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CARIBOU CALF MORTALITY STUDY 2003–2007

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Department of Environment and Conservation

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CARIBOU CALF MORTALITY STUDY

A summary and analysis of the patterns and causes of caribou calf mortality in Newfoundland during a period of rapid population decline: 2003-2007.

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EXECUTIVE SUMMARY

Caribou populations are declining globally. Newfoundland's caribou population is not designated as 'At-Risk', but they have declined from nearly 100,000 animals in the late 1990s animals to just over 38,000 in 2008. Population modeling suggests that Newfoundland caribou could be assessed as 'At-Risk' by 2012. Ongoing research and monitoring efforts suggest that the population decline was partially attributable to high levels of calf mortality. The Calf Mortality Study (2003-2007) was initiated to empirically identify the causes, rates, and timing of calf mortality in three herds: the Middle Ridge, Gaff Topsails, and Mount Peyton.

The study was conducted by the Sustainable Development and Strategic Science Branch (Department of Environment and Conservation) of the Government of Newfoundland and Labrador. The Calf Mortality Study has shown that:

1. Annual survival estimates for neonate calves were extremely low (4% survival) when compared to historical estimates (66% survival), in particular for those calves at Middle Ridge.
2. Predation by bears, coyotes, lynx and eagles was the single greatest cause of calf mortality across herds and years.
3. The importance of different predator species varied among herds. At Middle Ridge, black bear were primarily responsible for calf mortalities. At Gaff Topsails, eagle and coyotes caused the most mortalities, while lynx were most important in Mount Peyton.
4. Predator-caused calf mortality events occurred primarily during the first eight weeks of calf life, especially in the first four.
5. Survival estimates of calves from 6-months to 1-year (i.e. overwinter) were 87% and comparable to adult survival. Contrary to anecdotal reports, overwinter mortality was not found to be a significant contributor to calf mortality.
6. The weight of calves at capture had no influence on survival.

These results, combined with the Caribou Data Synthesis, form the basis of the Newfoundland Caribou Strategy. The Strategy is another five year effort to identify the factors underlying the extremely low calf survival and the caribou population decline.

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INTRODUCTION

Over the last decade, most populations of caribou and reindeer *(Rangifer tarandus)* have declined over their circumpolar range due to a variety of stressors, including climate change and anthropogenic landscape change (Vors and Boyce 2009). With the exception of Newfoundland, all populations of woodland caribou across Canada are designated as 'At-Risk' by the Committee on the Status of Wildlife in Canada (COSEWIC 2002) warranting protection under the Species At Risk Act (SARA). Many of these herds are listed as 'Endangered'. The situation in Alberta is so dire that Schneider et al. (2010) advocate the term and application of "conservation triage" to the provinces caribou, i.e. allocate available resources to save the herds that can be saved.

In 2002, Newfoundland harbored approximately 82,000 caribou island-wide, representing nearly 80% of the woodland caribou in North America, and the population was assessed as 'Not-At-Risk' by COSEWIC (COSEWIC 2002). However, concurrent with, and following this review, the Newfoundland caribou population decreased from a high of nearly 100,000 animals in the late 1990s to just under 38,000 animals in 2008. Population modeling indicates that under current demographic conditions, the caribou population will continue to decline and that the next COSEWIC review, scheduled for 2012, will trigger some level of 'At-Risk' designation (Randell et al. *in prep*).

A variety of indices have suggested potential mechanisms underlying the population decline in Newfoundland. Hunter harvest records and herd composition surveys showed that calf recruitment to one year of age was very low (<10%) in the late 1990s through early 2000s compared to the 1970-80s (30-40%). Herd composition surveys also indicated that the productivity and adult survival were comparable to historically high rates for most herds (Mahoney 2000; Mahoney and Weir 2009) suggesting that low calf survival was driving the low recruitment rates. Further, anecdotal reports suggested that overwinter mortality was high due to predation by non-native coyotes *(Canis latrans)*.

The Calf Mortality Study was initiated in 2003 to assess rates and patterns of calf survival. Specifically, we sought to 1) estimate annual survival rates, 2) determine causes and timing of mortality, and 3) explore factors influencing calf survival rates for three herds (Gaff Topsails, Mount Peyton, Middle Ridge). The investigation was limited to the Middle Ridge from 2005 onwards due to funding restraints.

METHODS

Study areas

The Calf Mortality Study was conducted on the Gaff Topsails (2003 and 2004), Mount Peyton (2003) and Middle Ridge (2003-2007) caribou herds. The calving grounds for all three herds are in the interior of Newfoundland **(Figure 1).**

The Gaff Topsails herd range is within the Long Range Barrens Ecoregion (Daaman 1983). The region is dominated by bog, fen and barrens, but also includes patches of black spruce *(Picea mariana)* and fir *(Abies balsamea)* forest, commonly found in sheltered valleys (Damaan 1983; Soulliere 2008). The dominant shrub is sheep laurel *(Kalmia angustifolia)* but rhodora *(Rhododendron canadense)* is also common. The calving grounds were on a high plateau dominated by shrub barrens.

The Middle Ridge and Mount Peyton caribou herd ranges are 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 dappled with 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 to the rest of insular 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 *(Larix laricina)* are found on the windswept barrens (Daaman 1983). The dwarf shrub heath is comprised 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 contained more herbs, shrubs, and exposed land than the rest of the study areas.

