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Noninvasive genetic sampling and predator density estimates for black bear (*Ursus americanus*) and coyote (*Canis latrans thamnos*) in Newfoundland 2009-2011

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Newfoundland Caribou Strategy

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Newfoundland Labrador
Environment and Conservation

Noninvasive genetic sampling and predator density estimates for black bear (*Ursus americanus*) and coyote (*Canis latrans thamnos*) in Newfoundland 2009-2011

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July 2013

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Executive Summary

Estimating abundance or density of an organism is central to many ecological studies. Estimating the density of black bear (*Ursus americanus*) and coyote (*Canis latrans*), the major predators of caribou calves (*Rangifer tarandus*), has become a research priority for the *Caribou Strategy* because calf predation is the primary, proximate cause of the declining caribou population. Further, density estimates are also critical for predator management generally, and for any predator manipulation efforts. Adding to the usual challenges of obtaining reliable density estimates for large, mobile animals, the areas of interest in this study are remote, requiring a sampling design minimizing the financial implications of helicopter support while maintaining sample quality. Furthermore, caribou may select calving sites with relatively low predator activity, making the task of gaining reliable density estimates even more difficult.

In the last decade, various noninvasive genetic sampling techniques have been employed to census large predators at relatively low cost. Noninvasive genetic sampling requires that a sample of tissue be obtained from an animal and then DNA extracted to identify the species and perhaps the individual animal. This study employed three different noninvasive techniques: hair snag stations, dogs trained to locate predator scats (detector dogs), and scat collected from a diversionary feeding experiment. The use of snow-tracking surveys, trapping, and telemetry data were also explored to determine density but were not successful. Application of all these methods was initiated based on the best available information. When the data stream showed a poor success rate, the program was either adapted or eliminated.

This study was conducted in the Middle Ridge, La Poile, and the Northern Peninsula regions from 2009-2011 during and after the annual caribou calving season. Diversionary feeding occurred only in Middle Ridge South. The Predator Density Study showed that:

1. Detector dogs were the most efficient means to collect samples. Detector dogs obtained samples for both bears and coyotes in all study areas while hair snags only obtained sufficient samples for bears in the Middle Ridge.
2. Genetic samples from detector dogs had a high rate of species and individual identification for coyotes but less for bears.
3. Estimates of density for bears and coyotes are amongst the lowest on record. For coyotes, estimates are in some cases two orders of magnitude lower than in other areas of North America.
4. However, estimates are highly variable. This is a product of estimating density for large, highly mobile predators and we used an extremely conservative approach.
5. Density estimates apply to the calving grounds and surrounding areas. Extrapolating these findings to larger areas is not recommended.
6. Future work includes examining the influence of land cover and other factors on density, as well as variation in density across the island.

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Introduction

Estimating the number of individuals of a given species is central to many ecological studies. There are numerous methods for estimating abundance (the number of organisms) and density (the ratio of abundance to sample area). These methods largely depend on an organism's size and mobility and become more difficult to obtain as these variables increase. Density is often much more expensive and difficult to calculate than abundance, but necessary if direct and comparable inferences are to be made to a variable of interest, such as caribou calf survival (Krebs 1999, but see Buckland et al. 2001).

Obtaining reliable estimates of predator density is critical to several aspects of the Newfoundland *Caribou Strategy*. Density estimates will be used to inform predator management decisions and facilitate planning of predator manipulation studies. Where predator manipulation involves removal of predators, predator density must be measured before and after the manipulation and at a control site(s) to determine the effectiveness of the removal treatment. These estimates will also be used in caribou habitat use studies to determine whether predator density influences caribou habitat selection or caribou calf survival.

In the last decade, various noninvasive genetic sampling techniques have been employed to census large predators in North America at relatively low cost (Long et al. 2008). Noninvasive genetic sampling requires that a sample of tissue (hair, epithelial cells on scat, urine, and blood) be obtained from an animal. DNA extracted from the tissue samples can then be used to identify the species and, in some cases, the individuals. This information can then be used in a mark-recapture analysis to inform density estimates (Miller et al. 2005, Gardner et al. 2009, 2010, Russell et al. 2012; Appendix 1). This study employed three different noninvasive techniques: hair snag stations, dogs trained to locate predator scats (detector dogs), and scat collected from a diversionary feeding experiment. In addition, snow-tracking surveys, trapping, and the use of telemetry data to determine density were explored but were not successful. Application of all these methods was initiated based on the best available information. When the data stream showed a poor success rate, the program was either adapted or eliminated (Appendix 2).

The objectives of this report are to summarize the noninvasive sampling techniques employed to obtain predator density estimates for black bear (*Ursus americanus*) and eastern coyote (*Canis latrans thamnos*) and to quantify predator density for the three study areas of the *Caribou Strategy* from 2009–2011. The report also provides recommendations for future study designs and analytical approaches.

Study Areas

The *Caribou Strategy* ecological research is conducted mainly in three study areas: Middle Ridge, La Poile, and the Northern Peninsula (Figure 1). These areas were selected using the following criteria: 1) geographic separation among study areas and herds, 2) an abundance of existing information on the Middle Ridge and La Poile herds, 3) the caribou herds that occupy

these regions represent about 50% of the island population, and 4) the regions encompass a wide range of the island's ecoregions.

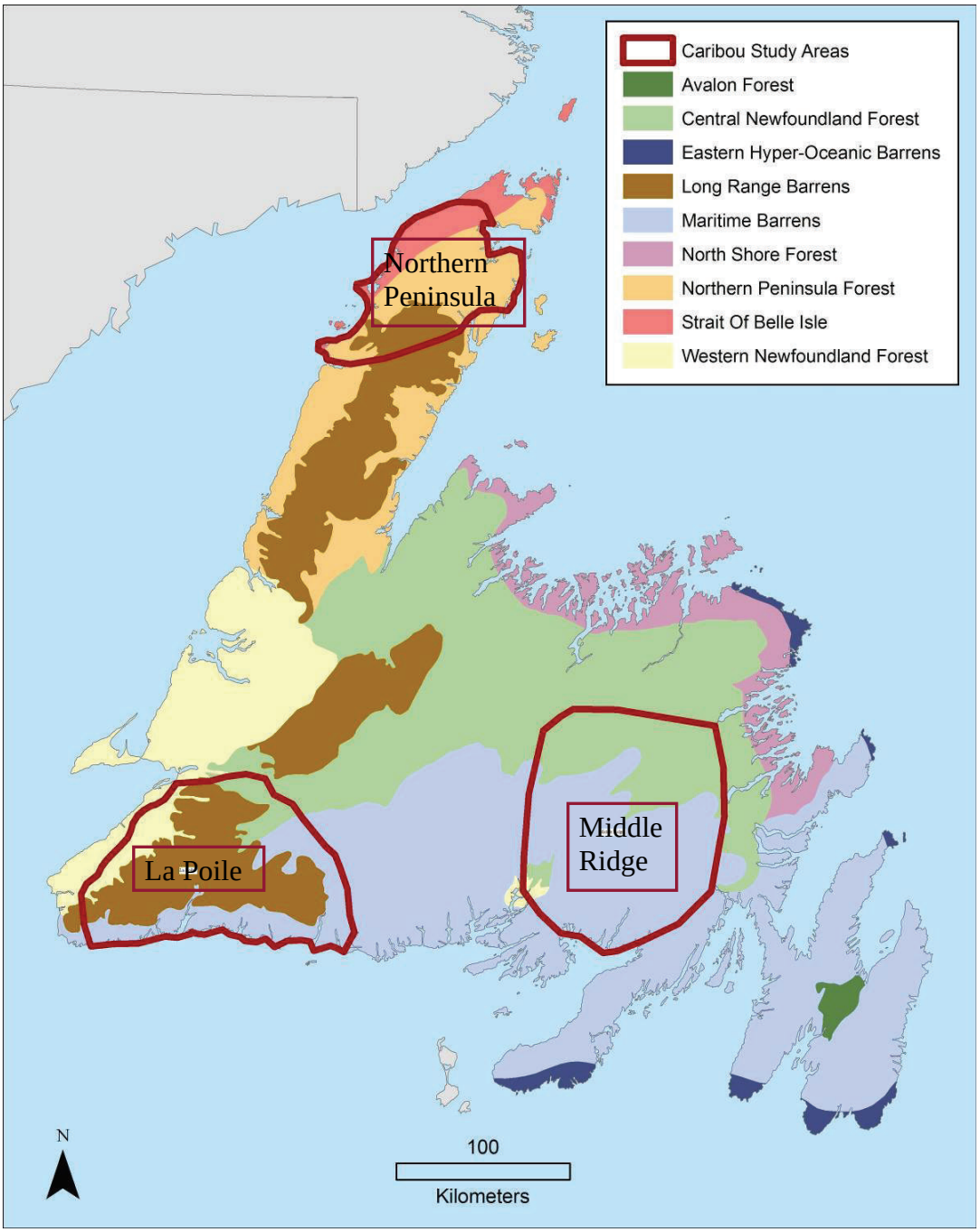

Figure 1. The ecoregions of Newfoundland and the *Caribou Strategy* study areas: Middle Ridge in the east, La Poile in the west, and the Northern Peninsula in the north.

Middle Ridge

The Middle Ridge study area (13,369 km^2) is located in the interior of eastern-central Newfoundland, and encompasses the Bay du Nord Wilderness Area and the Middle Ridge

Wildlife Reserve that cover 22% and 4.5% of the total study area, respectively (Figure 2). Bogs are prevalent throughout this region and balsam fir is the dominant tree species in forested areas. This study area has two main calving areas: the northern part of Middle Ridge in the Central Newfoundland Forest Ecoregion, and the extreme southern portion 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. Forest fires have been historically common in much of the Middle Ridge area, altering the successional trajectory from balsam fir (*Abies balsamea*) to black spruce (*Picea mariana*) and sometimes birch (*Betula* spp.) to aspen (*Populus* spp.) (Meades 1990). The disturbance history of Middle Ridge also includes widespread insect outbreaks (i.e., hemlock looper (*Lambdina fiscellaria*) and spruce budworm (*Choristoneura fumiferana*)). Among these study areas, human disturbance is probably lowest in Middle Ridge. The Bay d'Espoir Highway runs through the western portion of Middle Ridge but the only communities are in the Conne River area southwest of the study area. Logging roads are prevalent off the highway, especially in the north-western section. Disturbance is minimal in southern Middle Ridge.

