry has been prevalent in this ecoregion, but overlap with caribou range is small suggesting a minimal influence. Roads border La Poile to the west, north, and east while the area extends to the coastline in the south. Logging roads are extensive in the northern areas but communities are few. Human disturbance is minimal in the south and interior.

Table 1: Potential mechanisms relating population size, calf condition, and seasonal climate to calf survival in Newfoundland caribou. NAO = North Atlantic Oscillation, NDVI = Normalized Difference Vegetation Index.

Variable	Mechanism	Possible metrics	Reference
Density	Predation increases with caribou density, i.e., density dependence.	Population size is used as a proxy for density[1]	(Fowler, 1981, Eberhardt, 2002, Gaillard et al., 1998)
Calf size	Newborn calves are essentially defenseless against predators. Smaller calves are vulnerable for longer.	Calf mass (kg) at capture[1]	(Jenkins and Barten, 2005, Pettorelli et al., 2007)
$\text{Winter}_{\text{(t-1)}}$[2]	Winter severity, i.e. increased snow depth and lower temperatures can decrease maternal condition and calf birth weight. Increases predator hunting efficiency.	NAO (averaged over-winter months)[1]	(Post et al., 1999, Adams, 2005, Hegel et al., 2010)
$\text{Spring}_{\text{(t)}}$	Increased snow depth can limit access to predator-free sites and forage opportunities, which negatively influences maternal condition and calf survival.	Snowfall	(Bergerud and Elliot, 1986, Adams et al., 1995)
	Early growing season may equate to increased quantity or quality (high-protein) of food, better maternal condition, and greater birth mass thus improving calf survival.	$\text{Spring start}_{\text{(t)}}$[1]	(Pettorelli et al., 2005a, 2007)
	Rapid green-up will reduce the period of access to high quality forage reducing maternal condition.	Spring rate $_{\text{(t)}}$[1] = maximum slope between NDVI periods	(Pettorelli et al., 2007)
$\text{Summer}_{\text{(t)}}$	Insect harassment increases energy expenditure or reduces foraging time.	Degree-days, wind and cloud cover	(Weladji et al., 2003)
	Post-calving is a period of peak lactation and energetically costly. Summer forage conditions may influence calf growth and development.	Annual vegetative productivity of year of birth = $\text{meanNDVI}_{\text{(t)}}$[1]	(Crête and Huot, 1993, Pettorelli et al., 2007)
$\text{Summer}_{\text{(t-1)}}$	Maternal condition is influenced by summer foraging conditions prior to fall conception. Important for sustaining females through the winter leading to improved productivity, birth weight, earlier calving, and improved calf survival.	Annual productivity of year before birth = $\text{meanNDVI}_{\text{(t-1)}}$[1]	(Reimers, 1983)

[1] Indicates the metric that is being used in this study.

[2] (t) indicates year of birth, (t-1) indicates the year before birth.

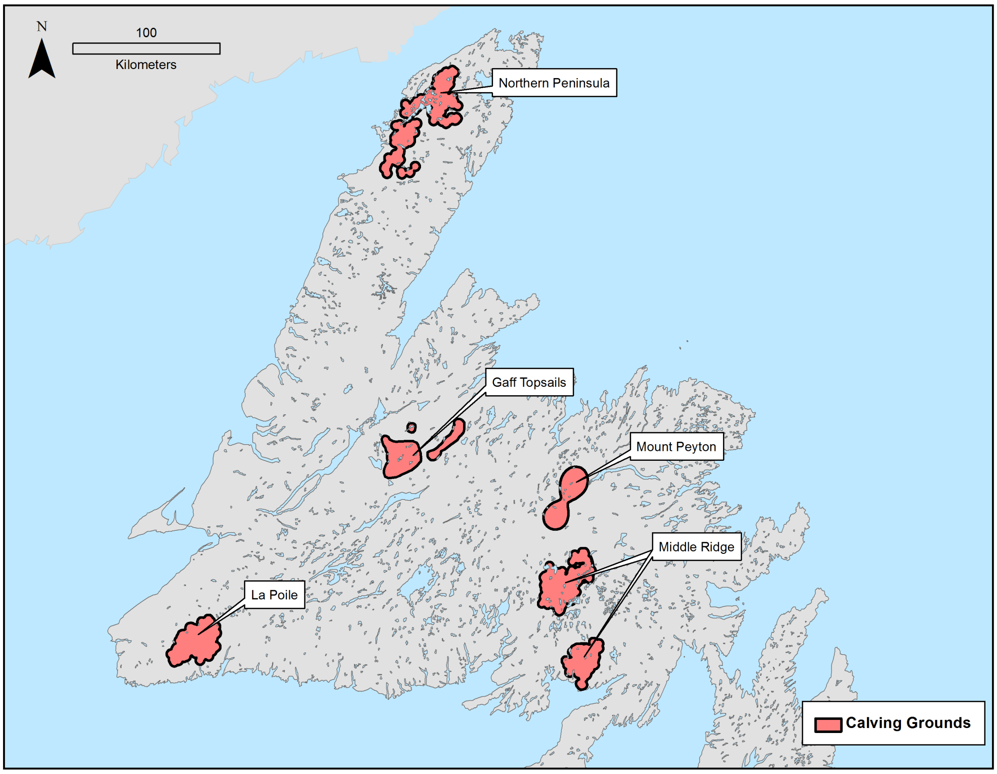

Figure 1: The location of the calving and post-calving areas for the three herds examined in the *Caribou Strategy* as well as the additional two calving areas from the *Calf Mortality Study*. Middle Ridge North and South are indicated separately.

The La Poile caribou herd increased from a count of 500 animals in 1960 to an estimated 11,210 in 1988 and fell slightly to 10,565 in 1997 (Mahoney, 2000, vol 10, pg 54). In 2008, there were an estimated 5,397 ± 867 (90% CI) animals in this herd (Callahan, 2009) but by 2011, there were 4,200 ± 642 (90% CI; G. Luther, pers. comm.).

Middle Ridge and Mount Peyton

The Middle Ridge and Mount Peyton caribou herd ranges are located within the Central Newfoundland Ecoregion to the north and the Maritime Barrens Ecoregion to the south (Daaman, 1983). The Central Newfoundland Ecoregion is heavily forested with a wet and gently rolling landscape with many lakes, streams, and raised bogs. The predominant forest type is balsam fir with a stair-step moss (*Hylocomium splendens*) and/or Schreber's moss (*Pleurozium schreberi*) ground layer. Extended dry spells result in more frequent forest fires compared with the rest of Newfoundland, resulting in a higher occurrence of black spruce and sheep laurel in these areas (Daaman, 1983).

The southern limit of these herds' distributions extends into the Maritime Barrens Ecoregion, which is a wide, gently rolling expanse of dwarf shrub heath, bogs, and fens. Lakes and ponds are numerous on these barrens. Patches of balsam fir forest occur in valleys, and stunted black spruce and eastern larch are found on the windswept barrens (Daaman, 1983). The dwarf shrub heath is composed mainly of sheep laurel, rhodora, Labrador tea (*Rhododendron groenlandicum*), low-bush blueberry (*Vaccinium angustifolium*), and crowberry (*Empetrum nigrum*). *Cladonia* spp. lichens are common. The northern and southern calving grounds typically contain more herbs, shrubs, and exposed land than the rest of the study areas.

The Middle Ridge caribou herd increased from a count of 257 animals in 1960 to an estimated 19,765 in 1995. By 2006, the number had decreased by 55.7% to 8,748 animals (Mahoney and Weir, 2009). In 2010, the herd was estimated at 8,814 ± 761 animals (90% CI; Dyke, 2009) and increased in 2012 with 10,445 ± 372 animals (90% CI). The Mount Peyton herd is fairly small in comparison with Middle Ridge. It increased from a count of 140 animals in 1952 to 1,762 animals in 1994. There were only 674 ± 86 animals (90% CI) in 2007 and 627 ± 59 animals (90% CI) in 2011 (G. Luther, pers. comm.).

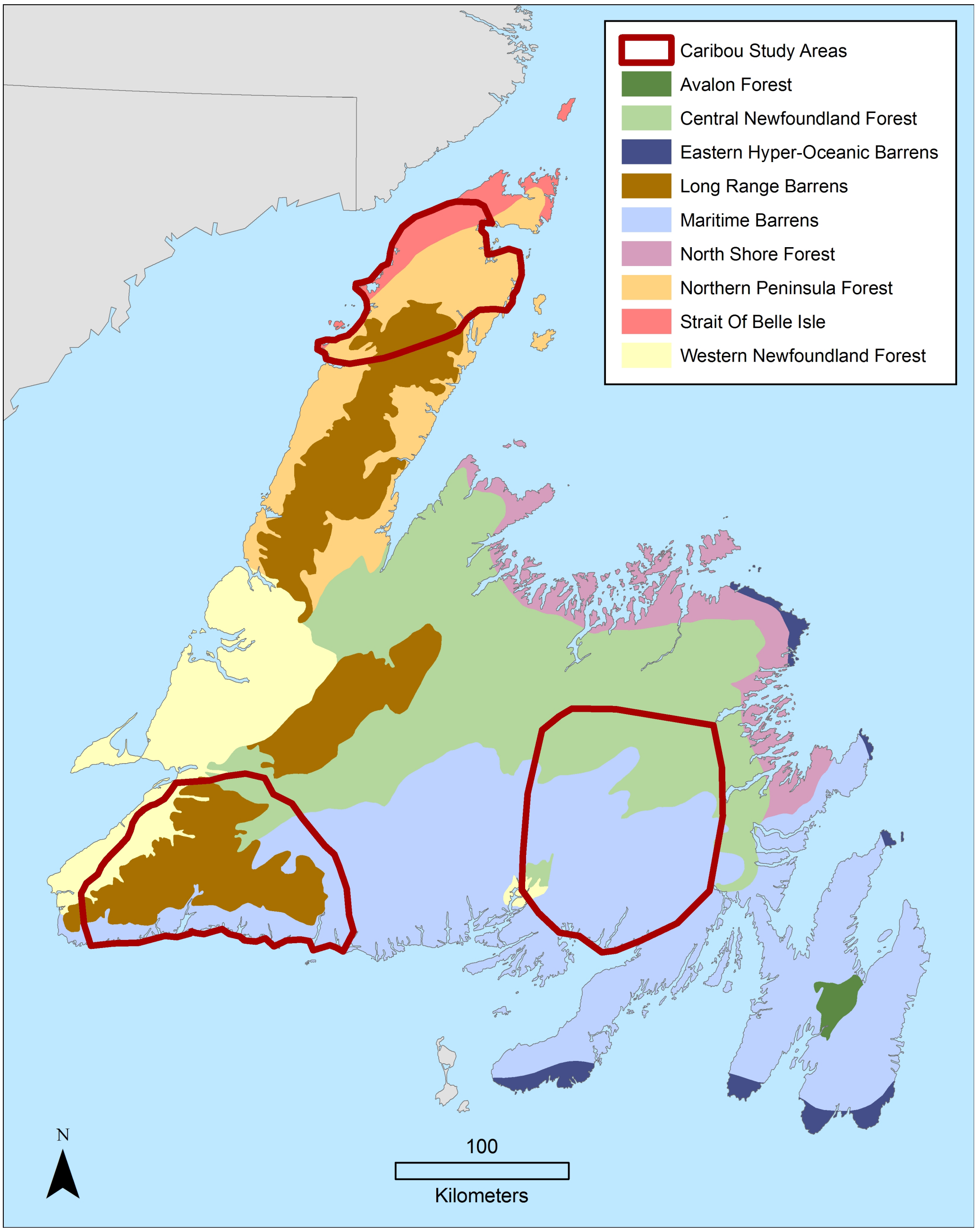

Figure 2: The ecogregions of Newfoundland and the main study areas of the *Caribou Strategy* — Middle Ridge in the east, La Poile in the west, and the Northern Peninsula in the north.

Middle Ridge study area

The Middle Ridge study area (13,369 km^2) surrounds the Bay du Nord Wilderness Area and the Middle Ridge Wildlife Reserve that cover 22% and 4.5% of the total study area, respectively. The Middle Ridge study area has two distinct calving areas. The northern part of the Middle Ridge study area, Middle Ridge North, is in the Central Newfoundland Ecoregion Forest. The southern portion of the Middle Ridge study area is in the Maritime Barrens Ecoregion. In addition to the two main calving areas, some calves are born to the east of the northern calving ground in the Meta Pond area. Some collaring efforts have been made here, particularly in 2007.

Forest fires have been historically common in much of this area, altering the successional trajectory from balsam fir to black spruce and sometimes birch (*Betula* spp.) to aspen (*Populus* spp. Meades, 1990). The disturbance history also includes insect outbreaks (i.e., hemlock looper (*Lambdina fiscellaria*) and spruce budworm (*Choristoneura fuminferana*). Bogs are prevalent throughout this region. Among the study areas, human disturbance is probably the lowest in Middle Ridge. The Bay d'Espoir Highway runs through the western portion of Middle Ridge but the only communities are at the head of Bay d'Espoir and the Connaigre Peninsula. Logging roads are prevalent off the highway, especially in the northwestern section, but disturbance is minimal elsewhere.

Northern Peninsula

The Northern Peninsula study area (5,711 km^2) overlaps three ecoregions: the Strait of Belle Isle, the Northern Peninsula Forest, and the Long Range Barrens. The Strait of Belle Isle Ecoregion is characterized by an abundance of wetlands, particularly lowlands of sloping bog plateaus. The Northern Peninsula Forest Ecoregion is on the eastern side of the highlands and is primarily composed of balsam fir and black spruce forest. Limestone barrens are common along the west coast, with dwarf shrub and crowberry (*Empetrum* spp.) barrens on the east coast. The Long Range Barrens Ecoregion includes the highlands of the Long Range Mountains, above the treeline. The trees of this ecoregion are mostly windswept spruce and larch (tuckamore). The vegetation is primarily that of alpine barren, dominated by arctic-alpine plants or crowberry barren. Fens and bogs also cover much of this ecoregion (Meades, 1990). Human disturbance is probably greatest in this study area. Highways border the western side of the study area and smaller roads run east–west across the Great Northern Peninsula. There are a number of communities in the study area.

The Northern Peninsula caribou herd increased from a counted 375 animals in 1958 to an estimated 8,246 in 1996 (Mahoney, 2000, vol 10, pg 55). In 2008, there were an estimated 5,811 ± 593 animals (90% CI) in this herd (Callahan, 2009) but by 2012, there were 2,770 ± 553 (90% CI; G. Luther, pers. comm.). Less is known about this herd than most other herds on the island.

Data collection

Neonate calf capture and handling

Neonate calves were located from helicopter and captured on foot during late May – early June each year (2003–2012; see Appendix 3, Table A.5 for number by study area, year, and sex of animal). The vast majority of captured calves were 1 to 3 days post-partum but they could be up to 7 days post-partum. From 2003 to 2010, calves were fitted with expandable 200 g VHF radio-collars with an estimated battery life of 3 years (Telemetry Solutions, Concord, Califo.). These collars are well under the recommended 5% of the individuals body mass (Sikes and Gannon, 2011). Collars were modified by replacing some factory stitching with staples to allow for more gradual expansion of the elastic collar during calf growth. This elastic deteriorated over time and broke free, usually within 2 years of collaring. In 2011, calves were fitted with 68 g and 70 g VHF radio collars (Advanced Telemetry Systems, Isanti Minn.; SirTrack; North Liberty Iowa).

Captured calves were ear-tagged, sexed, and weighed. In addition, standard morphological measurements were taken (total length, heart girth, shoulder height, and hind foot length) but these data were not examined here. The age-at-capture was estimated by observing the amount of hoof pad wear and the condition of the umbilicus (i.e., whether it was wet, dry, or had fallen off) but this was not consistently taken. A coloured, numbered ear tag was attached to each animal. Handling time was minimized to mitigate capture-mediated abandonment and was typically under 5 minutes per calf.

