Evaluation of satellite collar sample size requirements for mitigation of low-level military jet disturbance of the George River caribou herd

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Abstract: Wildlife radio-telemetry and tracking projects often determine a priori required sample sizes by statistical means or default to the maximum number that can be maintained within a limited budget. After initiation of such projects, little attention is focussed on effective sample size requirements, resulting in lack of statistical power. The Department of National Defence operates a base in Labrador, Canada for low level jet fighter training activities, and maintain a sample of satellite collars on the George River caribou (*Rangifer tarandus caribou*) herd of the region for spatial avoidance mitigation purposes. We analysed existing location data, in conjunction with knowledge of life history, to develop estimates of satellite collar sample sizes required to ensure adequate mitigation of GRCH. We chose three levels of probability in each of six annual caribou seasons. Estimated number of collars required ranged from 15 to 52, 23 to 68, and 36 to 184 for 50%, 75%, and 90% probability levels, respectively, depending on season. Estimates can be used to make more informed decisions about mitigation of GRCH, and, generally, our approach provides a means to adaptively assess radio collar sample sizes for ongoing studies.

Key words: adaptive assessment, caribou season, Kernel home range, probability, radio-telemetry, radio-tracking.

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Introduction

When initiating wildlife radio telemetry and tracking research projects, researchers must initially determine transmitter sample sizes that suit project objectives. With conventional Very High Frequency (VHF) telemetry, this usually involves a trade-off between number of transmitters and relocation frequency (Garton et al., 2001). With satellite telemetry, relocation frequency is a function of collar programming and therefore dependent on the objectives of the project and the financial resources required for transmitter purchase and system access (Rodgers, 2001). Due to the relatively high cost of satellite telemetry, these projects are often used either to augment conventional VHF telemetry projects, or proceed with the maximum number of collars that can be maintained within a specified budget. Such constraints lead to reduced statistical power of subsequent data analyses (Steidl et al., 1997).

The Canadian Department of National Defence (DND) operates a low-level jet training base for foreign military aircraft out of 5 Wing Goose Bay military base in Goose Bay, Labrador, Canada (53°21'N, 60°25'W). Part of the Military Training Area (MTA) overlaps in space and time with the George River caribou herd (*Rangifer tarandus caribou*) (GRCH). As a result DND, in cooperation with provincial governments, attempts to minimize noise disturbance by maintaining spatial and temporal separation between jets and individual caribou fitted with Platform Terminal Transmitters (PTTs, Telonics, Inc., Mesa, AZ) using satellite telemetry (Service Argos). When location data indicate the presence of caribou inside the MTA, DND erects either blanket closures around groups of collars or buffers around individual collars, to reduce the probability of disturbing caribou. It is assumed that due to the gregarious nature of caribou, randomly collared individuals provide a reasonable approximation of caribou herd location and movement, assuming adequate sample size.

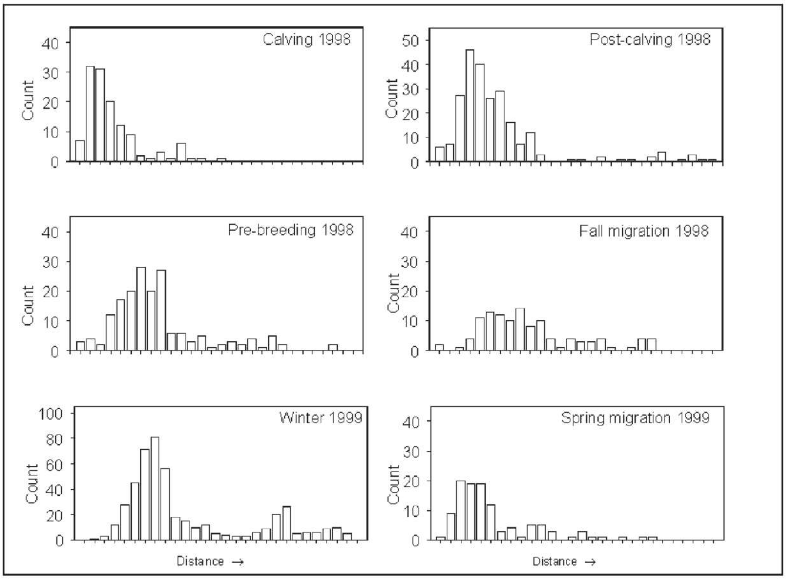

Fig. 1. Distance class from centroid histograms for satellite collared caribou, by caribou season, George River caribou herd, 1998-1999. Note difference in y-axes scale for Post-calving 1998 and Winter 1999 seasons.

