The effect of temporal sampling regime on the characterization of home range for female boreal woodland caribou (*Rangifer tarandus caribou*) in Labrador, Canada

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Abstract: Our objective was to determine the influence of temporal sampling regime on the characteristics of individual female caribou home ranges and to explore implications of these findings to the conservation of caribou. The study population was 24 adult female caribou monitored for between 4 and 11 consecutive years between 1986 and 2009 from the Red Wine Mountain (RWM) and Lac Joseph (LJ) herds of boreal caribou in Labrador. We evaluated the influence of length of the monitoring period on the size of home ranges and fidelity of caribou to their ranges by measuring the percent overlap of multi-annual ranges on the total time period a caribou was collared and by calculating displacement between centroids of annual and multi-annual ranges for a given caribou. We found that the size of the range increased with each additional year of monitoring—initially at a rate greater than 20% per year, and then more slowly until an asymptote was reached after 7 years. The distance ratio declined with an increase in the monitoring interval until after approximately 6 years of monitoring. Finally, we evaluated trade-offs between monitoring interval and sample size by measuring the proportion of the total herd range captured by multi-annual ranges for given monitoring interval and sample size combinations. Caribou with the longest monitoring interval inevitably captured the greatest portion of the range at each given sample size. Only monitoring intervals of 4 years or greater captured more than 65% of the herd range even when sample size was doubled for shorter monitoring intervals. Our results suggest that long term monitoring is important when defining the extent of caribou ranges.

Key words: fidelity; home range; monitoring regime; *Rangifer tarandus caribou*; temporal scale.

Introduction

Boreal caribou *Rangifer tarandus caribou* have experienced range contractions and population declines over the past three decades in North America. Forest-dwelling caribou belong to the sedentary ecotype and are distinguished by their dispersion during calving and because they are distributed as individuals and small groups (rather than large aggregations) throughout their range (Bergerud *et al*., 2008). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has assessed boreal caribou as 'threatened', and they are legally listed under the

federal Species at Risk Act (SARA) and are afforded protection in several provincial and territorial jurisdictions. A central requirement of recovery planning for Boreal caribou is the identification of critical habitat, or habitat essential to the survival and recovery of the species. A crucial element of the determination of critical habitat is the determination of individual and local population ranges (Environment Canada, 2008). Range size and the tendency of an animal to return to the same range during consecutive years (fidelity) reflect the interaction between an individual and its environment, and have direct ramifications for survival, predation and reproduction. Caribou range use varies over different spatial and temporal scales (Rettie & Messier, 2000; Schaefer et al., 2000; Johnson et al., 2004; Mayor et al., 2009) as foraging strategies, and reducing risk of exposure to parasites and predators occur at fine and coarse scales. Anthropogenic footprints can also influence range use (Nellemann & Cameron, 1998; Nellemann et al., 2003; Dyer et al., 2001, 2002; Banks et al., 2007; Courtois et al., 2007; Faille et al., 2010). Collectively, this suggests that a conceptually simple task (e.g. mapping) is fraught with complexity imbued by the ecology of caribou themselves and the properties of the landscapes they occupy.

Home range is the area used by an animal over a given time interval (White & Garrot, 1990), and is described through the compilation of radio telemetry data over time. There are significant costs associated with radio telemetry of long-lived animals over vast areas and there is little guidance in the literature on how to prioritize sampling effort. The null model of home range area is that a 'true' home range size is reached with increasing sample size. Correspondingly, numerous efforts have been directed at determining the minimum number of fixes (e.g., Seaman et al., 1999) and the methods used to accurately describe a home range (Burgman & Fox, 2003; Laver & Kelley, 2008). However, other studies suggest there may be trade-offs between the number of fixes, the number of individuals sampled, and the sampling interval (Hansteen et al. 1997). In their study of moose habitat selection under various sampling regimes, Girard et al. (2006) suggested that researchers prioritize the number of individuals studied rather than the number of locations per individual. Similarly, Börger et al. (2006) found that inter-animal variation affected home range size, and recommended that more individuals should be sampled over long periods at the expense of sampling rate per individual.

Sampling a representative distribution over time is complicated for boreal caribou as they are long-lived and occur over vast areas in dynamic landscapes. In Labrador, boreal caribou populations exhibit subpopulation structure where the population is comprised of numerous subpopulations, isolated by distance and sometimes by geographic barriers (Schaefer et al., 2001). This poses considerable difficulty in obtaining a representative sample which accurately describes the local population range particularly where subpopulation structure is not known and the allocation of sampling effort is not distributed equally throughout the range. Populations are composed of groups of individuals which are exposed to varying environmental conditions over space and time. Home ranges are the manifestation of interactions between an individual and its environment (Brown et al., 1996). For this reason many resource selection analyses use individuals as the sampling unit (Manly 1993) and measure use at the home range scale (2nd order design of Johnson, 1980). While several studies have characterized caribou home ranges, the potential influence of the monitoring interval on the size of and fidelity of caribou to home ranges for caribou has not yet been reported. In general, studies are restricted to 2-3 years of consecutive monitoring (Rettie & Messier, 2000; Brown et al., 2001; Mosnier et al., 2003). However, caribou use of landscapes is affected by factors such as fire, insect harassment and snow and ice conditions, all of which may vary temporally in terms of their effect on the landscape, and suggest that time itself may be a component of home range expression in caribou, particularly given their longevity. Consequently the interpretation and comparison of existing studies, and any recommendations pertaining to a sampling regime, are constrained.