From 2003 to 2008, calves were visually relocated by helicopter within 24 hours of initial capture to ensure they had rebonded with their dams and then daily during the first week post-capture. Starting in 2009 in La Poile, and after 2010 on all sites when possible, field staff stayed on site and watched for rebonding before leaving the area. For the next 5 weeks, aerial monitoring was reduced to every 2–4 days and following this, every 5–10 days until August. Monitoring was typically conducted on a bi-weekly or monthly basis after August.

Over-winter calf capture

Over-winter survival rates (ca. 6–12 months) could not be determined because of the almost complete loss of radio-collared calves by 6-months of age in 2003 and 2004, which also made it difficult to empirically determine whether coyote predation on calves was occurring in winter. Therefore, beginning in 2005, additional caribou calves were collared in fall between mid-October and mid-December. Over-winter calves were initially captured only in Middle Ridge, but these efforts were extended to La Poile and the Northern Peninsula in 2008 (see Appendix 3, Table A.5 for number by study area, year, and sex of animal). These calves were captured by aerial darting from helicopter using xylazine hydrochloride (Xylamax® delivered via tranquilizer pistol; a modified Cap-Chur brand (Powder Springs, Ga.)). Once immobilized, calves were sexed, measured, and weighed. A coloured, numbered ear tag was attached to each animal. Calves were visually relocated 2–9 days post-collaring to determine whether they had survived and remained with their mothers. Subsequently, calves were aerially monitored bi-monthly.

Yearlings and 2-year-olds

Yearlings (12–24 months) and 2-year-olds (24–36 months) were not collared as a part of this study but neonate and over-winter calves were monitored opportunistically throughout the study.

Adult capture

As part of a previous study, 136 GPS and 268 ARGOS satellite collars were deployed in central and western Newfoundland as well as the Northern Peninsula from 2006 to 2011 and 2004 to 2011 respectively. Specifically, a mixture of GPS and satellite collars were deployed on the following herds: Gaff Topsails, Buchans, Grey River, Pot Hill, Mount Peyton, and La Poile. Satellite collars were deployed in the Northern Peninsula in the St. Anthony, Hampden Downs, and Aides Lake herds (Fig. 3). Caribou were captured using a net gun or darting using the immobilizing agent carfentanil. Whenever a caribou mortality occurred, collars were redeployed when possible. Collars were removed from caribou by spring 2013. For this project, the following collars were used: GPS4400M collars (1250 g, Lotek Wireless Inc., Newmarket, Ont.), Telonics satellite ST-20 collars (1150 g, Telonics Inc, Mesa, Arizona), and Lotek Argos Track M satellite collars (950g, Lotek Wireless Inc., Newmarket, Ontario). A fix was taken every 2 hours for GPS collars (Neville, 2009). ARGOS collars obtained locations every 2 days.

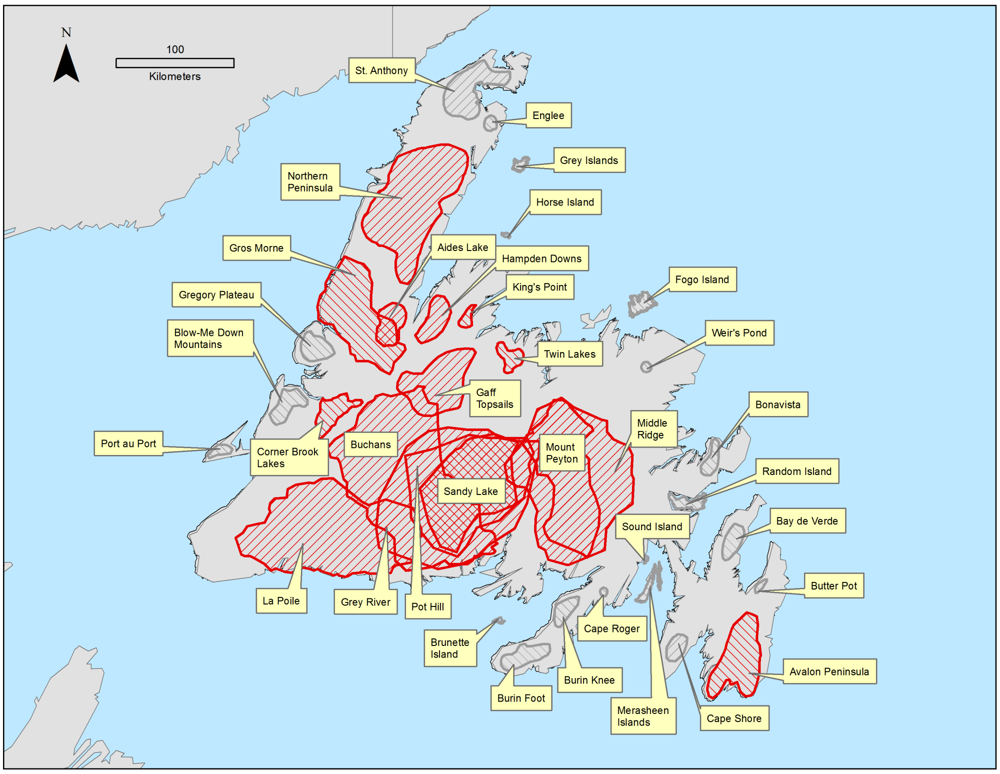

Figure 3: The location of the caribou herds in Newfoundland. Those in red are the native herds; those in grey are introduced.

As part of the *Caribou Strategy*, an additional 40 caribou were collared at various times in Middle Ridge between 2009 and 2011. Twenty-seven adult female caribou were collared in Middle Ridge on the wintering areas, either Middle Ridge North or the Meta Pond area in late April of 2009 prior to spring migration (Fig. 1). A further four were collared in the fall of 2009 [note: none were collared in 2008 or 2010]. Nine animals were collared in the winter of 2010/2011: three in November and six in January. Two of these had originally been collared as yearlings in 2004. Females were not collared on the calving grounds because of concerns over milk transfer of immobilizing drugs to the calves.

Caribou were immobilized by darting from helicopter using a mixture of Telazol (a dissociative anesthetic) and xylazine (0.75 mg/kg xylazine + 1.5 mg/kg Telazol) or the opioid etorphine hydrochloride (0.06 mg/kg) depending on availability of the reversal drug M-50/50 (0.12 mg/kg). Carfentanil (0.03 mg/kg) was used occasionally. Each animal in 2008–2009 was fitted with an ear-tag as well a GPS4400M collar (1,250 g, Lotek Wireless Inc.). A fix was taken every 2 hours from May 21 – July 31 (the calving season) and every 5 hours the remainder of the year. In 2010, caribou were fitted with IridiumTrack 3D collars (1,600 g, Lotek Wireless Inc.). A fix was taken every hour.

Weight and size measurements of each caribou were recorded, and in 2009, a blood sample was taken for a pregnancy test to confirm visual assessment of productivity. Pregnancy tests were performed by Conception: Animal Reproduction Technologies (Beaumont, Que.). These data were not examined in this report.

Determination of caribou fate and the cause of mortality

Neonates

When a mortality signal was detected (triggered after 4 hours of radio-collar immobility), the collar was located aerially and recovered. A standardized field investigation of the caribou remains and the field site was conducted to determine the fate of the caribou. The detection of a mortality signal does not necessarily indicate a mortality. Collars often break or fall off the animal (i.e. a collar-slip) and at times there is not enough evidence to determine whether the animal died or not (see below). Therefore, calf fate is a more general term applied to whether the calf was alive, lost its collar, died because of a variety of causes, or could not be determined. A mortality indicates that the animal died, either because of predation, an accident, natural causes (e.g., disease, starvation, orphaned), predation, or unknown causes (see Appendix 5).

Calf remains were examined for indicators of the cause of mortality such as wounds, inflicted by predators, signs of disease or infection, or some indication of accidental death such as broken bones coupled with the absence of predator inflicted wounds. When predation was the cause of death, indicators of predator species, such as the location and type of wounds were recorded. For intact carcasses, the field researcher sometimes investigated for wounds under the pelt by skinning back suspected areas of contusions/punctures, hemorrhaging, and other signs of disguised trauma. Predator handling techniques were recorded such as skinning of calves, crushing of the large limb bones and skull, viscera removal, holes in the abdomen, rib chewing and/or removal, decapitation, and dismemberment. The means by which partial remains were buried, and which portions of the carcass were interred, were also recorded.

A general description of the field sites was conducted to obtain additional evidence for cause of mortality and included vegetation type, topography, and position of calf. Any additional signs of predation, such as blood stained or damaged radio-collars, blood-stained vegetation, as well as predator tracks, scats, and hair were also recorded. An area within at least 30 m from the carcass was searched for additional remains, especially if an intact radio collar was discovered without a carcass or remains. Collars found intact, with few staples pulled out, and with no remains nearby were assumed to be from predated calves since manipulation is the only way to remove intact collars. To complement field notes and assist in identifying the cause of mortality, photographs were taken of the mortality sites to record the overall arrangement of the remains, the position of predator signs relative to those remains, scat, tracks and other predator signs, as well as the topography and general vegetation cover.

Similar to George et al. (2008), when sufficient calf remains were available, these were forwarded to a veterinarian for independent necropsy and evaluation. Photographs were again taken of the remains and the location and degree of trauma, bite mark/puncture patterns, bone breakage, and presence of disease or infection. In addition, the general nutritional and physical condition of the calf was recorded whenever possible. The diagnosis of the veterinarian was then compared with the field diagnosis and a final decision was made as to the most likely cause of predation.

Beginning in 2010, sterile cotton swabs were used to sample hemorrhaged and non-hemorrhaged wounds for residual predator DNA from saliva. Samples were genetically analyzed to determine the predator species, individual, and sex (Mumma et al., In press).

Over the course of the study it became apparent that some mortality characteristics overlapped among predator species, resulting in some uncertainty with regards to predator identification. In addition, some carcasses were heavily scavenged. In cases where uncertainty persisted, mortalities were classified as “suspect” if evidence suggested a particular predator but was not completely certain, “unknown predator” when it was clear a predation occurred but there was little certainty, or “unknown fate” where no specific cause of death could be determined.

Finally, individual calf fates were assessed collectively by experienced SDSS staff. Field, necrospy, and genetic evidence was carefully scrutinized and weighed against each other. The most likely outcome was then chosen by SDSS staff based on the weight of evidence. For details on characteristics used in determining cause of death at the mortality site, see Appendix 1.

Older cohorts

The above field protocols were also followed for over-winter calves, yearlings, 2-year-olds, and adults. These cohorts were not monitored with the frequency that neonate calves were, often resulting in a lengthy interval between a mortality and the field investigation. Because of scavenging and degradation of the carcass over these longer intervals, there was often less evidence to determine the cause of mortality than for the neonate calves. Further, remains were usually so scant that necropsies and DNA samples were of little value. Therefore, these results must be more cautiously interpreted than the results for neonates.

Population estimates

Estimates of the caribou population in Newfoundland are based on intermittent aerial surveys of individual herds (Mahoney et al., 1998, Mahoney, 2000) and mathematical modeling of individual herds to estimate population size during years when surveys were not completed. Individual herd estimates were pooled to provide annual, island-wide population estimates (G. Luther, pers. comm.). We used population size as a proxy for density and these terms are used interchangeably in the rest of this document.

Climatic variables

NAO

Winter climate is strongly correlated with the status of the NAO, which is a synoptic-scale system of ocean–atmosphere interactions over the North Atlantic. The NAO is an index of the normalized difference in sea-level atmospheric pressure recorded over two semi-permanent pressure cells: the Azores high, located near Lisbon, Portugal; and the Icelandic low, located over Reykjavik, Iceland (Hurrell, 1995). When the difference in barometric pressure recorded between these two poles is large, the NAO is said to be in a positive state, which results in more cold temperatures and lower precipitation over much of North America (Post and Stenseth, 1999). However, in Newfoundland, a positive NAO is correlated with low temperature and more snow (Appendix 2, Table A.2).

NAO data were downloaded from the National Oceanic and Atmospheric Administration website (http://www.cpc.ncep.noaa.gov) that provides monthly means for the NAO (Appendix 2, Table A.3,A.4). We calculated the average NAO values during winter, defined as the December to April period preceding calving since this covers winter weather in Newfoundland (Mahoney, 2000). We did not consider post-breeding winter mortality (i.e. the calves first winter) to be an important factor because of consistently high over-winter survival (Mahoney and Weir, 2009, Trindade et al., 2011).

NDVI

The NDVI is based on the absorption of visible (or red) light by plant pigments such as chlorophyll and the reflectance of near-infrared light related to leaf cellular structure. Specifically, it is the ratio of the difference of near-infrared and visible light and the sum of near-infrared and visible light. The NDVI can be used to measure plant growth, vegetation cover, or biomass production as well as other metrics (Pettorelli et al., 2005a,b). In this study, time series of NDVI observations were used to extract proxies for the rate of spring green-up, the start of spring, and annual productivity.

NDVI 10-day composites from 2003 to 2012 at 1 km spatial resolution were processed by the Canadian Centre for Remote Sensing following the methods described in Latifovic et al. (2005). A correction for systematic bias between AVHRR-2 and -3 sensors was applied as described in Latifovic et al. (2012) to improve radiometric consistency over the period. The average cloud and shadow free NDVI value for each 10 day composite was extracted for the entire island of Newfoundland to be comparable with the island wide telemetry data. The time series of average NDVI values was temporally smoothed to remove outliers using a robust Lowess filter where in each iteration data falling below the fit line was removed for the next iteration (Fernandes et al., 2005). For this analysis 3 iterations were used. Several time series metrics were extracted for each year and included 1) the maximum difference between 10 day composites from May to July as a measure of the rate of spring green-up (spring_rate$_{(t)}$), 2) the beginning of the growing season taken as the point where 50% of the maximum NDVI was observed (spring_start$_{(t)}$), and 3) the average seasonal NDVI for each year as a measure of annual vegetation productivity (meanNDVI). The annual NDVI-based productivity for the birth year and the preceding year was used in the modeling analysis to account for previous year conditions (NDVI$_{(t)}$, NDVI$_{(t-1)}$).

Data analysis

Data screening

Before modeling, all variables were screened for outliers and multi-collinearity but we found no significant issues (Burnham and Anderson, 2002). A total of 18 calves weighed in excess of 12 kg and were censored from all analyses because it is unlikely they were a few days old at capture. An additional 16 calves from the Northern Peninsula in 2010 were censored since over half of the these calves lost their collars that year and many that remained were quite heavy (> 10 kg), suggesting that they were older than one week. The presence of a large number of heavy calves is likely due to the late arrival of the field crews on the calving grounds as the result of inclement weather. In addition to these animals, a further 42 calves were captured but were excluded from the analysis because they were either abandoned by the doe, died during capture, or were never found again. In total, < 8% of the calves were censored.

Methods for estimating survival rates

Survival was estimated using two methods: the Heisey–Fuller (HF) method (Heisey and Fuller, 1985) and the nest survival (NS) model (Dinsmore et al., 2002, Rotella et al., 2004). Survival to 6 months of age was estimated for neonate calves and used in most of the analyses because of concerns over sparse data beyond 6 months and the influence this would have on the precision of the estimates. We also estimated 6-month, over-winter survival rates, defined as survival to 6 months after the calves were collared in the fall of the year or the second 6 months of a calf's life if it was collared as a neonate. Annual estimates were generated for the older sub-adult and adult animals. Fate and cause of mortality are also reported for the same time periods except for adults that are reported over the course of the study. Average survival rates over the time series were weighted by the sample size and associated variance has approximated using the delta method (Powell, 2007).

Heisey–Fuller

The HF method estimates daily survival rates, and, assuming constant survival, i.e., that the daily survival rate does not change over a given time period, exponentiates this estimate over a given interval (e.g., if daily survival rate = 0.99, then annual survival rate ($\hat{S}_{HF}$) = $0.99^{365} = 0.026$). The assumption of constant daily survival is reasonable for over-wintering calves, yearlings, 2-year-olds, and adults since survival is uniformly high throughout the year for these age classes (Mahoney, 2000).