Past reviews of this mitigation program have concentrated on attempting to determine the variance of numbers of animals associated with collared animals (Renewable Resources Consulting Services, Ltd., 1994) or correlating collar presence with visual observations of groups of animals (Trimper & Chubbs, this issue). To date, however, there has been no effort to estimate collar sample size requirements for this type of program, central to determining effectiveness of mitigation efforts. Additionally, statistical analyses could suffer from lack of power (Steidl et al., 1997). It is noteworthy that earlier studies have identified potential negative impacts of the jet activity on caribou (Harrington & Veitch, 1991; Harrington & Veitch, 1992). We present an evaluation of the estimated sample size requirements for mitigation of the George River caribou herd in Labrador and Quebec exposed to low level jet fighter activity.

Methods

Individual animals from the George River caribou herd were captured using a net fired from a helicopter, physically restrained, and fitted with ST-3, ST-4 or ST-14 Platform Terminal Transmitter collars (Telonics, Inc., Mesa, AZ, USA). Animals were eartagged, and standard morphological measurements obtained. Captures were in support of an ongoing telemetry project of the Department of National Defence, Goose Bay.

We used location data of quality (NQ) >0, from 1 June 1998 to 31 May 1999 (Keating, 1994). Lower quality (NQ≤0) locations were not used because of inherent imprecision, resulting in a data set containing locations for multiple individual caribou with a precision of 1 km or less (Rodgers, 2001). Collars transmitted on both 4- and 5-day cycles. To ensure that each collared animal had the opportunity to be present in each 5-day period, all locations were then divided into consecutive, 5-day periods. When more than one location was present for an animal within a 5-day period, the higher quality location was retained or where locations were of the same quality, the earlier location was retained. Each 5-day period was then assigned to one of six annual caribou seasons: calving, post-calving, pre-rut, fall migration, winter, and spring migration (Bergman et al., 2000). Five-day periods that overlapped two successive seasons were omitted, removing from the analysis locations recorded on the cusp of season changeover. During the study period the number of collared animals per 5-day period ranged from 9 to 21 animals.

For each five day period, we generated a Jennrich-Turner ellipse (JTE), including centre of mass, for all individual animals (Jennrich & Turner, 1969). We then calculated the distance from the centre of mass to each individual animal location. For the six caribou seasons, we pooled all centroid distances, creating one larger list of centroid distances for each caribou season.

We defined caribou groups based on a defined radius around a point in space. For our analysis, we used a 27.8 km buffer, one of the larger radial distances currently used by DND to create no-fly zones around satellite-collared caribou. Using a relatively large buffer will produce a relatively smaller estimate of required collars, while the smallest buffer could produce collar number estimates that are unrealistic. This approach suited the original intent of the analysis (spatial avoidance mitigation), avoids the potential pitfall of attempting to define caribou groups based on variation in distance between animals, and facilitates modifying grouping criteria to assess effect on sample size estimates. We generated histograms of centroid distances for each caribou season, using 27.8 km as bin width (Fig. 1). This method provided an objective means of determining bin width which is important since histogram shape is highly dependent on bin width.

The number of caribou locations in each distance class was determined for each caribou season by extrapolating the proportion of locations to the estimate of herd size (700 000, Russell et al., 1996; Couturier et al., 1996). We converted the distance class measure to caribou group size by using the equation: $Y=mX+b$, where, Y=caribou group size and X=distance class. This equation assumes a linear decline in group size as distance from centre of mass increases; i.e., that caribou locations at greater distance from the centre of mass represent smaller groups of caribou than locations closer to the centre of mass. This assumption was supported by field observations (S. Couturier & R. Otto, unpubl. data). To determine the slope of the equation, we assumed the average distance class corresponded to the average caribou group size and the maximum distance class corresponded to one caribou.