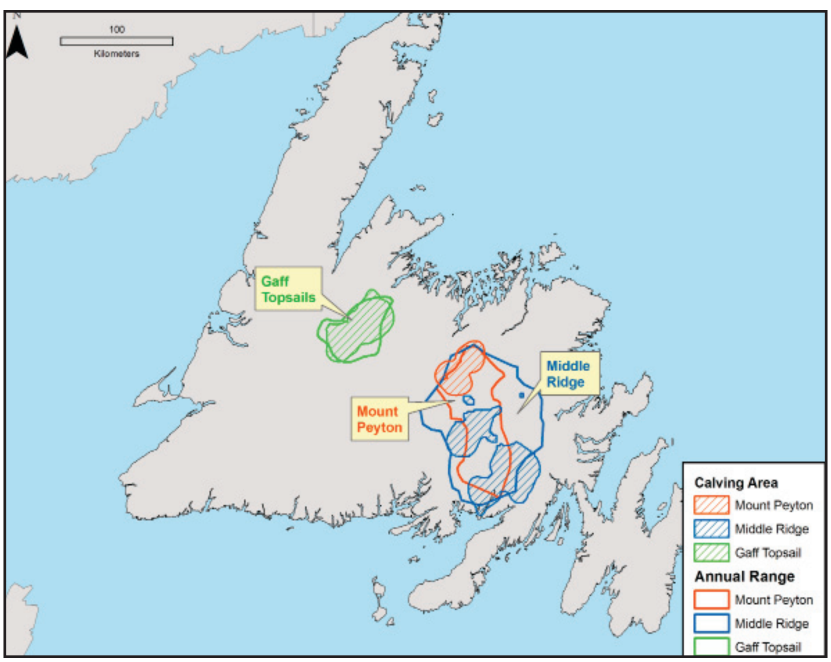


Figure 1. The location of the calving areas and annual ranges for the three herds examined in the Calf Mortality Study.

Data collection

Calf capture and handling

Neonate calves were located from helicopter 1-5 days post-partum and captured on foot during late May- early June each year (2003-07). Calves were fitted with expandable 200g VHF radio collars with an estimated battery life of three years (Telemetry Solutions; Concord, CA). 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 two years of collaring. Captured calves were ear-tagged, sexed, weighed and standard morphological measurements were taken (total length, heart girth and shoulder and hind foot length). The age-at-capture of each calf 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). 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.

Calves were visually relocated by helicopter within 24 hours of initial capture to ensure they had re-bonded with their dams and then daily during the first week post-capture. 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.

Overwinter survival

Overwinter survival rates could not be determined due to 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 if coyote predation on calves was high in winter. Therefore, additional caribou calves were collared in November/December 2005-2007 (Middle Ridge herd only). These calves were captured by aerial darting from helicopter using xylazine hydrochloride (Xylamax®) delivered via tranquilizer pistol (a modified Cap-Chur brand (Powder Springs, Georgia) tranquilizer gun). 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 if they had survived and remained with their mothers. Subsequently, calves were aerially monitored bi-monthly.

Determination of cause of mortality

When a mortality signal was detected (triggered after four hours of radio-collar immobility), the collar was located aerially and recovered. A standardized field investigation of the calf remains and the mortality site was conducted to determine the cause of death.

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 skin was peeled back to look for bite marks, 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 mortality 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 radius from the carcass was searched for additional remains, especially if an intact radio collar was discovered without 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.

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, presence of disease or infection. In addition, the general nutritional and physical condition of the calf was reported whenever possible. The diagnosis of the veterinarian was then compared to the field diagnosis and a final decision was made as to the most likely cause of predation.

Over the course of the study, there was mounting evidence 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 still persisted after the veterinary necropsy, mortalities were classified as either “unknown predator” or, where no specific cause of death could be implicated, mortalities were classified “unknown”.

Data analysis

All herds were used for analysis where appropriate but in-depth analyses are restricted to Middle Ridge (indicated in text) due to the longer data time series and larger sample size.

Survival rates for calves collared as neonates and those collared at 6-months of age was estimated separately using the Heisey-Fuller (HF) method (Heisey and Fuller 1985). The HF method estimates daily survival rates, and, assuming constant survival, exponentiates this estimate over a given interval (e.g. if daily survival rate = 0.99, then 0.99^{365} = annual survival rate). Annual survival rates were estimated for neonates while 6-month survival rates were estimated for fall calves to assess overwinter survival.

Comparisons of survival rates among herds and years were conducted with the procedure described by Sauer and Williams (1989) based on χ^2 tests that incorporate the associated variance estimates. Unplanned post-hoc analyses were conducted to assess whether survival rates were equal between sexes, among years when survival was pooled by herd, among herds when survival was pooled by years, and between Middle Ridge and the pooled survival rates of Gaff Topsails and Mount Peyton. A Bonferroni correction factor was applied.

When the response, or dependent variable, is binary (e.g. alive or dead), logistic regression is a more appropriate statistical test than standard linear regression. To determine if there were differences among individual calves that lived or died in Middle Ridge, logistic regression was used to investigate whether capture-weight or sex influenced the likelihood of survival while controlling for age-at-capture (Zuur et al. 2008).

Analysis of variance (ANOVA) was used to explore the influence of calf sex, predator, and year on differences in age-at-death at Middle Ridge. Interaction terms between two factors were included in the analyses where appropriate; for example the interactive effect of sex and predator-type on age at time of death was analyzed, but it was assumed that there was no interaction between these factors and years. Unplanned post-hoc Tukey tests were used to determine the influence of predator species on age-at-death. The category 'unknown predator' was significantly different from other predator-types. Due to the potential confound, the ANOVA was repeated with the 'unknown predator' category removed. Statistical assumptions were verified and met in all cases.