The objective of this study is to determine the extent to which temporal sampling regime influences the characterization of individual female caribou home ranges. A secondary objective is to evaluate trade-offs between the length of the monitoring interval and sample size in describing herd ranges, and to make recommendations regarding alternatives which allow for an optimal allocation of monitoring effort. The study populations in Labrador, Canada, occur in a relatively pristine landscape and therefore allow consideration of range use under natural conditions.

Methods

Study area

The Red Wine Mountain (RWM) and Lac Joseph (LJ) are boreal caribou herds in central Labrador, Canada (Fig. 1). They are two of three 'threatened' populations that form a continuum across south-central Labrador and northeastern Québec, with respec-

tive range sizes of 5900 km² and 4600 km². Herd ranges overlap to a small degree, and during winter migratory forest-tundra caribou enter northern portions of the RWM (and to a lesser degree, LJ ranges) resulting in intermingling of animals (Schmelzer *et al.*, 2004). The Lac Joseph herd currently numbers approximately 1300 animals (Schmelzer, 2011). Historical surveys suggest this population declined from 1300 caribou in 1977 to less than 500 during the mid 1980s. Between 1986 and 2000 the population grew at 10%/yr to more than 2000 individuals, and since then has undergone a decline of approximately 7%/yr (Schmelzer *et al.*, 2004; Schmelzer, 2011). Declines have been attributed to overharvest and partial loss of a calving area due to hydro-electric development (Bergerud *et al.*, 2008; Schmelzer *et al.*, 2004). The Red Wine Mountain population currently numbers less than 100 individuals, a significant decline from the 600 to 750 individuals surveyed during the 1980s. Between 1989 and 1997 the herd declined by 85%, from 741 to 129. Since 2001, incursion of migratory George River caribou into the winter ranges of this herd has precluded a census. A count (2009) of all caribou associated with radio-collared individuals (conducted while populations were still separate) indicates that there are at least 75 caribou remaining in this population. The cause of the population decline remains unclear, however Bergerud *et al.* (2008) suggest a demographic explanation, specifically low adult female survival and poor calf recruitment during the mid 1990s. Mean survival rates between 1997 and 2009 indicate that these have returned to levels observed prior to the decline. Wolf predation is the primary source of mortality in both populations (Wildlife Division, unpubl. data). Other sources of mortality include incidental and subsistence hunting, which occurs primarily during incursion of migratory caribou.
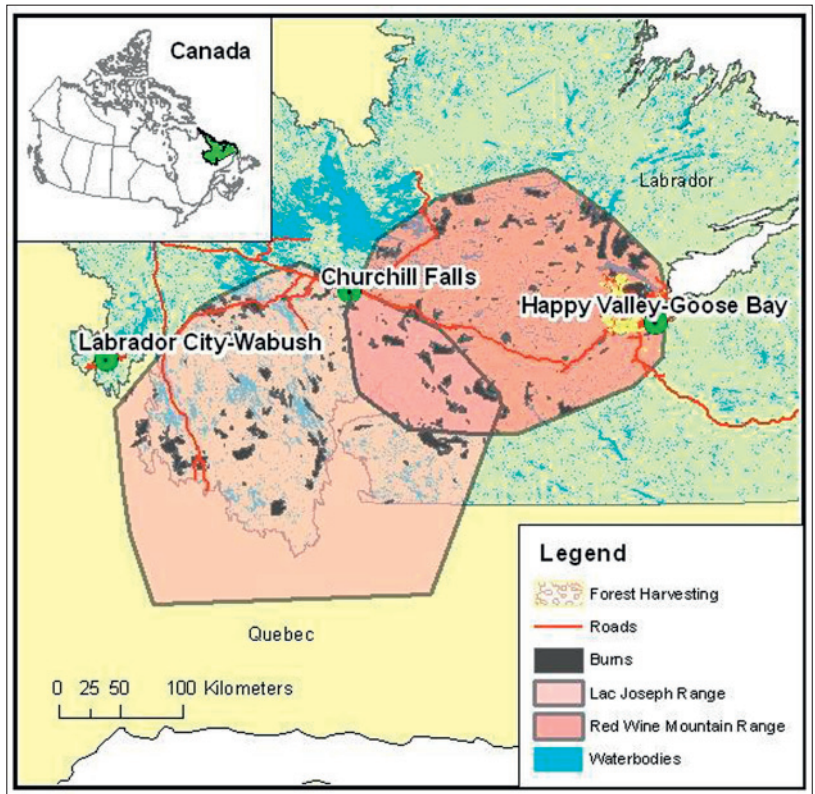

Fig. 1. Range boundaries of the Lac Joseph and Red Wine Mountain caribou populations.