Because caribou density changes with season (Bergman et al., 2000) we calculated, for each of the six caribou seasons a 95%. Kernel Home Range (KHR) using Animal Movement Analysis software (Hooge & Eichelaub, 1997) and Arcview GIS (Environmental Systems Research Institute, Redlands, CA), employing the ad-hoc smoothing option. This method is a fixed-kernel range estimate, and appears to be the best method for calculating range estimates from location data (Seaman & Powell, 1996, Seaman et al., 1999, Kernohan et al., 2001). We used these estimates of area to calculate the density of 95% of the estimated herd size (665 000). Knowing the number of caribou within a group and the total number of caribou within each bin allowed us to calculate the number of caribou groups within each bin and, therefore, the total number of groups for each caribou season.

Table 1. Minimum and maximum caribou group size estimates for each caribou season, by distance class, George River caribou herd, 1998-1999.

Season	Group size estimates (Means) Min	Max
Calving	1 872	28 228
Post-calving	192	12 940
Pre-breeding	319	10 040
Fall migration	188	31 099
Winter	10 036	11 946
Spring migration	297	14 295

We defined protection probability as the chance that any one randomly selected caribou would be "captured" within one of the caribou "groups" found inside the associated KHR. By repeating the above density calculations for 75%, and 50% (525 000 and 350 000 animals, respectively) of the total herd size, it was possible to adjust our overflight tolerance from 5%, to 25% and 50%. For the 75% and 50% estimates, we calculated the number of groups, starting from the largest (and therefore closest to the centre of mass), that were required to contain 525 000 and 350 000 animals respectively.

Results

Our procedure for extracting and omitting locations from the analysis resulted in a range of 110 to 469 locations per caribou season (Table 1). There was large variation in the minimum mean estimated group sizes between seasons, almost two orders of magnitude, while maximum mean estimated group sizes varied by only a factor of three (Table 1). The number of locations per season was primarily the result of the length of the particular caribou season (range 30 to 152 days), but also depended on the presence of high-quality location data.

Calculated KHR's ranged from 10 845 to 37 690 km^2 for the 50% probability level, 24 773 to 87 279 km^2 for the 75% probability level, and 73 597 to 228 629 km^2 for the 95% probability level (Table 2). Estimated group sizes of caribou varied by season, with minimums ranging from 188 to 10 036 and maximums ranging from 10 040 to 31 099 caribou (Table 2). Estimated satellite collar sample sizes also ranged by caribou season, from 36 to 184 for the 95% probability level, from 23 to 68 for the 75% probability level, and from 15 to 52 for the 50% probability level (Table 3).

Table 2. Areas (km²) of Kernel Home Range, by caribou season and percent range, for the George River caribou herd 1998-1999. Number of locations used in calculations are indicated in brackets.

	Percent of total range		
Season	95%	75%	50%
Calving (127)	73 597	24 773	10 845
Post-calving (237)	157 121	53 340	19 737
Pre-breeding (175)	227 102	58 762	22 565
Fall migration (114)	90 510	44 966	23 041
Winter (469)	228 629	87 279	37 690
Spring migration (110)	150 956	39 826	23 802

Table 3. Estimated number of satellite collars required to protect individual caribou from the George River caribou herd, by probability level, 1998-1999. Rank, smallest to largest, of sample size for given probability level, as well as overall rank (bold), is given in parentheses.

	Probability level		
Season	95%	75%	50%
Calving 1998 **(1)**	36 (1)	23 (1)	15 (1)
Post-calving 1998 **(2)**	100 (4)	48 (4)	32 (3)
Pre-breeding 1998 **(6)**	131 (5)	68 (6)	52 (6)
Fall migration 1998 **(4)**	184 (6)	26 (2)	18 (2)
Winter 1998 **(5)**	64 (2)	49 (5)	34 (4)
Spring migration 1998 **(3)**	97 (3)	44 (3)	35 (5)

Discussion

The procedure used to extract and filter location data resulted in a small percentage of locations (NQ<1) being omitted from the analysis. Briefly, collars used to collect location data were on four-day cycles, and some were on five-day cycles during the study period. Thus, in order to maximize number of locations used to calculate JTE's, the five-day period was chosen as our sampling interval. This meant that multiple locations for an individual caribou were used in the JTE and distance-to-centroid calculations. However, we do not believe this approach constitutes pseudoreplication (Hurlbert, 1984). Recall that our intention was to estimate total seasonal ranges used by the GRCH for spatial mitigation, as well as the distribution of caribou locations throughout the season within the associated KHR, requiring all locations of all collared animals.