To explore differences in neonatal calf size among years and between sexes, a partial redundancy analysis (RDA) was performed on morphometric data from Middle Ridge calves, specifically body length (nose to tail), shoulder height, and girth (chest). This test expresses the amount of variance in a set of response variables (in this case, caribou morphometric data) that is explained by a set of explanatory, or independent variables (sex and year) while controlling for age-at-capture. The F-statistics provided here are more correctly "pseudo-F" as they are based on permutations and are the ratio of the constrained and unconstrained variance. Survival rates and subsequent χ^2 tests (Sauer and Williams 1989) were calculated using Excel (Microsoft 2003). All other analyses were conducted using R statistical software (R Development Core Team 2009). RDA was performed using package vegan (Oksanen et al. 2009) in R. Confidence intervals are reported for survival estimates, standard deviations in all other analyses.

RESULTS

A total of 295 calves were collared between 2003 and 2007 (Table 1). Between 2003 and 2007, 159 neonate and 76 6-month old calves were collared at Middle Ridge; 15 calves were never observed to have re-bonded with their dam and were excluded from the data analyses. Between 2003 and 2004, 50 neonates were collared in Gaff Topsails and 10 calves were collared in Mount Peyton in 2003.

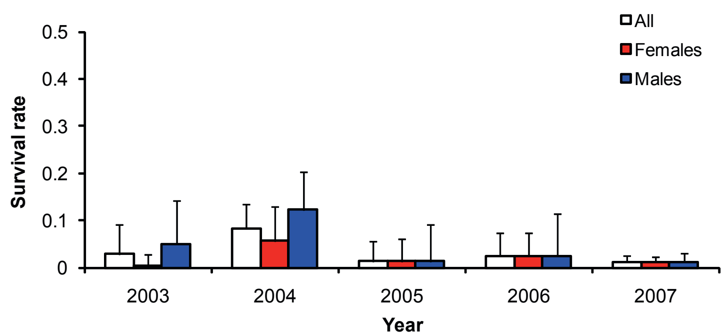
Year	Herd	Neonates			6-month olds			Annual sample	Cumulative annual sample
		♂	♀	Total	♂	♀	Total		
2003	Gaff Topsails	9	8	17	--	--	--	**17**	**57**
	Mount Peyton	8	2	10	--	--	--	**10**	
	Middle Ridge	16	14	30	--	--	--	**30**	
2004	Gaff Topsails	15	18	33	--	--	--	**33**	**69**
	Middle Ridge	24	12	36	--	--	--	**36**	
2005	Middle Ridge	13	10	23	15	9	24	**47**	**47**
2006	Middle Ridge	21	11	32	11	14	25	**57**	**57**
2007	Middle Ridge	16	22	38	12	15	27	**65**	**65**
	Total	**122**	**97**	**219**	**38**	**38**	**76**	**295**	**295**

Table 1. The number of collared calves by sex in Middle Ridge, Mount Peyton, and Gaff Topsails (2003-07).

Calf survival estimates (all herds)

Overall, annual neonate survival rates were 0.04 ± 0.05 between 2003 and 2007. Preliminary statistics indicated that there were differences in survival among years and herds ($\chi^2 = 21.8$, df = 7, p = 0.002) (**Figure 2 A & B**). A Bonferroni correction factor (α=0.0125) was applied to four unplanned, post-hoc comparisons. Overall, survival was equal between sexes (females = 0.02 ± 0.04, males = 0.05 ± 0.07, $\chi^2 = 0.3$, df = 1, p = 0.6; **Figure 2A**), among years ($\chi^2 = 5.4$, df = 4, p = 0.25; **Figure 2A**) and among herds ($\chi^2 = 5.4$, df = 2, p = 0.07; **Figure 2B**). Survival rates for Middle Ridge calves (0.01 ± 0.01 overall) were lower than those at Gaff Topsails (0.08 ± 0.08) and Mount Peyton (0.08 ± 0.17) ($\chi^2 = 6.6$, df = 1, p = 0.01; **Figure 2B**).

A)



B)

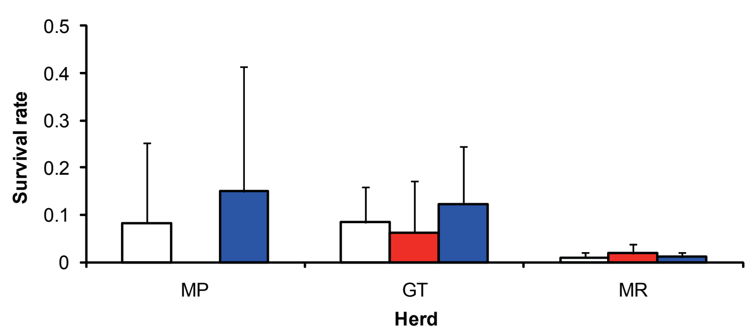


Figure 2. Estimates of neonate survival rates (+ confidence intervals) by sex from 2003-07 for Mount Peyton (MP), Gaff Topsails (GT), and Middle Ridge (MR) by A) year and B) herd.

Overwinter survival rates of 6-month old calves at Middle Ridge were 0.87 ± 0.07. There were no differences in survival between sexes (females = 0.9 ± 0.07, males = 0.79 ± 0.12, $\chi^2 = 2.4$, df = 1, p = 0.12; **Figure 3**).