The study populations are located in the Taiga Shield Ecozone (NRCAN, 2007). The landscape includes many glacial features such as eskers and moraines. Lakes, extensive peatlands and open-canopied spruce-lichen woodlands dominate the landscape of the Taiga Shield. Black spruce (*Picea mariana*) is the dominant tree species; however, white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*) and white birch (*Betula papyrifera*) also occur intermittently. Lichens (*Cladonia* and *Cladina* spp) are the primary understory species in lichen woodlands, and often co-occur with ericaceous plants such as northern blueberry (*Vaccinium boreale*) and mountain cranberry (*Vaccinium vitaes-idaea*) (Roberts *et al.*, 2006). Only 5.9% and 10.8% of the population's range for LJ and RWM, respectively, is affected by anthropogenic or natural disturbances (Environment Canada, 2008; Appendix 6.5). Range disturbance is primarily due to fire, but also included industrial disturbance such as linear features (roads, railroads, transmission corridors and skidoo trails) and commercial forestry.

Radio telemetry

We evaluated the effect of the monitoring period on the size and location of home ranges using two methods: by measuring the percent overlap of multi-annual ranges on the total monitored range, and by calculating displacement between centroids of annual ranges for a given caribou. The study population was 24 adult female (> 20 months) caribou monitored for between 4 and 11 consecutive years. Caribou were selected on the basis of having a) at least 4 consecutive years of monitoring and b) at least 12 locations per year distributed among all seasons, and a minimum of 100 locations in total (range 12 – 597 locations/yr). The sample unit is the individual animal. Adult female caribou were captured and fitted with either ARGOS satellite collars or GPS collars between 1986 and 2009 and equipped with satellite-tracked ultra-high frequency Platform Terminal Transmitters (PTTs; Service ARGOS, Landover Maryland, USA) or GPS (2007-2009) receivers. PTTs were programmed to a 4-day transmission cycle, and GPS collars to a daily or twice daily transmission cycle. When possible, collars were replaced prior to battery exhaustion. Annual rates of parturition were obtained by post partum aerial surveys of radio-collared adult females between 1982-88 and 1993-1997 for the RWM population and indicated a parturition rate of 78%, and 71% respectively for these periods. Parturition rates are unknown for LJ caribou; however the mean recruitment rate 1998 to 2009 in this population is 21%, double that of the RWM herd (Wildlife Division, Government of Newfoundland and Labrador, unpubl. data).

In order to identify potentially erroneous locations, we calculated Keatings epsilon (Keating, 1994) and retained locations in the 95th or greater percentile only if they could be corroborated by a second transmission (of class 1-3) from the same time period, or were part of a uni-directional movement such as a movement to a different area. Locations belonging to location quality (NQ) class 3 (error < 150 m, ARGOS User's manual) were retained on the basis of one location per transmission day per collar. The total monitoring period for each individual and the number of ARGOS and GPS locations used in each analysis is given in Table 1.

Data analysis

Each annual range, as well as every possible combination of multi-annual home ranges was calculated for all female caribou included in the study using Hawth's Tools (version 3.27 for ArcGIS 9.3; Beyer, 2004). In all cases, Minimum Convex Polygons (100% MCPs) were used (Mohr, 1947). A 'total

Table 1. A list individual caribou, their associated population, total number of years monitored, and the corresponding number of ARGOS and/or GPS telemetry data points.

Population	Years	Number of locations
RWM1	4	167
RWM2	4	300
RWM3	4	256
RWM4	5	251
RWM5	6	359
RWM6	6	159
RWM7	6	315
RWM8	7	345
LJ1	7	702
LJ2	7	134
RWM9	8	183
RWM10	8	1023
RWM11	8	244
LJ3	8	217
LJ4	8	303
LJ5	8	187
LJ6	8	1237
RWM12	9	986
RWM13	9	197
RWM14	10	129
LJ7	10	448
LJ8	10	1340
LJ9	10	1176
RWM15	11	332
Total		10990

range', using all locations from an individual's entire monitoring period, was also calculated. The percent overlap of each annual and multi-annual range on the 'total range' was calculated for each individual. Multi-annual ranges were constructed for every possible combination of consecutive-year values. For example, for an animal monitored for 10 consecutive years, there are 9 combinations of consecutive 2-year combinations, eight combinations of consecutive

3-year monitoring periods, seven 4-year monitoring periods and so on. Areas for each polygon were calculated in km². Finally, the mean and standard error of the percent overlap between multi-annual and 'total' ranges was calculated as a function of the length of the monitoring interval for each population. The latter was plotted and fitted with a polynomial trend line summarizing the relationship and its explanatory power via a coefficient of determination (r^2). The difference in mean values in area and percent overlap between populations was explicitly compared using an independent sample t-test for each monitoring interval. All tests were set at α = 0.05/10 or 0.005 (Bonferonni adjustment for 10 comparisons) and were two-tailed.

Sample size
We created 9 random subsamples of radio locations which incrementally removed between 10 and 90 percent of the data at 10% intervals. This process was repeated five times for each individual. A MCP was generated for each iteration, and the mean area calculated and compared to the MCP generated for that individual using all data over its sampling period. We felt this approach was preferable to the conventional one which plots range size versus sample size given inter-animal variability in range size and differences in the length of monitoring intervals between individuals (e.g. more locations are required to describe a larger range size). The mean proportion and standard error of the 100% MCP captured for a given individual was plotted as a function of the subset of data retained and sample size.