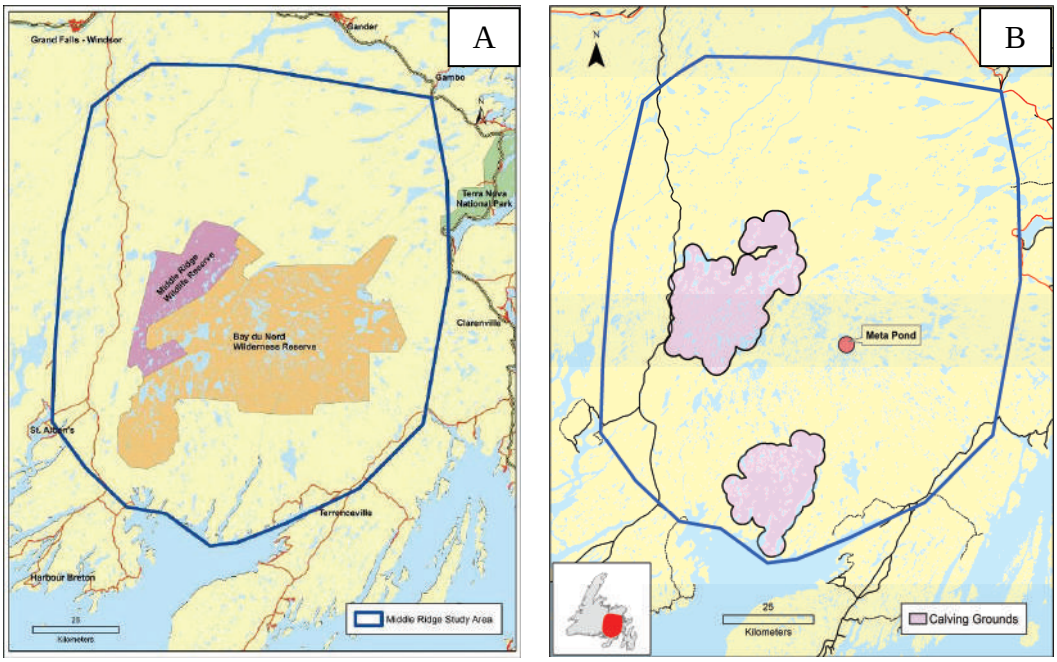

Figure 2. The Middle Ridge study area depicting A) the boundaries of the Bay du Nord Wilderness Area and the Middle Ridge Wildlife Reserve and B) the Middle Ridge North and South calving grounds, as well as the Meta Pond area.

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 (Figure 1). The Long Range Mountains Ecoregion is mostly covered by heath and moss barrens, rock outcrops, with some sparse forest patches. West of that ecoregion 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 activity has been prevalent in this ecoregion, but its 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.

The 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 (Figure 1). The Strait of Belle Isle Ecoregion is on the northern tip of the Peninsula and is characterized by an abundance of wetlands, particularly lowlands of sloping bog plateaus. The Northern Peninsula Forest Ecoregion lies on both sides of the central 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 Northern Peninsula. There are a number of communities in the study area.

Methods

Hair snags

Design and layout

Modifying the methods of Kendall and McKelvey (2008), we deployed hair snags and attractants to collect hair from target animals (black bear, coyote, and lynx). We deployed the snags along 600 m transects in the calving areas of the three study areas (Middle Ridge $n = 44$; La Poile $n = 20$; and the Northern Peninsula $n = 22$) from late June to late August 2008 (Figure 3). Calving and post-calving areas were delineated based on radio locations of collared calves from previous years and known patterns of recent post-calving movements (Rayl 2012). Transects were spaced approximately 5 km apart in a grid pattern and established in the closest available suitable habitat (within 500 m, Figure 3).

Each hair snag transect consisted of two black bear hair snags and three hair snags each for both lynx and coyote (Figure 4). Bear hair snags were placed at the end of each transect while lynx and coyote snags were placed every 150 m between bear snags. Lynx and coyote snags were alternated on the left and right hand side of each transect and placed opportunistically between 10–30 m from the transect line. The lynx snags were placed in forest or scrub, when available, to maximize the probability of these animals encountering the snags.

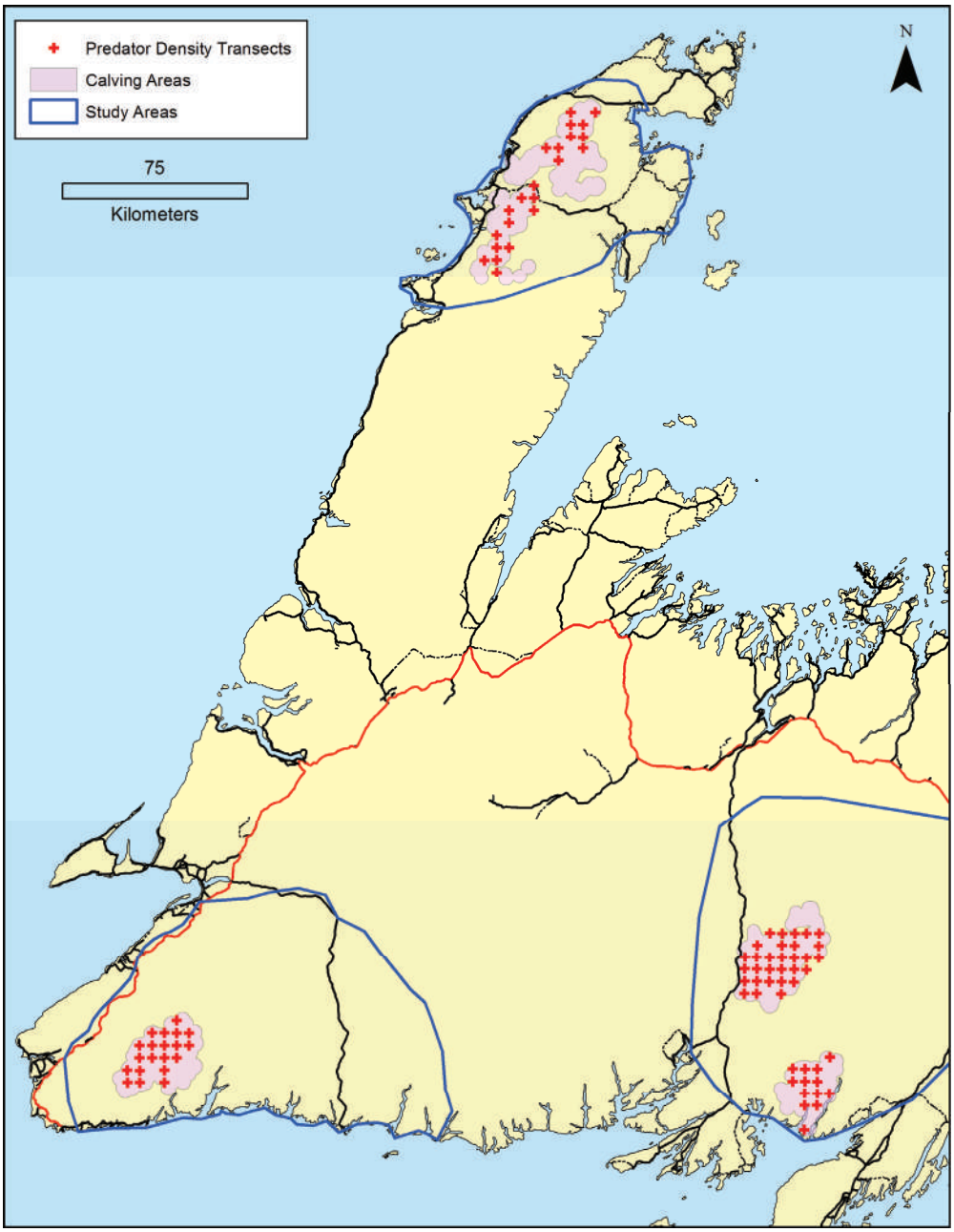

Figure 3. Location of the hair snag transects along with calving areas that were determined from radio-telemetry data (2003-10, Rayl 2012).

Each bear hair snag consisted of 2-layered circles of barbed wire 6 m in diameter, with bait in the center. Barbed wire was strung between 20–30 cm and 50–70 cm above ground, using existing vegetation when possible and wooden stakes when necessary (Figure 5A). Bear lure consisted of 2–3 half opened tins of sardines in oil, which has been used successfully for this purpose in Ontario (Obbard and Howe 2008). Cans were hung at a high point in the center of the barb wire circle (wherever possible). Sardine oil was also drizzled on foliage and woody stems so that the scent would carry farther.

Lynx and coyote hair snag stations consisted of 10 cm × 10 cm pieces of natural fiber (coconut) matting/carpet with ten 2.5-cm nail gun nails pushed through such that barbs were exposed. Mats were placed approximately 30–45 cm above ground on a post or tree for lynx (Figure 5B) and on the ground for coyote. To visually attract the predators, a compact disc was hung above the station. Skunk oil and lynx lure were used at lynx stations (Pikauba bobcat/lynx caller); coyote urine, skunk oil, and coyote lure were used for coyotes (Schlexer 2008).

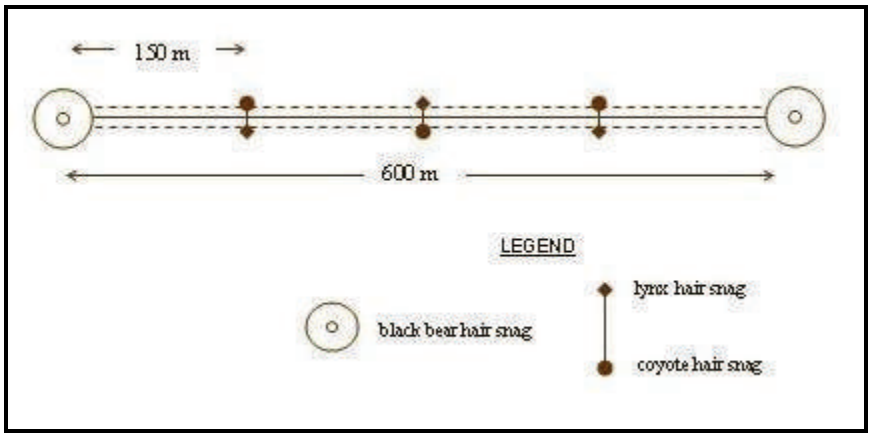

Figure 4. Schematic of the hair snag transects.

Timing and frequency

Transects were established in late July and August of 2008. Sample collection occurred once in September and November 2008. Transects were re-established in May 2009 and sample collections occurred in June/July (early summer), August (late summer), and September (early fall).

Owing to the poor success rate, the grids for the Northern Peninsula and La Poile study areas were discontinued after 2009. Middle Ridge hair snag stations were re-established on 23–24 May 2010 and checked twice: 22, 29–30 June and 19–20 July 2010. In 2011, the Middle Ridge grids were re-established on 23–24 May and checked twice: 13–14 June and 4–6 July. During collection visits, all baits and lures were refreshed and repairs were made to the hair snags. Signs of predator activity (scratches, digging, etc.) and the presence of hair and/or scat were recorded.

Specimen collection

Hair and scat were collected from snags during re-visits. Tufts of hair from each barb were removed and placed in separate coin envelopes. Scats found near hair snags were collected and catalogued for future analysis.