However, constant survival is not a reasonable assumption for neonate calves that experience very low survival rates in the first weeks and months of life but have sharply improved survival thereafter (Mahoney et al., 1990, Jenkins and Barten, 2005, Trindade et al., 2011; see also Fig. 8). However, annual $\hat{S}_{HF}$ estimates were generated for neonates to maintain direct comparability with past reports but statistical comparisons were not performed on these estimates (Mahoney and Weir, 2009, Trindade et al., 2011; see Appendix 4 Table A.6).

$\hat{S}_{HF}$ estimates were generated in Program R 2.15.2 (R Core Team, 2013) using scripts developed for this purpose. Animals killed by hunting were included in the calculations for adults but excluding these animals made a difference of $< 1\%$ in the $\hat{S}_{HF}$ estimates.

Nest survival

Owing to concerns over non-constant survival in neonate calves and to facilitate more in-depth analyses, we also used the nest survival model option within Program MARK (White and Burnham, 1999, Dinsmore et al., 2002, Rotella et al., 2004). Briefly, Program MARK is the free field standard for calculating survival rates of marked/collared animals. The HF method is simply a special case of the more general Mayfield methods that are easily handled in MARK. Survival estimates generated by Program MARK and the HF method should be similar if the assumption of constant survival is valid. However, the great advantages of MARK is that in addition to easily handling non-constant survival rates (see next paragraph), a far wider range of hypotheses concerning survival can be tested in a robust, statistical framework (see next section) while the HF estimates can only be compared using a single categorical explanatory variable, e.g., the influence of calf sex on survival, or if survival changed between years.

The nest survival model in MARK was developed for measuring survival in monitored bird nests, but is appropriate for estimating survival ($\hat{S}_{NS}$) in radio-telemetry studies where the interval between succeeding monitoring episodes varies (i.e., ragged intervals) and the fate of the animal at each monitoring effort is not known with a high degree of certainty[1]. This approach has been used in many studies of nest survival and increasingly with mammals (George et al., 2008, Kindall et al., 2011, Villemey et al., 2013). The nest survival model requires four types of information: 1) the day of radio attachment, 2) the last day the calf was known to be alive, 3) the last day that a live calf was detected or that a mortality event was discovered, and 4) the fate of the calf, i.e., whether it lived, lost its collar, or died.

Assumptions of the nest survival model described here are 1) homogeneity of daily survival rates (i.e., daily survival rate is the same for all days (see below) but can vary with explanatory variables such as population size or NAO), 2) calf fates are correctly classified, 3) calf collaring does not influence survival, 4) calf fates are independent of each other, 5) all monitoring visits to a calf are recorded, and 6) monitoring the calves has no influence on calf fate (Rotella et al., 2004). These assumptions are largely met by the 2003–2012 data set with the exception of the influence of calf collaring on survival and homogeneity of daily survival rates. Although the effect of collaring on caribou survival rates was not tested, it likely reduces survival to some degree. However, the influence of collaring on survival rates has been tested on other ungulate and mammal species and is thought to be small (Côté et al., 1998, Murray and Fuller, 2000). As mentioned previously, neonate calves experience very low survival rates early in life but these rates improve sharply thereafter. We controlled for this heterogeneity in daily survival rates in neonate calves by fitting a linear trend (hereafter "Trend"), i.e., by allowing daily survival rates to vary, or in this case increase, over the time interval of interest. This contrasts with the HF estimates where daily survival is assumed constant over the interval of interest

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[1] For consistency with other documents in the *Caribou Strategy,* 90% confidence intervals (CI) were used for $\hat{S}_{HF}$, whereas following Program MARK, 95% CIs were used for $\hat{S}_{NS}$.

and calculating survival over large numbers of shorter intervals ("span" survival in Heisey and Fuller, 1985) is computationally much more difficult than in MARK[2].

Although the potential exists for calf age at capture to be a source of heterogeneity that could influence the estimates of survival rates, most calves were captured at less than 3 days old because it becomes problematic for them to be captured on foot after they are 1 week old. We did not use calf age at capture as a covariate in the models because this was not recorded for many calves. Further, estimating calf age using morphology and weight was not possible because of the large amount of variation in these data. Therefore, all calves are assumed to have been captured at 1 day old, which may slightly increase the estimated survival rates.

Multimodel inference

We used the information–theoretic approach with Akaike's Information Criterion corrected for small sample sizes ($\mathrm{AIC_c}$) and AIC weights (ω_i; Burnham and Anderson, 2002) to evaluate multiple models of survival over a 6-month period[3]. Two model sets were constructed. First, we estimated survival on a year-by-year basis (2003–2012) with a separate "Trend" for each year in the design matrix but without ecological or climatological variables. Second, to test factors that could influence survival, we considered survival to be a function of population size, calf condition, i.e., weight at capture, and climate (Tables 1, 2). Climatic variables included the NAO of the winter before birth (NAO), the annual productivity of the year the calf was born ($\mathrm{meanNDVI_{(t)}}$) and the year before ($\mathrm{meanNDVI_{(t\text{-}1)}}$), the start of spring ($\mathrm{spring\_start_{(t)}}$), and the rate of green-up ($\mathrm{spring\_rate_{(t)}}$). In addition, we examined how combinations of climate variables could influence survival (i.e., additive combinations, e.g. NAO + $\mathrm{meanNDVI_{(t)}}$; Burnham and Anderson, 2002). Calf weight was introduced as an individual covariate, i.e., the probability of survival of each individual calf is influenced by the weight of the calf at the time it was captured. When there was no measurement of weight for an individual calf, we used the average value of that year Cooch and White (2010). Finally, we tested for differences in survival between the sex of the neonate calves by including this term in the most supported model (i.e., the model with the lowest $\mathrm{AIC_c}$). "Trend" was included in each model but was applied in a consistent fashion to all years, not on a year-by-year basis as in the previous model set. We also fitted an "Intercept only" model and an "Intercept + Trend" model. These are effectively null models. The former tests the hypothesis that non-trended survival is constant among years, the latter that differences among years are due to differences in "Trend". Although not presented below, we also fitted models without "Trend". These models without "Trend" always had extremely low support relative to models with "Trend" and these models would result in an underestimate of survival rates for young calves.

We did not examine the influence of past climate beyond 1 year for lack of a demonstrated mechanistic link to survival and the relatively short time series (10 years of calf collaring). We did not test for the influence of the winter after birth on survival because past evidence suggests that over-winter survival is high (Mahoney and Weir, 2009, Trindade et al., 2011).

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[2] Note that HF estimates with varying daily survival rates could be calculated outside of MARK, but it would require generating an estimate for each day of the interval and then using the delta method (Powell, 2007) to calculate survival over the entire interval. MARK does this automatically and without any of the other limitations of the HF method.

[3] It is common practice in most mark–recapture analyses to first calculate a variance inflation factor to adjust for any lack of fit of the global model (i.e., a model with all of the relevant explanatory variables) to the data (i.e., encounter histories). However, the global model is saturated for the nest survival model and the variance inflation factor is not identifiable. Therefore, this adjustment is not possible for the nest survival model (Dinsmore et al., 2002), and therefore, we did not compute the global model for these analysis.

Results

Survival estimates

Neonate

A total of 959 calves were collared and monitored in the spring and fall from 2003 to 2012 (Appendix 3, Table A.5; censored animals not included) including 730 neonate and 229 over-winter calves. Survival rates were consistently high from 1979 to 1997, dropped sharply by 2003, but then increased steadily thereafter (Fig. 4). From 2003 to 2012, the average $\hat{S}_{\text{NS-6month}}$ was 0.35 (0.32 – 0.39 95% CI).

The two models that received overwhelming support (i.e., were the best explanation of survival) included population size and "Trend", with sex as an individual covariate in the best supported model ($\omega_{\text{i}} = 0.53$ and $\omega_{\text{i}} = 0.37$, Table 2, Fig. 5, Fig. 6). Survival was negatively related to population size ($\beta = -0.03$, –0.04 – –0.02 95% CI; Fig. 5). Although included in the most supported model, calf sex had little influence on survival; female survival was slightly better than males ($\beta = -0.0002$, –0.0005 – 0.00004 95% CI). The model with calf weight received moderate support ($\omega_{\text{i}} = 0.09$) suggesting calf weight has a modest influence on survival ($\beta = 0.18$, 0.10 – 0.25 95% CI; Fig. 6). Two climate models received considerably less support (Spring_start$_{(\text{t})}$, $\omega_{\text{i}} = 0.01$ and meanNDVI$_{(\text{t})}$ + Spring_start$_{(\text{t})}$, $\omega_{\text{i}} < 0.01$) and all others received essentially none.

Survival was broadly similar and synchronous among the three main study areas over the course of the study, but was very low in Middle Ridge South with the exception of 2012 when a lethal removal of coyotes was conducted in this area (Fig. 7).

Male neonate calves were slightly heavier than females (2003–2012: 8.7 ± 1.3 kg vs. 8.5 ± 1.4 kg, respectively; $F_{1,\,722} = 30.31$, $p < 0.0001$) and calf weight increased by < 1%/year from 2003 to 2012 (0.06 ± 0.03, t = 2.0, $p = 0.047$).

Timing of mortality in neonate caribou

In general, calf mortality was very high in the first weeks and months after birth but decreased over time and the proportion of dead calves to calves that lived or had an unknown fate became more even (Fig. 8). From 2003 to 2012, 25% of the collared calves died or lost a collar by 12.5 days, 50% by 38.5 days, and 75% by 166 days.

Survival in older cohorts

For over-winter calves, $\hat{S}_{\text{HF-6month}} = 0.91$ (0.79 – 1.0 90% CI, Fig. 9, Appendix 4, Table A.7). Sample sizes were very low in 2003–2004 largely because of high predation on neonate calves, which spurred the initiation of the collaring of young of the year calves in the fall to measure over-winter survival, but survival rates from 2005 to 2012 were 0.913 (0.91 – 0.92 90% CI). Survival for yearlings and 2-year-olds averaged 0.92 (0.91 – 0.94 90% CI) and 0.95 (0.94 – 0.96 90% CI), respectively (Fig. 10, Fig. 11). Sample sizes for 2-year-olds were small because of difficulties in locating calves. Adult annual survival averaged 0.87 (083 – 0.91 90% CI, Fig. 12).

Causes of mortality

Neonate

Of the 730 neonate calves used in this study, 419 (57%) were confirmed dead within half a year of being collared including 376 from predation (52% of total, 90% of mortalities). Of the predated calves, 62% were taken by black bear (n = 128, 34%) and coyote (n = 107, 28%) combined. Bald Eagle, lynx, and remains where the predator was uncertain (e.g., suspect black bear) accounted for 60 calves

Table 2: Model selection summary for neonate caribou survival in Newfoundland (2003–2012)[1]. Pop = Population, CWeight = Calf weight (kg) measured as the mean value for that year or as an individual covariate (ind-cov), NAO = North Atlantic Oscillation, NDVI = Normalized Difference Vegetation Index. The subscript $_{(t)}$ indicates the year of birth, $_{(t\text{-}1)}$ indicates the summer before conception.

Candidate model	AIC_c[a]	ΔAIC_c[b]	ω_i[c]	Model likelihood[d]	K[e]	Deviance
Pop + Sex	3151.7	0.00	0.53	1.00	4	3143.7
Pop	3152.4	0.74	0.37	0.69	3	3146.4
CWeight(ind-cov)	3155.3	3.65	0.09	0.16	3	3149.3
Spring_start	3159.2	7.55	0.01	0.02	3	3153.2
$\text{meanNDVI}_{(t)}$ + Spring_start	3161.0	9.34	0.00	0.01	4	3153.0
CWeight	3163.1	11.46	0.00	0.00	3	3157.1
NAO	3173.5	21.83	0.00	0.00	3	3167.5
NAO + $\text{meanNDVI}_{(t)}$	3174.7	23.02	0.00	0.00	4	3166.7
Trend	3175.0	23.35	0.00	0.00	2	3171.0
$\text{meanNDVI}_{(t)}$	3175.2	23.53	0.00	0.00	3	3169.2
NAO + $\text{meanNDVI}_{(t\text{-}1)}$	3175.5	23.82	0.00	0.00	4	3167.5
$\text{meanNDVI}_{(t\text{-}1)}$	3175.9	24.20	0.00	0.00	3	3169.9
Intercept only	3518.1	366.47	0.00	0.00	1	3516.1

[a] Aikaike's Information Criterion adjusted for small sample size. The AIC_c is a measure of the balance between how well the model fits the data (Deviance) with the complexity of the model (K). Lower scores are considered more plausible models, i.e., better models, and are ranked as such.

[b] The AIC differences are the difference in AIC score between each model and the one with the lowest AIC score. The ΔAIC_c indicates how plausible the model is compared with the most supported model ($\Delta AIC_c < 2$ = substantial support, 4–7 = considerably less support, > 10 = essentially no support).

[c] AIC weight indicates the weight of evidence of a given model being the best model. Values sum to 1 with larger values indicating a greater strength of evidence. These values are used to measure model support and are presented in the text.

[d] ω_i for model of interest/ ω_i of the best model. The value represents the strength of evidence of the model compared with the other models. Values range from 0 to 1; larger values indicate a greater strength of evidence.

[e] The number of parameters in the model.

[1] An intercept term is in all the models; "Trend" is in all models except the "Intercept only" model.

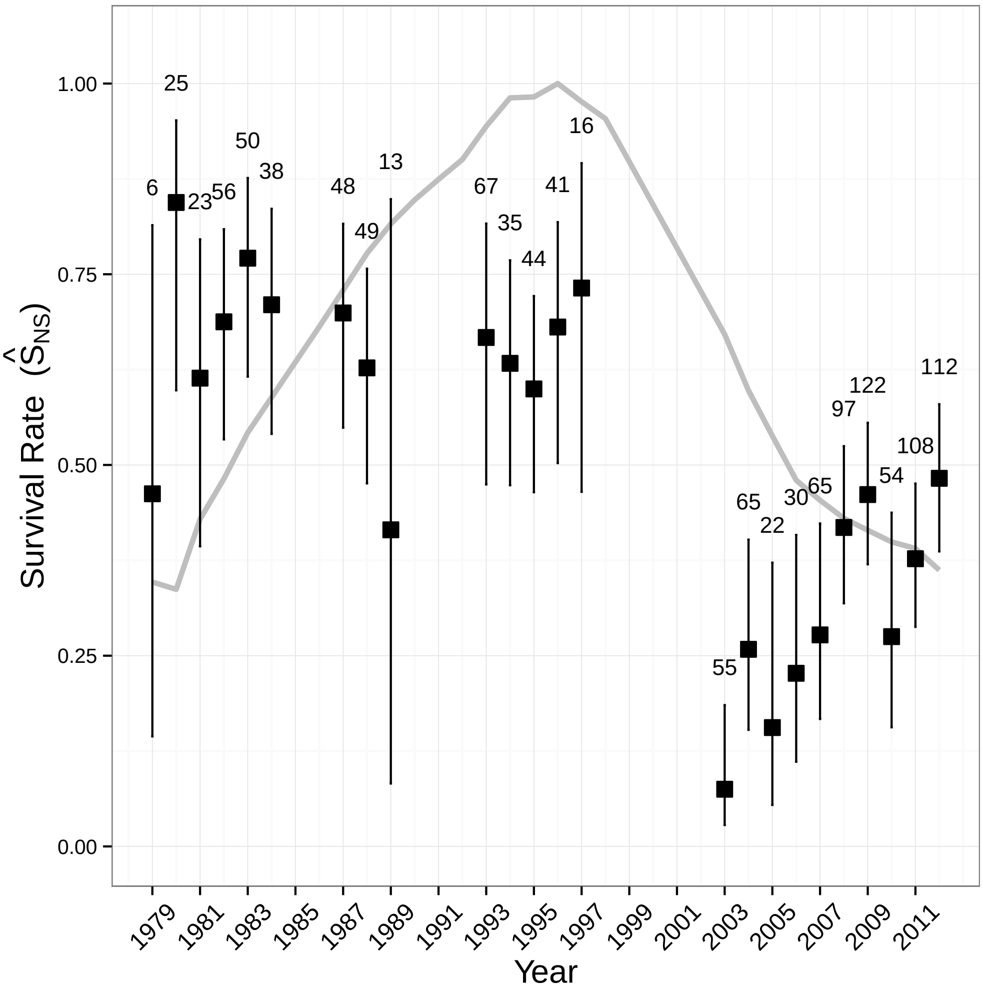

Figure 4: Estimated island-wide 6-month survival rates ($\hat{S}_{\text{NS-6month}} \pm 95\%$ CI) for neonate calves from 1979 to 2012. Sample size per year is given above each CI. The gray line is the island-wide population trend (see Weir et al. 2013 for full details).