Assessing dispersion
Displacement between annual ranges was determined using a displacement ratio (scaled between 0 and 1) which was a function of the distance between the first and last year for the 'total' or lifetime monitoring interval and the sum of distances between centroids of consecutive years:

$$DR = \frac{\text{Distance between centroïds of first and last year}}{\sum \text{Distance between centroïds of consecutive years}}$$

Centroids were created using the Hawth's Tools (version 3.27 for ArcGIS 9.3; Beyer, 2004). The displacement ratio (DR) was calculated for every possible combination of consecutive years for each animal, as for the prior analysis. A large ratio (close to 1) was indicative of an individual whose 'final' or total range was increasingly distant from its initial range (e.g. a lack of fidelity); while a small value (close to 0) represents an individual whose 'final' range was

relatively close to its initial range. For the purpose of this study, fidelity is defined as the tendency to return to the same or similar place (Schaefer *et al.* 2000), here expressed as the DR. The Displacement Ratio was plotted as a function of the difference (in years) between the first and last year, or the monitoring interval between centroids. In order to correct for inter-animal variation, 7 plots were drawn for each sample population—one for each combination of years of data between 4 and 10 years. Each plot was fitted with a best fit trend line and the coefficient of determination (r^2) was calculated for each model. Corresponding distances (and standard deviation) between centroids for every monitoring interval were also calculated in kilometres. Finally, the mean and standard error of the distance ratio as a function of the duration of the monitoring interval was calculated for each population. The latter was plotted and fitted with a polynomial trend line summarizing the relationship and its explanatory power via a coefficient of determination (r^2). The difference in mean values for distance ratios for each monitoring interval was compared between LJ and RWM populations using an independent sample t-test for each monitoring interval. All tests were set at α = 0.005 and were two-tailed.

Determining an optimal monitoring regime
We defined an optimal sampling regime as one which captured the greatest proportion of the herd range with the smallest allocation of effort, where effort is a function of the number of years of monitoring and the number of collared animals. We measured the proportion of the total herd range captured by multi-annual ranges for a given monitoring interval and sample size. This analysis was restricted to the RWM population, and to telemetry data collected for caribou monitored 4-11 years as in the prior analyses. To calculate the proportion of the total herd range captured we plotted and calculated total area for MCPs used in each monitoring interval/sample size pairing (using the merge and dissolve feature in Arc-GIS 9.3) and compared them to the total range area for each herd. The total herd range was determined by pooling all data excluding emigrations outside the herd range from 1982 to 2010 using a 100% MCP, a region encompassing 42 536.07 km².

As with the prior analyses, multi-annual ranges were constructed for every possible combination of consecutive-year values. The number of possible combinations (z) for each monitoring interval and sample size pairing was calculated using the following formula, where n equals the number of possible MCPs to select from, and r equals the number of caribou
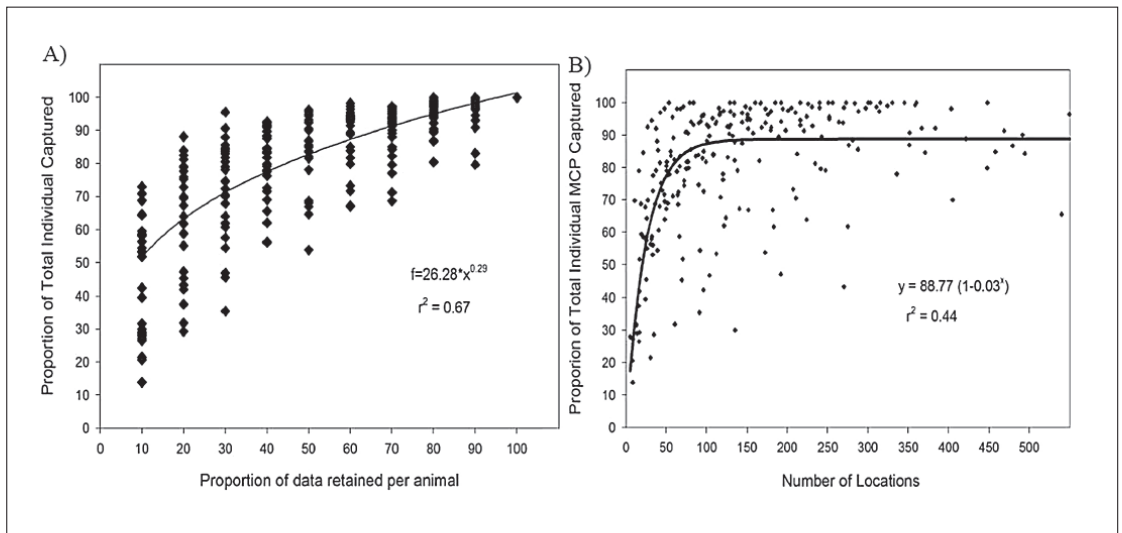
Fig. 2. Relationship between the proportion of individual 100% MCP range captured and a) the proportion of locations used per individual and b) the number of locations used.

included in each selection. The equation assumes that order of combinations is not important, and no repetitions of any combinations:

$$z = \frac{n!}{(n-r)!} \times \frac{1}{r!} = \frac{n!}{r!(n-r)!}$$

For example, there are 18 564 possible combinations of 6 animals monitored for 2 consecutive years. Consequently we included every other monitoring interval from 2 to 8 years, and stepped sample size by an interval of 2 from 2 to 18 animals. We also limited the number of comparisons from each number of animals/monitoring interval combination to twenty random selections. These twenty selections were chosen by assigning a random number between 0 and 1 (the number of decimal places included being determined by the number of possible combinations, i.e., for 18564 combinations, 5 decimal places were used) to each combination, and then choosing the twenty combinations with the lowest random numbers. Within each random grouping of animals, no animal was used more than once. If a combination was generated that included a given animal more than once, it was discounted and the next random combination of animal/monitoring interval was chosen. The mean and standard error of the proportion of total herd range captured as a function of the number of radio-collared animals was calculated and plotted for each interval.

