Government of Northwest Territories
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Determining Optimal Radio Collar Sample Sizes for Monitoring Barren-ground Caribou Populations

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The contents of this paper are the sole responsibility of the author.

ABSTRACT

This report addresses two complementary uses of radio collars to monitor dynamics in barren-ground caribou populations in the Northwest Territories. First, I employed power analysis to evaluate the number of radio collars required to detect a change in adult female survival over time. Second, I used computer simulations to evaluate how the number of radio collars in a herd affects the probability of detecting specific proportions of a herd in aerial surveys that depend on locating radio collared animals and counting the animals in the groups to which they belong. Independent simulations were conducted for the Bluenose-East, Bluenose-West, Cape Bathurst, and Upper Tuktoyaktuk Peninsula populations. The simulations relied on 2006 survey data for group size information but I also created four artificial herds by combining the population size from one herd with the number of groups and proportional distribution of animals among groups from a different herd. In this way I was able to examine what sample size requirements might be for Bluenose-East, Bluenose-West, and Cape Bathurst herds if the animals were distributed differently among groups. For comparison, I also simulated surveys for three Alaska caribou populations based on survey data from the 1980s.

To detect moderate changes in annual adult female survival (e.g. 6-7% per year, persistent for three or more years) would require 80 or more radio collars in a herd and the monitoring would need to be conducted in two or more discrete time periods. The number of radio collared animals required is the same for all herds.

From the simulations I provide the numbers of radio collars that would be required to have more than 80% probability of detecting at least 90% of each herd. Figures and tabled information provide an indication of the marginal value of each additional radio collar deployed in each herd. For each sample size, I have also provided the probabilities of missing groups comprising either 10% or 5% of the total population. The number of radio collars required for a given level of probability of detecting a given proportion of a population is different for each population. Group size at the time of the survey will play a key part in survey success and is an important determinant of the number of radio collars provided. Including an assumed 6.4% observations in addition to animals in groups containing a radio collared animal, the simulations based on 2006 survey data for each herd support the following numbers of radio collars for each herd: Bluenose-East = 38, Bluenose-West = 81, Cape Bathurst = 35, and Upper Tuktoyaktuk Peninsula = 21. The marginal value of each radio collar is particularly low for the Cape Bathurst herd and reasonably low for the Bluenose-West herd,

suggesting that lower sample sizes could be justified without much risk of underestimating herd size.

By also examining the results from artificial herd simulations and considering the marginal values associated with different numbers of radio collars my recommended sample sizes for each herd are: Bluenose-East 40-60 radio collars, Bluenose-West 60 radio collars, Cape Bathurst 30 radio collars, and Upper Tuktoyaktuk Peninsula 30 radio collars. My recommendations are without full consideration of budget limitations and other factors that affect management decision making.

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BACKGROUND

The objectives of this report are to evaluate the merits of various sample sizes of radio collars for barren-ground caribou (*Rangifer tarandus groenlandicus*) populations in the Northwest Territories (NWT). It is understood that radio collars will be placed only on adult female caribou.

Potential applications for radio collars in barren-ground caribou monitoring and management are:

(i) To estimate annual adult female survival through on-going monitoring of collared animals. This application is independent of applications (ii) through (vi) below.

(ii) By employing telemetry equipment in the aircraft, to direct the observers to groups containing marked individuals for direct count or photo surveys. Groups not containing a marked animal may be sighted and recorded while flying between groups containing marked animals.

(iii) To provide locations to delineate the area to be covered with pre-survey reconnaissance flights. The reconnaissance flights, in turn, would be used to stratify the survey area and direct a geographic based survey to yield an estimate of females in the population without further use of telemetry equipment to guide observers to animals.

(iv) If calving ground surveys are used, to determine the proportion of females in the population that is on the calving grounds. Results from the calving ground air photo surveys would then be multiplied to correct for the proportion of females not on the calving ground. This use is consistent with (ii) and (iii) above.

(v) To correct either population estimates or their standard errors for missed groups in a mark-resight approach in air-photo surveys. This use is consistent with (iii) and (iv) above but not with (ii).

(vi) During air-photo surveys, to ensure that the same group is not photographed on consecutive days (if it has moved between days).

Associated with each of these applications are assumptions and implicit or explicit study design questions. This report is concerned with applications (i) and (ii) above. In adult female survival, I consider the use of radio collared animals to determine annual survival rates and changes in

survival rate between two time periods. In using radio collared animals to locate groups during aerial surveys, I examine the use of radio collared animals to direct observers to groups of animals in aerial surveys. In each case I examine the specific monitoring questions to be addressed and the relationship between numbers of radio collars and the ability to answer those questions.

ADULT FEMALE SURVIVAL

At its basic level, knowledge of adult female survival may provide information about an important vital rate. Combined with information on recruitment, it can yield an estimate of the survival-fecundity rate of population increase (Caughley 1977). Survival can be estimated through a number of different equations but all are variations of the ratio of the proportion of animals surviving a time interval to those alive at the start of the time interval. The values are weighted variously to account for the number of time intervals and the number of animals. In the end, survival is presented as a proportion between 0 (none surviving) and 1.0 (all surviving).

Regardless of the means used to estimate survival, the precision of that estimate relates to two things: the estimate itself and the sample size. With proportional data, the precision declines (i.e., SE increases) as the value nears 0.5 and precision increases in both directions as it nears either 0 or 1.0. For a given proportion the precision will increase as the sample size increases. The increase in sample size can be achieved through the addition of radio collars or an increased duration of monitoring. Table 1 below demonstrates the relationships among sample size, monitoring period, and the survival rate and its precision.

The simple question is: what level of precision is associated with each sample size and each survival rate? Ultimately, however, the management question is more likely to be: Did the survival rate change between one period and another? From a study design perspective the question becomes: How many animals do we need to radio collar to detect change of a given size in adult female survival and how is sample size affected by different rates of survival? The solution to the question is found through power analysis. For reference, I have included a primer on power analysis (Appendix A).

Table 1: Precision of survival estimates. The values in the five columns on the right are the standard errors associated with different survival rates, different initial sample sizes, and different monitoring periods.

		Sample Size at the Start of Year 1				
Survival Rate	**Years Monitored**	**20**	**40**	**60**	**80**	**100**
0.81	1	0.09	0.06	0.05	0.04	0.04
0.81	2	0.07	0.05	0.04	0.03	0.03
0.81	3	0.06	0.04	0.03	0.03	0.03
0.81	4	0.05	0.04	0.03	0.03	0.02
0.84	1	0.08	0.06	0.05	0.04	0.04
0.84	2	0.06	0.04	0.04	0.03	0.03
0.84	3	0.05	0.04	0.03	0.03	0.02
0.84	4	0.05	0.03	0.03	0.02	0.02
0.87	1	0.08	0.05	0.04	0.04	0.03
0.87	2	0.06	0.04	0.03	0.03	0.02
0.87	3	0.05	0.03	0.03	0.02	0.02
0.87	4	0.04	0.03	0.02	0.02	0.02
0.90	1	0.07	0.05	0.04	0.03	0.03
0.90	2	0.05	0.03	0.03	0.02	0.02
0.90	3	0.04	0.03	0.02	0.02	0.02
0.90	4	0.04	0.03	0.02	0.02	0.02
0.93	1	0.06	0.04	0.03	0.03	0.03
0.93	2	0.04	0.03	0.02	0.02	0.02
0.93	3	0.03	0.02	0.02	0.02	0.02
0.93	4	0.03	0.02	0.02	0.02	0.01

Methods to Calculate Sample Sizes to Detect Change in Adult Female Survival

Following Murray (2006), I applied a continuous time monitoring process (Lachin and Foulkes, 1986) to determine the power associated with various sample sizes. To accomplish this I used log-rank survival analysis in the software package PASS (Hintze 2006a). Log-rank survival analysis in PASS accounts for multiple year monitoring and declining sample sizes owing to mortalities through the monitoring period (Hintze 2006b, Chapter 705). Because the procedure requires the specification of two separate sample groups for comparative purposes, I doubled the sample sizes and allocated each sample group half the samples. I set the sample sizes in the analyses to 40, 80, 120, 160, and 200. This is equivalent to monitoring 20, 40, 60, 80, or 100 animals in each of two time periods. Though historic data for various populations have involved different numbers of samples and different numbers of years of monitoring, this power analysis was meant to serve a more general purpose. I assigned a survival rate of 0.87 to Sample 1 - this is the chosen reference

value. I selected a two-tailed test and set the survival rate for Sample 2 to vary from 0.61 to 0.99 for comparison with the 0.87 rate of Sample 1. I assumed all collar deployment would occur at the beginning of the study period (accrual time =1, % time until 50%, accrual = 1) and the monitoring period equals three years following collar deployment. I ran the analyses twice, once each with confidence set to 90% and 80%.