(16% of predated calves). Predators could not be identified for 60 calves (16% of predated calves). The remaining calves died from a number of causes including accidental deaths, natural mortalities, orphaning, and starvation. A further 86 calves lost their collars and 23 had an unknown fate (combined $n = 109$; 15%) while 202 calves survived (28%).

The patterns of calf fate and cause of mortality in the four main study areas and by year are summarized in Appendix 5. Patterns varied but in almost all cases, the majority of calves died from predation. In Middle Ridge North, black bears were the dominant cause of mortality while coyotes predominated in Middle Ridge South after 2007. Results were more variable for La Poile and the Northern Peninsula.

When predation was compared with other types of mortality pooled together, the proportion of caribou calf predation was different between the period when the population was increasing compared with decreasing, i.e., 1979–1997 and 2003–2012 ($\chi^2 = 72.3$, df $= 1$, $p < 0.0001$, Fig. 13)[4].

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[4] Note that these comparisons are to 1 year.

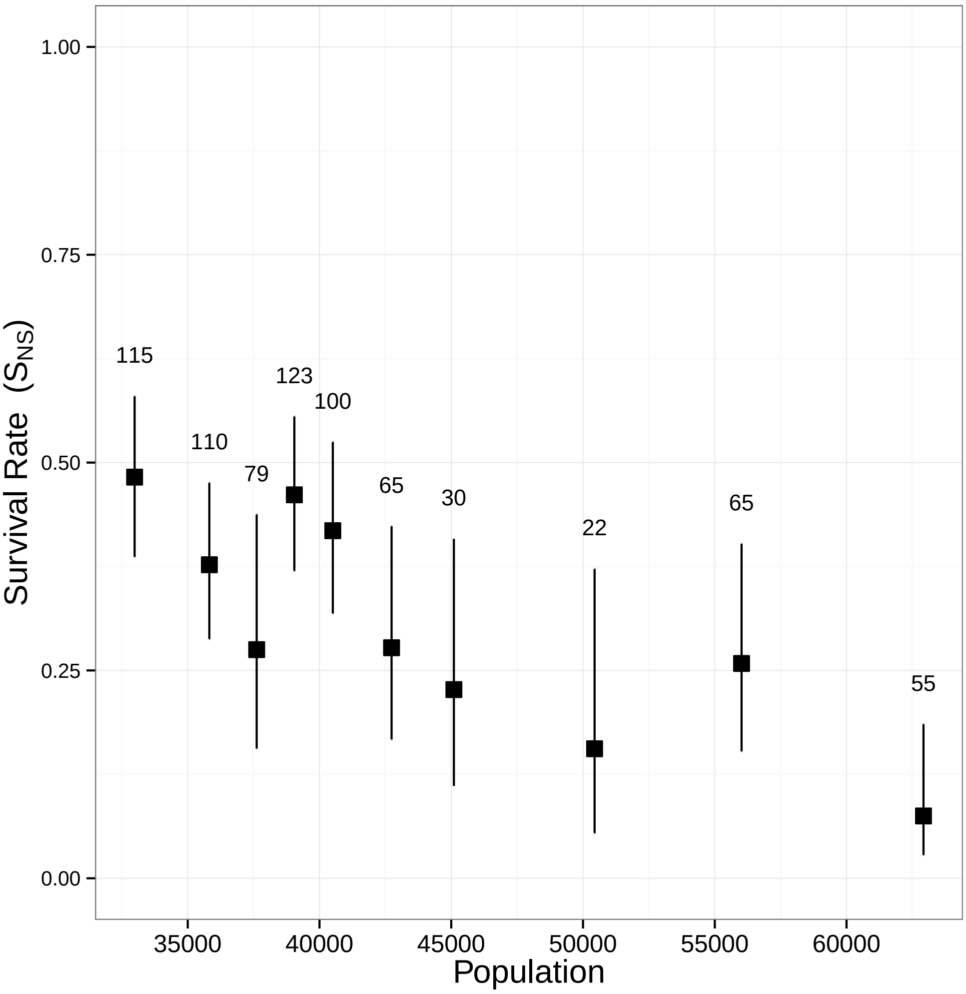

Figure 5: Estimated island-wide 6-month survival rates ($\hat{S}_{\text{NS-6month}}$ ± 95% CI) for neonate calves and caribou population size from 2003 to 2012 (years run right to left). Sample size per year is given above each CI.

Older cohorts

Calf fate and cause of mortality were very different for the older cohorts than the neonate calves. Of the 401 calves that were collared from 6 to 12 months (i.e. surviving neonate and over-winter calves), 363 (91%) remained alive, 14 (3%) lost their collars, and 2 ($< 1\%$) had unknown fates. A total of 22 animals died (5%) including 8 unknown mortalities, 2 accidental deaths, and 12 that died from predation: 2 were by coyote and 8 suspected to be by coyote as well as 1 by lynx and 1 suspected lynx. Of 156 yearling calves (12–24 months), 115 remained alive (74%), 27 lost their collars (17%), and a further 5 had unknown fates (3%). Only 9 died (6%), four from predation: 2 by black bear, 1 by coyote, and 1 by an unknown predator. Two yearlings died from accidental causes (1%) and 3 were unknown causes (2%). Of 65 two-year-olds (24–36 months), 50 remained alive after a year (77%), 11 lost their collars (17%), and 2 had unknown fates (3%). Only 2 died (3%), 1 from an unknown predator and 1 by hunting/poaching.

Over the course of the adult collaring effort (2004–2011), 20 animals died during capture. Of the remaining 424 adult caribou, 232 (55%) remained alive, 30 had unknown fates (7%), and 162 adults

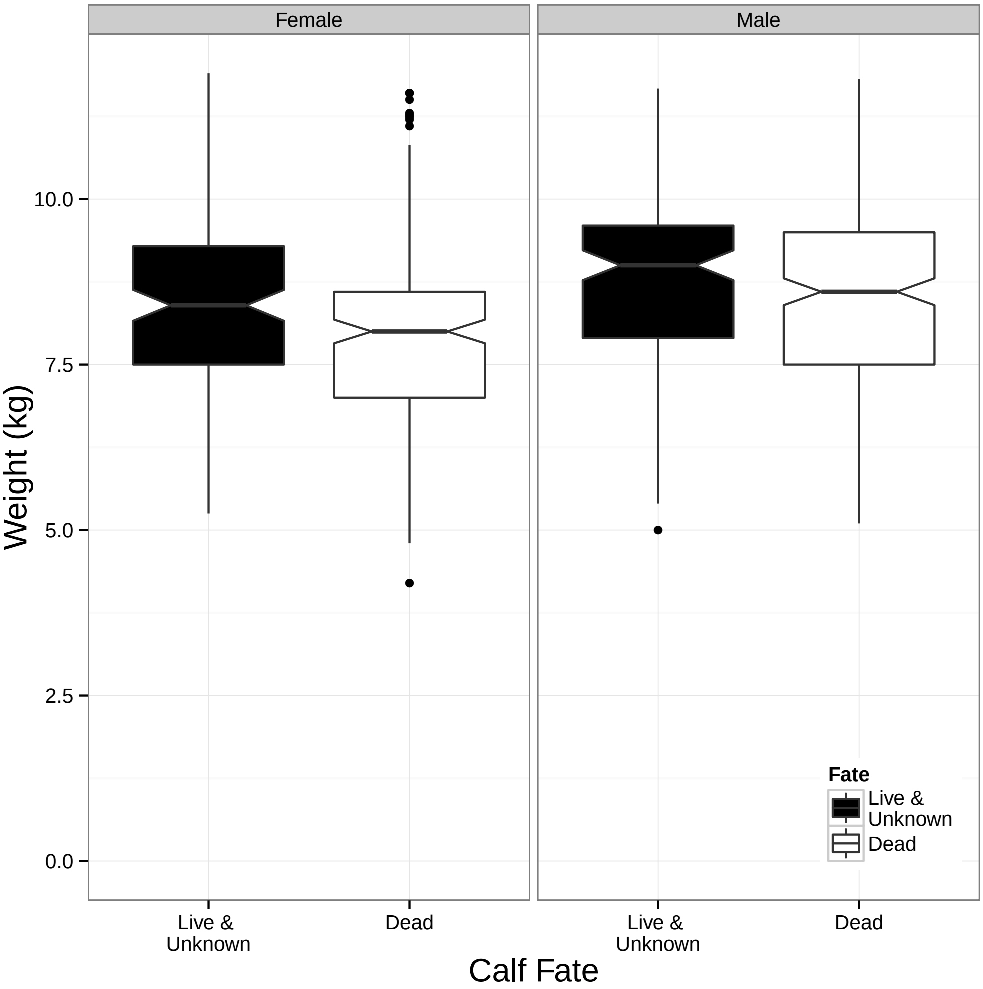

Figure 6: Weight (kg) of male and female neonate caribou calves at capture according to fate. Unknown animals are usually those that lost a collar. Overlap in the notches of the box-plots suggests there is "strong evidence" that the two medians do not differ. Animals that lived (or had unknown fate) tend to be heavier than those that died.

were known to have died (38%). Of the mortalities, 24 (6% of all animals) were from predation: 5 by black bears, 18 by coyotes, and 1 by an unknown predator. There were 23 non-predation mortalities (5%) including 10 by hunting/poaching, 1 by injury/infection, 2 by accidental, 1 by natural causes, 7 by non-predation, and 2 were killed due to vehicle collisions. There were 115 (27%) mortalities from unknown causes.

Discussion

This study represents the longest, most comprehensive analysis of caribou calf survival in North America that simultaneously examined multiple factors influencing survival. Further, this study presents a comprehensive overview of caribou survival and fate since 2003, and indicative of the Government of Newfoundland and Labrador's commitment to studying caribou, has perhaps the greatest number of large mammals ever collared in a single study. Results of this study demonstrate that neonate calf

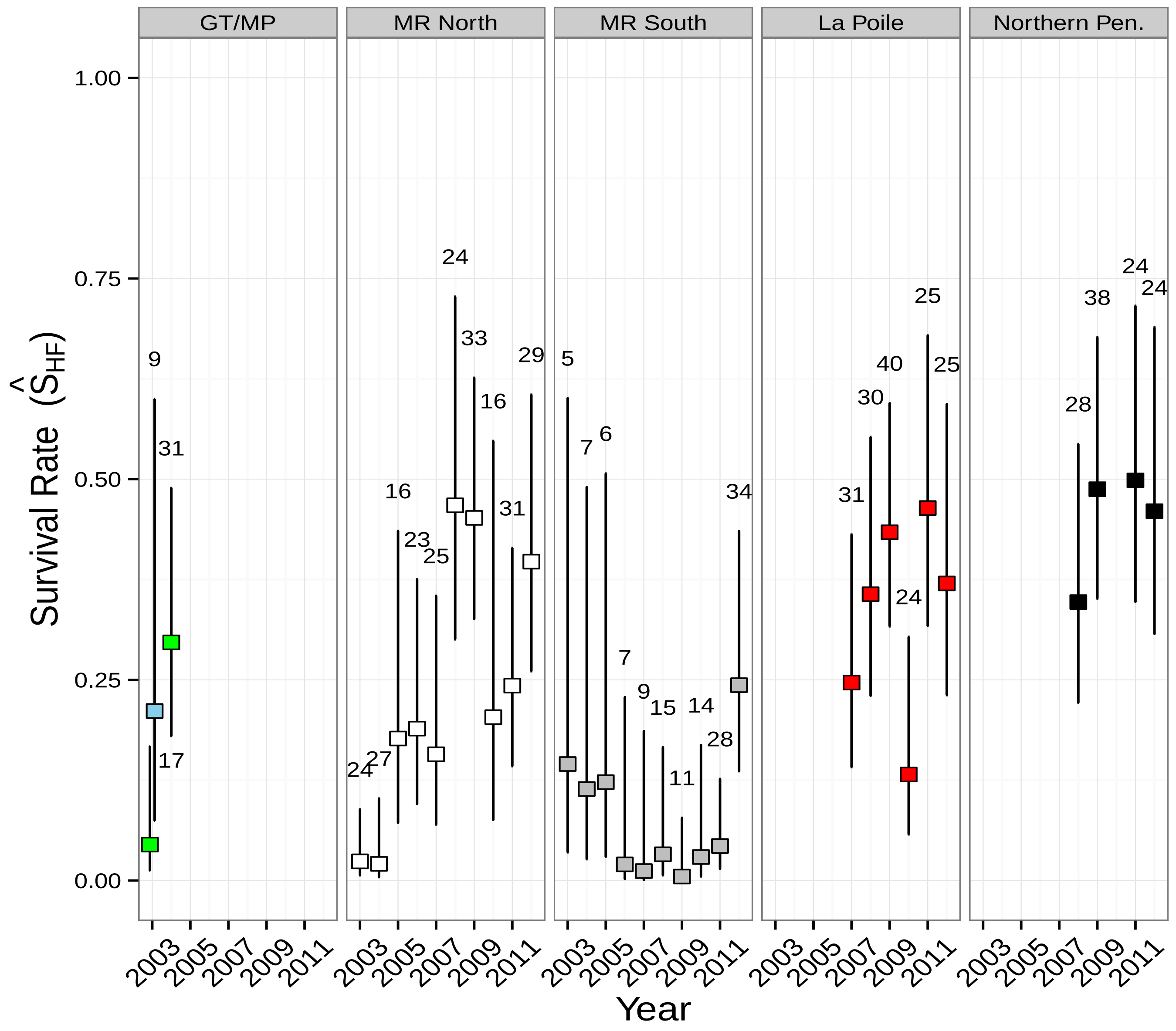

Figure 7: Estimated survival rates ($\hat{S}_{\text{HF-6month}}$ ± 90% CI) for neonate calves by study area from 2003 to 2012. Sample size per year is given above each CI. Annual estimates are given in Appendix 4 (Table A.6). GT/MP = Gaff Topsails or Mount Peyton, MR = Middle Ridge.

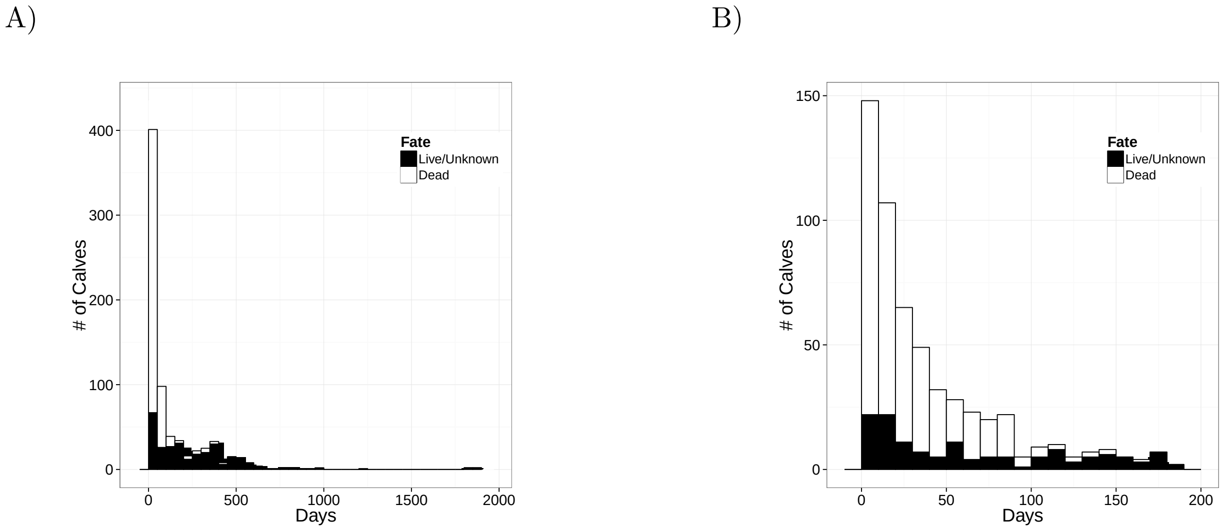

Figure 8: The stacked frequencies of the number of calves that lived (or had an unknown fate), or died by number of days monitored (Heisey and Fuller, 1985) for A) all data where bin size of histogram = 50 days and B) 1/2 year where bin size = 10 days (this figure simply shows the left side of Fig. 8A in more detail). Calf age roughly corresponds to the number of days. Most calves die in the first few months, and the proportion of dead to live or unknown calves becomes more even over time.

survival rates, although still less than when the population was increasing, have generally increased from 2003 to 2012, and that calf mortality is largely due to predation. Predation, primarily by black bear and the non-native coyote, in the first 2–3 months of a calf's life was the single most important proximate cause of mortality. Calf survival has increased as the population (Fig. 5) has decreased, and larger calves had a better chance of survival (Fig. 6). Coupled with an increase in calf weight over time, presumably because of better female condition (Weir et al., 2013), these results suggest a density-dependent effect during this time period. Survival amongst all other cohorts (yearlings through adults) was quite high (generally > 0.80); predation accounts for roughly half of the known mortalities.