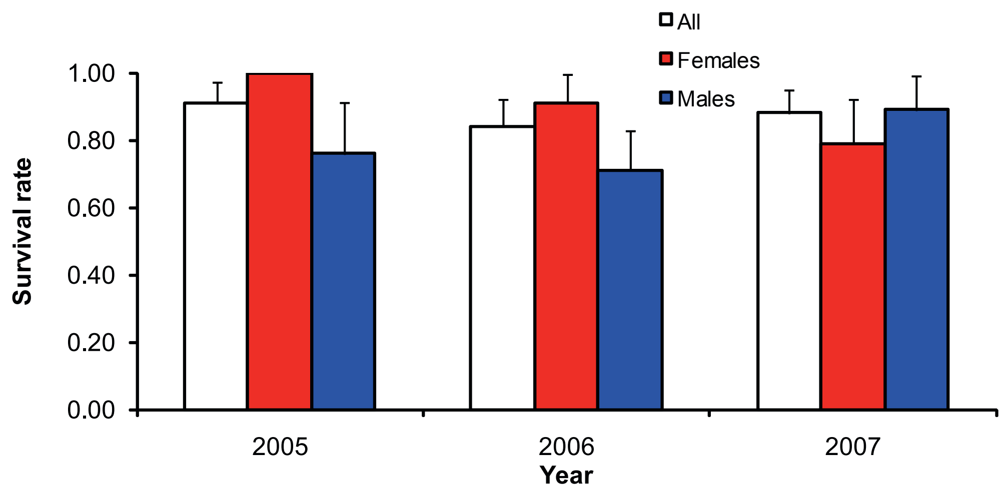
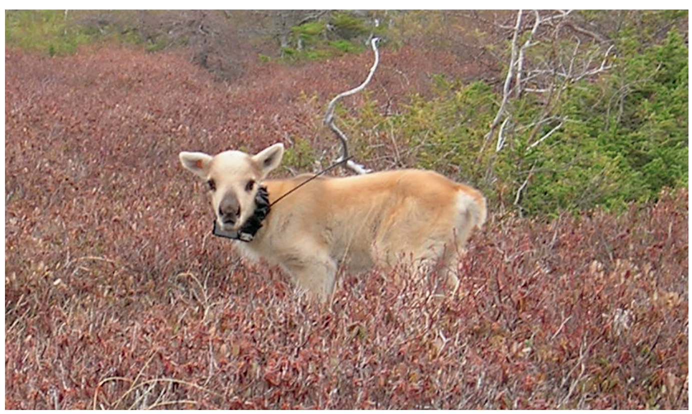


Figure 3. Estimates of overwinter survival rates (+ confidence intervals) of caribou collared at 6-months of age by sex from 2005-07 in Middle Ridge. Confidence interval values are not shown when survival rates = 1.0.



Factors influencing survival

Individual calf capture weight did not influence the likelihood of calf survival ($\chi^2 = 1.9$, df = 1, p = 0.17) nor did sex ($\chi^2 = 2.7$, df = 1, p = 0.10) at Middle Ridge (**Appendix 1**).

Causes of mortality (all herds)

Predation was the primary cause of mortality throughout the study in all areas (range: 65-89%; (**Figure 4A**). Other causes of calf mortality, which accounted for 21% of the collared calves' deaths between 2003 and 2007, included doe abandonment/death, accidental (i.e. drowning) and infection.

Of predation related deaths, the majority were due to bears (35%), followed by 'unknown' predators (24%), coyotes (17%), lynx (16%), and eagles (8%). The proportion of mortalities by predator species varied with study area. At Middle Ridge, bears accounted for the majority of predation events, especially in 2003-05 (**Figure 4B**). Eagle and coyote kills were particularly frequent at Gaff Topsails in 2003 and 2004. Lynx followed by bears were the most important predators at Mount Peyton. The number of mortalities classified as 'unknown predator' rose from 2003 (3%, n=1) to 2007 (38%, n=8; **Figure 4B**).

There were seven predation related overwinter mortalities for the 6-month calves: 1 'unknown predator' mortality in 2005, 1 bear, 1 lynx and 2 'unknown predator' in 2006, and 2 'unknown predator' 2007.