Results of Power Analysis to Detect Change in Adult Female Survival

Figures 1 and 2 show the relationships between power (Y-axis value) to detect various effect sizes (i.e., change from 0.87 survival to some other value; X-axis value) and sample size. Sample sizes represent the number of radio collars initially deployed in each period of monitoring. Both figures relate future annual survival rate, calculated over a three year period, against a current survival rate of 0.87. Figure 1 shows power to detect a given effect at various sample sizes when the confidence level is set to 90%. Figure 2 shows the same relationship with a confidence level of 80%. Note that for the same sample size, as confidence is decreased power is increased. For example, with a sample size of 40 radio collars there is 80% power to detect a decline in survival rate from 0.87 to 0.74 when the confidence level is 90% (blue line, Figure 1). With the same 40 radio collars, if we were willing to accept a confidence level of 80% we could detect a decline in survival rate from 0.87 to 0.77 (rather than 0.74) with 80% power (blue line, Figure 2).

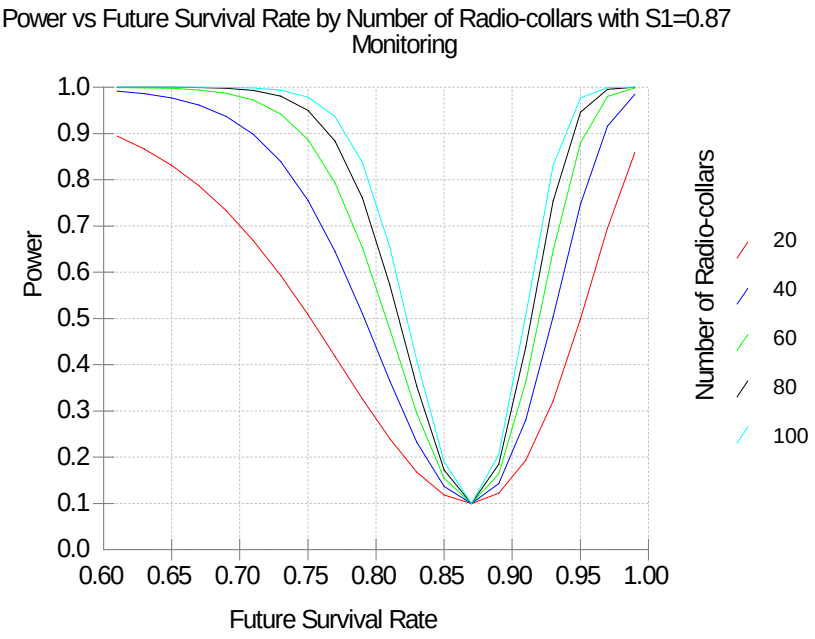

Figure 1: Power to detect changes in survival from a historic survival rate of 0.87. Sample sizes modeled range from 20-100 radio collars monitored for a period of three years (legend on right). Log-rank survival analysis with confidence of 90% (Alpha = 0.10).

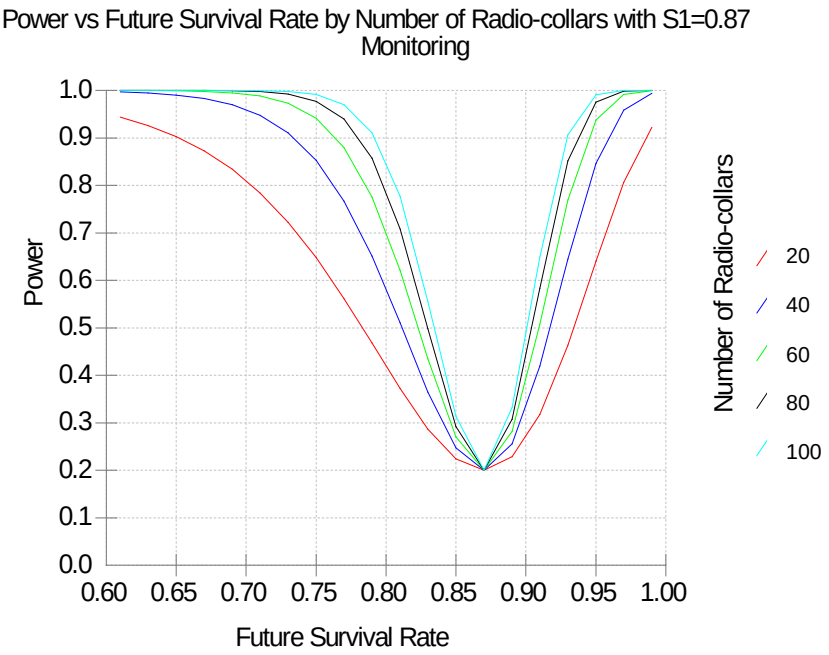

Figure 2: Power to detect changes in survival from a historic survival rate of 0.87. Sample sizes modeled range from 20-100 radio collars monitored for a period of three years (legend on right). Log-rank survival analysis with confidence of 80% (Alpha = 0.20).

The 0.87 survival rate is somewhat arbitrary; however it is within the rage of normal survival rates for barren-ground caribou. The consequence of selecting a different reference survival rate will be to (i) shift the curves left or right so that the reference survival rate is always at the minimum of all the curves (note the current curves are minimal at 0.87), and (ii) narrow the curves slightly if the reference survival rate is increased (e.g. to 0.90) or widen them slightly as the reference survival rate is decreased (e.g. to 0.83). The overall effect will not be great and the relationships between power and sample size are well represented.

Discussion

Even sample sizes of 100 or more radio collars monitored for three years will not permit confident detection of small (e.g. 4 or 5%) changes in adult survival rates. Over the same three year monitoring period, a moderate sample size of 40-60 radio collars will have 90% confidence and 80% power to detect a decline in survival from 87% only when survival drops to between 74% and 77% (Figure 1). At moderate sample sizes, adult survival rates will not reveal changes in population size beyond those detected by aerial surveys.

USING RADIO COLLARED ANIMALS TO LOCATE GROUPS DURING AERIAL SURVEYS

To establish the sampling requirements for a monitoring program it is necessary to determine the effect size (i.e., the degree of change) that you are seeking to detect, the desired power to detect that change, and the confidence that you wish to have in your result. Confidence relates to the precision of consecutive estimates and when radio telemetry is used to locate groups to be counted a measure of precision cannot be determined. I interpreted the power associated with the number of radio collars to be the probability of estimating the population to be greater than or equal to a specific proportion of the simulated population. All values may be read from the curves generated for various sample sizes for each population. The values that I have focused on are: 80% probability of detecting at least 90% of the population. In the simulation that are described below and presented in the tables in Section 3.3, it means that out of 10,000 simulations run for any given sample size, the recommended number of radio collars resulted in 8,000 of the simulations returning a value of at least 90% of the simulated population.

Methods: Computer Simulations of Population Survey

I started with the raw survey data from the most recent survey data from each herd (Table 2) to represent the population size and its partitioning into groups of various sizes. Specifically, I employed the numbers of groups and the number of adult females in each of those groups. I restricted group size to non-calf caribou as calves were not and will not be collared (and will only be picked up incidentally when searching for collared animals). I used all data regardless of whether or not there had been a collared caribou in the group.

Table 2: Summary of the barren-ground caribou survey information employed in simulated caribou surveys. Simulations also incorporated individual group sizes observed in each survey.