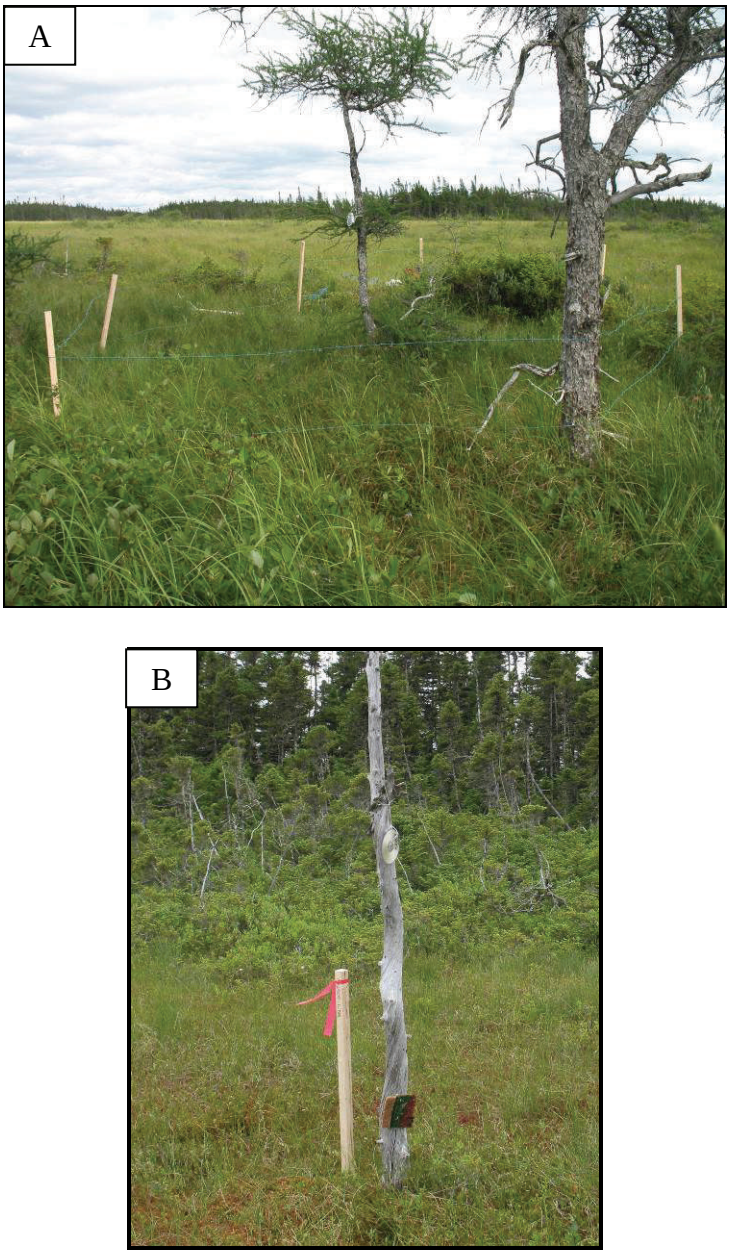

Figure 5. A) An example of a bear snag. Barbed wire encircles the posts and the bait is set inside the circle. B) Lynx snag with the scent lure post, carpet pad for hair collection, and compact disc attached to the tree as a visual attractant. Coyote pads were of similar construction but were on the ground.

Detector dogs

Dogs trained to detect and locate scat while walking off lead have been successfully used to survey large areas for the collection of scats that subsequently inform estimates of predator populations (Wasser et al. 2004, Thompson et al. 2012). In the summer of 2009, a series of 12 km × 12 km grids were established in the Northern Peninsula. In La Poile, limitations on study design due to existing hunter/trapper bait stations, the road network, and the preliminary nature

of study design development prevented establishment of grids and therefore, general locations were simply revisited. Grids were added to the Middle Ridge in 2010.

Depending on conditions, dogs searched freely along a quasi-circular path of variable length beginning and ending on the road. A GPS was attached to the dog, and the tracking function continually recorded movement during the entire data collection period so that effort could be quantified ("dog tracks" hereafter). Different but overlapping sections of the grid were searched on subsequent visits (Figure 6).

Scat was collected during the summer in La Poile in 2009, Middle Ridge in 2010 – 2011, and the Northern Peninsula in 2009–2011. Collection dates were 31 May – 11 August in 2009, 16 June – 8 August in 2010, and 3 July – 31 August in 2011.

Diversionary feeding

As part of the *Caribou Strategy*, Sustainable Development and Strategic Science (SDSS) was tasked with exploring means to manipulate and/or control predator populations. As part of this effort, diversionary feeding grids were established in Middle Ridge South for bears in 2010 and for both bears and coyotes in 2011 in an effort to experimentally reduce predation on caribou calves (see Gullage et al. *in prep.*). Bakery waste was used for bears and beaver carcasses were used for coyotes. Bear and coyote scat was collected around the feeding stations and used to generate density estimates.

Other methods

In addition to hair snags, detector dogs, and diversionary feeding, SDSS made three significant attempts to document predator density early in the *Caribou Strategy* using trapping, snow-tracking surveys, and telemetry data. Despite following methodologies from the peer-reviewed literature and advice from the Caribou Strategy's appointed academic team of advisors, these efforts were not successful but are documented in Appendix 2.

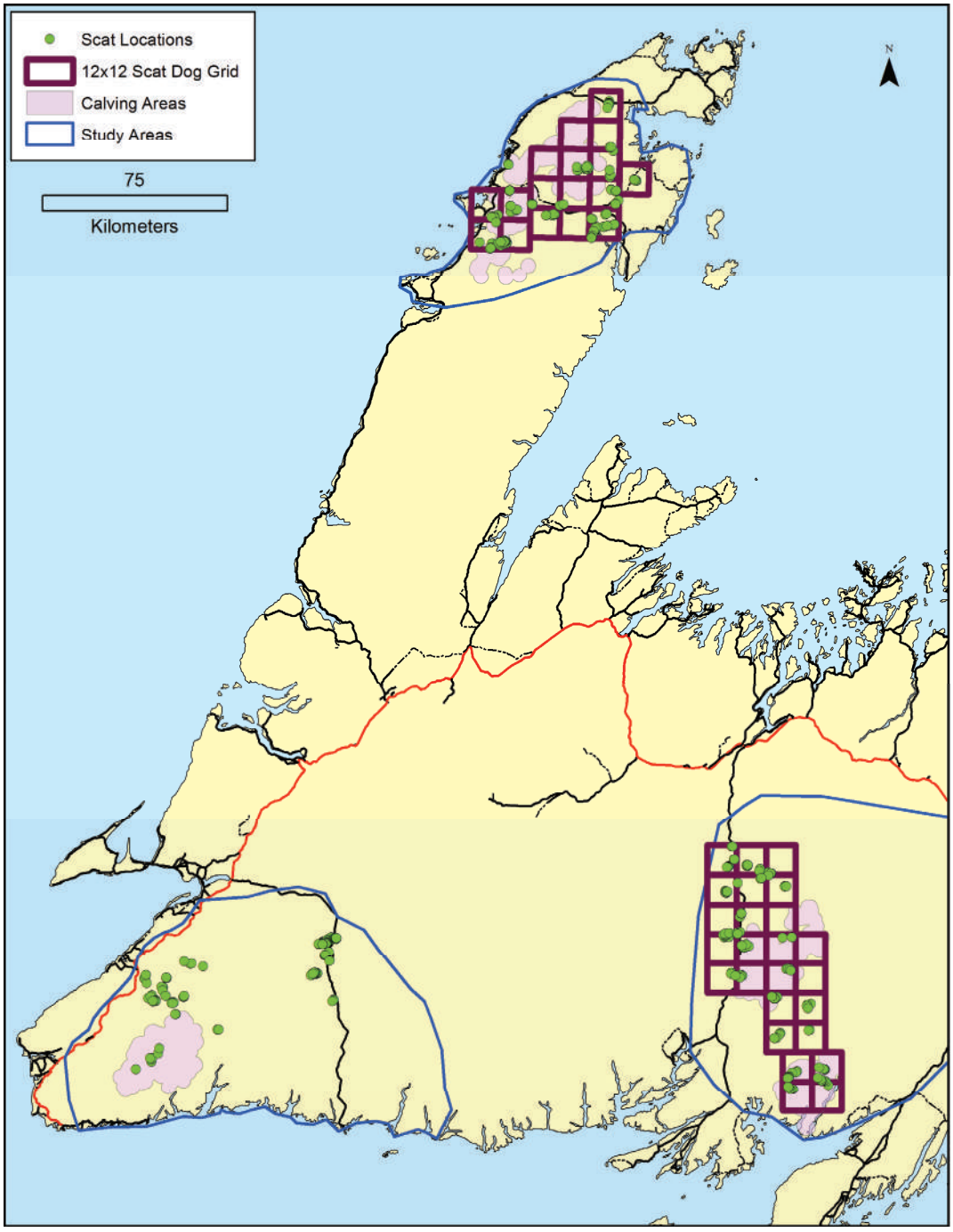

Figure 6. Location of the 12 km × 12 km grids with scat locations in 2010 in Middle Ridge and in 2009 for the Northern Peninsula and La Poile (grid approach not feasible here).

Genetic analyses

All genetic analyses were conducted by the Laboratory for Conservation and Ecological Genetics (University of Idaho, Moscow ID). For 2011, there were not enough samples for Middle Ridge to estimate density. Further analyses have not yet been performed on the diversionary feeding work and are not presented.

Analytical approach

Calculating abundance

There are numerous ways to calculate density (Appendix 1). For the hair snag and detector dog approaches, abundance was calculated using program CAPWIRE (CApture WIth REplacement) (Miller et al. 2005). CAPWIRE is a relatively new approach for estimating wildlife abundance using genetic sampling in the place of traditional mark-recapture techniques. CAPWIRE is an extension of classic, closed capture population models that assume no births/deaths and immigration/emigration and are therefore conducted over a short period of time. CAPWIRE extends this model to allow multiple "captures" of an individual per sampling effort, i.e., multiple samples of hair, scat, and/or visual sightings per individual can all be used to estimate abundance (Appendix 3). To obtain accurate abundance estimates, an average of greater than 1.7 observations per individual is required (Stengelein et al. 2010). When this requirement is not met, the results should be treated with caution.

Calculating effective sampling area

Estimating the appropriate area to generate density estimates is not straightforward because individuals move on and off of the sampling area (e.g., hair snag grid or detector dog transect) and their home ranges do not fit neatly within this area. Therefore, the physical size of the sampling area (nominal size) is less than the size of the area being sampled (effective size). Estimates of the effective size of the hair snag grids were obtained using boundary strip methods (Krebs 1999, pg. 97; Appendix 4). There are a number of boundary strip methods, but we used the home range size of the organism of interest to calculate the effective size. However, following Wilson and Anderson (1985), we extended these methods to include an estimate of the associated variance of the sampling areas.

To calculate the effective size of the sampling area, the dog tracks and hair snag grids were buffered by a width proportional to the size (hereafter "buffer size") of a two-week home range for the species of interest; two weeks is approximately how long DNA remains viable in samples in Newfoundland's climate. The width of this buffer was computed by two methods: 1) the radius of a circle with an area equal to the home range size (this would be the home range radius if home ranges were circular) (Soisalo and Cavalcanti 2006, Dillon and Kelly 2008) and 2) ½ the length of the longest dimension of the kernel home range. The second method was compared with the first to investigate the effect of assuming that home ranges are circular. The area of the sampled region extended by this buffer (minus any water) was then the effective survey area (Wilson and Anderson 1985). We did not use the commonly employed "mean maximum distance moved" on the hair snag grids as a proxy for home range radius (Karanth 1995, Karanth and Nichols 1998) because of its inherent bias (Soisalo and Cavalcanti 2006, Dillon and Kelly 2008, Maffei and Noss 2008) and because more direct measures of home range radius were available from the telemetry data. A separate buffer size (and thus effective survey area) was computed from the home range of each tracked animal. Some coyotes were transient, ranging widely across the island, and were not included in the calculation of home-range-based effective survey areas.