Results

The relationship between the number of locations and the proportion of the total range of a given individual being captured was curvilinear and indicated no improvement after 100 locations irrespective of the size (Fig. 2b). Caribou with fewer than 100 locations in total were removed from the analysis. In contrast, as few as 40 locations described 70% of the total range for a given caribou. A significant portion of an individual animals' data could be removed and still describe the total home range adequately; removing 30% of the data still captured approximately 90% of the total range (Fig. 2a). Note that since these locations were selected randomly from the dataset collected over the lifetime of an individual they cannot be assumed to be equivalent to the first 40 locations collected in a monitoring program.

Caribou in both populations added new areas into their annual ranges with each additional year of monitoring—initially at a rate greater than 20% per year (between the first and second year of monitoring), and then more slowly, at a rate of less than 5% /yr after 7 consecutive years of monitoring, when an asymptote is reached (Fig. 3a). In both populations, mean percent overlap for a single annual home range is less than 20% of the total estimated range. After 3 years of consecutive monitoring, only 50% of the 'total' range for a given animal had been described in either population. Between 4 to 7 years of consecutive years of monitoring, the rate of overlap increased from 59% to 80% (LJ) and 65% to 90%, (RWM). Limited additional area (an increase of less than 2%
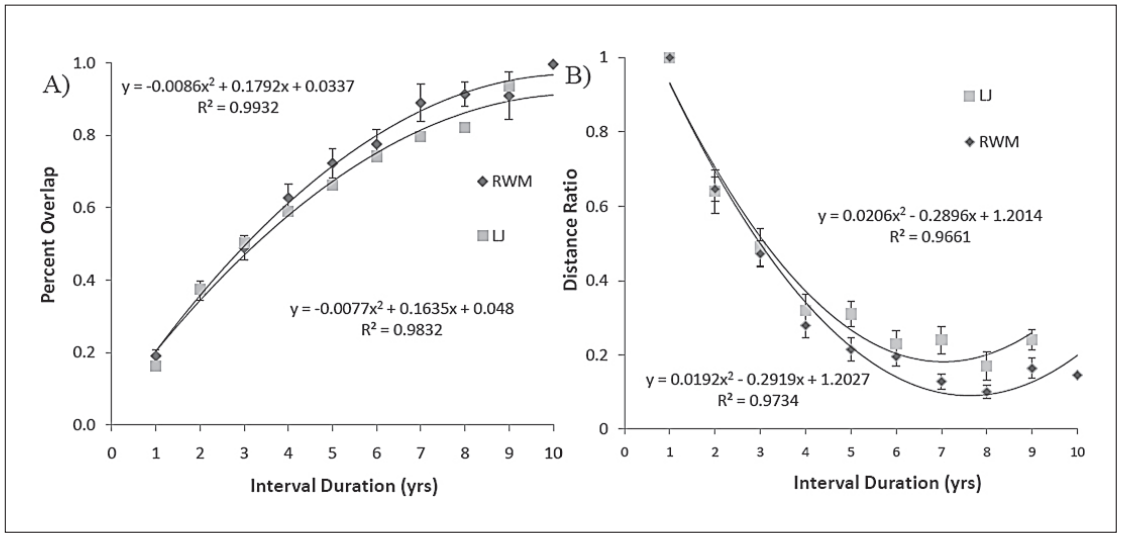
Fig. 3. A) Mean percent overlap (and standard error) between annual and multi-annual ranges on the 'total' range used by each caribou in RWM (r^2=0.993) and LJ (r^2=0.983) populations. Multi-annual ranges were constructed for every possible combination of consecutive-year values for each individual.

B) Mean displacement ratio (and standard errors) shown in relation to the monitoring interval duration (consecutive years). A large ratio (close to 1) indicates an individual's lifetime range was distant from its initial range (e.g. a lack of fidelity) while a small value (close to 0) suggests site fidelity.

Table 2. Mean range area (and standard error) for all calculated ranges, the corresponding duration of the monitoring interval and number of ranges in LJ and RWM populations. There were no significant differences at $P < 0.005$ (Bonferroni adjustment for 10 comparisons) in mean range area for any time interval.

	LJ			RWM	
Years	Mean km² (SE)	N (# Ranges)	Years	Mean km² (SE)	N (# Ranges)
1	2090.44 (251.98)	72	1	1820.58 (221.30)	99
2	3318.05 (350.67)	61	2	3579.10 (394.66)	82
3	4600.54 (491.43)	52	3	4960.21 (559.72)	68
4	5584.29 (644.02)	44	4	6615.25 (731.52)	55
5	6482.66 (826.30)	36	5	8286.15 (941.88)	43
6	7216.9 (1075.53)	29	6	10346.60 (1182.45)	31
7	7658.31 (1358.36)	21	7	12456.84 (1477.95)	22
8	8151.48 (1858.24)	13	8	13304.27 (1768.96)	14
9	10177.76 (3685.64)	6	9	13423.62 (2514.29)	7
10	10561.34 (5770.02)	3	10	11693.77 (412.68)	3
			11	12152	1

per additional monitoring year) was added into the total range after 7 years of monitoring. There were no significant differences in mean percent overlap at any of the time intervals between the two populations.