Herd	Animals in Groups with Radio Collars	Animals in Groups Without Radio Collars	Number of Groups Identified	Mean Group Size	Typical Group Size*	Number of Radio Collars in Herd	Incidental Observations	Data Source
Bluenose-East	62,614	1,026	30	2,121	15,819	49	1.6%	**Nagy and Tracz (2006, Table 2)**
Bluenose-West	16,378	1,703	65	278	1,147	65	8.6%	**Nagy and Johnson (2006, Table 5)**
Cape Bathurst	1,389	125	23	66	154	30	9.0%	**Nagy and Johnson (2006, Table 8)**
Upper Tuktoyaktuk Peninsula	2,894	184	14	220	979	27	6.4%	**Nagy and Johnson (2006, Table 11)**
Western Arctic	151,974	18,565	12	14,212	33, 720	30	12.2%	**Valkenburg et al. (1985, Table 1)**
Delta	4,552	503	30	169	798	39	11.1%	**Valkenburg et al. (1985, Table 2)**
Fortymile	**8,223**	**3,564**	**22**	**536**	**1,228**	**19**	**43.3%**	**Valkenburg et al. (1985, Table 3)**

* A measure of group size weighted by the number of individuals in each group (Jarman, 1982, p.336)

I also simulated surveys in four artificial herds. The first had the population size of the Bluenose-East herd (63,640) but the number of groups (65) of the Bluenose-West herd with the same proportion of the herd in each group as had been observed in the 2006 Bluenose-West survey. The second had the Cape Bathurst population size (1,514) with the Bluenose-West numbers of groups and proportional distribution across groups. The third and fourth each had the Bluenose-West population size (18,081); the third with number of groups (23) and proportional distribution of the 2006 Cape Bathurst herd, and the fourth with the number of groups (30) and proportional group membership as observed in the 2006 Bluenose-East survey.

Computer Simulation Assumptions

In conducting the computer simulations of population surveys I made the following assumptions:

(1) Within each population, the group sizes are the same as they were during the last survey (Table 2).

(2) The deployment of radio collars and the subsequent movement of marked animals will give each adult female animal in each population an equal probability of having a radio collar.

Mathematically: $$p_{irc} = \frac{j}{N}$$

Where p_{irc} is the probability of animal i having a radio collar, j is the number of radio collars deployed, and N is the population size.

(3) At the time of the survey, radio collared animals are distributed at random among all the groups in the population. Over an infinite number of surveys the total number of radio collared animals in a group can be expected to be the product of the number of animals in a group and p_{irc}. In each individual survey there will be random variation in the distribution of radio collared animals among groups.

(4) Each survey will be directed solely by the location of radio collared animals and the objective of the survey is to locate all radio collared animals and count the animals in their groups.

(5) The location of all radio collared animals will be known prior to the survey and all radio collared animals will be located during the survey.

(6) All groups encountered will be recorded and counted (either by survey staff or via group photo counts). This includes incidental observations of groups with no radio collared animals.

Factors Affecting Aerial Surveys and the Survey Simulations

Under the assumptions above, there are five key factors that affect the population estimates resulting from caribou population surveys:

(1) The population size;

(2) The number of radio collared animals;

(3) The proportion of animals seen through incidental observations (groups without radio collared animals);

(4) The distribution of radio collared animals among groups; and

(5) The number of groups of different sizes at the time of the survey.

Of these factors, for each population in a given survey period I assume Factors (1) and (2) are constant, this is a reasonable assumption in real surveys. Factor (3) may vary, but with standardized survey methodology it is likely to remain relatively stable. Factor (4) is random and will vary among surveys. Factor (5), the number of groups and the sizes of those groups may vary among years and within the period of the survey itself. Factor (5) is a confounding factor and I have not addressed it in the simulations, though I raise the issue in the Discussion.

In the simulations for each number of radio collars, in each herd I ran 10,000 simulations: Factors (1), (3), and (5) were held constant for all simulations for a given population; and Factor (4) is controlled for through replication.

Range of Potential Sample Sizes of Radio Collars Considered in Simulations

I simulated a range of sample sizes of radio collars to consider deploying. Initially, the numbers of radio collars simulated were the same for all herds but it was apparent from the results that the optimal solutions lay in different ranges of collar numbers and I made adjustments to provide additional data for different sample sizes for different herds. By herd the sample sizes presented in the simulation results are:

a. Bluenose-East: 20, 40, 60, 80, 100, 150, 200

b. Bluenose-West: 20, 40, 60, 80, 100, 150, 200

c. Cape Bathurst: 10, 20, 30, 40, 60, 80

d. Upper Tuktoyaktuk: 10, 15, 20, 25, 40, 60

e. Western Arctic: 20, 40, 60, 80, 100, 150, 200

f. Delta: 20, 30, 40, 60, 80, 100

g. Fortymile: 10, 20, 30, 40, 60, 80, 100

The sample size ranges can be expanded, but a scan of the results suggest that the inflection point in the sample size vs. population estimate curve was reached for each herd.

Computer Simulation Process

For each simulated herd I simulated the random deployment of various numbers of radio collars. To accomplish this each animal in a herd received a unique identification number and was assigned as belonging to a specific group of a specific size. I generated random numbers to randomly selected individual animals (without replacement, meaning no animal could be "collared" twice); if the sample size in the simulation was 40, then 40 unique random numbers were selected. Any group containing one or more radio collared animals was considered to have been observed and counted. As the groups containing radio collared animals and the number of radio collared animals each group contained depended on chance inclusion of one or more radio collared animals (consistent with Assumption (2) above), it is likely that not all groups would be observed during the survey. Other groups might be observed multiple times but would be counted only once. For each herd and each sample size (i.e., the number of radio collared animals in the simulation) I repeated the simulation 10,000 times – the virtual equivalent of flying 10,000 different surveys on the same animals, but with different animals having radio collars each time. Manly (1997, Chapter 5) recommended a minimum of 5,000 randomizations as a reasonable minimum for 99% confidence limits around the result.

Fitting a Line to the Results

For each herd and each sample size I ranked the simulated population estimates by size, selected every 100th record (each represented a 1% step through the set of 10,000 ranked population estimates) and fitted a third order polynomial line through the 100 data points. In this way I plotted population estimate against the probability of achieving an estimate of that magnitude or greater. For reference I added horizontal lines representing 80% and 90% of the observed population size from the survey data in Table 1. I also added vertical reference lines to show 80% and 90% probability of achieving a population estimate greater than or equal to the value on the Y-axis.

Accounting for incidental observations

I defined an incidental observation as a group of animals detected during the survey that did not contain a radio collared animal. Employing the most recent survey data, I determined the proportion of observations that were incidental to the search for radio collared animals (Table 1). I took the mean value (6.4%) from the four NWT populations' surveys and applied it as a correction factor to the simulation results. I used 11.1% for the three Alaska populations. I used the approach

described in fitting a line to the results and re-plotted the lines relating population estimate to probability of observation for each sample size.

Methods: Ensuring detection of large groups in each population

Valkenburg et al. (1985, p. 296) presented an equation to calculate the number of radio collars to deploy to ensure, with a specified confidence, groups corresponding to a minimum portion of a population. The equation holds for any population. For a select number of sample sizes for each herd, I calculated the probability of detecting any group representing 5% or 10% of each herd with 95% confidence. Note that this is different than the results of the simulations that reflect the total percentage of the herd that is detected. For example, Valkenburg et al.'s (1985) equation may show the probability of detecting any one group representing ≥10% of the herd; while the simulations relate to the probability of missing ≥10% of the herd in total.

Results

Following the survey simulations I generated two figures for each herd. Using the Bluenose-East herd as an example, the first Figure (3a) shows population estimates based only on groups containing radio collared animals. The second Figure (3b) show the same data multiplied by a constant to represent groups observed during aerial surveys that do not contain radio collared animals. The entire set of Figures, two for each herd, appears in Appendix B.

Tables 3-6 contain simulated survey results for four different radio collar sample sizes for each of the NWT populations based on 2006 survey population and group size information. The sample sizes in the tables were generated through additional simulations run iteratively until the specific criteria in the left-hand columns were met. They are: (a) 80% probability of detecting ≥90% of the simulated population based solely on groups detected because they contain radio collared animals; (b) 80% probability of containing ≥90% of the simulated population based on groups detected because they contain radio collared animals plus 6.4% animals presumed to be detected incidentally; (c) values from ten fewer radio collars than in (b), this value is presented to indicate the marginal value of the last ten radio collars deployed; and (d) a constant reference value of 30 radio collars, a number that has the property of having a 95% probability of having a radio collared animal in each group of ≥10% of the population.

Tables 7-10 contain results from the simulations for four artificial herds, in which I used 2006 population estimates from one herd with the numbers of groups and proportional distribution of animals among groups observed for a different herd in the 2006 surveys (methods: computer

simulations of population survey above). They contain the same information and the same presentation format as Tables 3-6.