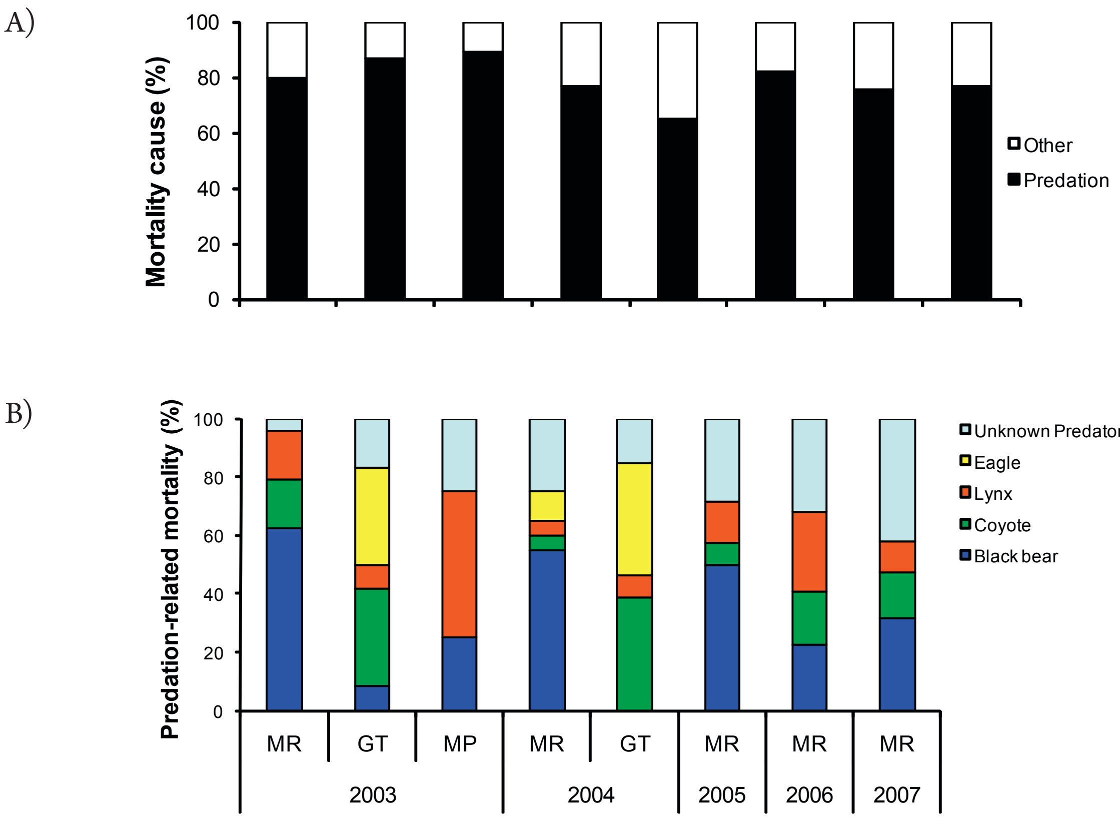


Figure 4. The cause of neonate calf mortality from 2003-07 for Mount Peyton (MP), Gaff Topsails (GT), and Middle Ridge (MR) by A) predation and other causes, and B) predator species.

Schedule (timing) of predation (all herds)

Due to predation accounting for the majority of calf mortalities (**Figure 4A**), the following analyses on calf mortalities were conducted on predator-related deaths only. Trends in cumulative mortality due to predation varied among herds and years, but were usually over 80% by 12 weeks (**Figure 5**). Results were grouped in 2-week intervals to capture the high levels of mortality in the first 8 weeks.

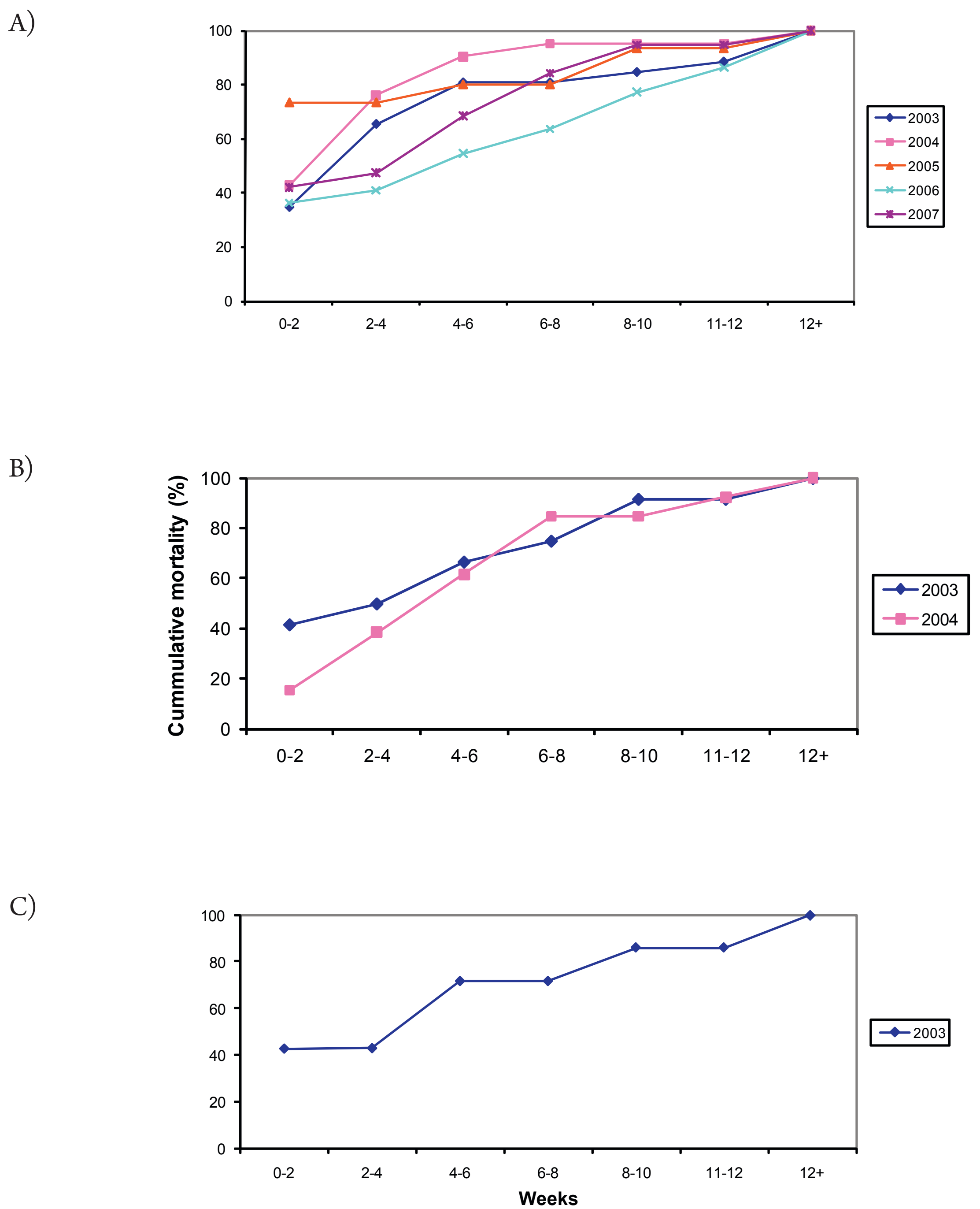


Figure 5. The cumulative percent mortality of neonate calves to 12+ weeks by two-week increments at A) Middle Ridge (2003-2007, n=103), B) Gaff Topsails (2003-2004, n=25) and C) Mount Peyton (2003, n=7).

Timing of predation by predator type

Neonate calves 0-12 weeks of age were killed by all predator species. Most predation by eagles and lynx occurred during the first six weeks. Bear, coyote and those predations classified as 'unknown' occurred with decreasing frequency through 12+ weeks of age (**Figure 6**).