The density estimate was thus calculated as the CAPWIRE abundance estimate divided by the median of the effective survey areas (Figures 7 & 8). The variance of this density estimate (and thus the SE) depends on two sources of uncertainty due to 1) the variance of the CAPWIRE estimate of abundance and 2) the variance in effective survey area arising from variation in individual animal home range sizes. Both of these sources of variation must be included in the

calculation of the density variance. This was accomplished by combining these sources of variation using the delta method (Seber 1982) according to the formulae in Wilson and Anderson (1985).

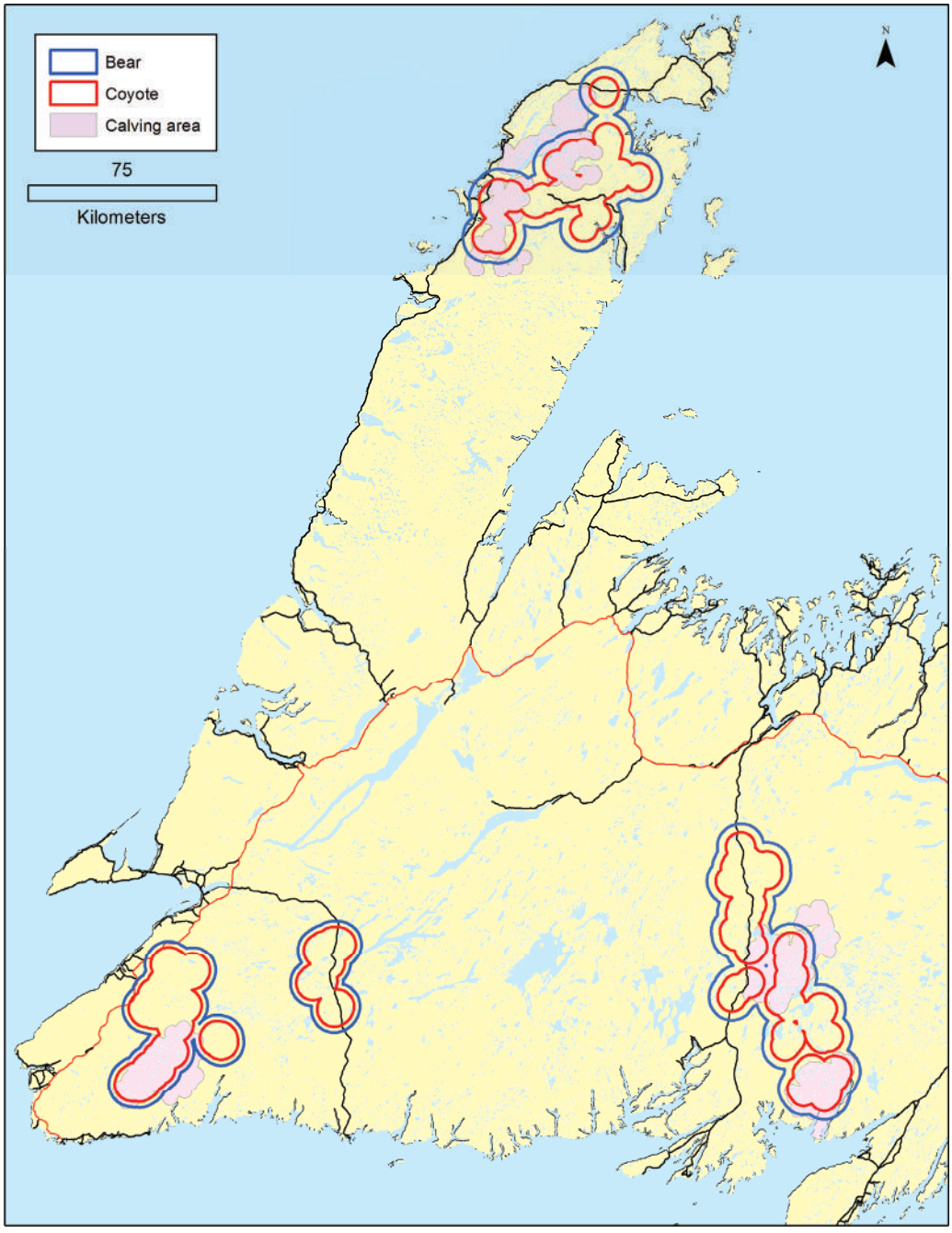

Figure 7. Median effective scat dog track survey areas for bears and coyotes.

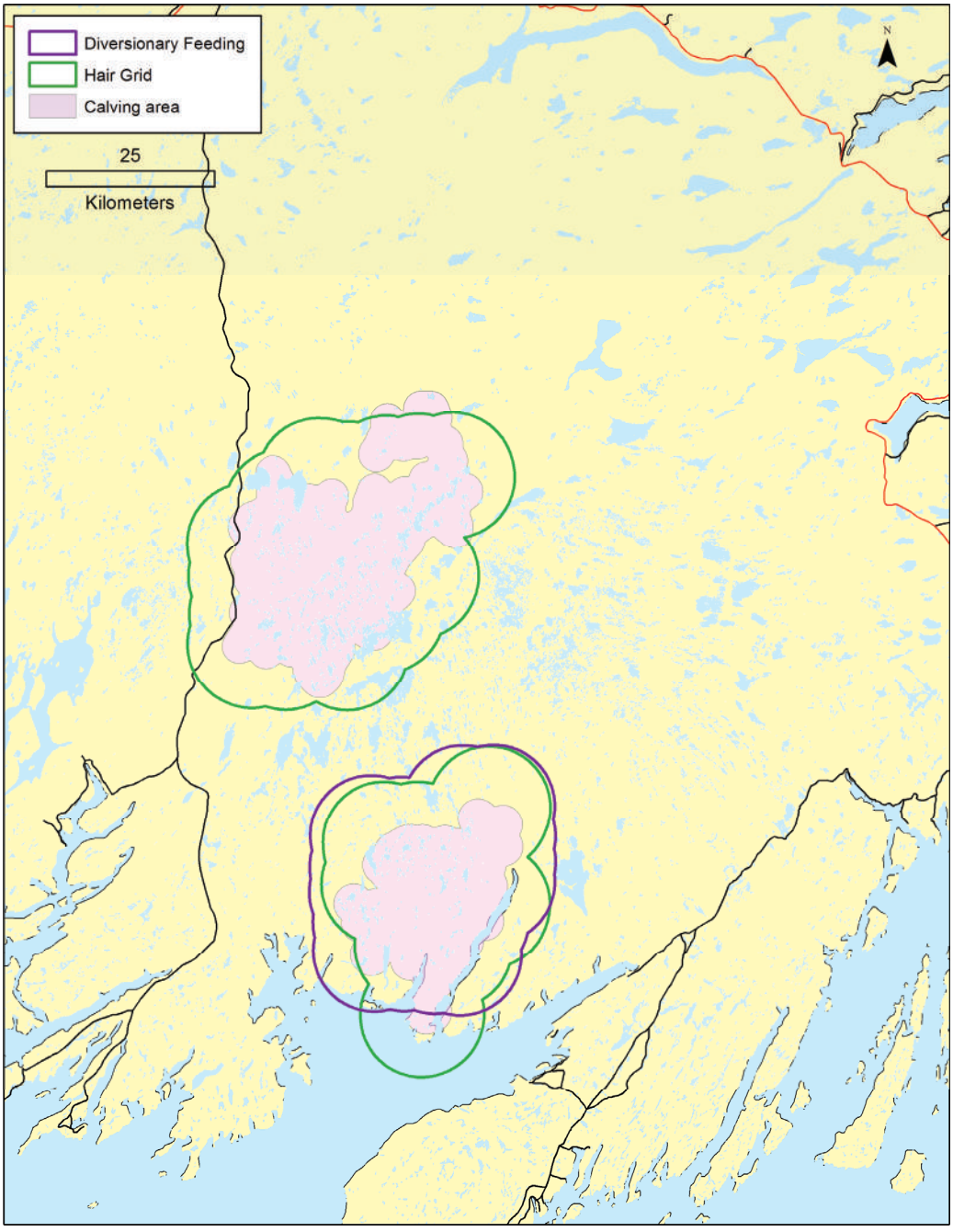

Figure 8. Median effective diversionary feeding and hair snag grid survey areas for bears.

Results

Hair snags

There were 344 hair samples collected in 2008. Of these, 279 (81%) could be identified to species; 271 were bears (97%) and 245 of these were in Middle Ridge (90%). Density estimates were not performed on these data because of concerns over sample quality that prevented the identification of individuals. Briefly, the humid climate of Newfoundland rapidly degrades DNA, and sample quality suffered from infrequent collection as well as less than optimal storage of samples (air dry v. silica desiccation).

In 2009, there were 434 hair samples of which 235 (54%) were identified to species. All but two were bears; the other two samples were coyotes, but neither was identified to individual (Table 1). The majority (83%) of the bear hair was collected in Middle Ridge followed by the Northern Peninsula and La Poile. Of these, 132 samples were identified to individual black bears (56%): one in La Poile, seven in the Northern Peninsula, and 39 in Middle Ridge (Table 1).

There were 361 hair samples from Middle Ridge in 2010 (Table 1) of which 188 were identified as bears (52%). Only bears were successfully identified to species and 46 were individually identified.

There were 665 hair samples from Middle Ridge in 2011 of which 632 were identified as bears (95%; Table 1). However, only 36% of these samples were successfully identified to individual; 61 bears were individually identified.

Table 1. The total number of samples (*n*) and the percentage of the samples successfully identified to individual (Ind %) for hair snags, detector dogs, and diversionary feeding sites during 2009–2011 at the three study areas (MR = Middle Ridge (combined Middle Ridge North and Middle Ridge South (MRS)), LP = La Poile, and NP = Northern Peninsula). Diversionary feeding only occurred at MRS.

			Year					
			2009		2010		2011	
Method	**Study Area**	**Species**	**n**	**Ind (%)**	**n**	**Ind (%)**	**n**	**Ind (%)**
Hair	MR	Bear	365	58	361	66	635	36[1]
	LP	Bear	14	100				
	NP	Bear	55	43				
Detector dogs	MR	Bear			43	44	95	16
		Coyote			72	61	114	47
	LP	Bear	56	33				
		Coyote	94	76				
	NP	Bear	84	29	187	26	178	11
		Coyote	62	85	100	70	112	68
Diversionary feeding	MRS	Bear			237	51	NA	
		Coyote			1	100		

[1] Note that these samples were not identified to species but only to individual and the percent is based on the total number of samples. This contrasts with the other values in the table that are based on the number of samples identified to species and then to individual. Therefore, this value is not directly comparable to the others.

Detector dogs

In 2009, a total of 386 scat samples were collected of which 350 (91%) could be successfully identified to species: 140 bears, 156 coyotes as well as 7 lynx, 45 red fox (*Vulpes vulpes*), and 2 domestic dogs (Table 1). Of these, 152 samples (51%) could be identified to the individual. A total of 28 bears and 41 coyotes were individually identified.

In 2010, a total of 598 scat samples were collected; 418 in the Northern Peninsula and 180 in Middle Ridge (Table 1). Of these, 492 samples (82%) could be successfully identified to species: 230 bears and 172 coyotes as well as 71 red fox and 19 lynx. A total of 181 samples (45%) could be identified to individual; 44 bears and 54 coyotes were individually identified.