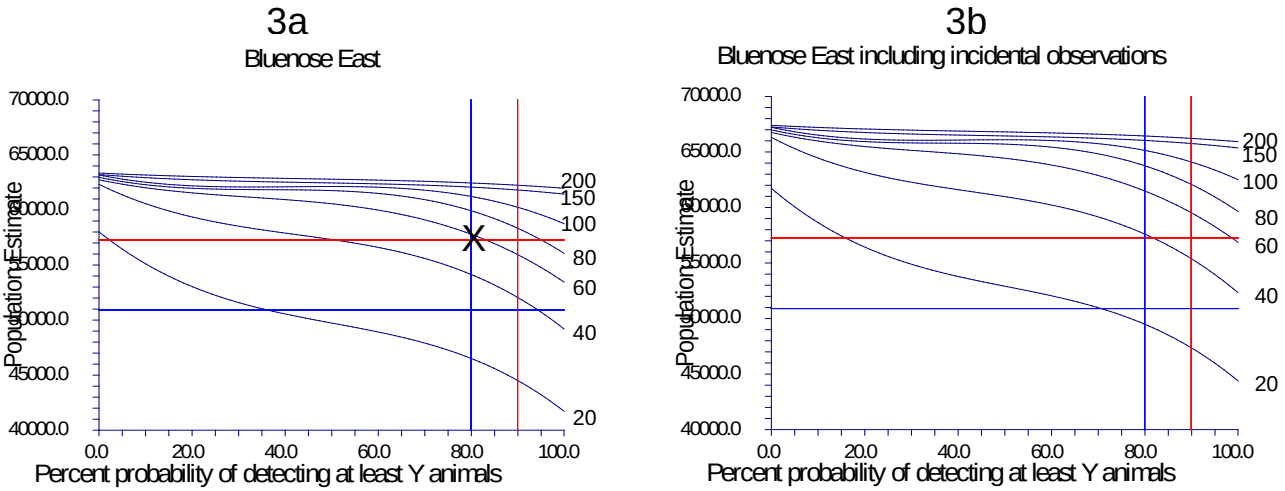

Figure 3: Relationship between sample size (number of radio collars) and the probability of detecting a minimum number of animals in simulated aerial surveys for the Bluenose-East caribou herd. The results are based on simulations using the population estimate and group observations from the 2006 Bluenose-East caribou survey (Nagy and Tracz 2006). There is one curve for each sample size and the number of radio collars associated with the line appears at the right-hand end of the line. The X-axis shows the percentage of the 10,000 simulations run for each sample size for which the population estimate is greater than or equal to the population estimate on the Y-axis. For example, at point X in Figure 3a, with 60 radio collars you would have an 80% probability of observing a minimum of 57,000 animals. Following the curve to the right, there is a 90% probability of detecting at least 55,000 caribou with 60 radio collars. The blue lines in each figure represent 80% probability of observing a population value at least that great (vertical line) and 80% of the total population observed in 2006 (horizontal line). The red lines represent 90% probability (vertical) and 90% population (horizontal).

In Figure 3b, the curves include the addition of 6.4% incidental observations. The value of 6.4% is the mean proportion of incidental observations from the most recent surveys in each of four NWT barren-ground caribou surveys from 2006 (See Table 2). The consequence is to raise each curve, increasing the numbers of animals observed in the simulations. This mimics the increased numbers of animals observed when conducting aerial surveys and observing groups that do not contain marked animals.

Table 3: Likely survey outcomes of some radio collar sample sizes based on simulated survey results for the Bluenose-East barren-ground caribou herd using 2006 post-calving survey observations. 2006 population count was 63,640 animals.

Objective	Collars Required	80% of Population Estimates will Exceed X without Incidental Multiplier	80% of Population Estimates will Exceed X with Incidental Multiplier of 6.4%	Confidence that Groups Comprising >10% of Population will be Detected	Confidence that Groups Comprising >5% of Population will be Detected
Detect > 90% of population (57,276) without incidentals	55	57,276	60,942	99.6 %	**94 %**
Detect >90% of population (57,276) with incidentals	38	53,831	57,276	98 %	**85 %**
Ten collars fewer than above	28	50,462	53,692	94 %	**75 %**
Reference constant of 30	**30**	**51,154**	**54,428**	**95 %**	**78 %**

Table 4: Likely survey outcomes of some radio collar sample sizes based on simulated survey results for the Bluenose-West barren-ground caribou herd using 2006 post-calving survey observations. 2006 population count was 18,081 animals.

Objective	Collars Required	80% of Population Estimates will Exceed X without Incidental Multiplier	80% of Population Estimates will Exceed X with Incidental Multiplier of 6.4%	Confidence that Groups Comprising >10% of Population will be Detected	Confidence that Groups Comprising >5% of Population will be Detected
Detect > 90% of population (16,273) without incidentals	117	16,273	17,314	99.9 %	**99.7 %**
Detect >90% of population (16,273) with incidentals	81	15,294	16,273	99.9 %	**98 %**
Ten collars fewer than above	71	14,915	15,870	99.9 %	**97 %**
Reference constant of 30	**30**	**11,673**	**12,420**	**95 %**	**78 %**

Table 5: Likely survey outcomes of some radio collar sample sizes based on simulated survey results for the Cape Bathurst barren-ground caribou herd using 2006 post-calving survey observations. 2006 population count was 1,514 animals.

Objective	Collars Required	80% of Population Estimates will Exceed X without Incidental Multiplier	80% of Population Estimates will Exceed X with Incidental Multiplier of 6.4%	Confidence that Groups Comprising >10% of Population will be Detected	Confidence that Groups Comprising >5% of Population will be Detected
Detect > 90% of population (1,363) without incidentals	51	1,363	1,450	99.4 %	**93 %**
Detect >90% of population (1,363) with incidentals	35	1,281	1,363	97 %	**83 %**
Ten collars fewer than above	25	1,182	1,258	92 %	**71 %**
Reference constant of 30	**30**	**1,240**	**1,319**	**95 %**	**78 %**

Table 6: Likely survey outcomes of some radio collar sample sizes based on simulated survey results for the Upper Tuktoyaktuk Peninsula barren-ground caribou/reindeer population using 2006 post-calving survey observations. 2006 population count was 3,078 animals.

Objective	Collars Required	80% of Population Estimates will Exceed X without Incidental Multiplier	80% of Population Estimates will Exceed X with Incidental Multiplier of 6.4%	Confidence that Groups Comprising >10% of Population will be Detected	Confidence that Groups Comprising >5% of Population will be Detected
Detect > 90% of population (2,770) without incidentals	28	2,770	2,947	94 %	**75 %**
Detect >90% of population (2,770) with incidentals	21	2,604	2,770	88 %	**65%**
Ten collars fewer than above	11	2,257	2,401	68 %	**42 %**
Reference constant of 30	**30**	**2,798**	**2,977**	**95 %**	**78 %**

Table 7: Likely survey outcomes of some radio collar sample sizes based on simulated survey results for the Bluenose-East barren-ground caribou herd using numbers of groups and proportional group distributions from Bluenose-West 2006 post-calving survey observations. 2006 Bluenose-East population count was 63,640 animals.

Objective	Collars Required	80% of Population Estimates will Exceed X without Incidental Multiplier	80% of Population Estimates will Exceed X with Incidental Multiplier of 6.4%	Confidence that Groups Comprising >10% of Population will be Detected	Confidence that Groups Comprising >5% of Population will be Detected
Detect > 90% of population (57,276) without incidentals	104	57,325	60,994	99.9 %	**99.5 %**
Detect >90% of population (57,276) with incidentals	74	53,828	57,273	99.9 %	**98 %**
Ten collars fewer than above	64	51,322	54,607	99.8 %	**96 %**
Reference constant of 30	**30**	**41,671**	**44,338**	**95 %**	**78 %**

Table 8: Likely survey outcomes of some radio collar sample sizes based on simulated survey results for the Cape Bathurst barren-ground caribou herd using numbers of groups and proportional group distributions from Bluenose-West 2006 post-calving survey observations. 2006 Cape Bathurst population count was 1,514 animals.