Timing of predation by predator species varied among study areas. In Middle Ridge, black bear and, to a lesser extent, coyote predation occurred primarily in the first six weeks and declined afterwards. Lynx exerted a smaller influence, primarily on the younger (0-6 weeks) calves (**Figure 6A**). At Gaff Topsails, eagle predation was frequent during the first six weeks post-collaring but coyote predation occurred during most two week periods (**Figure 6B**). Most of the predation events in Mount Peyton were by black bears and lynx in the first six weeks (five out of seven) (**Figure 6C**).

A)

B)

C)

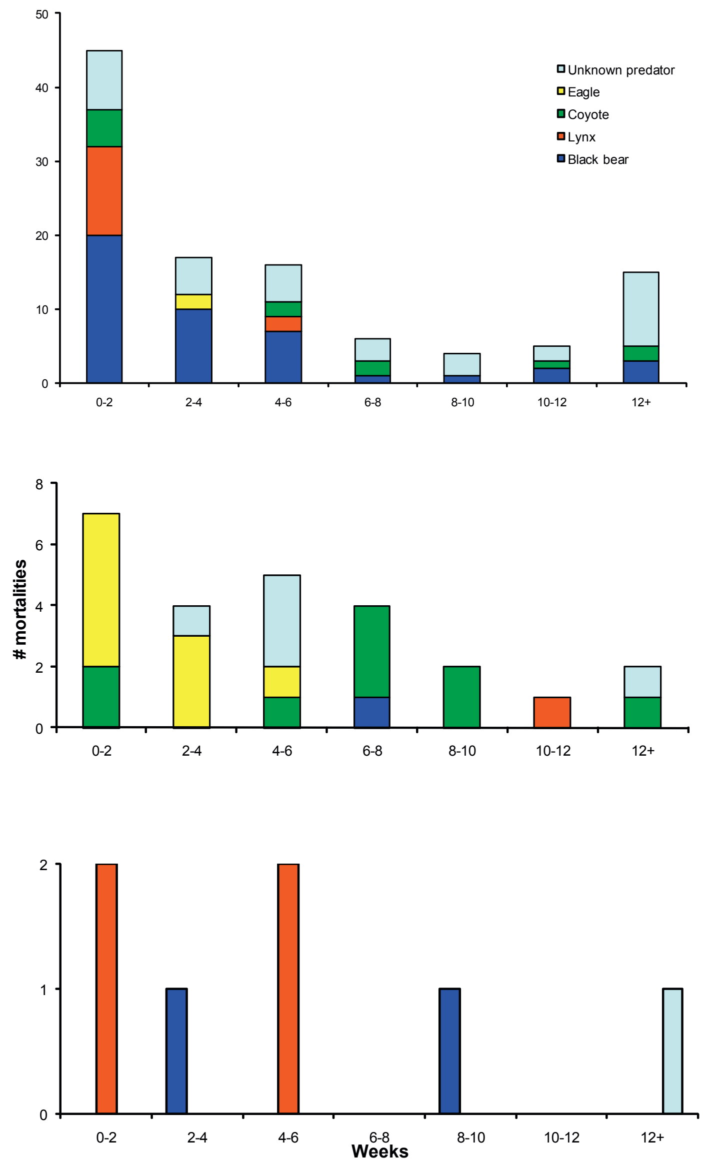


Figure 6. The number of predator-related deaths post collaring by two week-increments to 12+ weeks at A) Middle Ridge (2003-2007, n=112), B) Gaff Topsails (2003-2004, n=25) and C) Mount Peyton (2003, n=7). Note differences in y-axes.

The mean age at which neonate calves at Middle Ridge were predated was highly variable (34.2 ± 40.0 days or ~ 5 weeks ± 6 weeks) and did not significantly differ by sex (males=37.7 ± 43.0 days, females=29.4 ± 35.5 days), year, or predator-type when 'unknown predators' were removed (**Table 2 A & B, Table 3**).

Table 2. The mean age (i.e. number of days post-collaring; ± SD) at which neonate calves at Middle Ridge were predated by A) year and B) predator species.

A)

Year	Days
2003	39.0 ± 46.5
2004	22.8 ± 19.8
2005	22.6 ± 30.7
2006	48.4 ± 55.0
2007	32.2 ± 28.6

B)

Predator	Days
bear	25.7 ± 30.6
coyote	38.7 ± 46.1
lynx	10.4 ± 10.1
unknown	57.2 ± 49.4
eagle	23.0 ± 5.7

Table 3. The effect of sex, year, and predator on age-at-death for predated neonates at Middle Ridge (unknown predators removed).

Model terms	F	df	p
sex	1.034	1, 97	0.312
year	0.203	1, 97	0.653
predator	1.004	1, 68	0.320
sex* predator	0.425	3, 66	0.736

Calf size

Neonate calf size (i.e. length, height, and girth) did not vary by year and sex at Middle Ridge (**Appendix 1**). Year and sex explained only 5.37% of the variance in calf size when age-at-capture was controlled for and the RDA model was not significant ($F_{4, 68}$=1.31, p=0.27).

DISCUSSION

Results of the *Calf Mortality Study* demonstrate that neonate calf survival rates in all three caribou herds was low from 2003 to 2007, especially in Middle Ridge, and that predation in the first two months of a calf's life was the single most important proximate cause of mortality.

Neonate calf survival is low

Survival rates for Newfoundland calves (HF = 0.04 ± 0.05) from 2003 to 2007 were much lower than those estimated during the period of maximum caribou population increase (1979-1997, HF = 0.665 ± 0.35) (Mahoney and Weir 2009). It is not clear if the current survival rates are similar to those of the early 20th century decline and subsequent low in caribou populations in Newfoundland. However, low neonate survival rates or recruitment in herds with declining populations has been observed in Alaska (Jenkins and Barten 2005), Alberta (Stuart-Smith et al. 1997; McLoughlin et al. 2003), and Saskatchewan (Rettie and Messier 1998). This is a common trend in large herbivores (Gaillard et al. 1998) but there are exceptions when predation on adults drives population declines (Wittmer et al. 2005).