Neonate calf survival

Comparisons of survival rates

$\hat{S}_{\text{NS-6month}}$ for neonate caribou calves generally increased over the course of the study from a low of 0.07 in 2003 to 0.48 in 2012 (Fig. 4). With the exception of 2012, survival rates were extremely low in Middle Ridge South (Fig. 7) despite an attempt by SDSS to manipulate predator behaviour and numbers[5] but for Middle Ridge North, the study area with the longest time series, survival rates were much higher, in general, from 2008 onwards. The survival rate estimates approached the point where the caribou population is predicted to stabilize in 2011 for La Poile, 2011–2012 for the Northern Peninsula (Randell et al., 2012), and 2012 for Middle Ridge North (Appendix 4, Table A.6). These values are similar to other stable or increasing caribou populations (Jenkins and Barten, 2005 and

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[5] For a full discussion of predator manipulation studies, see Gullage et al. (2014). Note that the predator manipulation work in MR South should result in a slight overestimate of island-wide survival rates. However, the impact on these analyses should be minimal since MRS represented $< 30\%$ of the caribou collared in a given year and the influence, especially of the diversionary feeding, was generally small.

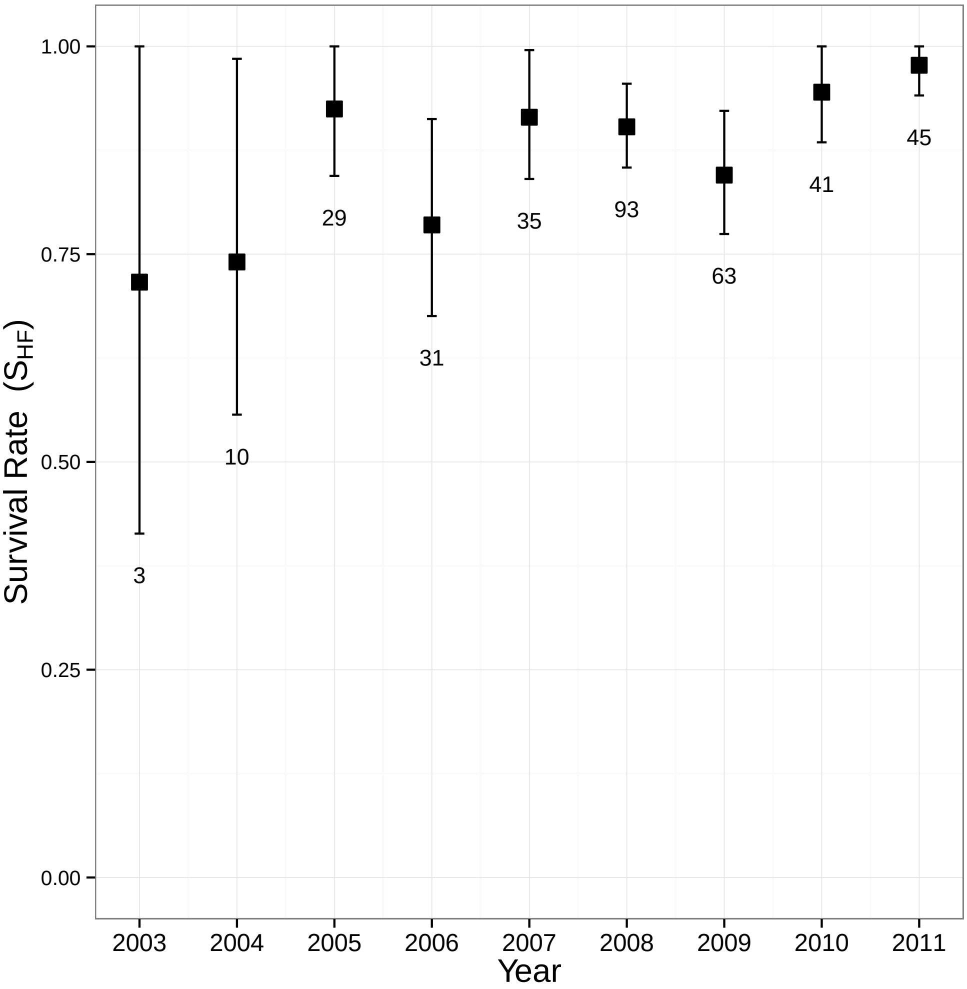

Figure 9: Estimated island-wide over-winter survival rates ($\hat{S}_{\text{HF-6month}} \pm 90\%$ CI) for caribou calves from 2003 to 2011. Sample size per year is given below each CI.

references therein, pg 1185).

Survival rates for Newfoundland calves from 2003 to 2012 ($\hat{S}_{\text{NS-6month}} = 0.350 \pm 0.018$ SE, $\hat{S}_{\text{HF-6month}} = 0.246 \pm 0.014$ SE) were much lower than during the period of population increase and maximum size (1979–1997, $\hat{S}_{\text{NS-6month}} = 0.674 \pm 0.091$ SE, Fig. 4; Mahoney and Weir, 2009). It is not known whether the current survival rates are similar to those of the early 20th century decline and subsequent low in Newfoundland caribou populations over the middle of the last century.

Low neonate survival or recruitment rates have been observed in herds with declining populations in Alaska (Jenkins and Barten, 2005), British Columbia (Bergerud and Elliot, 1986), Alberta (Stuart-Smith et al., 1997, McLoughlin et al., 2003), and Saskatchewan (Rettie and Messier, 1998). Low calf recruitment is also common in low-density mountain dwelling herds (Hegel et al., 2010) and generally in herds exposed to predators (Bergerud, 1980). Low calf recruitment commonly drives population declines in large herbivores (Gaillard et al., 1998) but low survival of adults can also drive population declines (Wittmer et al., 2005).

Calf survival rates were dramatically higher from 2008 onwards and may have been influenced by calf weight that steadily increased during the study period (Mahoney et al., in prep). It is not clear

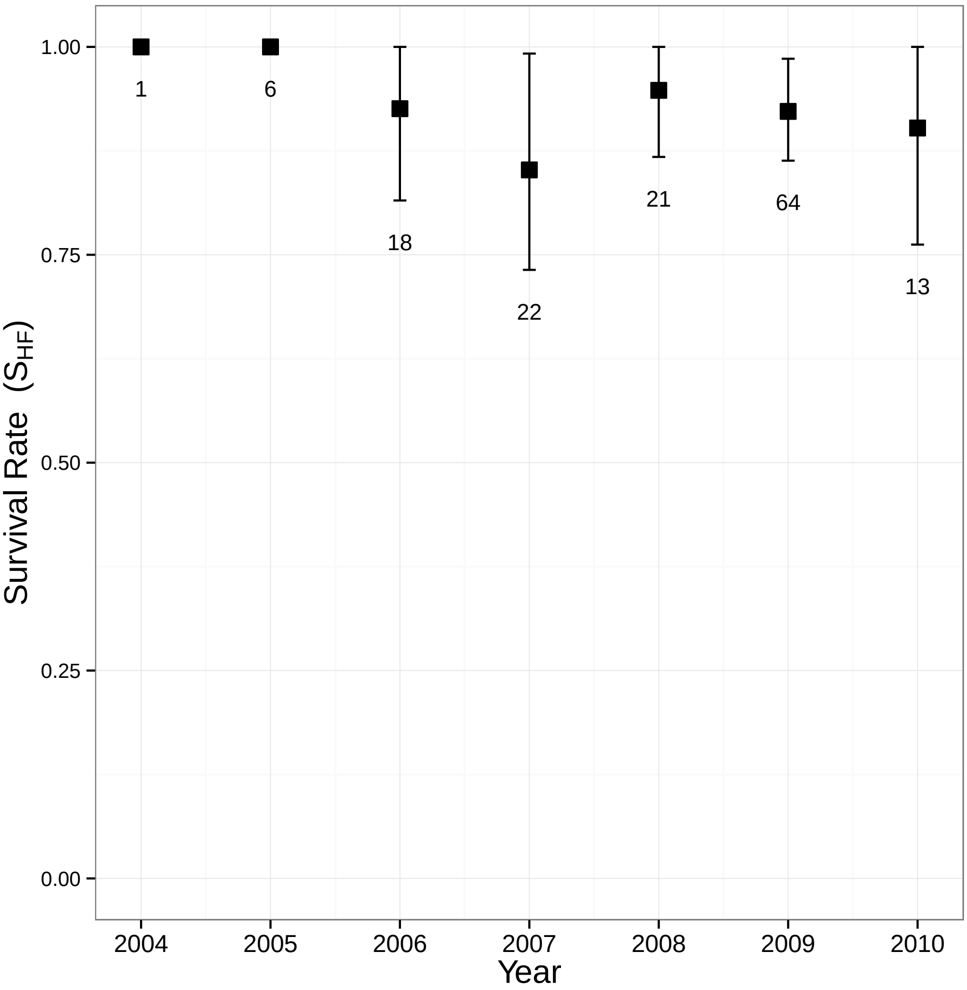

Figure 10: Annual estimated island-wide survival rates ($\hat{S}_{\text{HF-annual}}$ ± 90% CI) for yearling caribou from 2003 to 2010. Sample size per year is given below each CI. Estimates with no confidence intervals indicate an absence of recorded mortalities during this period. Estimates for 2011 are not presented due to low sample sizes

why calf survival was much lower in 2010 than 2008–2009 and 2011–2012. The unusually large number of lost collars in 2010 could bias these estimates (Fig. 4, Fig. 7), but exploratory analyses suggest this influence is rather small. The NAO in 2010 was one of the most negative in the last 30 years, but how a mild winter with little snow and rain could negatively influence calf survival is unknown.

Model comparisons

Population

Caribou calf survival had a negative relationship with population size during the 2003–2012 period (Table 2); however, during the population growth period (1965–1997), there was no relationship between calf survival and population size (Fig. 4; Mahoney et al. in prep). This pattern suggests a phase-dependent survival rate (Stenseth, 1999) with virtually no change in calf survival during the increasing population phase but a strong density-dependent change in survival rate during the pop-

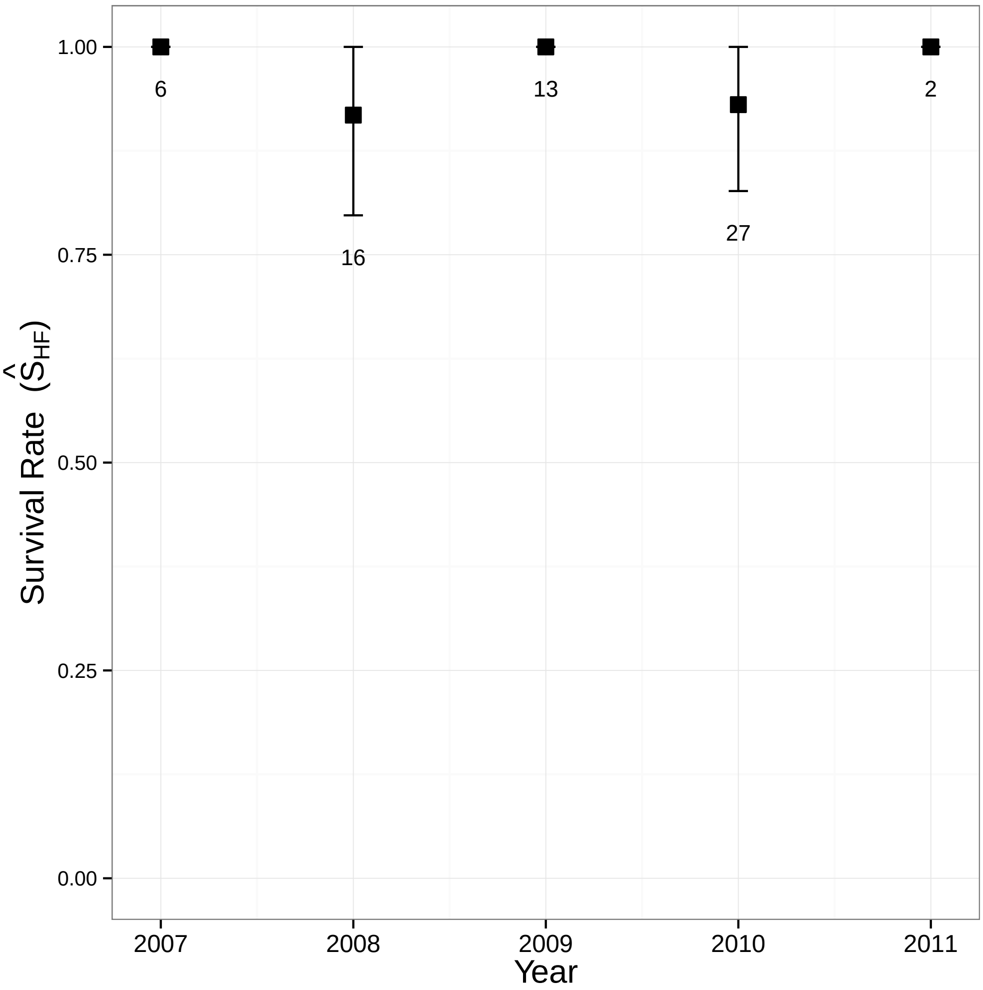

Figure 11: Annual estimated island-wide survival rates ($\hat{S}_{\text{HF-annual}} \pm 90\%$ CI) for 2-year-old caribou from 2003 to 2011. Sample size per year is given below each CI. Estimates with no confidence intervals indicate an absence of recorded mortalities during this period.

ulation decrease phase (Fig. 4). This finding is consistent with theory (Getz, 1996) and empirical evidence (Fowler, 1981, Skogland, 1985, Coulson et al., 2000), which suggests that population density must exceed a threshold before its effects on animal vigor and survival are detectable. These results are also consistent with results in British Columbia where predation is thought to keep caribou populations low enough to limit density-dependent effects (Hegel et al., 2010) and similar to those during a population decline in Alaska (Jenkins and Barten, 2005) and the Ungava Peninsula (Bergerud et al., 2007).