Objective	Collars Required	80% of Population Estimates will Exceed X without Incidental Multiplier	80% of Population Estimates will Exceed X with Incidental Multiplier of 6.4%	Confidence that Groups Comprising >10% of Population will be Detected	Confidence that Groups Comprising >5% of Population will be Detected
Detect > 90% of population (1,361) without incidentals	103	1,362	1,449	99.9 %	**99.5 %**
Detect >90% of population (1,361) with incidentals	74	1,283	1,365	99.9 %	**98 %**
Ten collars fewer than above	64	1,214	1,292	99.8 %	**96 %**
Reference constant of 30	**30**	**993**	**1,057**	**95 %**	**78 %**

Table 9: Likely survey outcomes of some radio collar sample sizes based on simulated survey results for the Bluenose-West barren-ground caribou herd using numbers of groups and proportional group distributions from Bluenose-East 2006 post-calving survey observations. 2006 Bluenose-West population count was 18,081 animals.

Objective	Collars Required	80% of Population Estimates will Exceed X without Incidental Multiplier	80% of Population Estimates will Exceed X with Incidental Multiplier of 6.4%	Confidence that Groups Comprising >10% of Population will be Detected	Confidence that Groups Comprising >5% of Population will be Detected
Detect > 90% of population (16,273) without incidentals	63	16,348	17,394	99.8 %	**96 %**
Detect >90% of population (16,273) with incidentals	42	15,341	16,323	99 %	**88 %**
Ten collars fewer than above	32	14,351	15,269	96 %	**80 %**
Reference constant of 30	**30**	**14,327**	**15,244**	**95 %**	**78 %**

Table 10: Likely survey outcomes of some radio collar sample sizes based on simulated survey results for the Bluenose-West barren-ground caribou herd using numbers of groups and proportional group distributions from Cape Bathurst 2006 post-calving survey observations. 2006 Bluenose-West population count was 18,081 animals.

Objective	Collars Required	80% of Population Estimates will Exceed X without Incidental Multiplier	80% of Population Estimates will Exceed X with Incidental Multiplier of 6.4%	Confidence that Groups Comprising >10% of Population will be Detected	Confidence that Groups Comprising >5% of Population will be Detected
Detect > 90% of population (16,273) without incidentals	51	16,290	17,333	99.4 %	**93 %**
Detect >90% of population (16,273) with incidentals	35	15,346	16,328	97 %	**83 %**
Ten collars fewer than above	25	14,152	15,058	92 %	**71 %**
Reference constant of 30	**30**	**14,868**	**15,820**	**95 %**	**78 %**

Discussion

The number of radio collars required for a given level of probability of detecting a given proportion of a population is different for each population. Including an assumed 6.4% observations in addition to animals in groups containing a radio collared animal, the basic simulations (Figures in Appendix B, Tables 3-6) support the following numbers of radio collars for each herd: Bluenose-East = 38, Bluenose-West = 81, Cape Bathurst = 35, Upper Tuktoyaktuk Peninsula = 21. The marginal value of each radio collar is particularly low for the Cape Bathurst herd and reasonably low for the Bluenose-West herd, suggesting that lower sample sizes could be justified without much risk of underestimating herd size. Ultimately the value of the additional information obtained with each additional radio collar must be evaluated against the management need for that information and the cost of obtaining it. Tables 3-6 and figures in Appendix B can assist in assessing the relative information gain.

Using 2006 herd estimates, the results suggest one radio collar for every 1,675 caribou in the Bluenose-East herd, one collar for every 223 caribou in Bluenose-West, one per 43 animals for Cape Bathurst, and one per 147 animals for the Upper Tuktoyaktuk Peninsula herd. From these results and the information in Table 2, it is apparent that population size does not affect the number of radio collars required nearly as much as a change in the number and sizes of groups in a herd. The number and sizes of groups is partly a feature of the population, partly a feature of timing, and partly a feature of local conditions at the time of the survey. In any case, group size at the time of the survey will be a key in survey success and is an important determinant of the number of radio collars required; fewer large groups will yield a more accurate count.

The results presented in Tables 7-10 provide some alternate possibilities of the distributions of a given number of animals into groups. The possible distributions of thousands of animals into various numbers of groups of various sizes are infinite when compared to the number of possibilities that can be practically modeled. My examination of sampling requirements from distributions (numbers of groups; proportion of herd in each group) observed for other herds provides a very small number of real world possibilities. The trend that becomes evident is that as either the number of groups increases or typical group size decreases, there is a need to deploy more radio collars to ensure that a pre-specified proportion of a herd is detected in a survey. When group sizes are small and group numbers are high the problem is compounded; this is the scenario that exists when a herd declines and becomes more fragmented. To offset the perceived need for additional radio collared animals in these circumstances there are two other key factors that should

be considered: the marginal value of each additional radio collar deployed and the absolute number of animals involved. The marginal value of additional collars is represented by the vertical spacing between the curves for different numbers of radio collars in the figures in Appendix B and through comparison of different rows of data in Tables 3-10. In each figure the lines get closer together as you increase the number of radio collars; each additional collar has less value than the last. Because population growth is typically measured as a proportional value we tend to think in proportional terms. Indeed, that is how I have presented the data and cut-off points in the tables and the figures. However, those proportions represent real numbers of animals and for small populations the real number of animals can be quite small; ten percent of the Cape Bathurst herd in 2006 was 151 animals. Deploying 40 additional collars to potentially detect 400 additional animals should be considered in terms of the cost and value of that information.

The Bluenose-East population size was considered in the examples presented in Tables 3 and 7. In Table 3 (the actual distribution of animals observed for that herd in 2006) results in a radio collar sample size requirement of 38 collars to have 80% probability of detecting at least 90% of the population including incidental observations. In Table 7 the same population size with the Bluenose-West 2006 distribution would require 74 radio collars to achieve the same result. Worth noting is that the last ten radio collars deployed in the Table 3 scenario raise the likely estimate from 84-90% of the population while the last ten collars in the Table 7 scenario result in an increase from 86% to 90%. In absolute terms the last ten collars should reveal 2,500-3,500 more animals depending on the actual group distribution.

The Cape Bathurst population size was considered in the examples presented in Tables 5 and 8. In Table 5 (the actual distribution of animals observed for that herd in 2006) results in a radio collar sample size requirement of 35 collars to have 80% probability of detecting at least 90% of the population including incidental observations. In Table 8 the same population size with the Bluenose-West 2006 distribution would require 74 radio collars to achieve the same result. Worth noting is that the last ten radio collars deployed in the Table 5 scenario raise the likely estimate from 83-90% of the population while the last ten collars in the Table 8 scenario result in an increase from 85% to 90%. In absolute terms the last ten collars should reveal 70-100 more animals, depending on the actual group distribution. In Table 8 scenario, the worse of the two cases, even 30 radio collars should detect 1,057 out of 1,514 animals. The last 44 radio collars deployed would raise the population estimate by 457; about ten animals per radio collar.

The Bluenose-West population size was used in the simulations presented in Tables 4, 9, and 10 and results show that its own 2006 distribution (Table 4) was the worst case scenario, worse than either the Bluenose-East or Cape Bathurst 2006 distributions. Considering the information in Table 4 the jump from 71-81 radio collars is likely to raise the population estimate by 400 animals from 88% of the population detected to 90%. From Appendix B Figure d, the difference from 60-80 radio collars is relatively small.

Recommendation

The simulations provide an assessment of requirements based on the assumptions of specific population sizes and specific numbers of groups and group sizes. Barring catastrophic decline, the assumed population sizes are likely to be reasonably accurate. The assumed distribution among groups is likely to be more variable. However, the ability to locate animals when they are most aggregated will be enhanced by the use of satellite transmitters rather than VHF radio collars and groups sizes observed may increase as a result. So, accounting for potential population decline and increased herd fragmentation and considering the potential for more optimal timing of surveys my recommendations, in round numbers are:

- Bluenose-East: 40-60 radio collars.
- Bluenose-West: 60 radio collars.
- Cape Bathurst and Upper Tuktoyaktuk Peninsula: 30 radio collars each.

The simulations suggest that about 40 radio collars would have been adequate in the 2006 survey for the Bluenose-East herd but concerns over population decline and fragmentation of the largest of the four herds considered suggest that additional radio collars may be a prudent investment if they are affordable. The Bluenose-West simulation suggests that up to 80 radio collars might be warranted. However, the distribution of animals in that herd was the worst observed in 2006. With more optimal aggregations for the survey the distribution may improve and, in any case, the marginal value of the number of radio collars beyond 60 appears small. I would consider a lower number of radio collars an acceptable risk. Both the Upper Tuktoyaktuk Peninsula and Cape Bathurst herds are small with low marginal values on additional radio collars. Thirty radio collars should ensure that all groups of more than 10% of each population will be detected. My recommendations are without full consideration of budget limitations and other factors that affect management decision making.