Overwinter survival is high

Overwinter (six-month) survival rates of caribou calves was high (0.87 ± 0.07) and comparable to historical levels (Bergerud 1971; 1983) and lower but statistically indistinguishable from annual adult female survival rates (0.86; Mahoney and Weir 2009). These results are consistent with findings in Alaska of high overwinter calf survival (Jenkins and Barten 2005) and suggest that overwinter survival of calves had little influence on the population decline.

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; Whitten et al. 1992; Adams et al. 1995). Predation accounted for most calf mortalities in this study. These results are similar to earlier research in Newfoundland (Bergerud 1974; Mahoney et al. 1989; Gaillard et al. 1998; Mahoney and Virgil 2003), and other regions in North America (Rettie and Messier 1998; McLoughlin et al. 2003; Jenkins and Barton 2005; Wittmer et al. 2005).

The importance of predator species varied with herd

Although the sample size was very small, the results from Mount Peyton are similar to past findings that lynx are the primary caribou predators in Newfoundland (Bergerud 1971, 1983). Black bear predation was high in Middle Ridge and Gaff Topsail which differs from Bergerud (1971, 1983) but was similar to Mahoney et al. (1989) who also found high black bear as well as lynx predation on the south coast. There are at least three possible, non-mutually exclusive explanations for these differences among the three studies. 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. Second, the addition of coyotes may

have altered the availability of caribou for the other predators through exploitation and/or interference competition. Third, that predation is proportional to predator species abundance that varies across the landscape. Therefore, we expect to see variation in predation by the various predator species. Studying the whole predator guild will be required to distinguish among these explanations in order to improve caribou management (Gustine et al. 2006; **Figure 4B**).

Well before the detection of the current population decline, COSEWIC reports (2002) suggested that the arrival of coyotes in the mid-1980s could further impact caribou population levels. Prior to this study however, there was no measure of the influence of the non-native coyote on calf predation which accounted for 5-38% of all predation events among herds and years in this study. Calf mortality in Quebec increased after the arrival of coyotes (Crete and Desrosiers 1995) and it is likely that this has occurred in Newfoundland. However, it is not clear to what degree coyote predation is additive or compensatory, and therefore it is difficult to determine their role in the caribou population decline. Like other predators, coyotes largely preyed on young calves. There was no evidence in this study for high levels of overwinter caribou calf mortality due to coyote predation. Indeed, the influence of other predators on overwinter predation should be minimal since bears are hibernating and calves are thought to be too large to take by lynx and eagles.

The influence of this guild of predators may not diminish with further declines in the caribou population. None of these species specialize on caribou and therefore, their 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.

Identification of unknown predators

In the present study, there were a high number of mortalities classified as 'unknown predator', especially in 2007. Identification of predator species based on calf remains was problematic for two reasons. First, logistical constraints on the frequency of calf monitoring flights and/or scavenging by multiple predators at the field site sometimes resulted in insufficient remains and/or too much conflicting evidence to make a definitive conclusion on predator identification. Second, there was a growing recognition that the different predator species may handle prey in a similar fashion and that particular signs on the calf carcass may not indicate a specific predator. The use of veterinary necropsy clarified predator identity in some instances but sometimes conflicted with strong field site evidence, rendering final decisions difficult to make. The result was a proportional increase in 'unknown predators' over time.

SDSS supported two Honour's theses that explored that landscape matrix around the mortality site and one that compared field evidence and veterinary evidence to determine the cause of consistencies and inconsistencies in interpretation. The latter thesis confirmed that there was significant overlap in how predators handle caribou carcasses (Jeha 2010).

Calves are primarily predated within the first few weeks of life

Our results are similar to those reported for three caribou herds in south central Newfoundland by Mahoney et al. (1989), who found that most calves were killed by predators within the first four weeks. Similarly, studies in Alaska, where wolves (*Canis lupis*) are present, have shown that predator-caused calf mortality can lead to 85% death rate within the first 8 days of life (Adams et al. 1995, Gustine et al. 2006). Calves appear to be vulnerable to all predator species in early life but vulnerability decreases with time.

CONCLUSION AND FUTURE DIRECTIONS

Survival rates for Newfoundland's caribou calves in the three study areas were extremely low from 2003-2007, the result of predation in the first four weeks of life, primarily due to black bears and coyotes.

During this period, herd composition surveys and telemetry data indicate that adult survival rates were high and comparable to the historical averages (Mahoney and Weir 2009). Together with the combination of low neonatal and high over-winter calf survival rates presented here, these results suggest 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. Although the mechanisms underlying this shift are not fully known, density dependent responses in caribou size and vigor, evidenced by decreasing adult female body size, decreasing birth weight, and decreasing male antler size are of obvious relevance and may have predisposed calves to higher predation rates. The expanding guild of predators, particularly coyote, undoubtedly influenced caribou population dynamics and may have also contributed to the overall population decline (Mahoney and Schaefer 2002; Mahoney and Weir 2009). Our results have confirmed that an expanded guild of predators take juvenile caribou. These results clarify the roles of these predators and dispel the notion that coyotes are the greatest cause of neonatal losses. Furthermore, the data do not support the anecdotal evidence of high coyote predation on calves in winter.