Individual calf weight

The evidence that individual calf weight positively influenced survival during 2003–2012 (Table 2, Fig. 6) is similar to that found by Jenkins and Barten (2005) and we agree with their conclusions that very young calves (< 2 weeks old) are essentially defenseless against predators and that lighter calves have an extended period of vulnerability that drives the low survival rates (see also Bergerud et al., 2007,

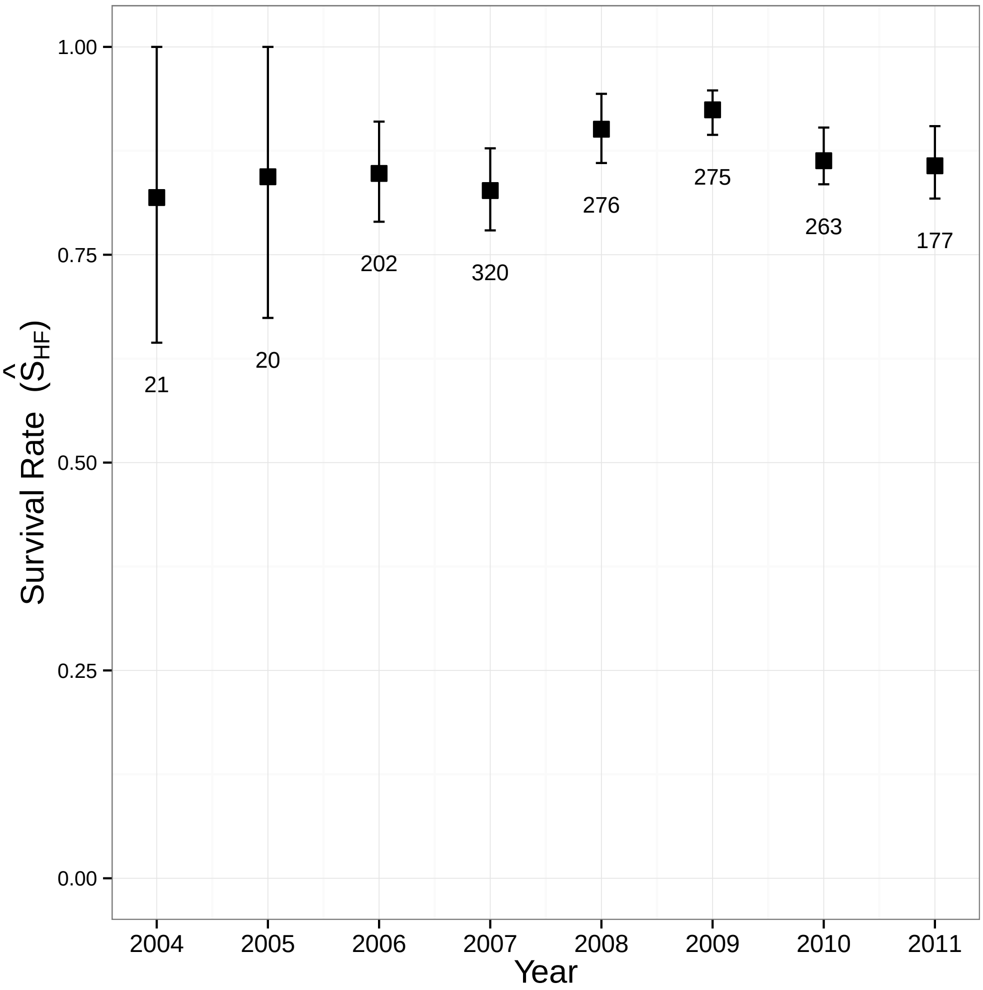

Figure 12: Estimated island-wide survival rates ($\hat{S}_{\text{HF-annual}} \pm 90\%$ CI) for adult caribou from 2004 to 2011 including hunting. Sample size per year is given below each CI.

pg 193).

Calf weight increased over the study period and is likely related to decreased competition for resources amongst breeding females as the population declined. Calf birth weight is generally correlated with maternal weight or food intake during late pregnancy (Cameron et al., 1993) and this is consistent with other evidence that caribou condition has improved since 2003 (Weir et al., 2013).

Male calves were heavier than female calves, similar to past work in Newfoundland (Bergerud, 1971) and elsewhere (Jenkins and Barten, 2005), and both weights were similar to those reported in the past (Bergerud, 1980). There was no significant difference in survival between sexes but survival rates for females were slightly higher than for males, which is consistent with Bergerud (1971) who speculated that differences in survival may be due to male calves wandering farther distances from their dams than female calves.

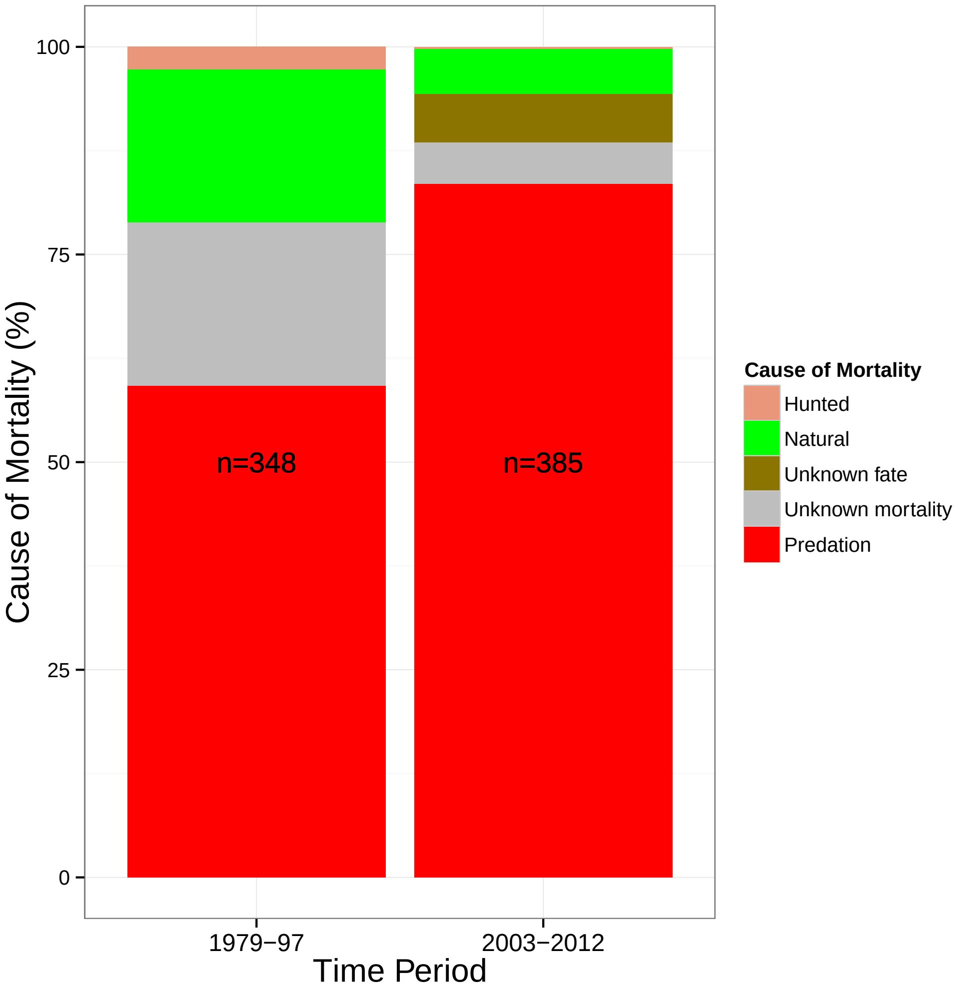

Figure 13: The causes of mortality for calves from 1979 to 1997 and 2003 to 2012. Note that the above comparisons are for calf fate to one year to facilitate comparisons with the *Synthesis*.

Climate

The weak support for models with climatic variables is inconsistent with a number of recent studies that have shown an influence of climate on ungulates (Pettorelli et al., 2005b, Gustine et al., 2006, Pettorelli et al., 2007, Mahoney et al., 2011 and see Hegel et al., 2010 and references therein). Winter severity may not be as important for caribou in Newfoundland for several reasons. First, *Rangifer* are superbly adapted to winter climates and are at the southern limit of their range in Newfoundland, where winter weather is mild relative to most of *Rangifer's* range. Although *Rangifer* populations can be limited by exceptionally severe snow or ice conditions (Solberg et al., 2001) and generally harsher winter conditions (White et al., 2011), these events are rare in Newfoundland, even during locally extreme winter conditions (Bergerud, 1971). Second, *Rangifer* are highly vagile, allowing them to escape locally extreme conditions through movement to more sheltered or ice-free areas. Third, many studies have shown that when climate does influence ungulate populations, it is most often in systems where adult ungulates are subject to year-round predation by wolves (Post and Stenseth, 1998, 1999, Post et al., 1999, Hegel et al., 2010). The proposed mechanism linking climate (i.e., NAO) and population dynamics is that winters with deeper snow hamper the movement and foraging of adult ungulates making them more vulnerable to wolf predation (Post et al., 1999). However, these conditions do not occur in Newfoundland because of the absence of wolves. Predation pressure is minimal in the winter because black bears are hibernating, calves are too large for lynx and Bald Eagles to take, and coyotes take few animals.

However, other studies have shown a relationship between morphological traits and the NAO; caribou tend to be smaller in Newfoundland when born after severe winters when population levels are high (Mahoney et al., 2011). At the same time, we are unaware of any relationship between the NAO and caribou pregnancy rates, which appear to have been resilient over periods of population increase. This suggests that caribou may allocate resources to survival and reproduction rather than growth (Crête and Huot, 1993). Bastille-Rousseau et al. (2013) showed a correlation between 5-year averages of the NAO and the caribou population. If indicative of a causal effect, this lag effect may be due to the long-term influence of more severe winters influencing the population through variables other than juvenile survival (Patterson and Power, 2002).

The poor support for the climatic models could be due to other factors. Given the relatively mild winter temperatures in Newfoundland, freeze–thaw cycles or freezing rain events may be more important for caribou survival than the variables measured here. The lack of a relationship with climate may be partially due to the island-wide nature of this study that could mask local climate effects. A study focusing on a single herd, perhaps Middle Ridge, and local climate variables, such as freeze–thaw cycles, may detect an influence of climate on caribou vital rates. The lack of a relationship among the start of spring, the rate of green-up in spring, and summer conditions could be due to the relatively short study interval that makes it difficult to detect lag effects. However, we strongly suspect demographic influences may be more important than climactic ones during this study period (Weir et al., 2013).

One climatically linked factor not explored in this report is insect harassment that can be debilitating, especially if caribou become infested. Insect harassment has been shown to influence vital rates in caribou and cause death in extreme cases (Cuyler et al., 2012 and references therein) as well as reduce autumn weight in calves (Weladji et al., 2003). Caribou in Newfoundland exhibit typical avoidance behaviours towards warble (*Hypoderma tarandi*) and bot (*Cephenemyia trompe*) flies. However, the level of harassment by these flies has not been quantified in Newfoundland, and their influence on caribou populations in Newfoundland, if any, is unknown. Insect harassment was not examined in this study because climate data in close proximity to a herd is required (Weladji et al., 2003).

Timing of mortality and constant survival

It is clear that caribou calf survival is not constant over the course of a year. Most calves died within the first 3 months of life and especially the first 5 to 6 weeks (Fig. 8). These results are similar to those previously reported for Newfoundland (Bergerud, 1971, Mahoney et al., 1990), where it was found that most calves were killed by predators within the first 4 weeks. Similarly, low calf survival in the first few weeks has been shown across North America (Bergerud, 1980). In Alaska, for various herds, calf predation led to an 85% death rate within the first 8 days of life (Adams et al., 1995, Gustine et al., 2006) and 79% within 4 weeks (Jenkins and Barten, 2005). A 55% calf mortality rate was found in the first 2 weeks in British Columbia (Bergerud and Elliot, 1986), and the number of calves/100 females decreased precipitously in the first 3 weeks but not thereafter in Alberta (Stuart-Smith et al., 1997).

Properly accounting for non-constant survival is critical for any survival analysis as failure to do so will result in an underestimate of survival, clouding subsequent inference and management decisions. Although estimates from the nest survival model with constant survival are similar to HF estimates (without Trend: $\hat{S}_{NS} = 0.230 \pm 0.013$ SE, $\hat{S}_{HF} = 0.246 \pm 0.014$ SE), adjusting for non-constant survival produces a higher and more realistic estimate (with Trend: $\hat{S}_{NS} = 0.350 \pm 0.018$ SE). Non-constant survival is especially easy to implement in Program MARK and should be controlled for in any analysis. While non-constant survival can be accommodated by the HF estimate by multiplying survival estimates over a number of intervals (i.e., span $\hat{\mathrm{S}}^*$), the inability of HF to examine anything but very simple hypotheses severely limits the utility of this approach (Heisey and Fuller, 1985). We propose that while $\hat{\mathrm{S}}_{\mathrm{HF}}$ is appropriate for calculating survival for cohorts that experience constant survival, is easy to calculate, and is directly comparable with previous survival estimates of Newfoundland caribou, it should be abandoned for cohorts that experience non-constant survival, i.e., neonate calves, and instead be calculated using Program MARK as in this report.

Survival of older cohorts

Over-winter survival of caribou calves in Newfoundland has remained high as indicated in earlier reports that summarized research from 2003 to 2007 (Mahoney and Weir, 2009, Trindade et al., 2011). These results are also consistent with studies in British Columbia and Alaska that found high over-winter calf survival (Bergerud and Elliot, 1986, Jenkins and Barten, 2005). Similarly, high survival rates for yearlings, 2-year-old calves, and adults were reported during the period of increasing and maximum caribou population (Mahoney and Weir, 2009, Weir et al., 2013). Adult survival for Newfoundland caribou was similar to herds in other areas in North America (Bergerud, 1980, Stuart-Smith et al., 1997, Wittmer et al., 2007) and other ungulates (Gaillard et al., 1998). Although low survival of these older cohorts, especially adults, can be an important factor in population declines (Jenkins and Barten, 2005), the similarities in survival rates for these cohorts between the observed population increase and decline phase in Newfoundland caribou suggest that this was not a major influence on the population decline (Mahoney and Weir, 2009). The high survival of older cohorts and over-winter calves is likely due to the lack of a year-round predator capable of efficiently killing adults, i.e., wolves.

Predation is the primary cause of neonate calf mortality

Across the species' range, the primary causes of caribou calf mortality include predation, extreme winter weather, disease, accidents, desertion, and birth defects (Bergerud, 1974, 1980, Whitten et al., 1992, Adams et al., 1995). Predation accounted for most calf mortalities in every year of this study (83%). These results are similar to earlier research in Newfoundland (Bergerud, 1974, Mahoney et al., 1990, Mahoney and Virgl, 2003), earlier components of the *Calf Mortality Study* (Trindade et al., 2011), and other regions in North America (Rettie and Messier, 1998, McLoughlin et al., 2003, Jenkins and Barten, 2005, Wittmer et al., 2005, Gustine et al., 2006).

However, the situation is different for older animals. Less than 5% of the sub-adult caribou died, and of those, roughly half were due to predation: over-winter (55%), yearling (44%), and 2-year-old calves (50%). An average of 9.7% of adults died per year and 27% of these were due to predation[6].

There were a number of mortalities classified as "unknown predator" (16%), especially in 2007 and 2008 (for a full discussion, see Trindade et al. 2011). Because of the nature of gathering data on caribou fates, a large percentage of unidentified predators and fates is not uncommon (Stuart-Smith et al., 1997, Wittmer et al., 2005). The use of veterinary necropsy and genetic testing clarified predator identity in some instances but sometimes conflicted with strong field site evidence, rendering final decisions difficult to make. However, the percentage of carcasses designated as "unknown predator" decreased over time suggesting that the addition of necropsy and genetic testing were beneficial.

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[6] The cause of death for these animals should be cautiously accepted given the longer interval between death and field examination.

The importance of predator species varied with herd

Black bears and coyotes were the dominant predators although their importance varied with herd (Appendix 5). These results differ from Bergerud (1971, 1983) who found lynx were the dominant predator, but they are similar to Mahoney et al. (1990) who found high black bear as well as lynx predation on the south coast (see Trindade et al., 2011 for results and discussion). There are at least three possible, non-mutually exclusive explanations for the differences between this study and previous work (Bergerud, 1971, 1983). First, other predators may have played a more important role than reported by Bergerud (1971, 1983) who did not have the benefit of radio-telemetry to find calf mortalities and examine them (Peek et al., 2012). Second, the arrival of coyotes may have altered the availability of caribou for other predators through exploitation and/or interference competition. Third, predation may be proportional to predator species abundance that varies across the landscape and over time. Studying the whole predator guild in more detail will assist in the ability to distinguish among these explanations to improve caribou management (Gustine et al., 2006).