Finally, different methods of employing radio collared animals in the population surveys should be examined. Rivest et al. (1998) employed a similar survey approach to that considered here. They noted that regardless of the number of radio collars deployed, a photo census is likely to underestimate the herd size. They recommended the use of a modeling approach to account for missed animals but Patterson et al. (2004) found its results to be biologically implausible when applied to Bluenose-East herd data.

In discussion on survey design, I present a discussion of radio collar based survey design approaches that may yield more efficient surveys. Sightability correction factors are discussed in sightability correction factors.

DISCUSSION ON SURVEY DESIGN

Aerial surveys are most efficient when there is a clear delineation of the geographic extent of the survey area and a stratification of the area into two or more survey strata based on probable animal density. Barren-ground caribou herds are characterized by the fidelity of females to annual calving grounds and the annual calving and post-calving aggregations provide an opportunity for aerial population surveys. The seasonal area used by a herd over several years may be extensive (tens of thousands km^2) of which only a fraction may be used in any one year. The survey area may be defined by the extent of known historic use for calving or the post-calving period, by an exhaustive survey throughout and beyond the limits of known historical use, and/or by tracking marked individuals in the period immediately prior to the survey.

The use of systematic surveys without using radio collared animals to identify the area to survey has both benefits and costs:

1. Benefit – The entire known seasonal area will be searched. Large aggregations of animals will be detected and any change in distribution will be noted;
2. Benefit – If the herd is scattered in small groups, they will also be detected and counted;
3. Cost – The majority of the area surveyed will have few or no animals and the cost of conducting the survey will greatly exceed the optimal cost;
4. Cost – If the seasonal range has shifted from areas used historically, caribou will go undetected.

The use of radio collared animals to provide focal areas for the reconnaissance surveys also has costs and benefits:

5. Benefit – The survey will be focused on areas known to contain caribou;
6. Benefit – Higher concentrations are likely to be located;
7. Benefit – If the herd shifts its seasonal range from historic areas it will be known before the survey begins;
8. Benefit – If satellite collars are employed, animal movements can be monitored remotely to ensure optimal timing of the survey;

9. Benefit – If a systematic survey approach is used with radio collared animals in the survey area, the detections of radio collared animals may be used to create correction factors for missed animals;

10. Cost – Animals must be captured and a minimum number of active radio collars must be maintained within the herd. The costs for this also include collar and data acquisition and processing costs;

11. Cost – If the herd is scattered, many groups may be missed if there are no radio collared animals in the vicinity.

The survey methodology used for the Bathurst herd in 2006 (Nishi et al. 2007) was primarily an extensive systematic survey in which a limited number of radio collared caribou were employed to increase the probability of finding the largest concentrations of calving caribou. Visually, their results appear to show that the highest concentrations of caribou would have been detected had their survey been more tightly focused only on areas occupied by radio collared animals. This is consistent with the observations of Patterson et al. (2004) for the Bluenose-East herd. Data from extensive systematic surveys similar to that conducted by Nishi et al. (2007) could be examined employing the radio collared caribou locations and a spatial density estimator. The objective would be to find the optimal area to survey around radio collared animals that would yield an estimate ± a specified proportion of extensive survey based estimates. Future reconnaissance surveys would then focus on radio collared animals; the intensity of the reconnaissance survey could decline with distance from the core area and continue at a vanishing intensity to some pre-specified geographic limit.

The required sample size of radio collared animals would relate to several factors:

(a) The spatial extent of the survey area;

(b) The sizes of groups;

(c) The spatial proximity of groups to each other; and

(d) The survey methodology to be effected around each radio collared animal.

Ultimately, there will be an inverse relationship between the number of radio collars to deploy and the intensity and extent of survey effort around each. I believe the solution to this problem can be acquired through spatial analyses. An adaptive survey methodology, beginning with high survey

effort at cores of radio collared caribou distributions and decreasing effort with distance from both cores and any concentrations of animals identified during surveys should provide the optimal solution. Historic survey data could be used in spatially explicit survey simulations and may yield a survey methodology requiring fewer radio collars and / or less flying time. At the same time survey accuracy and precision may be improved.

Sightability correction factors

Building correction factors for missed animals will assist with accurate population estimates and can also be achieved with the use of radio collared animals and an appropriate survey methodology that involves conducting the initial survey of an area without using radio-telemetry to locate groups. Like survey success, sightability correction factors are also dependent on group size. Eberhardt et al. (1998) suggested that a single sightability correction is inappropriate owing to a number of factors including group size, location, year, and season. Cogan and Diefenbach (1998) built a sightability model and found that of all the factors in their regression model, using only group size as an independent variable generated the most parsimonious model. From data based on mark-resight surveys in Alaska, a regression based approach has been used to produce group size specific probabilities of detection, which may be a promising future approach to correcting for missed animals (L. Adams, personal communication).

PERSONAL COMMUNICATION

Layne Adams, Research Wildlife Biologist, US Geological Survey, Anchorage, AK

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APPENDIX A: A PRIMER ON POWER ANALYSIS

Statistical power is the probability of correctly concluding that a difference exists in the data being tested. For example, if you are monitoring to detect a change in adult survival rate in a population and the adult survival rate actually changes then power is the probability that your monitoring will detect that change. A failure to conduct a power analysis may have two potentially detrimental outcomes:

(1) In the more likely case power will be too low and data may be collected for several years without ever detecting a change in survival, even though the survival rate has actually changed. Population management decisions will be based on the assumption that there is no change in survival because the monitoring program has failed to detect a change. Furthermore, the monitoring may require a considerable investment in time and money without having any reasonable hope of succeeding.

(2) A less likely but possible situation is that the sample size is higher than necessary. In other words the power may be higher than it needs to be and time and money are being used inefficiently. Is it important to have 99% power to detect a 2% decline in calf recruitment?

The Relationships between Statistical Confidence and Statistical Power

		What has really happened	
		(Null Hypothesis true) ***No change***	(Null Hypothesis false) ***Change***
What you concluded from your data	***No change***: Do not reject Null Hypothesis	Correct decision (**Confidence** = 1 - α)	Type II error (β)
	Change: Reject Null Hypothesis	Type I error (α)	Correct decision (**Power** = 1 - β)

Confidence and Type I Statistical Errors

Statistical confidence has been considered in biological decision making for decades. Confidence is the focus of most research work; it is the probability of avoiding a Type I statistical error. A Type I statistical error occurs when you reject the null hypothesis when the null hypothesis is true; essentially, a Type I error is a false alarm; you say something is different (e.g. a population has changed from one survey period to the next) when it really is not. The probability of making a Type I

error is denoted by α (alpha) and Confidence is calculated as 1-α. In research, confidence is typically set at 0.95 (95%; i.e., alpha = 0.05 or 5%). What this means is that if we were to repeat the sampling process a large number of times when the null hypothesis was true (i.e., no change had occurred) then we will wrongly reject it 5% of the time. When we conduct sampling only once and determine that a change has occurred, we will be correct 95% of the time. The confidence level is unrelated to whether or not the null hypothesis is rejected when the null hypothesis is false.

Power and Type II Statistical Errors

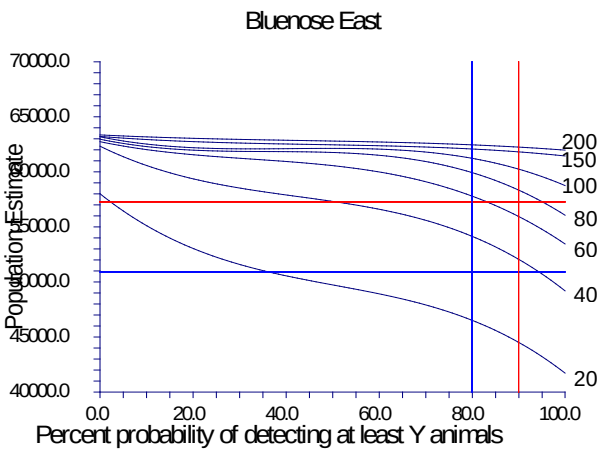
Statistical power is the probability of correctly concluding that a change has occurred when a change really has occurred. Like confidence, it is usually expressed as either a proportion (value between 0 and 1) or as a percentage; the higher the number the higher the power. It is the probability of avoiding a Type II error, which is failing to reject to null hypothesis when the null hypothesis is false. In other words, you make a Type II error when a change has occurred and you have missed it. As with the example above for confidence if we were to set power at 80% and then repeat our data collection many different times when the null hypothesis is really false then 20% of the time we would make a Type II error; we would wrongly conclude that no change had occurred.