In 2011, a total of 598 scat samples were collected: 319 in the Northern Peninsula and 279 in Middle Ridge (Table 1). Of these, 542 samples (91%) could be successfully identified to species: 273 black bears, 226 coyotes, and 43 red fox. A total of 165 samples (33%) were identified to individual; 24 bears and 62 coyotes were individually identified. Black bear abundance could not be estimated in Middle Ridge in 2011due to the extremely low number of samples per individual (M. Mumma, pers. comm.)

The rate of identification to species was lower for bears than coyotes and decreased over the course of the study.

Diversionary feeding

In 2010, 246 samples were obtained from the diversionary feeding grid. Of these, 238 (97%) could be identified to species. Thirty-seven individual bears were identified and one coyote (Table 1). A total of 876 scats were collected in 2011 but the genetic analyses have not been performed.

Density

Estimates of predator density are summarized in Figures 9 & 10 and in Appendix 5. Estimates were generally consistent within and among methods, although variance was generally high. Densities calculated using the circular radius method were consistently higher (although this difference was small) than those from the more conservative ½ long axis method indicating that the amount of bias introduced by assuming circular home ranges was small. Among study areas, Middle Ridge North had a substantially higher point estimate than other areas but high variance precludes making statistical inferences.

Discussion

This study provides the first estimates of density for black bears and coyotes on the island of Newfoundland. While costly and difficult to obtain, these estimates are critical for planning experimental predator removal studies and for managing the predators themselves in the context of the continuing decline of caribou. Further, unlike many studies, the approach used here

combines the statistical uncertainty of the abundance estimates as well as that of the effective sampling areas, providing a more conservative estimate of density variability.

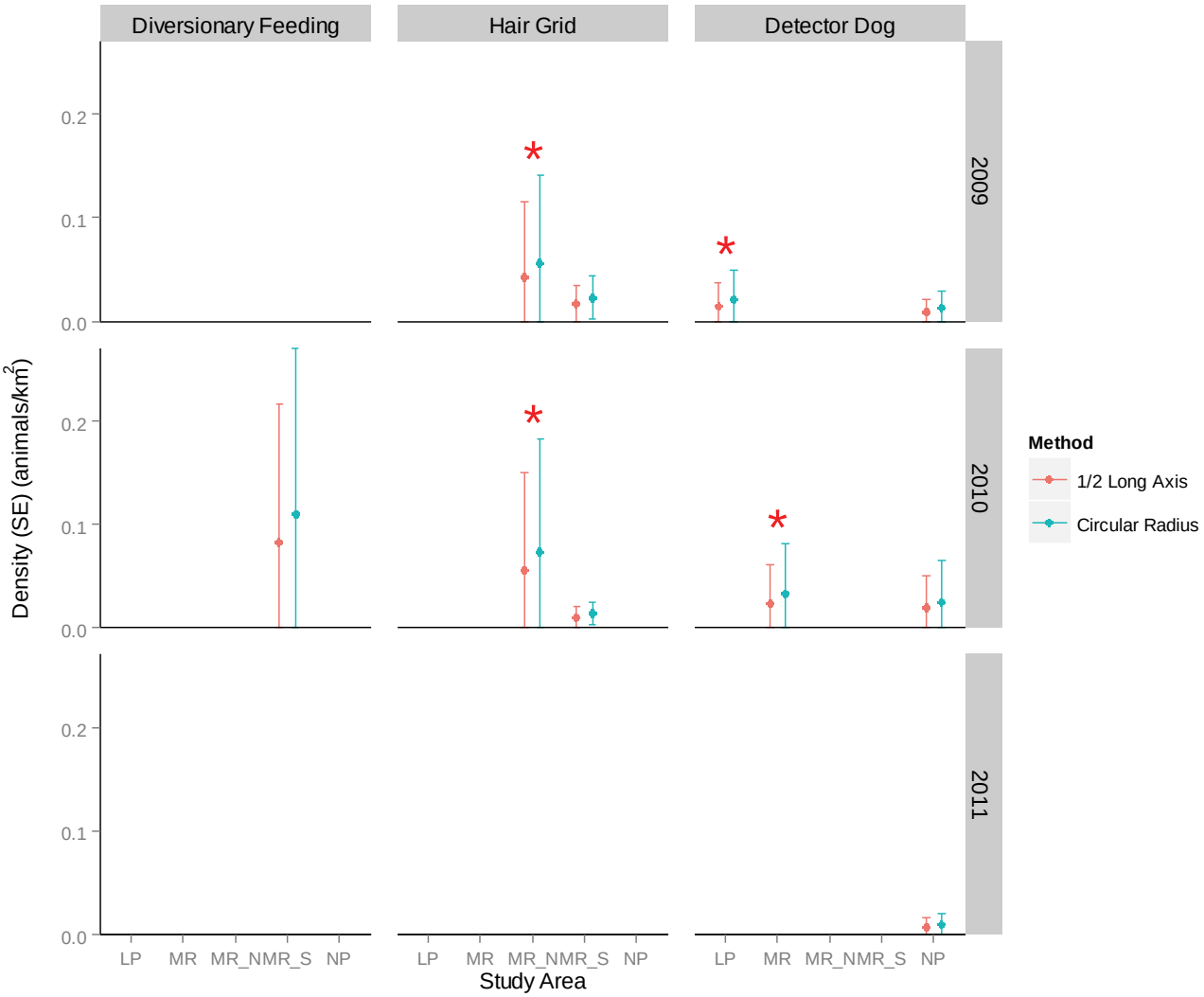

Figure 9. Black bear density (±SE) in 2009–2011 for three different collection methods in all three study areas (LP = La Poile, MR = Middle Ridge, MR_N = Middle Ridge North, MR_S = Middle Ridge South, and NP = Northern Peninsula). Stars over error bars indicate samples where the number of observations per individual in CAPWIRE analysis was < 1.7 and therefore should be regarded as preliminary. Note that there were not enough samples in 2011 for MR to estimate density.

In general, with the exception of other parts of the boreal forest, Newfoundland has low densities of coyotes and black bears compared with the rest of North America (Appendix 6). These low densities are likely due to food supply, e.g., small mammal populations are low (coyotes) and mast is not abundant (bears). However, it is possible that the low densities of coyotes in Newfoundland, as well as in Nova Scotia and Quebec (Samson and Crete 1997, Patterson and Messier 2001, Appendix 6), reflect the recent colonization of these areas by coyotes. Alternatively, it is possible that our results are lower than in other regions of North America because they were measured on and around caribou calving grounds and not necessarily

in areas that are good habitat for these predators; the density of these animals may be higher in other parts of Newfoundland.

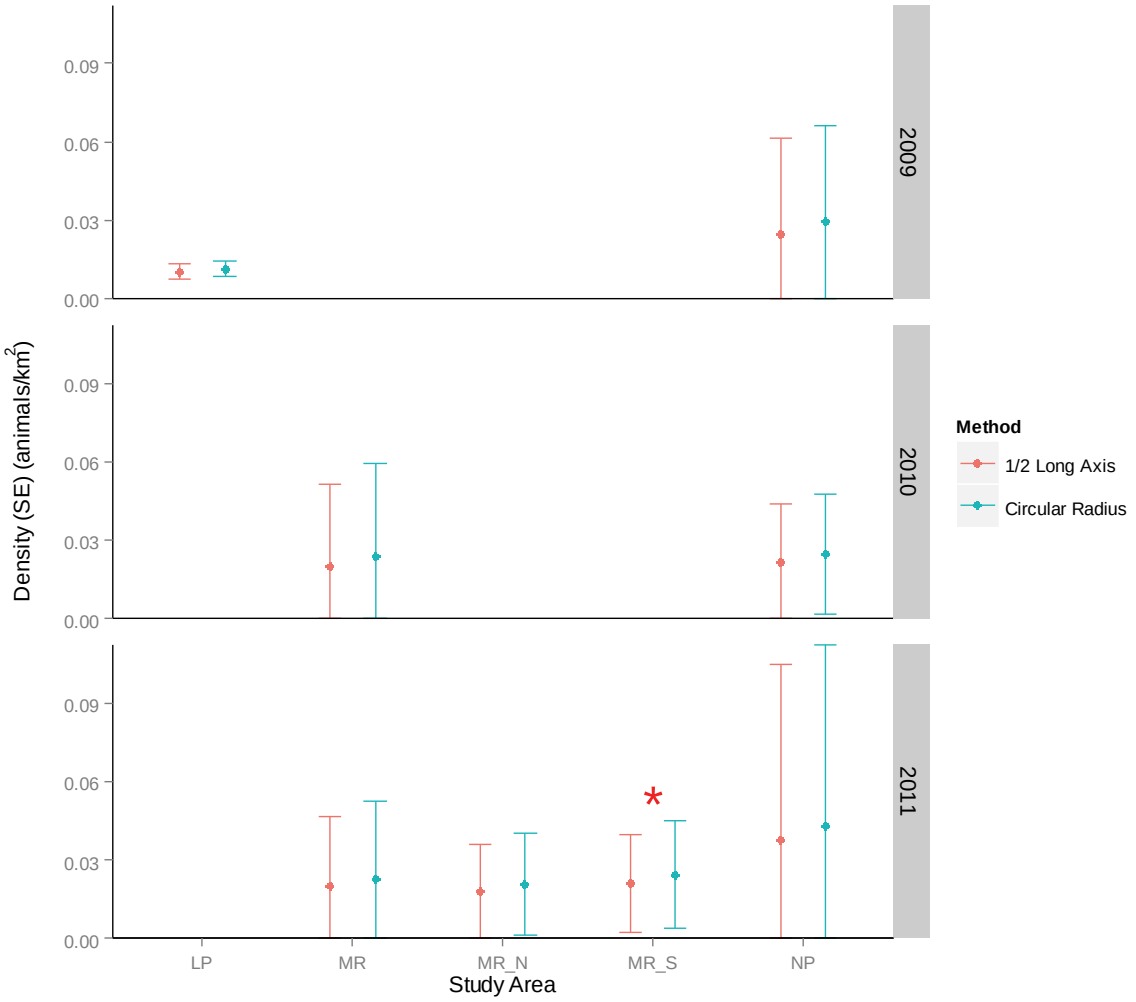

Figure 10. Coyote density (±SE) in 2009–2011 for the detector dog collection method in all three study areas (LP = La Poile, MR = Middle Ridge, MR_N = Middle Ridge North, MR_S = Middle Ridge South, and NP = Northern Peninsula). Stars indicate samples where the number of observations per individual in CAPWIRE analysis was < 1.7 and therefore should be regarded as preliminary.

Methods: a comparison

In contrast to hair snags that captured only black bear hair, detector dogs successfully secured samples of both bears and coyotes in all study areas. Although the identification of species and individuals was generally lower for samples located by detector dogs, remote hair snag stations cost almost twice as much to deploy and only sample the calving grounds rather than the larger areas covered by the detector dogs. Diversionary feeding did yield many scats with a good identification rate but the technique was confined to a single, relatively restricted location and

attraction to bait likely biased density estimates. Therefore, detector dogs appear to be the most cost effective and efficient option for future predator density estimates in remote areas. The differences in identification success rates for coyote and bear samples may be due to the quality of the samples themselves, i.e. the quality of the DNA in coyote scat seems to be better than black bear scat, but it is not clear why the success rate for bears declined over time.