The influence of this guild of predators is likely independent of the caribou population. Caribou are not the primary food for any of these predators, and therefore, predator populations are unlikely to be strongly influenced by further decreases in caribou numbers. Thus, we may expect continuing high levels of calf mortality even as the caribou population continues to decline.

The influence of coyote

Coyote are believe to have arrived in Newfoundland in the early 1980s. There were only a few recorded cases of coyote predation in Newfoundland prior to 2003 (Weir et al., 2013). However, calf mortality in Quebec increased after the arrival of coyotes (Crête and Desrosiers, 1995) and this may have occurred in Newfoundland (Fig. 13). However, it is not clear to what degree coyote predation is additive or compensatory, i.e., do coyotes kill calves that would otherwise have survived or do they take calves that would have been taken by other predators. Determining whether predation is additive or compensatory is extremely difficult, and expensive, and therefore it is difficult to determine the exact contribution of the arrival of coyote to the caribou population decline. What is clear is that there is little evidence to support anecdotal reports of high levels of over-winter caribou mortality due to coyote predation, which took a total of 18 animals of 424 collared animals from 2004 to 2011.

Conclusions and future directions

Survival rates for Newfoundland's caribou calves were extremely low from 2003 to 2007, and although the survival rates increased from 2008 to 2012, they are still low compared with survival rates during the caribou population increase phase in the 1980s and 1990s. The low survival rate is proximately due to predation in the first 6–7 weeks of life, primarily by black bears and coyotes. Over-winter, yearling, 2-year-old, and adult survival rates were high and comparable with the historical averages (Mahoney and Weir, 2009). These results confirm previous suggestions that 1) predation on young calves is a major factor in the caribou population decline and 2) the increase in calf predation likely began sometime in the mid-to-late 1990s.

Building upon previous studies (Mahoney and Weir, 2009, Trindade et al., 2011), this study analytically demonstrated a density-dependent effect of population size on calf survival and compared this to competing hypotheses (e.g., influence of climate). This study, coupled with lines of evidence from other components of the *Caribou Strategy*, i.e., density-dependent responses in caribou size and vigor evidenced by decreasing adult female body size, decreasing birth weight, and decreasing male antler size, support the conclusion that density-dependent factors may have predisposed calves to higher predation rates (Weir et al., 2013). The reversal of many of these trends and the decreasing rate of population decline (Weir et al., 2013), as well as the increase in calf survival rates in recent years, may indicate an improving situation for island caribou. However, the caribou population is still declining and this will likely change the COSEWIC recommendation from "Not-At-Risk" to some level of "At-Risk" designation (Randell et al., 2012). A change in COSEWIC status combined with the knowledge that populations that are appearing to recover can then decline rapidly (e.g., George River caribou, Atlantic cod (*Gadus morhua*)) suggest future monitoring of caribou populations is required.

The value of long-term data sets has been repeatedly demonstrated in ecology and this report supports this notion. Long time series also provide historical context; if data collection had only begun in 2003, there would be no historical context for comparing calf survival during the population increase and decrease, i.e., that calf survival is still relatively low in 2012 compared with the 1980s. The length of this time series also allows examination of trends over several decades and is long enough to permit the examination of multiple variables that could influence calf survival. The lack of monitoring between 1998 and 2002 makes an analysis of the entire time series problematic and inhibits analysis of delayed responses around this critical period. A continuation in collaring caribou calves is critical to maintain this valuable resource for management and research.

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Appendices

Appendix 1 - Characteristics used in determining cause of mortality.

Table A.1: Characteristics used in determining cause of death at the mortality site.

Cause of death	Possible characteristics of the mortality site
Black bear	Typically skin the calf but generally leave the pelt intact; pelt is often still attached and peeled back over the legs. Most of the skeleton is eaten and the skull cap present. Hooves are often chewed and hoof tips left next to the major remains. Bears also prefer to eat the brains and cartilaginous nose and ears. Can break and eat the long bones of the legs. Bears often leave “neat” piles of remains in a small area (10–50 m^2).
Coyote	Often attack the throat, causing considerable trauma and hemorrhaging to this area and bite marks in the throat and head regions. Calves are sometimes dismembered; limbs are removed and may be left at the mortality site or carried away. Coyotes often leave bite wounds on the rump and/or hind legs. Scattering of the remains over a wide area is common. Burial of remains was observed; coyotes dig holes to cache food rather than covering it with moss/litter.
Lynx	Small puncture marks in the area of the larynx with much less trauma than coyote kills. Head and/or neck and/or forelimbs are buried. Lynx cover the calf remains with moss/litter. Scratches/punctures on the hind or main portion of carcass.
Bald Eagle	Typically multiple, deep puncture wounds on the back, neck, or head.
Unknown predator	Field evidence is lacking/inconclusive. E.g., a chewed or blood-stained collar is found with small bone fragments and small pieces of caribou pelt or only the collar, with most of the staples intact, i.e., it is assumed that the collar could not have slipped off the calf but may have been removed as the calf was handled by a predator. Further, lack of any predator–specific indicators among the skeletal remains or calves killed in early winter can be covered in snow, resulting in remains that are too decomposed in spring to assign a specific predator.
Unknown mortality	A dead, non-predated, otherwise healthy-looking calf with no signs of predation, death by accident, disease, poor physical condition, or abandonment is occasionally recovered. Advanced decomposition can also result in an unknown mortality designation.
Natural causes/accidental	Carcasses without signs of predation (i.e., wounds from another animal). Causes include disease/infection, orphaning, drowning, and starvation. Calves are also recovered with broken legs, entangled in tree limbs, and wedged between boulders.

Figure A.1: A) A skinned calf often indicates a black bear, B) extensive throat damage is often characteristic of a coyote kill, and C) puncture wounds on the throat are common indicators of a lynx kill.

Appendix 2 - Correlations between climatic and weather variables at two weather stations in Newfoundland

Table A.2: Correlation between the North Atlantic Oscillation and average temperature (°C), snowfall (cm), and rainfall (mm) for two weather stations in Newfoundland (2003–2012). Weather[1] and climate[2] data are available on-line from Environment Canada. Bold values indicate a statistically significant correlation.

	Weather station	
Weather	Gander	Deer Lake
Temperature	**–0.59**	**–0.69**
Snow	0.35	**0.66**
Rain	**–0.58**	0.21

Station details

Number of Years	1937–2011	1965–2011
Latitude	48.95	49.22
Longitude	–54.58	–57.4
Elevation(m a.s.l)	151.2	21.9

[1] http://www.climate.weatheroffice.ec.gc.ca

[2] http://www.cpc.ncep.noaa.gov

Table A.3: Data used for correlations between weather and climate variables for Gander (2003–2012) in Table A.2 and in survival analyses including temperature °C (Temp), snowfall (cm, Snow), rainfall (mm, Rain), the North Atlantic Oscillation (NAO) for winter (i.e., December of year$_{(t-1)}$ to April of year$_{(t)}$), and several measures derived from the Normalized Difference Vegetation Index (NDVI) including annual productivity (meanNDVI$_{(t)}$), the Julian day for the start of spring (Spring_start$_{(t)}$), and the rate of green-up during spring (Spring_rate$_{(t)}$).

Year	Temp	Snow	Rain	NAO	meanNDVI$_{(t)}$	Spring_start$_{(t)}$	Spring_rate$_{(t)}$
2003	–3.48	52.46	21.52	0.51	0.36	121.94	0.07
2004	–4.36	52.52	15.96	–0.004	0.38	123.66	0.07
2005	–2.56	83.66	29.88	0.48	0.45	118.233	0.08
2006	–2.94	77.24	20.36	0.11	0.53	111.752	0.04
2007	–1.52	60.88	36.16	0.06	0.49	125.18	0.05
2008	–3.10	51.72	16.76	0.54	0.48	124.234	0.05
2009	–3.40	63.36	19.44	0.19	0.50	115.492	0.04
2010	–2.62	52.76	22.12	0.03	0.48	125.352	0.04
2011	–1.02	48.66	37.4	–1.32	0.42	124.28	0.03
2012	–2.32	82.04	17.82	0.21	0.48	112.147	0.04

Table A.4: Data used for correlations between weather and climate variables for Deer Lake (2003–2012) in Table A.2 and in survival analyses including temperature °C (Temp), snowfall (cm, Snow), rainfall (mm, Rain), the North Atlantic Oscillation (NAO) for winter (i.e., December of year$_{(t\text{-}1)}$ to April of year$_{(t)}$), and several measures derived from the Normalized Difference Vegetation Index (NDVI) including annual productivity (meanNDVI$_{(t)}$), the Julian day for the start of spring (Spring_start$_{(t)}$), and the rate of green-up during spring (Spring_rate$_{(t)}$).

Year	Temp	Snow	Rain	NAO	meanNDVI$_{(t)}$	Spring_start$_{(t)}$	Spring_rate$_{(t)}$
2003	–4.56	55.08	22.7	0.516	0.36	121.94	0.07
2004	–5.23	56.16	30.56	–0.004	0.38	123.66	0.08
2005	–3.56	66.1	22.32	0.476	0.45	118.23	0.08
2006	–3.70	55.14	8.12	0.108	0.53	111.75	0.01
2007	–2.26	45.82	27.18	0.056	0.49	125.18	0.05
2008	–3.68	41.32	18.16	0.54	0.48	124.23	0.05
2009	–4.40	72.1	16.04	0.194	0.50	115.49	0.04
2010	–3.24	66.6	13.9	0.028	0.48	125.35	0.04
2011	–0.79	19.22	15.32	–1.324	0.42	124.28	0.03
2012	–2.51	74.44	23.72	0.212	0.48	112.15	0.04

Appendix 3 - Number of collared calves by study area, sex, and age of collaring (2003–2012).

Table A.5: The number of collared calves by sex and age in the study areas (2003–2012; censored animals not included - see Data screening in Methods).

		Over-winter		Neonate			
Year	Study area	Female	Male	Female	Male	Unknown	Total
2003	Gaff Topsails	0	0	8	9	0	17
2003	Middle Ridge North	0	0	12	12	0	24
2003	Middle Ridge South	0	0	1	4	0	5
2003	Mount Peyton	0	0	2	7	0	9
2004	Gaff Topsails	0	0	18	13	0	31
2004	Middle Ridge North	0	0	8	19	0	27
2004	Middle Ridge South	0	0	3	4	0	7
2005	Middle Ridge	16	9	0	0	0	25
2005	Middle Ridge North	0	0	6	10	0	16
2005	Middle Ridge South	0	0	3	3	0	6
2006	Middle Ridge	11	14	0	0	0	25
2006	Middle Ridge North	0	0	7	15	1	23
2006	Middle Ridge South	0	0	2	5	0	7
2007	La Poile	0	0	13	18	0	31
2007	Middle Ridge	10	15	0	0	0	25
2007	Middle Ridge North	0	0	11	14	0	25
2007	Middle Ridge South	0	0	9	0	0	9
2008	La Poile	12	8	16	14	0	50
2008	Middle Ridge	11	9	0	0	0	20
2008	Northern Peninsula	10	10	12	16	0	48
2008	Middle Ridge North	0	0	9	15	0	24
2008	Middle Ridge South	0	0	8	7	0	15
2009	La Poile	2	2	20	20	0	44
2009	Middle Ridge	3	5	0	0	0	8
2009	Northern Peninsula	4	6	20	18	0	48
2009	Middle Ridge North	0	0	15	17	1	33
2009	Middle Ridge South	0	0	5	6	0	11
2010	La Poile	3	7	11	13	0	34

2010	Middle Ridge	7	6	0	0	0	13
2010	Northern Peninsula	7	6	0	0	0	13
2010	Middle Ridge North	0	0	7	9	0	16
2010	Middle Ridge South	0	0	5	9	0	14
2011	La Poile	4	2	15	10	0	31
2011	Middle Ridge	4	2	0	0	0	6
2011	Northern Peninsula	0	0	10	11	3	24
2011	Middle Ridge North	0	0	18	13	0	31
2011	Middle Ridge South	0	0	16	11	1	28
2012	La Poile	8	6	15	10	0	39
2012	Northern Peninsula	4	6	10	14	0	34
2012	Middle Ridge North	0	0	10	19	0	29
2012	Middle Ridge South	0	0	15	19	0	34
	Total	116	113	340	384	6	959

Appendix 4 - Calf survival by study area, 2003–2012

Table A.6: Estimated survival rates ($\hat{S}_{\text{HF-annual}}$) for neonate calves by study area from 2003 to 2012. Var = variance, LL = lower 90% confidence limit, UL = upper 90% confidence limit, n = sample size, mortality = number of animals confirmed dead.

Study area	Year	$\hat{S}_{\text{HF-annual}}$	Var	LL	UL	n	Mortality
Gaff Topsails	2003	0.04	0.00	0.01	0.17	17	15
Gaff Topsails	2004	0.17	0.00	0.08	0.33	31	18
La Poile	2007	0.21	0.01	0.12	0.40	31	17
La Poile	2008	0.24	0.01	0.14	0.44	30	16
La Poile	2009	0.29	0.01	0.19	0.46	40	21
La Poile	2010	0.05	0.00	0.01	0.17	24	16
La Poile	2011	0.40	0.01	0.25	0.63	25	11
La Poile	2012	0.26	0.01	0.14	0.49	25	12
Middle Ridge North	2003	0.02	0.00	0.01	0.09	24	22
Middle Ridge North	2004	0.01	0.00	0.00	0.05	27	17
Middle Ridge North	2005	0.12	0.01	0.04	0.37	16	10
Middle Ridge North	2006	0.06	0.00	0.02	0.17	23	19
Middle Ridge North	2007	0.06	0.00	0.02	0.21	25	14
Middle Ridge North	2008	0.36	0.02	0.21	0.63	24	9
Middle Ridge North	2009	0.34	0.01	0.22	0.53	33	16
Middle Ridge North	2010	0.20	0.01	0.07	0.54	16	7
Middle Ridge North	2011	0.17	0.00	0.09	0.33	31	19
Middle Ridge North	2012	0.38	0.01	0.24	0.59	29	13
Middle Ridge South	2003	0.15	0.02	0.04	0.60	5	5
Middle Ridge South	2004	0.11	0.01	0.03	0.49	7	6
Middle Ridge South	2005	0.12	0.01	0.03	0.51	6	6
Middle Ridge South	2006	0.02	0.00	0.00	0.23	7	7
Middle Ridge South	2007	0.00	0.00	0.00	0.13	9	7
Middle Ridge South	2008	0.02	0.00	0.00	0.14	15	12
Middle Ridge South	2009	0.00	0.00	0.00	0.08	11	10
Middle Ridge South	2010	0.00	0.00	0.00	0.07	14	11
Middle Ridge South	2011	0.01	0.00	0.00	0.06	28	23
Middle Ridge South	2012	0.23	0.01	0.13	0.43	34	16
Mount Peyton	2003	0.11	0.01	0.03	0.44	9	7

Northern Peninsula	2008	0.25	0.01	0.14	0.43	28	17
Northern Peninsula	2009	0.29	0.01	0.17	0.49	38	15
Northern Peninsula	2010	0.03	0.00	0.00	0.24	16	8
Northern Peninsula	2011	0.41	0.01	0.26	0.65	24	10
Northern Peninsula	2012	0.41	0.01	0.26	0.65	24	10

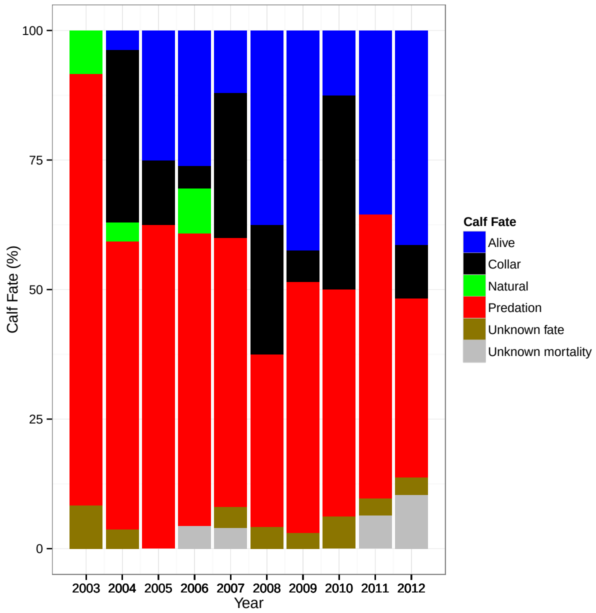
Table A.7: Estimated survival rates ($\hat{S}_{\text{HF-6month}}$) for over-winter calves by study area from 2003 to 2012. Var = variance, LL = lower 90% confidence limit, UL = upper 90% confidence limit, n = sample size, mortality = number of animals confirmed dead.