Power and Confidence in Monitoring

The selection of power and confidence levels is largely a matter of convention. Research studies have routinely adopted confidence levels of 95% or 90% (alpha = 0.05 or 0.10 respectively). More recently, the convention for monitoring programs is to seek a power of 80% when designing studies. Ultimately, the power and confidence adopted must relate to the levels of acceptable risk and cost. These will vary in each case and are important considerations prior to initiating a monitoring program. A prospective power analysis will prepare those involved for the likely results and their strengths and weaknesses.

APPENDIX B: RESULTS FROM RADIO COLLAR SURVEY SIMULATIONS

a



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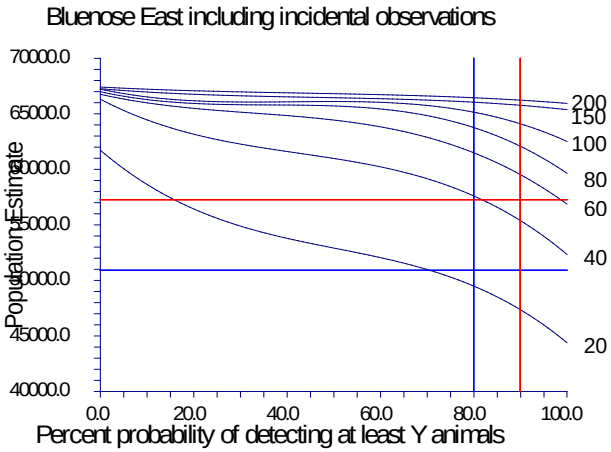

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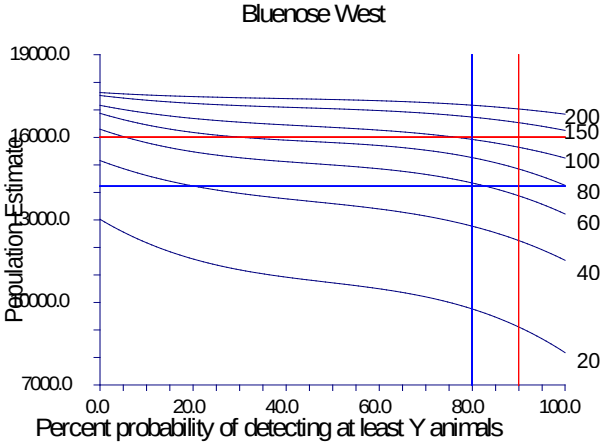

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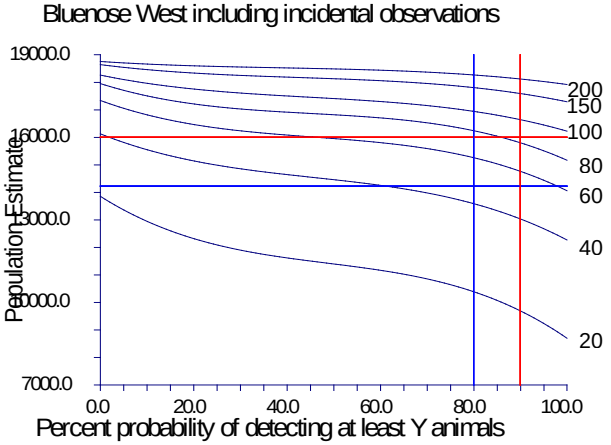
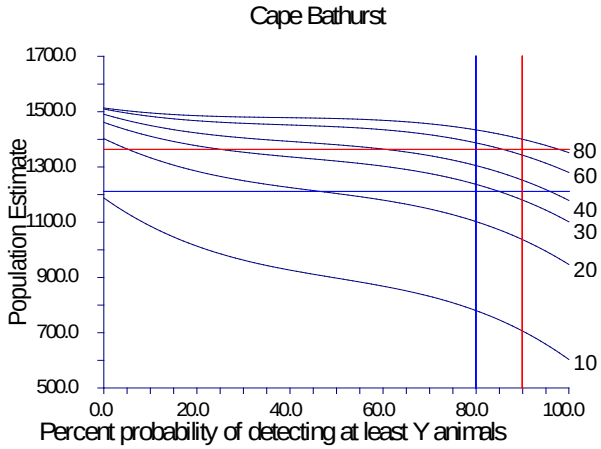
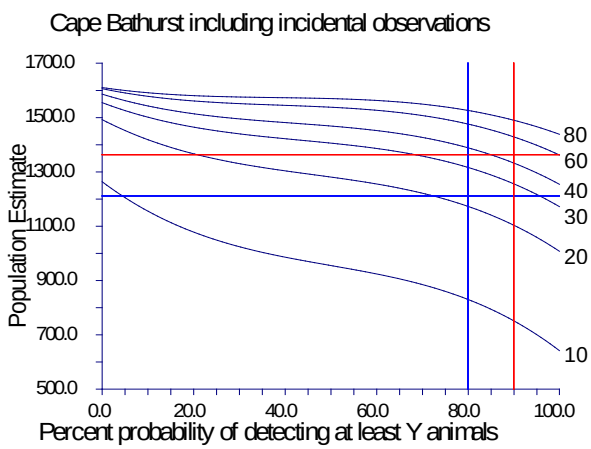


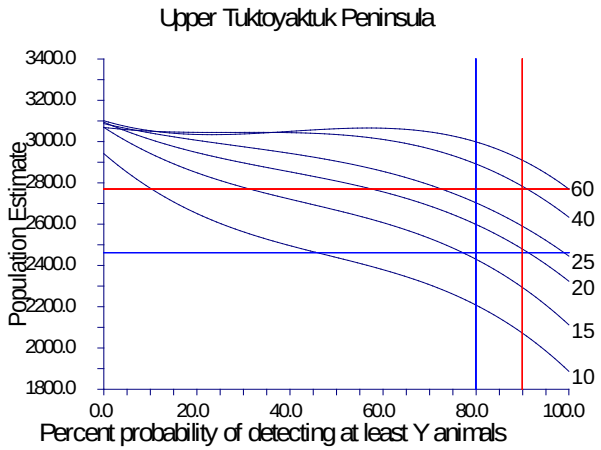
e


Cape Bathurst
Population Estimate
1700.0
1500.0
1300.0
1100.0
900.0
700.0
500.0
0.0
20.0
40.0
60.0
80.0
100.0
Percent probability of detecting at least Y animals
80
60
40
30
20
10

f


Cape Bathurst including incidental observations
Population Estimate
1700.0
1500.0
1300.0
1100.0
900.0
700.0
500.0
0.0
20.0
40.0
60.0
80.0
100.0
Percent probability of detecting at least Y animals
80
60
40
30
20
10

g


Upper Tuktoyaktuk Peninsula
Population Estimate
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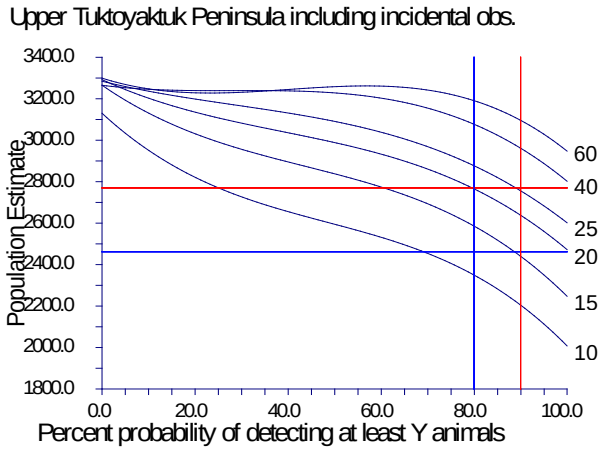
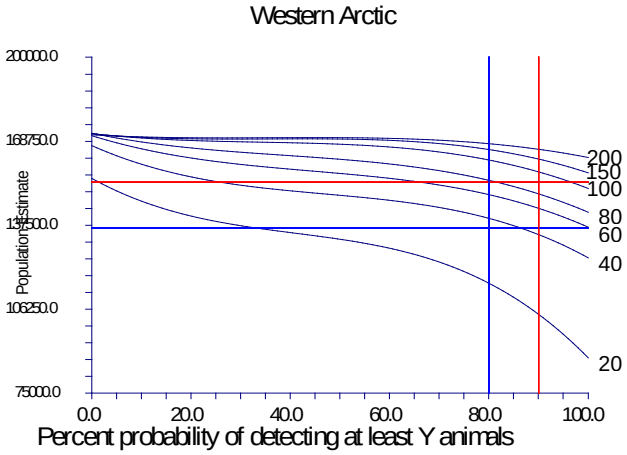
3200.0
3000.0
2800.0
2600.0
2400.0
2200.0
2000.0
1800.0
0.0
20.0
40.0
60.0
80.0
100.0
Percent probability of detecting at least Y animals
60
40
25
20
15
10