Mean areas for annual and multi-annual ranges also increased with the length of the monitoring period (Table 2). There was a linear relationship between the overlapping area of multi-annual ranges and range size for both the LJ and RWM populations (r^2 = 0.97 for both). As a whole range sizes were significantly larger for the RWM caribou, at 5650 ± 259 km² versus 4866± 256 km² for LJ caribou (F

= 5.26, *P* = 0.02). These sizes were attained after approximately 4 years of consecutive monitoring in both populations (Table 2). After 2 years of monitoring, range sizes were approximately 3300 km^2 for each population. Range sizes were remarkably similar for LJ and RWM caribou for the first 3 years of monitoring (Table 2), but after 4 years of monitoring there was a tendency for larger ranges in each monitoring interval for RWM caribou. Range sizes were marginally significant for RWM caribou after 7 years of monitoring (t = 2.17, *P* = 0.03), and also for intervals of 6 and 8 years (*P* < 0.1; Table 2). Fewer than 10 animals were monitored for more than 9 consecutive years so range sizes for intervals of 9 and 10 should be interpreted cautiously.
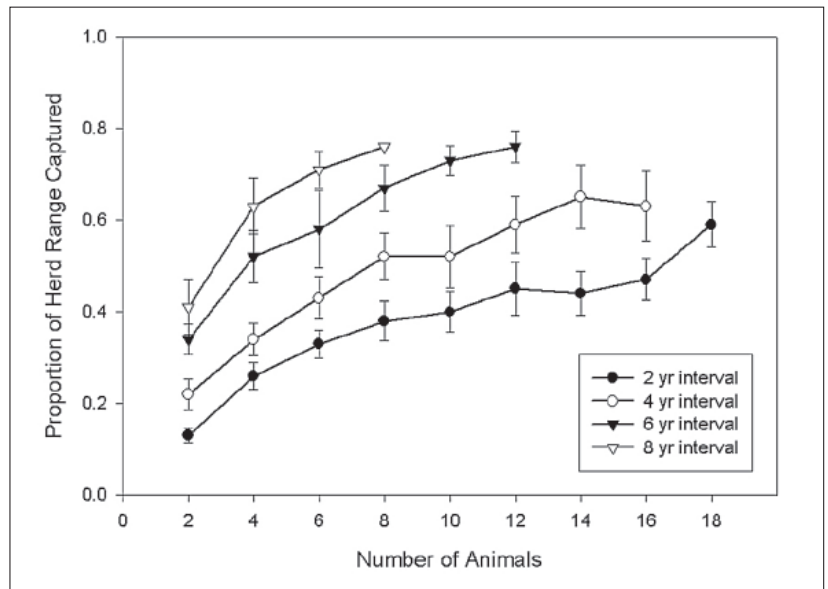

Fig. 4. Trade-offs between length of monitoring interval and number of caribou monitored with description of the population range for the Red Wine Mountain herd, Labrador. Each curve represents a monitoring interval of a different length. Values represent averages calculated from twenty repetitions randomly sampled from potential combinations of sample size/interval length groupings.

Displacement
The distance between centroids of annual or multi-annual ranges declined with an increase in the monitoring interval until it reached a plateau after approximately 5 years of monitoring (Fig. 6). The relationship is well-described by the second order polynomial y = 0.0206x^2 - 0.2896x + 1.2014 for LJ and y = 0.0192x^2 - 0.2919x + 1.2027 for RWM, respectively (Fig. 3b). For monitoring periods of less than 3 consecutive years, the distance ratio was high (> 0.4), indicating that the centroid of a caribou's 'total range' range was distant from its initial range (e.g., a lack of fidelity). As the length of the monitoring interval increased, the distance between lifetime and monitoring interval centroids also decreased, suggesting fidelity to a particular region (e.g., the center of the range had been captured during the monitoring interval). After 6 years of monitoring, there was little further decline in the distance ratio for the LJ population while RWM continued to decrease the DR for one additional year. Mean distance between centroids ranged from 17.66 km to 39.5 km for LJ caribou and 11.86km and 43.8km for RWM, though distances were quite variable overall. The mean distance

between centroids was 22 km for LJ caribou and 28 km for RWM caribou, a result that is consistent with the larger range sizes observed in RWM caribou.

Monitoring regime
Caribou with the longest monitoring interval inevitably captured the greatest portion of the range at each given sample size (Fig. 4). Further, only monitoring intervals of 4 years or more captured greater than 65% of the herd range, a rate that was never achieved even when 18 animals were followed for two years. The proportion of herd range captured also increased with sample size, with the greatest increases occurring between sample sizes of two and four across all monitoring intervals, particularly for monitoring intervals of six or eight years (18% and 22% increase respectively). Increasing the sample size from four to six caribou resulted in an increase of 6-9% across all intervals, a result that was duplicated over the sample sizes six to eight. The rate at which the herd range was captured reached an asymptote after eight animals had been collared across all monitoring intervals, though there was a tendency for longer monitoring intervals to continue to describe the herd range at larger sample sizes. For example, at a monitoring interval of two years, the proportion captured increased by less than 10% even when sample size was doubled from 8 to 16 caribou (0.38 to 0.47; Fig.