Our method of fitting a regression line to the distance class histograms probably over-estimates the number of collars required to "capture" the smaller and more distant groups of animals. This is due to the regression line extending to the extreme distal end of the histogram, where there were usually relatively few and usually low histogram values, meaning the curve was actually above the true values, and hence overestimating number of caribou groups. However, the converse is true as well; at small to medium distance classes (larger caribou groups) the estimate was probably too low as the curve would be below the actual values, and hence underestimating number of caribou groups. The degree of trade-off between these competing forces was not investigated for the purpose of this analysis, and is probably minimal. Further, regardless of the assumption and model used to perform this portion of the analysis, a similar trade-off will occur, although the relative weight of under- and overestimation will probably vary.

The large variation in the minimum mean estimated group sizes indicates that the core area of use, by season, remained much more stable than the peripheral areas, with small minimum mean values indicating very dispersed distributions and higher rates of movement. The minimum mean value for Winter is substantially higher than the next lower value, and probably reflects the large number of locations derived from Winter season, the longest of the six caribou seasons, as well as the fact that groups of the GRCH move relatively little during the winter (Bergman et al., 2000).

The KHR analysis revealed large variations in the total range estimate for the GRCH, indeed, more than an order of magnitude (Table 2). A seasonal pattern did emerge, with Winter consistently exhibiting the largest KHR's, and Calving the smallest KHR's. It is not surprising that calving season had the smallest range estimates, as congregation of females on calving grounds is one characteristic of the migratory caribou ecotype (Gunn & Miller, 1986), like the GRCH. Additionally, the winter range of the GRCH can span the entire land mass from Hudson Bay to the Labrador Sea, north of 53°N, and this cumulative range is expanding (Schmelzer & Otto, this issue). The winter distribution of the GRCH is probably multimodal, graphically reflected in the winter distance to centroid distribution (Fig. 1). Two modes are more obvious, although rigorously determining number of modes can be problematic (Silverman, 1981; Manly, 1996).

Multimodality would cause the KHR to be relatively large, causing an underestimate of density of caribou, hence overestimating the number of collars required for that season. The other seasons exhibited variability in ranking of range estimate (Table 2), most likely reflecting movement distance and rate of travel between calving grounds and winter foraging ranges.

Estimated collar sample sizes varied both by season and probability level (Table 3). A distinct pattern emerged here as well, with Calving having the lowest estimated required sample sizes and Prebreeding and Winter seasons having generally the highest estimated required sample sizes. Aside from season, important variables that will modify the required collar number estimate is the spatial seasonal range use in relation to the boundaries of the military training area (MTA) as well as seasonal training period for aircraft. Jet training usually commences in late March or early April and usually finishes by early November. Also the identified MTA encompasses only a portion of the total range of the herd. Caribou are usually present in the MTA during Winter, Spring migration, Post-calving, Pre-breeding, and Fall migration, but not during Calving. Protection of the GRCH at any desired probability level can be as easy as choosing the highest estimated number of collars of those seasons exhibiting spatial and temporal overlap with the MTA. Alternatively, mitigation can employ minimum collar sample size estimates for some caribou seasons, and invoke other mitigative measures for remaining seasons. For example, during Pre-breeding, the GRCH usually overlaps with a relatively small portion of the MTA, where block closures to flight training could provide increased protection from overflights. Further, variable buffering distances around individual collars can be used as well. Both of these measures are presently used by DND to protect caribou from overflights, but both implicitly depend on being able to extrapolate from collar locations to herd distribution.

This analysis serves as a basis from which decisions can be made about the degree to protect the GRCH from jet overflights. Such decisions can be made based on estimated sample size requirements, level of probability of protection, costs associated with such programs, and augmentation of avoidance of collars with other mitigative measures. But further, these procedures and results form an alternative to pure statistical evaluation of sample sizes. Our approach allows researchers to adaptively evaluate sample size requirements for radio telemetry and tracking studies where a portion of data already exist, producing estimates based on the life history characteristics, movement patterns, and abundance of the animals studied.

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