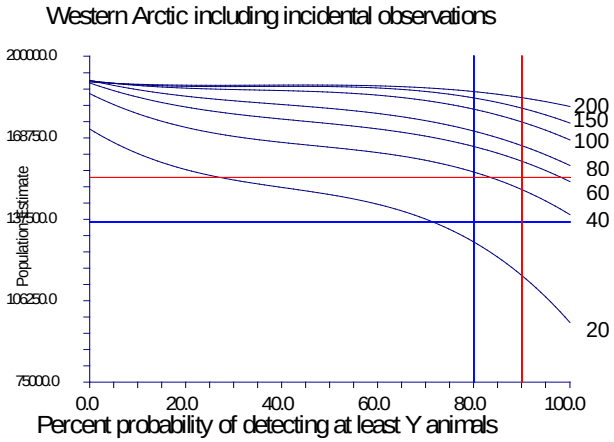
h


Upper Tuktoyaktuk Peninsula including incidental obs.
Population Estimate
3400.0
3200.0
3000.0
2800.0
2600.0
2400.0
2200.0
2000.0
1800.0
0.0
20.0
40.0
60.0
80.0
100.0
Percent probability of detecting at least Y animals
60
40
25
20
15
10

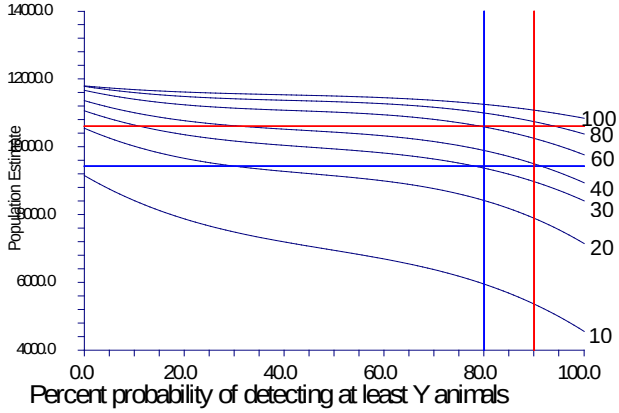
i


Western Arctic
200000.0
168750.0
137500.0
106250.0
75000.0
Population Estimate
200
150
100
80
60
40
20
0.0
20.0
40.0
60.0
80.0
100.0
Percent probability of detecting at least Y animals

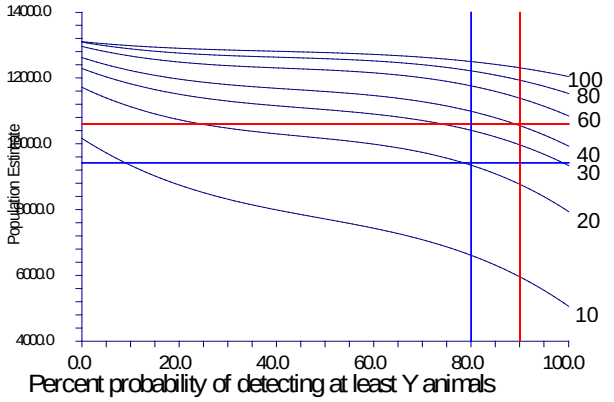
j

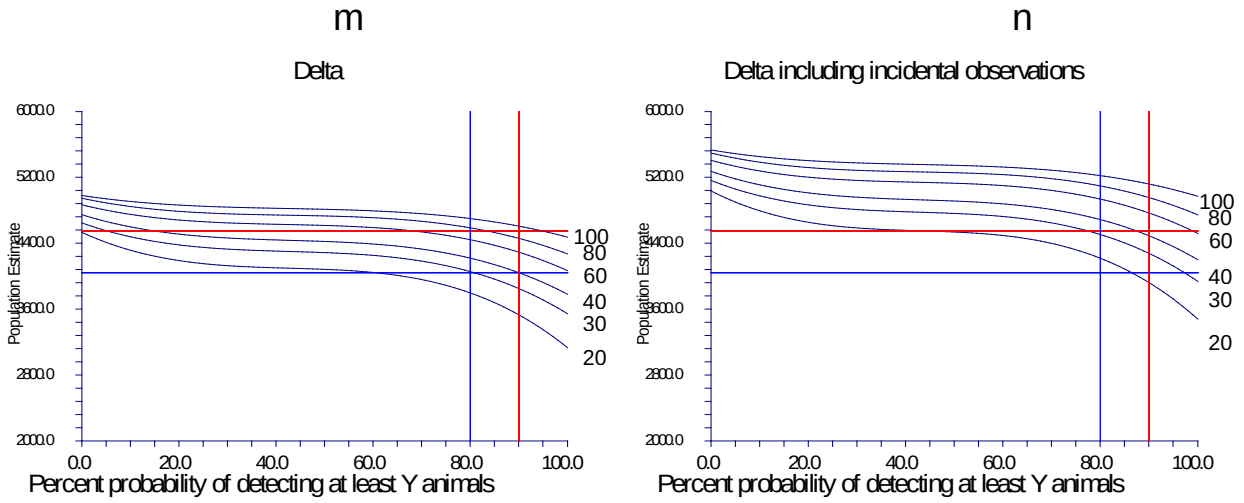

Western Arctic including incidental observations
200000.0
168750.0
137500.0
106250.0
75000.0
Population Estimate
200
150
100
80
60
40
20
0.0
20.0
40.0
60.0
80.0
100.0
Percent probability of detecting at least Y animals

k


Fortymile
140000.0
120000.0
100000.0
80000.0
60000.0
40000.0
Population Estimate
100
80
60
40
30
20
10
0.0
20.0
40.0
60.0
80.0
100.0
Percent probability of detecting at least Y animals

l


Fortymile including incidental observations
140000.0
120000.0
100000.0
80000.0
60000.0
40000.0
Population Estimate
100
80
60
40
30
20
10
0.0
20.0
40.0
60.0
80.0
100.0
Percent probability of detecting at least Y animals



Figures a-n: Relationships between sample sizes (number of radio collars) and the probability of detecting a minimum number of animals in simulated aerial surveys for seven caribou herds. The results are based on simulations using the population estimate and group observations noted in Table 2. There is one curve for each sample size and the number of radio collars associated with the line appears at the right-hand end of the line. The X-axis shows the percentage of the 10,000 simulations run for each sample size for which the population estimate is greater than or equal to the population estimate on the Y-axis.

The left hand figures (a, c, e, g, i, k, and m) show population estimates based only on groups containing radio collared animals. The right-hand figures (b, d, f, h, j, l, and n) show the same data multiplied by a constant to represent groups observed during aerial surveys that do not contain radio collared animals. The consequence is to raise each curve, increasing the numbers of animals observed in the simulations. This mimics the increased numbers of animals observed when conducting aerial surveys and observing groups that do not contain marked animals.

The blue lines in each figure represent 80% probability of observing a population value at least that great (vertical line) and 80% of the total population observed in 2006 (horizontal line). The red lines represent 90% probability (vertical) and 90% population (horizontal).

Figures a-h: Represent herds from the NWT: Bluenose-East (a and b), Bluenose-West (c and d), Cape Bathurst (e and f), and Upper Tuktoyaktuk Peninsula (g and h).

In the right-hand figures (b, d, f, and h) the constant value used is 6.4%, the mean proportion of incidental observations from the most recent surveys in each of four Northwest Territories barren-ground caribou surveys from 2006 (See Table 2).

Figures i-n: Represent herds from Alaska: Western Arctic (i and j), Fortymile (k and l), and Delta (m and n). In the right-hand figures (j, l, and n) the constant value used is 11.1%, the minimum proportion of incidental observations from the 1982-1984 surveys for each of the Alaska caribou surveys (See Table 2).