Significantly, none of the methods provided an estimate of lynx density. Hair sampling seems to work effectively when lynx are at relatively high densities (McDaniel et al. 2000) but may simply not be an effective method when densities are low. Lynx in Newfoundland were at a low in their population cycle in 2008–2009 based on harvesting records. Automatic camera grids deployed in the winter could be an effective means to estimate lynx density at relatively low cost. This method has been effectively used to monitor other elusive felids (Karanth and Nichols 1998, Dillon and Kelly 2008, Royle et al. 2009).

Other methods of obtaining density estimates did not work well because of a combination of snow conditions and remote locations for the snow-tracking surveys, exorbitant costs for the trapping, and the requirements needed to produce density estimates from the telemetry approach were not met because predators were not systematically captured (see Appendix 2 for full details and discussion).

Hair snags

It is not clear why the hair snag grids were only successful for bears in Middle Ridge. There does not appear to be a significant difference in bear density among the study areas based on the detector dog estimates (Figures 9 & 10). Furthermore, the landscapes of Middle Ridge North is similar to the Northern Peninsula and Middle Ridge South is similar to La Poile which suggests that differences in habitat cannot account for differences in obtaining samples at the hair snags. It is possible that differences in habitat selection by black bears across the study areas could have influenced encounter rates of hair snags by black bears, and therefore influenced sample deposition rates, but we have no evidence to date for such regional differences.

The low numbers of hair samples for coyotes may have been due biological and/or methodological factors. Coyote densities are thought to be low based on large home range sizes and harvesting records (Fifield et al. *in prep.*, McGrath et al. 2009). Territorial coyote home ranges are large and generally do not overlap and therefore, there may be few coyotes in the hair snag area. Also, approximately one quarter of the coyote population have been shown to rapidly move large distances (McGrath et al. 2009, Fifield et al. *in prep*.) and therefore may not be in the sampling area long enough to be attracted to the hair snags. Methodologically, although protocols that were effective in other studies were used (Fannin and Ausband 2009), the hair sampling stations may not have been attractive enough to lynx and coyotes for them to rub against the stations.

A further complication with hair snags was the frequency of the visits. Studies using hair snags often collect samples once every seven to ten days and have four to eight sampling periods (Apps et al. 2004, Gardner et al. 2009, 2010). This was not possible in the remote study areas because of budgetary and logistic constraints, and as a result, many samples were not usable in subsequent analyses because insufficient DNA remained to identify species and individuals. This is likely due to the degradation of the DNA in the wet climate of Newfoundland and the long interval between sampling periods.

The timing of the deployment of hair snag stations did not seem to influence the success rate. In 2009, hair snags were visited post-calving season, compared with September and October for 2008, with little influence on the results.

Density estimates

The density estimates for black bears and coyotes generally had high variance making comparisons among study areas difficult. It will also be difficult to compare these results with other studies that failed to incorporate variation in the effective survey area as we have, and therefore overestimate the precision of their estimates (e.g., Bales et al. 2005, Clark and Smith 1994, Doan-Crider and Hellgren 1996, but see Frary et al. 2011, Tredick and Vaughan 2009, and Gardner et al. 2009).

An examination of our two sources of variance in the density estimates, i.e., abundance and effective survey area, indicated that this variability was largely driven by the variation in the abundance estimates; the variation in the effective survey area was fairly constant. For example, the 95% confidence intervals for the abundance of coyotes in La Poile in 2009 was 19–23 animals, whereas in 2011 on the Northern Peninsula, they were 39–74 animals (Appendix 5) and the width of these confidence intervals was reflected in the density estimates (Figure 10).

The precision of the density estimates could be improved, i.e. a decrease in the width of the confidence intervals, by sampling more frequently (5-8 times per season) in order to increase the number of samples. In order to be logistically and financially feasible, efforts with numerous sampling periods should occur in easily accessible areas, especially for hair snag grids. Detector dogs are the less expensive option in general, but when operating in remote areas, transportation of the dogs and crews can be linked with other activities in the area further reducing the cost; this is generally not practical when operating a hair snag grid. However, vehicle access is critical to keeping costs down for either approach. Increased numbers of samples will also increase the utility of CAPWIRE. CAPWIRE estimates abundance well when the number of observations per individual is >1.7 (Stengelein et al. 2010). This requirement was met for two of the four estimates based on the hair grids while it was met for twelve of the sixteen detector dog estimates (Figure 9 &10). More frequent sampling could improve the number of observations per individual.

Future analyses could also employ several recent developments using Bayesian statistics or spatially explicit capture-recapture models that have a number of advantages over the above approach. These advantages include the relaxation of critical assumptions such as geographic closure as well as simultaneously providing estimates of both abundance and the effective sample area (Gardner et al. 2009, 2010, Thompson et al. 2012, Russell et al. 2012). The approach we used is inefficient because of the need to independently estimate the effective sampling area and its associated variance and may contribute to the large standard errors. However, only the Bayesian approaches have been extended to detector dogs. Further, these approaches are at the very forefront of quantitative ecology and are not a trivial undertaking.

Summary

These methods have provided the first rigorous estimates of black bear and coyote densities in Newfoundland and will be important for managing these species as well as determining their

influence on caribou. The precision of the estimates could be improved by sampling more frequently and using the latest analytical approaches.

A final cautionary note: density estimates apply to only the areas sampled, which include the calving grounds and surrounding areas in all cases (Figures 3 & 6). Extrapolating the findings of this study to larger areas is not recommended.

Through the *Caribou Strategy*, knowledge of caribou predators has greatly increased (Fifield et al. *in prep*). However, many questions remain, including the influence of land cover on density, variation in density across the island, as well as factors that influence populations and therefore density. To explore these questions, and to better manage the resource, the Government of Newfoundland and Labrador may consider investing in detector dogs for this and other work.

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Appendices

Appendix 1. A brief history of density estimation

Methods for calculating abundance have increased in complexity over the last 70 years. Essentially, the more sophisticated models allow more of the assumptions to be relaxed.

Calculating area has received less attention than calculating abundance until recently. The essential problem is that animal home ranges do not fit perfectly into the sampling area. The original and most widely used solution is to calculate a boundary strip (1930s), a correction factor that increased the size of the sampling area relative to the animal's home range. Other methods include the nested sub-grid method (MacLulich 1951), naïve density (Boutin 1984), and mean maximum distance moved (Karanth and Nichols 1998). All of these methods use some aspect of movement or home range to correct the grid size and though widely used, have little theoretical foundation (Gardner et al. 2010). Many studies of large carnivores use some index of abundance divided by the size of the study area (e.g., Kluane valley, O'Donoghue et al. 1997).

Recently, Efford (2004) proposed a general method for estimating density that avoids the problems of previous methods. In this method, the location of the captures, which has traditionally been ignored, is incorporated into the analysis where the probability of capture is a declining function of distance between an animal's range center and a given trap. This method, sometimes called spatially explicit capture-recapture (or unified capture-recapture), has been greatly expanded upon in a series of papers that employ hierarchical Bayesian models (Royle et al. 2009, Gardner et al. 2009, 2010, Russell et al. 2012). Bayesian models are especially useful for estimating density from non-invasive genetic sampling, can handle variable "trap" arrays, and a variety of methods including cameras, hair snags, and detector dogs.

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Appendix 2. An overview of other efforts to obtain predator density

Predator snow-tracking survey methods

Quadrats

Snow-tracking surveys were conducted on the calving grounds at each study area, as defined by the 2008 calving areas (25 May – 30 June) in order to develop another metric to estimate predator density. Snow-tracking surveys were the most efficient method for detecting lynx in Maine (Crowley et al. 2008).

Each study area was divided into a number of 10 km × 10 km quadrats, the number of quadrats depended on the size of the calving areas (Figure A1). By convention, transect length is the square root of the average home range of the target species (Heinemeyer et al. 2008) with one transect length per home range. In the interest of balancing good survey design and logistic considerations, transect length and density were based on 100 km^2 home ranges (a compromise between typical coyote and lynx home range size, M. McGrath pers. comm.) giving10 km transects. Middle Ridge had nine quadrats (90 km of transects, 60 + 30 for each calving area), La Poile had six quadrats (60 km of transects), and the Northern Peninsula had seven quadrats (70 km of transects, 40 + 30 for each calving area). In each quadrat, transects of varying lengths were traveled (Figure A2). A total of 10 km of transects within a block was considered a sampling unit.

Quadrats were surveyed in early March 2009 along predetermined transects on snowmobiles by a two-person team 48–120 hours after a track-covering snowfall, in conditions conducive to track detection, i.e., reasonably low wind and good snow conditions for traveling by snow machine (Figure A2). Footprint width and length as well as stride and straddle were measured.

Lynx, coyote, and fox tracks encountered along transects were followed to find scat, urine, or hair, i.e., genetic material from which DNA could be extracted to identify individuals for use in a mark-recapture analysis. Only scats and urine associated with tracks crossing the transect line were used for population estimates to avoid collecting samples that had been dropped before the last snowfall and subsequently exposed by wind. All genetic materials not associated with the tracks were collected to contribute to other ongoing projects (food habits, etc.).

One snow-tracking survey was completed in the La Poile and Northern Peninsula areas but because of sporadic snow conditions, only half of the blocks could be completed at Middle Ridge. High winds and a thick snow crust on the Northern Peninsula and La Poile areas rendered the conditions unacceptable for tracking for most of the winter and a second survey was not completed. Tracks from three coyotes were found on the surveys. Due to poor returns for the effort, this program was discontinued.

Trapping

In 2008, predator capture in Middle Ridge focused on trapping but was met with poor success (Table A1). This effort was abandoned in 2009. After 2009, bears were captured primarily by aerial darting in Middle Ridge and by trapping in La Poile and the Northern Peninsula. Coyotes were captured primarily by net gunning in Middle Ridge and La Poile and a combination of net gunning and trapping in the Northern Peninsula.