Study area	Year	$\hat{S}_{\text{HF-6month}}$	Var	LL	UL	n	Mortality
La Poile	2007	1	0	1	1	6	0
La Poile	2008	0.97	0.00	0.91	1.00	30	1
La Poile	2009	0.85	0.01	0.73	0.99	19	3
La Poile	2010	1.00	0.00	1.00	1.00	13	0
La Poile	2011	1.00	0.00	1.00	1.00	16	0
La Poile	2012	1.00	0.00	1.00	1.00	17	0
Middle Ridge	2004	0.37	0.14	0.07	1.91	1	1
Middle Ridge	2005	0.92	0.00	0.84	1.01	29	2
Middle Ridge	2006	0.79	0.01	0.68	0.91	31	7
Middle Ridge	2007	0.90	0.00	0.81	0.99	29	3
Middle Ridge	2008	0.90	0.00	0.82	0.99	31	3
Middle Ridge	2009	0.95	0.00	0.88	1.03	22	1
Middle Ridge	2010	1.00	0.00	1.00	1.00	15	0
Middle Ridge	2011	0.94	0.00	0.86	1.04	19	1
Middle Ridge	2012	1.00	0.00	1.00	1.00	15	0
Northern Peninsula	2008	0.85	0.00	0.75	0.96	32	5
Northern Peninsula	2009	0.74	0.01	0.60	0.91	22	6
Northern Peninsula	2010	0.83	0.01	0.66	1.00	13	2
Northern Peninsula	2011	1.00	0.00	1.00	1.00	10	0
Northern Peninsula	2012	1.00	0.00	1.00	1.00	19	0
Gaff Topsails	2004	0.80	0.02	0.62	1.04	9	2
Mount Peyton	2003	0.72	0.06	0.41	1.00	3	1

Appendix 5 - Fate of neonate calves and source of mortality to 6 months in four study areas, 2003–2012.

Gaff Topsails and Mount Peyton are not presented here; see Trindade et al., 2011.

A)



B)

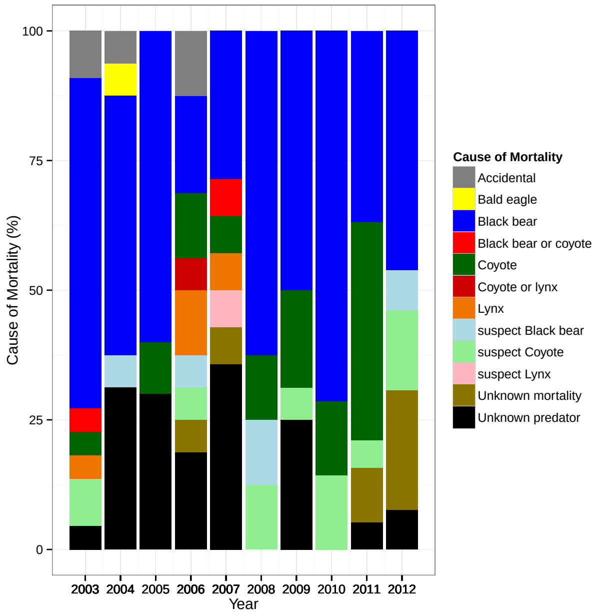


Figure A.2: A) The fate and B) cause of death of neonate calves in Middle Ridge North from 2003 to 2012. Collar = collar slipped or broke.

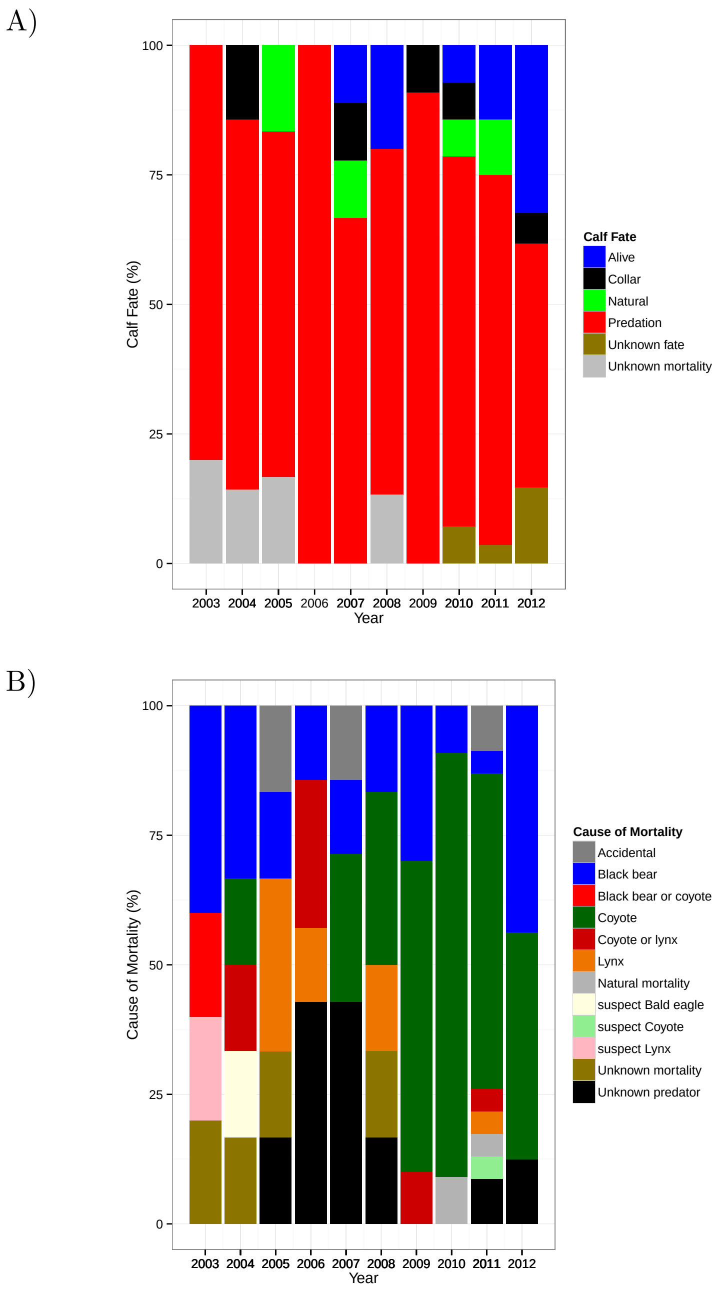
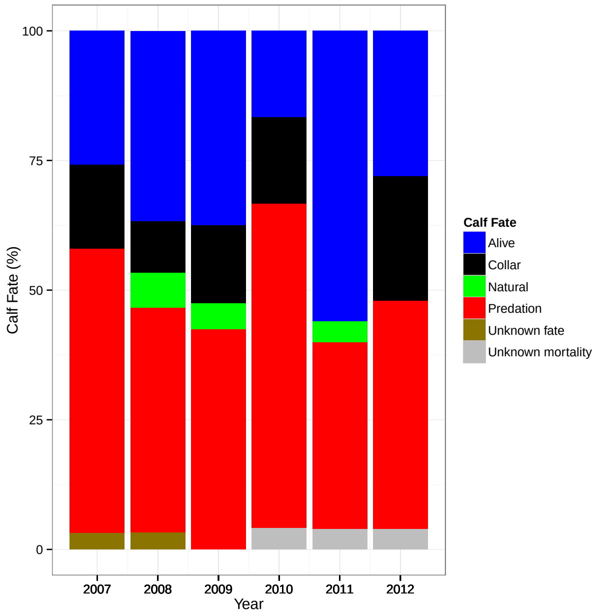


Figure A.3: A) The fate and B) cause of death of neonate calves in Middle Ridge South from 2003 to 2012. Collar = collar slipped or broke.

A)



B)

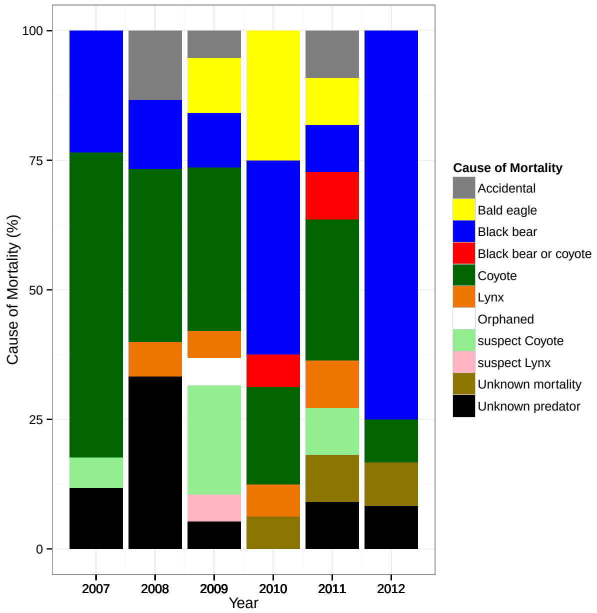
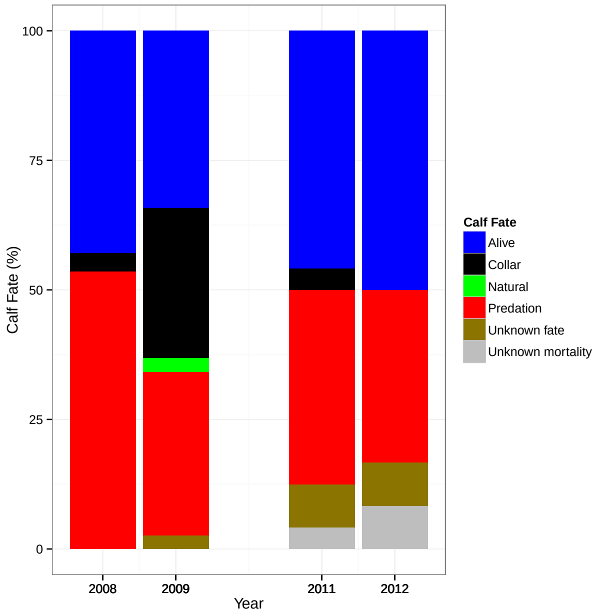


Figure A.4: The fate (A) and cause of death (B) of neonate calves in La Poile from 2007to 2012. Collar = collar slipped or broke.

A)



B)

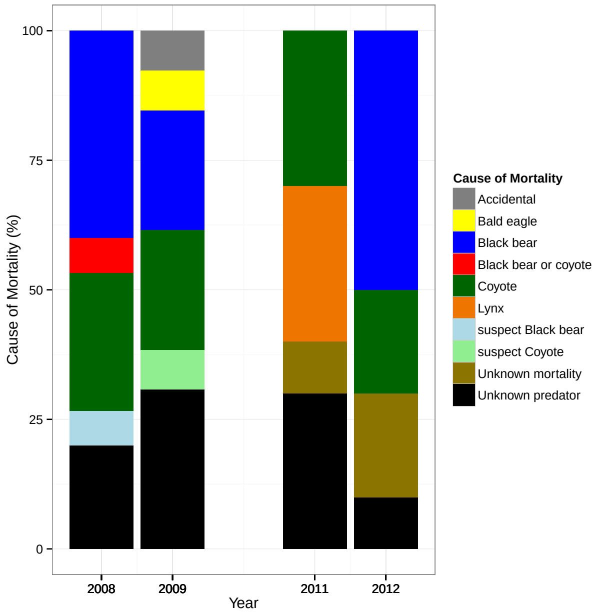
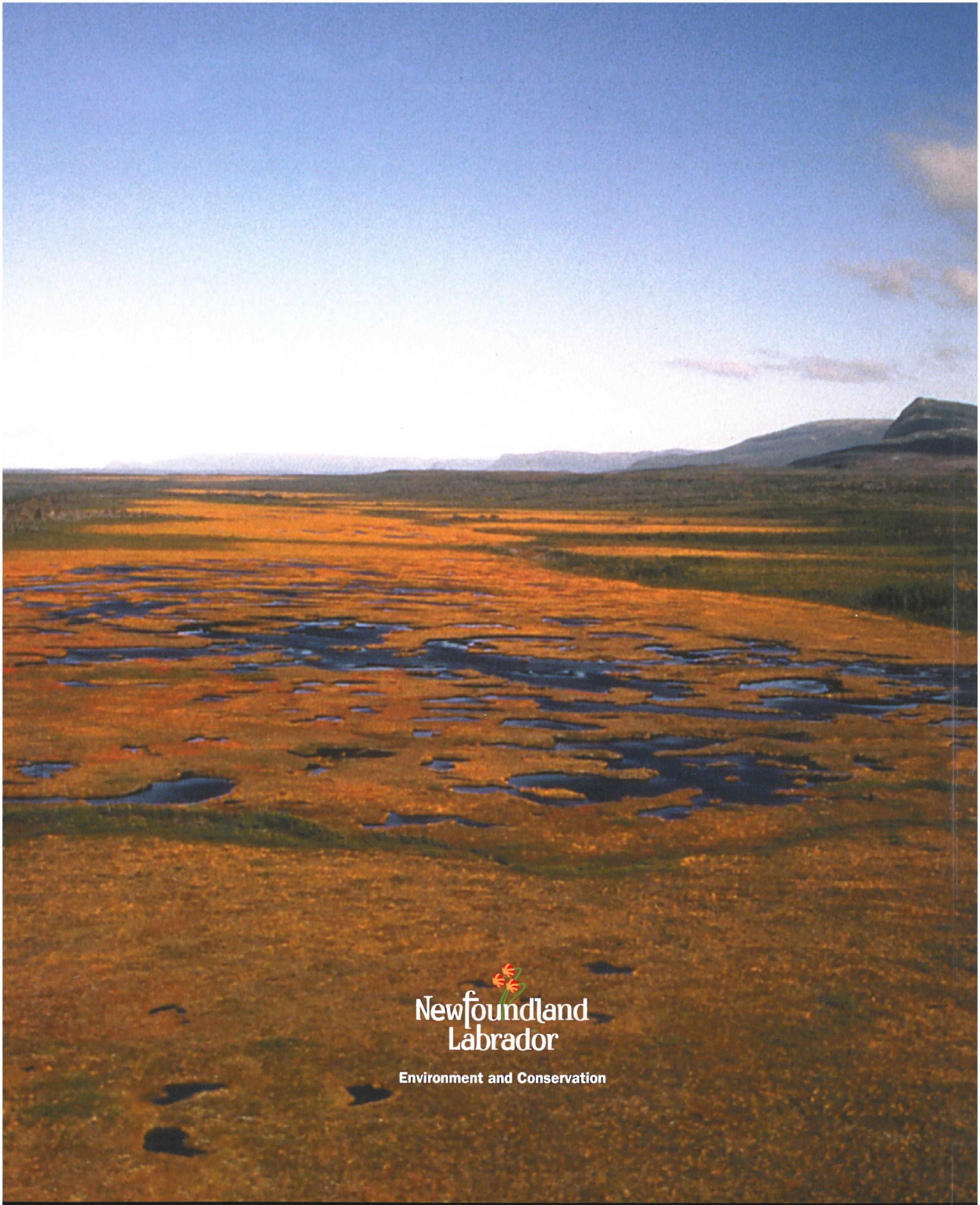


Figure A.5: A) The fate and B) cause of death of neonate calves in the Northern Peninsula from 2008 to 2012. Data from 2010 was censored - see Methods. Collar = collar slipped or broke.



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