4). However, the proportion of the range described increased by 12% between 16 and 18 individuals monitored for two years, (0.47 to 0.59). The herd range was best described (76% of the range captured) by monitoring 8 animals for 8 years (though it was not possible to evaluate a larger sample size for this monitoring interval).

Discussion

Our results demonstrate that duration of monitoring influences the measured size of female caribou home ranges in Labrador. Overall, results were consistent between the analyses and between the two populations; asymptotes occurred at similar sampling intervals. For example, few additional areas were added after 7 years of monitoring, which captured 80 and 90% respectively, of the total range for the LJ and RWM individual caribou studied, and the majority of the lifetime range had been previously defined in both populations after 5 years of consecutive monitoring. Similarly, caribou home ranges exhibited fidelity after 6 years of monitoring (LJ) and 7 (RWM) years respectively.

For cows in the two herds, a monitoring interval of 2 years captured only 38% of the lifetime range and exhibited displacement consistent with a lack of fidelity to the previous year's range. Notably, the degree of inter-annual range fidelity over the 3-year monitoring period (50%) was similar to that reported by Faille *et al.* (2010), and Rettie & Messier (2001), which reported 0.45 and 0.52, respectively, for caribou monitored for the same duration and in relatively undisturbed landscapes. Mean overlap reported in Tracz *et al.* (2010) was 0.76, though caribou in their study were located in a landscape heavily impacted by petroleum development. A sampling framework that would allow the description of 80% of the total range of an individual caribou and a relatively stationary location (DR < 0.25) and 75% of the total area would require six years of consecutive monitoring. The minimum length of the monitoring period should be considered as four years, as this marks the initiation of the asymptote in both Distance Ratio and degree of overlap between lifetime and monitoring interval ranges, and any temporal sampling regime shorter than that would be associated with a high degree of uncertainty in the description of the individual range. Conversely, there is little benefit to a monitoring period of longer than seven years per individual, though it is possible that this is related to reproductive senescence associated with older age (e.g., Rettie & Messier, 2001).

There were several alternative designs for a monitoring program that balanced length of the monitoring interval and sample size for a desired level of herd range description. For example, to capture 40% of the RWM herd range, two caribou could be monitored for eight years (16 animal years), four animals for six years, six animals for four years (24 animal years) or 10 animals for two years (20 animal years). In this case the smallest allocation of effort is given by the first scenario. There were no alternatives with a monitoring interval of less than six years that captured at least 70% of the herd range (six animals for eight years or 10 animals for six years), though this might change if more than 20 caribou were included in a telemetry program at once. These similarities show that in this instance a longer monitoring interval can be used in conjunction with a smaller sample size and yield a comparable result with fewer total monitoring years. An ideal allocation of field effort should attempt to capture lifetime ranges of individual caribou as well as describe the range as a whole. In this study these objectives were mutually supportive; long-term monitoring enhanced description of both the individual and herd range.

One of the strengths of this study is that it does not use simulated data (e.g. Burgman & Fox, 2003). However, field derived data sets are invariably governed by logistical and financial constraints that limit the size and properties of the dataset. As a result, we could not partition the individual effects of fix rate and length of the temporal sampling regime due to the relatively late advent of the use of GPS collars (2007) and the long time frame of the monitoring intervals we evaluated. Accordingly, we cannot explicitly rule out the possibility that our result is an artefact of relatively low sample size per animal per year (e.g. that the length of the monitoring interval required would decline with a larger number of fixes per individual). However our analyses suggest that our findings are robust: we could remove a third of the data for a given caribou and still capture the vast majority (90%) of a total home range. Under ideal circumstances however, each annual range would have 100 telemetry locations distributed equally throughout the seasons, and the increase availability of multi-year datasets from GPS-collared individuals should facilitate meeting this criteria in the future. Finally, we examined the influence of the monitoring period on the description of caribou home ranges in isolation of other factors that may influence range size. For example, fidelity has previously been found to be associated with individual reproductive status or population social structure (Rettie & Messier, 2001; Wittmer *et al.*, 2006). Consequently the

relative influence of these or other factors cannot be assessed in conjunction with the temporal sampling regime.

Home range sizes were compiled for 10 different studies throughout Canada which monitored adult female caribou (Table 3). The monitoring intervals of these studies ranged from 10 months to 8 years, and mean annual caribou range sizes varied from 208 km^2 to 4790 km^2. The majority of studies tracked individuals for less than 3 years, and often home ranges sizes were constructed from data pooled over a variety of monitoring intervals.