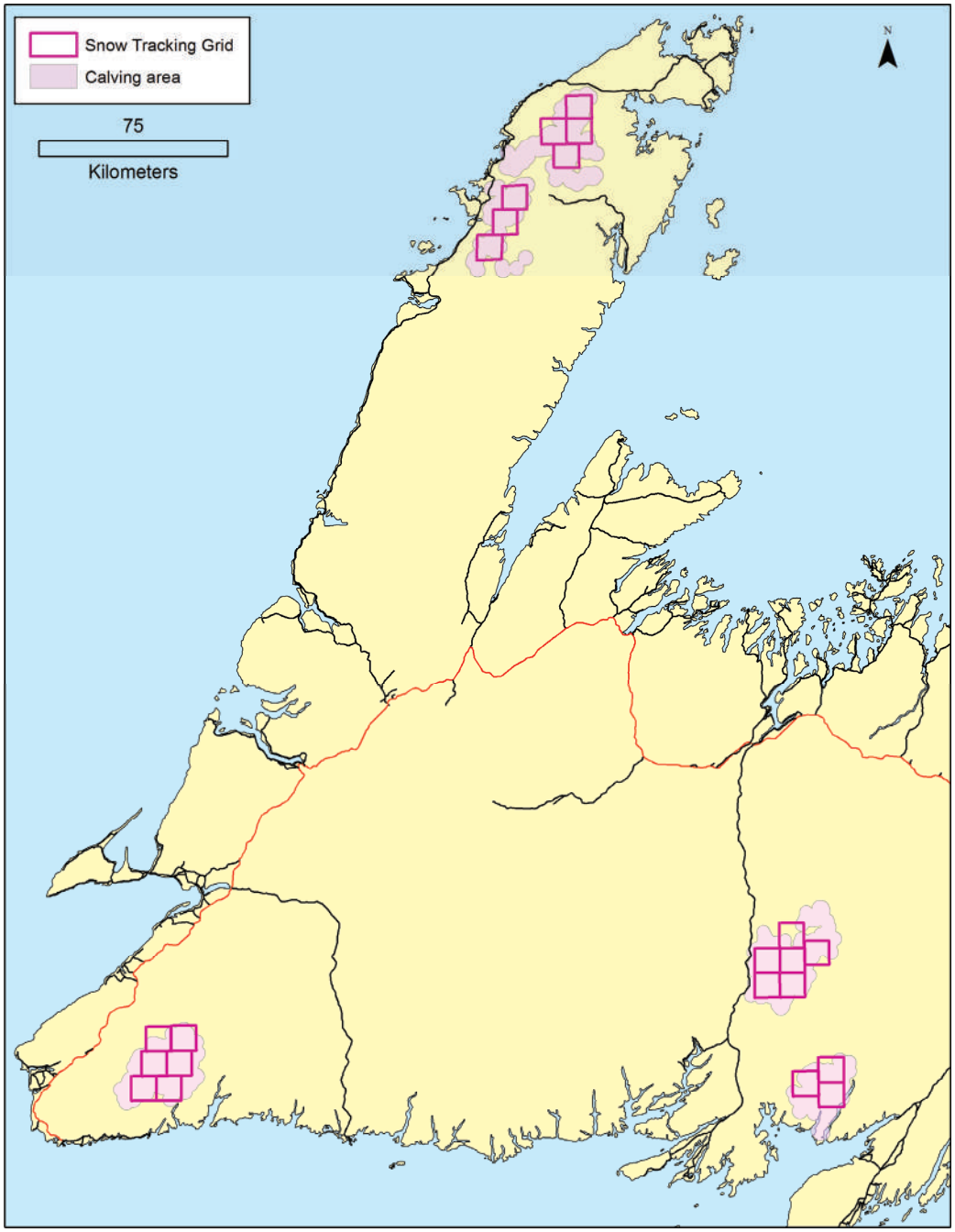

Figure A1. Snow-tracking survey blocks overlaying the calving areas.

Telemetry

A large number of bears (n = 95) and coyotes (n = 102) have been fitted with GPS and ARGOS collars as part of the *Caribou Strategy*. Given the inherent delays in obtaining DNA from the other methods, and as part of a larger contract to determine home range size and overlap of predators, the Alberta Research Council (ARC; now Alberta Innovates) was commissioned to determine whether telemetry data could generate predator density estimates (Fisher and Hiltz 2009). It is possible to use these types of data to generate predator density estimates, but a series of the following assumptions must be met: 1) animals have been sampled with a probabilistic

design, i.e., random or systematic sampling design such as trapping grids, 2) there are no spatial gaps in capture effort, and 3) habitat is homogeneous across the study area. The third assumption can be ameliorated by obtaining information on habitat heterogeneity and relating this information to the probability of occurrence of telemetry locations using resource selection functions. However, given the opportunistic sampling of predators (Fifield et al. *in prep.*), the first and second assumptions were not met; therefore, these data could not be used to determine density by themselves although they were critical for calculating effective survey area (see below).

Based on the recommendations of the ARC, predator density was not calculated using telemetry data (Fisher and Hiltz 2009).

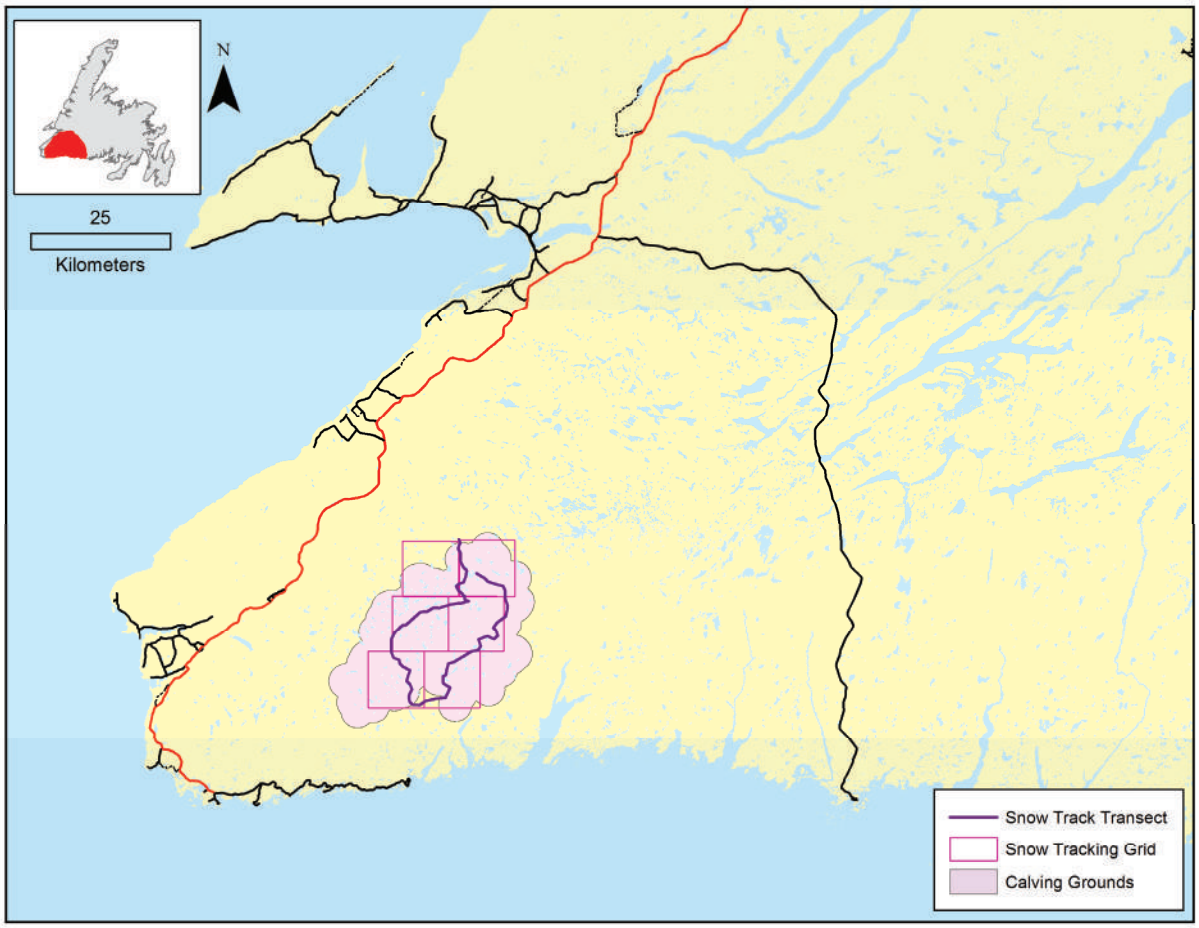

Figure A2. Example of a snow-tracking survey in the La Poile study area.

Table A1. Summary of the bear trapping methodology, trapping effort, and success in 2008 for all three study areas.

Site	Method	Strategy	# Bait/Trap Sites	# Captures	Days	Trap Nights	Success (%)
Middle Ridge	Helicopter Access	All baits	82/82	2	20	1400	0.14
	Road Access	All baits	90/90	6	45	1338	0.45
La Poile	Road Access	Active baits	65/10[1]	9	16	32	28
Northern Peninsula	Road Access	Active baits	109/11[1]	11	22	42	26

[1] Trap sites in La Poile and the Northern Peninsula were pre-baited

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Appendix 3. A summary of the input for analyses in CAPWIRE

See Miller et al. (2005) for more information on the theory underlying CAPWIRE.

Input:
Input into CAPWIRE is very simple (see Brief instructions for CAPWIRE in Miller et al. (2005) for full details). All independent samples of each individual are tallied. Hair sampled on the same day and same transect are NOT considered independent and are pooled.

Multiple populations can be entered at one time. The largest number of captures is required as is the number of "capture counts", i.e., the number of individuals caught per capture class. For example, in Bears_LP_2009_June below, there were eleven individuals captured once and three that were captured twice.

Input Datasets: Bears 2009(JUNE) - Mumma genetic data from scats and hair
3 # of populations
31 Largest # of observed types in any population (for dimensioning)
42 Largest sample size among all populations (for dimensioning)
Bears_LP_2009_June
2 largest # captures
capture counts:
11 3
Bears_MR_2009_June
4 largest # captures
capture counts:
22 8 0 1
Bears_NP_2009_June
7 largest # captures
capture counts:
7 3 2 0 0 0 1

An abbreviated output:

Pop	SS	Tobs	N^	lowCI	upCI	CIWidth
Bears_LP_2009_June	17	14	40	17	130	113
Bears_MR_2009_June	42	31	64	43	109	66
Bears_NP_2009_June	26	13	15	13	18	5

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Appendix 4. Contact information

The effective area of the hair snag grids was estimated using an extension of the boundary strip methods in Krebs (1999, pg. 97). Following Wilson and Anderson (1985), we extended these methods to include an estimate of the associated variance of the sampling areas. For the complete metadata and code, contact:

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Appendix 5. Estimates of predator density (# animals/km^2) in the three study areas for bears and coyotes

The average number of observations per individual (Avg. Obs. per Ind.) is optimally > 1.7. SS = the number of samples, Tobs = the number of individuals, N = estimated abundance, CI = confidence interval, CR = circle radius, ½ LA = half long axis, LS = linear search, div feed, diversionary feeding, MRN = Middle Ridge North, MRS = Middle Ridge South, MR = Middle Ridge, NP = Northern Peninsula, and LP = La Poile**.**

Bears

Survey Type	Method	Year	Study Area	SS	Tobs	N	lowerCI	upperCI	Avg. Obs. per Ind.	Density	Density SE	Method
grid	Hair	2009	MRN	49	30	62	37	86	1.63	0.057	0.085	CR
grid	Hair	2009	MRN	49	30	62	37	86	1.63	0.043	0.073	½ LA
grid	Hair	2010	MRN	64	40	81	53	107	1.60	0.074	0.109	CR
grid	Hair	2010	MRN	64	40	81	53	107	1.60	0.056	0.094	½ LA
grid	Hair	2009	MRS	19	10	16	10	26	1.90	0.023	0.021	CR
grid	Hair	2009	MRS	19	10	16	10	26	1.90	0.017	0.018	½ LA
grid	Hair	2010	MRS	11	6	10	6	20	1.83	0.014	0.011	CR
grid	Hair	2010	MRS	11	6	10	6	20	1.83	0.010	0.010	½ LA
grid	div feed	2010	MRS	52	37	92	57	135	1.41	0.110	0.161	CR
grid	div feed	2010	MRS	52	37	92	57	135	1.41	0.083	0.133	½ LA
LS	scat dog	2010	MR	19	17	86	31	200	1.12	0.032	0.050	CR
LS	scat dog	2010	MR	19	17	86	31	200	1.12	0.024	0.038	½ LA
LS	scat dog	2009	NP	25	13	23	13	37	1.92	0.013	0.016	CR
LS	scat dog	2009	NP	25	13	23	13	37	1.92	0.009	0.012	½ LA
LS	scat dog	2010	NP	48	27	57	33	74	1.78	0.025	0.040	CR
LS	scat dog	2010	NP	48	27	57	33	74	1.78	0.020	0.032	½ LA
LS	scat dog	2009	LP	19	15	41	19	86	1.27	0.022	0.028	CR
LS	scat dog	2009	LP	19	15	41	19	86	1.27	0.015	0.023	½ LA
LS	scat dog	2011	NP	20	10	19	10	30	2	0.009	0.011	CR
LS	scat dog	2011	NP	20	10	19	10	30	2	0.007	0.009	½ LA