The findings represented here, combined with the *Caribou Data Synthesis* (Mahoney 2000; Mahoney & Weir 2009), form the basis of the *Newfoundland Caribou Strategy* launched in April 2008. The Strategy is a five year effort to further identify the factors underlying the extremely low calf survival presented here and the caribou population decline overall. The Strategy is comprised of an intense program of empirical research on caribou and caribou predator ecology, augmented by a thorough review of historical knowledge. The objective is to better understand the current decline in woodland caribou and the role of predators and habitat in this decline. Predator ecology research results will be used to determine means to alleviate predation pressure and increase caribou calf survival.

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Appendix 1. The mean (± SD) morphological measurements of live and dead neonatal calves in Middle Ridge (2003-07).

Year	Metric	Female Dead	Live	Male Dead	Live	Total
2003	Count	12		15		27
	Weight	7.8 ± 1.0		8.0 ± 0.9		7.9 ± 1.0
	Length	81.4 ± 5.0		81.9 ± 4.8		81.7 ± 4.8
	Girth	47.1 ± 3.1		48.3 ± 5.3		47.8 ± 4.4
	Height Shoulder	54.4 ± 3.4		57.3 ± 3.7		55.9 ± 3.8
	Height Hind Foot	26.7 ± 1.2		26.9 ± 1.1		26.8 ± 1.1
	Capture Age	2.4 ± 0.6		2.5 ± 0.5		2.5 ± 0.5
2004	Count	9	2	13	9	33
	Weight	7.8 ± 0.6	7.8 ± 0.1	8.8 ± 1.2	8.8 ± 1.0	8.5 ± 1.1
	Length	81.7 ± 2.7	80.3 ± 2.5	81.8 ± 4.4	81.9 ± 5.5	81.7 ± 4.1
	Girth	44.2 ± 2.4	44.8 ± 1.1	46.5 ± 2.5	46.0 ± 4.1	45.6 ± 3.0
	Height Shoulder	51.6 ± 4.3	52.5 ± 2.1	52.8 ± 2.5	52.8 ± 4.5	52.5 ± 3.5
	Height Hind Foot	26.8 ± 1.1	27.0 ± 2.1	27.2 ± 0.9	26.8 ± 1.3	27.0 ± 1.1
	Capture Age	1.9 ± 0.7	2.5 ± 0.0	2.2 ± 0.6	2.3 ± 0.7	2.2 ± 0.6
2005	Count	8	1	7	5	21
	Weight	7.7 ± 1.2	8.5	8.7 ± 1.3	9.3 ± 1.0	8.4 ± 1.3
	Length	81.2 ± 6.6	83.8	84.9 ± 3.4	87.7 ± 4.9	84.1 ± 5.6
	Girth	45.9 ± 3.3	50	48.8 ± 4.2	49.7 ± 2.1	47.9 ± 3.6
	Height Shoulder	54.7 ± 3.7	57	54.6 ± 4.1	59.0 ± 2.7	55.9 ± 3.8
	Height Hind Foot	26.9 ± 1.7	26.4	28.1 ± 1.4	27.5 ± 0.8	27.3 ± 1.4
	Capture Age	2.4 ± 0.7	3.0	2.6 ± 1.1	2.9 ± 0.4	2.6 ± 0.8
2006	Count	7	2	16	1	28
	Weight	8.6 ± 2.5	8.9 ± 1.8	8.8 ± 1.8	9.1	8.7 ± 1.8
	Length	87.5 ± 6.1	89.0 ± 7.1	85.8 ± 7.7	89.0	86.4 ± 6.7
	Girth	47.8 ± 4.8	50.5 ± 3.5	50.3 ± 5.7	50.0	49.5 ± 5.0
	Height Shoulder	52.5 ± 3.0	53.0 ± 5.7	54.8 ± 4.9	51.0	53.7 ± 4.3
	Height Hind Foot	26.7 ± 1.0	27.0 ± 0.0	27.0 ± 1.2	28.0	27.0 ± 1.1
	Capture Age	2.3 ± 1.0	2.8 ± 1.1	3.2 ± 1.1	3.5	2.9 ± 1.0
2007	Count	11	7	11	2	32
	Weight	8.4 ± 1.3	8.6 ± 1.4	8.9 ± 1.8	8.9 ± 1.6	8.6 ± 1.4
	Length	84.4 ± 7.8	87.9 ± 6.3	84.9 ± 6.2	87.5 ± 3.5	85.4 ± 6.5
	Girth	46.4 ± 3.1	47.0 ± 3.4	46.6 ± 4.4	46.0 ± 2.8	46.5 ± 3.4
	Height Shoulder	54.2 ± 4.0	52.9 ± 2.6	54.6 ± 4.8	54.5 ± 2.1	53.9 ± 3.8
	Height Hind Foot	27.4 ± 1.3	27.2 ± 1.3	27.6 ± 1.4	27.5 ± 2.1	27.4 ± 1.3
	Capture Age	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Total	Count	47	12	62	17	141
	Weight	8.0 ± 1.3	8.5 ± 1.2	8.6 ± 1.4	9.0 ± 1.0	8.4 ± 1.3
	Length	82.8 ± 5.9	86.3 ± 6.0	83.7 ± 5.8	84.7 ± 5.6	83.7 ± 5.8
	Girth	46.2 ± 3.4	47.5 ± 3.4	48.2 ± 4.7	47.3 ± 3.7	47.3 ± 4.1
	Height Shoulder	53.5 ± 3.7	53.2 ± 2.9	54.9 ± 4.2	54.7 ± 4.6	54.2 ± 4.0
	Height Hind Foot	26.9 ± 1.3	27.0 ± 1.2	27.2 ± 1.2	27.1 ± 1.2	27.1 ± 1.2
	Capture Age	2.3 ± 0.7	2.7 ± 0.6	2.6 ± 0.9	2.6 ± 0.7	2.5 ± 0.8