In this study, caribou occurred in ranges several thousand square kilometres in size (as also seen in Brown *et al.*, 2001), and added new areas with each passing year, a life history strategy consistent with that of a long-lived animal maintaining low densities on the landscape. In Labrador, the density of caribou measured during surveys in the core ranges varies between 0.03-0.05 caribou per km^2 (Schmelzer *et al.*, 2004; WD unpubl. data). Maintaining large home ranges and low densities is a life history strategy that allows caribou to avoid detection and predation by wolves and other predators (Bergerud, 1992), and limit exposure to parasites which influence body condition and fitness (Bordes *et al.*, 2009; Gunn & Irvine, 2003). Fragmentation and direct or effective loss of available habitat as a result of anthropogenic change has been linked to range loss and caribou extirpation (e.g., Schaefer, 2003; Vors *et al.*, 2007). Caribou have been shown to avoid roads and seismic lines (Dyer *et al.*, 2001, 2002), transmission corridors, (Nellemann *et al.*, 2003), forest harvesting (Smith *et al.*, 2000; Schaefer, 2003; Houle *et al.*, 2010) and other types of disturbance. This effective loss of area fragments ranges and likely constrains choice (e.g., to selection of remnants of high value habitats). Given the small anthropogenic footprint within the herd ranges of the two populations we studied, our results suggest that in undisturbed landscapes caribou shift ranges and make use of large areas throughout their lifetime. However, given the relative lack of pristine areas throughout the distribution of boreal caribou in North America (Environment Canada, 2008), the likelihood that caribou movements within more disturbed landscapes would be constrained—and hence that the 'lifetime' range of a caribou might be measured over a shorter timeframe and at a smaller spatial scale—is possible. This phenomenon was recently documented by Faille *et al.* (2010), who found that the degree of anthropogenic disturbance was the mirror image of annual home range size. Similarly, caribou living in ranges with a lower disturbance rate occupied greater areas (Smith *et al.*, 2000; Dyer *et al.*

2002). Several other studies are in agreement with the latter studies: range overlap over time was much higher (0.76) for caribou ranges in Alberta with high levels of petroleum development (Tracz *et al.*, 2010), and home range size and movement rate of adult female caribou decreased as the anthropogenic footprint increased in central Saskatchewan (Arlt & Manseau, 2011). Similarly, home range sizes measured for populations in western Canada (excluding the NWT), which tend to include greater anthropogenic footprints (Environment Canada, 2008) were much smaller as a whole. In Labrador, cows in both study populations had annual range size very comparable to those of other studies of caribou in relatively intact boreal forest of Eastern Canada.

In conclusion, our results highlight the importance of conducting baseline ecological studies of caribou space use and fidelity to interpret, and manage for, spatial and temporal properties of caribou ranges. Sampling regimes that balances length of the monitoring interval with sample size can be an efficient means of fully describing both individual ranges and that of the population as a whole. While it may take six years to capture range use for a given individual female caribou in Labrador, different ecological conditions and higher densities of caribou elsewhere may result in a different optimal sampling regime. Our intent here is less to emphasize the length of the temporal sampling regime required *per se* but rather to underscore the necessity of evaluating the possible influence of the monitoring interval on the description and interpretation of range sizes for caribou in general, particularly over short monitoring intervals and where these are being used in management and landscape planning. Our review of other studies indicates that home range size is most often reported from data pooled over a variety of monitoring intervals, and generally for monitoring programs of less than three years in duration. This precludes direct comparison of the results of this study to others. If monitoring interval were standardized in the reporting of home range sizes in the future, variability of reported range sizes may well decrease, and inter-annual fidelity of caribou to these ranges may increase. Additional long-term studies, perhaps through retrospective analyses of ongoing monitoring programs, would provide insightful comparisons. As technology associated with radio telemetry improves, studies which include more individuals monitored at a higher sampling intensity will allow for explicit comparison of trade-offs between sampling intensity (number of fixes), relocation interval, and study duration for the design of an optimal sampling regime.

Table 3. Summary of studies reporting home range sizes for woodland caribou.

Study	Eco-type	Range size	# individuals	Monitoring length	Estimator
Brown *et al.*, 2001	Boreal woodland (Ontario)	3664	13	1 year	95% MCP
		4790	20	1 year	
		3212	13	1 year	
		4026	46	3 years	
Courtois *et al.*, 2007	Boreal woodland (Québec)	224	30	1-3 years	100% MCP
		607	55		
		558	19		
		1198	7		
		153	9		
Dalerum *et al.*, 2007	Moutain (Alberta)	1450	28	Mean = 3.25 years	95% fixed kernel
		650	33	Mean = 1.9 years	
		400	44	Mean = 3 years	
Faille *et al.*, 2010	Boreal woodland (Québec)	350	20	1-3 years	100% MCP
		700	17		
		1375	10		
Fuller & Kieth, 1981	Woodland (Alberta)	539	1	3 years	MPP
Larter & Allaire, 2005	Boreal (NWT)	900	1	10 months	MCP
Nagy *et al.*, 2005	Woodland (NWT)	1796	1	1 year	MCP
		1914	1		
Rettie & Messier, 2001	Woodland (Saskatchewan)	208	6	1-3 years	100% MCP
		221	3		
		1240	5		
		413	5		
		404	4		
Schindler, 2005	Woodland (Manitoba)	1235	6	1-8 years	MCP
		1651	9		
		705	12		
		461	5		
		1847	2		
Tracz *et al.*, 2010	Boreal woodland (Alberta)	382	45	Mean = 3.87 years	100% MCP

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