Coyotes

Survey Type	Year	Study Area	SS	Tobs	N	lowerCI	upperCI	Avg. Obs. per Ind.	Density	Density SE	Method
LS	2009	NP	53	22	32	22	44	2.41	0.029	0.037	CR
LS	2009	NP	53	22	32	22	44	2.41	0.024	0.037	½ LA
LS	2010	NP	70	29	39	31	51	2.41	0.025	0.023	CR
LS	2010	NP	70	29	39	31	51	2.41	0.022	0.023	½ LA
LS	2009	LP	71	19	20	19	23	3.74	0.011	0.003	CR
LS	2009	LP	71	19	20	19	23	3.74	0.010	0.003	½ LA
LS	2010	MR	44	25	44	26	60	1.76	0.024	0.036	CR
LS	2010	MR	44	25	44	26	60	1.76	0.020	0.031	½ LA
LS	2011	MR	54	29	43	29	59	1.86	0.023	0.030	CR
LS	2011	MR	54	29	43	29	59	1.86	0.020	0.027	½ LA
LS	2011	MRN	32	16	23	16	34	2.00	0.020	0.019	CR
LS	2011	MRN	32	16	23	16	34	2.00	0.018	0.018	½ LA
LS	2011	MRS	22	13	19	13	33	1.69	0.024	0.021	CR
LS	2011	MRS	22	13	19	13	33	1.69	0.021	0.019	½ LA
LS	2011	NP	76	33	60	39	74	2.30	0.043	0.069	CR
LS	2011	NP	76	33	60	39	74	2.30	0.037	0.067	½ LA

Appendix 6. A summary of coyote and black bear populations across North America including land cover, density, and methodology

Table A2. Densities of coyotes in North America (CI = confidence interval).

Population	Study area details	Density (coyotes/km^2)	Type of data and methods used
Newfoundland (Fifield and Lewis 2013 – this study)	Open, calving areas: Middle Ridge (2010) (2011) Northern Peninsula (2009) (2010) (2011) La Poile (2009)	 0.020 (CI: 0.002–0.184) 0.020 (CI: 0.003–0.151) 0.024 (CI: 0.003–0.211) 0.022 (CI: 0.004–0.118) 0.037 (CI: 0.004–0.401) 0.010 (CI: 0.006–0.017)	DNA sampling of scat detected by dogs (~2 months of surveys each year), program CAPWIRE
Quebec (Samson and Crete 1997)	Mountains, mixed forest, no hunting or trapping (1991)	0.02–0.03 (±35%–36%)	Radio-telemetry, radioactive isotope mark-recapture, Peterson index
Nova Scotia (Patterson and Messier 2001)	Forests (1995–1997), Queens County, and Cape Breton Island	0.043–0.139	Radio-telemetry, snow-tracking of family group members (586 occasions), program TRACKER
Idaho (Stoddart et al. 2001)	Desert, bush, and scrub (1975–1985)	0.25–2.1 (cyclic with diet over study years)	Scat count indices converted to density using mark-recapture regression
California (Fedriani et al. 2001)	Scrub habitat with low-high human pressure (1997–1998)	0.3–3.0	Genotyping scat, foot-hold trapping surveys

Tennessee (Babb and Kennedy 1989)	Open pasture (1986)	0.35	Trapping, radio-telemetry
Oregon (Dunbar and Giordano 2002)	Hart Mountain National Antelope Refuge (1997–1999)	0.42–0.53	Howl surveys
Colorado (Hein and Andelt 1995)	Grassland (1990–1991)	0.71 (CI: 0.49–1.16)	Mark-resight, NOREMARK
Kansas (Gipson and Kamler 2006)	Mixed grass prairie and woodlands (1995–1997)	0.8–0.9	Trapping, radio-telemetry
Texas (Andelt and Andelt 1984)	Bessie Welder Wildlife Refuge (1978–1979)	0.8–1.0	Radio-telemetry
Massachusetts (Way and Timm 2011)	Cemetery/woodland (2004–2005)	1.95–3.41	Radio-telemetry, mark-resight
Arizona (McClure et al. 1996)	Desert scrub (1991–1992)	3.2–4.6	Radio-telemetry, mark-resight (6 surveys), NOREMARK, Lincoln-Petersen estimates

Table A3. Densities of black bears in North America (CI = confidence interval).

Population	Study area details	Density (bears/km^2)	Type of data and methods used
Newfoundland (Fifield and Lewis 2013 – this study)	Open, calving areas:		DNA sampling of scat detected by dogs (~2 months of surveys each year), CAPWIRE
	Middle Ridge		
	(2010)	0.024 (CI: 0.002–0.237)	
	Northern Peninsula		
	(2009)	0.009 (CI: 0.001–0.067)	
	(2010)	0.020 (CI: 0.002–0.188)	
	La Poile		
	(2009)	0.015 (CI: 0.002–0.135)	
	Middle Ridge North		DNA sampling of hair, 2-3 sampling periods per year, CAPWIRE
	(2009)	0.043 (CI: 0.004–0.434)	
	(2010)	0.056 (CI: 0.006–0.55)	
	Middle Ridge South		
	(2009)	0.017 (CI: 0.003–0.10)	
	(2010)	0.010 (CI: 0.002–0.053)	
Kentucky (Frary et al. 2011)	Mesophytic forest (2007)	0.075 (CI: 0.054–0.096)	DNA sampling of hair, 5 sampling periods, spatially explicit capture-recapture, Program DENSITY
Arkansas (Clark and Smith 1994)	Forested, flat-topped mountains (1989, 2 sites)	0.075 and 0.09	Mark-recapture, Jolly-Seber method, program JOLLY
Alaska (Miller et al. 1997)	Inland forest, sympatric with brown bears	0.089 (CI: 0.077 – 0.103)	Radio-telemetry, mark-resight
British Columbia and Alberta (Mowat et al. 2005)	Mountains, sympatric with brown bears (1999)	0.100 (CI: 0.055–0.210)	DNA sampling of hair, 3-4 sampling periods, mark-recapture, Program MARK and CAPTURE, Boulanger and McLellan method, time based correction method, boundary
	Plateau, sympatric with brown bears (1999)	0.257 (CI: 0.173–0.458)	

			strip correction method
Quebec (Roy et al. 2012)	Mature deciduous forest (2005)	0.10–0.55	DNA sampling of hair, ~ 6 weekly sampling periods, mark-recapture
New York (Gardner et al. 2009)	Adirondack black bear range	0.159	DNA sampling of hair, spatially explicit capture-recapture, 8 weekly sampling periods, WinBUGS (Bayesian analysis using data augmentation)
Minnesota (Rogers 1987)	Boreal and temperate forest (1969–1985)	0.16–0.24	Capture-mark-recapture/resight of all bears on study area, radio-telemetry
Oregon (Immell and Anthony 2008)	Mixed forest, Steamboat (2003) (2004) Toketee (2003) (2004)	 0.18 (CI: 0.12–0.24) 0.20 (CI: 0.14–0.26) 0.23 (CI: 0.17–0.29) 0.21 (CI: 0.16–0.26)	DNA sampling of hair, mark-recapture, three 3-week sampling periods each year, Program CAPTURE, Pollock and Otto estimator model
Alaska (Schwartz and Franzmann 1991)	Burned forest stands, Kenai Peninsula (2 sites, 1982–1985)	0.189 and 0.211	Mark-recapture, radio-telemetry, extrapolation method, estimated using proportion of bear area use that overlapped center of study area
New Hampshire (Coster et al. 2011)	Forest and towns, 2 areas Pittsburg (2006) (2007) Milan (2006) (2007)	 0.19 (CI: 0.15–0.24) 0.20 (CI: 0.16–0.24) 0.21 (CI: 0.16–0.25) 0.21 (CI: 0.17–0.25)	DNA sampling of hair, mark-recapture, 8 weekly sampling periods, Program MARK, Huggins closed capture models, Pledger mixture models
Montana (Jonkel and Cowan 1971)	Mountainous, forested region (1960 and 1966)	0.23–0.48	Marked-unmarked ratios, Petersen Index method
Oregon (Akenson et al. 2001)	Coniferous forest (1996) (1997)	0.252 (CI: 0.194–0.368) 0.205 (CI: 0.164–0.292)	Scent detection by dogs, mark-recapture, 53 surveys,

			NOREMARK with joint hyper-geometric maximum likelihood estimator
Ontario (Obbard and Howe 2008)	Boreal forest, hunted (1989–1999, 2 sites)	0.228 (CI: 0.21–0.27) and 0.140 (CI: 0.12–0.23) (females only)	DNA sampling of hair, one sampling period each year, mark-recapture, Program MARK, program RELEASE, Cormack-Jolly-Seber model assumptions
	Boreal forest, unhunted (1997–2000)	0.352 (CI: 0.29–0.53) (females only)	
Arizona (Waddell and Brown 1984)	Mountainous, semi-desert grassland and conifer forest (1971–1981)	0.24–0.33	Capture-recapture, Seber method of Lincoln Index
North Carolina/ Tennessee (McLean and Pelton 1994)	Smoky Mountains, temperate rain forest (1973–1987)	0.292	Capture-mark-recapture, Jolly-Seber method, program JOLLY
Arizona (LeCount 1982)	Mountainous region, dominated by shrub and oak (1973–1978)	0.33	Capture-recapture, radio-telemetry, Leslie and Petersen methods
Mexico (Doan-Crider and Hellgren 1996)	Rocky, hilly terrain dominated by oak and shrub (1991–1994)	0.35	Mark-recapture, Lincoln-Peterson estimator method
Louisiana (Boersen et al. 2003)	Forested water basin (1999)	0.36	DNA sampling of hair, mark-recapture, ~15 weekly sampling periods, Program CAPTURE (assumed population closure)
North Carolina and Virginia (Tredick and Vaughan 2009)	Forested wetlands (2002–2004)	0.37–1.30	DNA sampling of hair, mark-recapture, 8 weekly sampling periods, Program DENSITY

Wisconsin (Belant et al. 2005)	Deciduous forest, Sand Island Stockton island	 0.50 0.64	DNA sampling of hair, mark-recapture, four 2-week sampling periods, Program CAPTURE
Washington (Lindzey and Meslow 1977)	Long Island, shrub and timber lands (1973)	1.12–1.64	Capture-mark-resight of all bears on island
Alaska (Peacock et al. 2011)	Kuiu Island, dense forest, hunting (2000–2002)	1.55	DNA sampling of hair, 2 hair sampling periods, mark-recapture using tetracycline marks on bone as submitted by hunters

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