Government of Northwest Territories Gouvernement des Territoires du Nord-Ouest

# Sample Sizes of Collared Barren-ground Caribou Required to Estimate Herd Size in Winter and Fall Management Areas to Allow Assessment of Harvest Risk

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Integrated Ecological Research

2016

Manuscript Report No. 261

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# ABSTRACT

One challenge to harvest management of caribou herds on winter range areas is the uncertainty of caribou herd status when winter ranges of multiple herds overlap. In this paper I develop a methodology to estimate relative herd sizes on winter range management polygons through the use of location data from collared caribou and herd size estimates from calving ground surveys. In this paper, analyses were carried out to assist in recommending numbers of collars needed to reliably define proportions of each herd in harvest areas in fall and winter, using multi-strata models, existing management areas, and information from 2010-2013 on collar locations and herd size. In general, at least 20 collars would be needed for each herd in each area to define herd distribution and harvest risk with acceptable precision.

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# INTRODUCTION

The Bathurst herd of migratory barren-ground caribou was estimated at 476,000 in 1986 and still numbered over 100,000 in 2006 but by 2009 had declined to 32,000 (Boulanger et al. 2011). While there was a stable trend between 2009-2012, surveys in June 2014 suggested a large decline (Adamczewski et al. 2016 In Prep) thus there is a continuing need to manage harvest carefully for this herd. As a result of this rapid decline, harvest of Bathurst caribou was restricted to 300 caribou/year and 80% bulls in 2010 (WRRB 2010). One of the main current management objectives for the Bathurst caribou herd is assessment of which herds (Bathurst and its neighbours, the Bluenose-East and Beverly, Ahiak, and Qamanirijuaq herds) are being hunted in the winter. Overlap of the Bluenose-East and Bathurst herds on the winter range has been substantial in recent winters. Given that harvest of Bathurst caribou was restricted to 300 per year (WRRB 2010), managers needed to be able to delineate the main areas where each herd is wintering with confidence, and assess the herd membership of hunted caribou spatially. One of the challenges to management of the Bluenose-East and Bathurst herds is that management area boundaries are fixed and therefore it can be difficult to ascertain actual proportions of each herd in areas in winters where the herds' winter ranges overlap. Interpretation is further complicated by the different sizes of each herd and the often different numbers of collared caribou in each herd.

Previous analyses have considered the number of collared caribou needed to adequately delineate winter range areas as well as estimate proportions of caribou in different winter range management areas (Boulanger 2016 In Prep.). These analyses concluded sample sizes of at least 30-40 collared caribou per herd were needed to define proportions of each herd in winter range areas. However, these analyses did not fully assess risk of harvest given that the Bluenose-East and Bathurst herds are of different sizes. Therefore, the relative proportion of each herd in a given winter range polygon will result in different actual numbers of caribou being harvested from each herd. For example, based on calving ground surveys, herd size for the Bluenose-East was estimated at 102,704 (CI=62,470-142,669) in 2010 and then 68,292 (CI=50,796-85,788) in 2013 (Adamczewski et al. 2014, Boulanger et al. 2014). This compares to herd size of the Bathurst of roughly 32,000 in 2009 and 2012 (Nishi et al. 2014, Boulanger et al. 2013). Therefore, the actual risk of harvest for Bathurst caribou on winter ranges depended on the proportion of Bluenose-East caribou that intermingled with Bathurst caribou on winter range polygons but also the relative sizes of the two herds.

In this paper I develop methods to assess risk of harvest based on yearly population size estimates on calving grounds and estimates of movement of each herd from respective calving grounds to winter range areas. Risk in this context is defined as the probability that a caribou on a given winter range polygon belongs to the Bathurst or Bluenose-East herd. I use multi-state models to estimate movements of caribou to fall and winter harvest areas. I then consider statistical uncertainty in these estimates, and statistical uncertainty in the original calving ground estimates to estimate overall statistical certainty in predicted risk for each of the main winter range polygons. Finally, I conduct simulations to determine adequate sample sizes of collared caribou needed to have reasonable certainty in population size estimates for each herd on each winter range polygon.

# METHODS

## Compilation of Data Sets

Collared caribou data for the fall and winters of 2010-2013 were assimilated for the Bluenose-East and Bathurst caribou herds. Fall was defined as August through November and winter was defined as December through April. Herd membership was based upon previous calving ground membership or the assignment of herd during collaring efforts. Locations for caribou during each season were then used to determine the management areas where the majority of points occurred for each season (Figure 1).

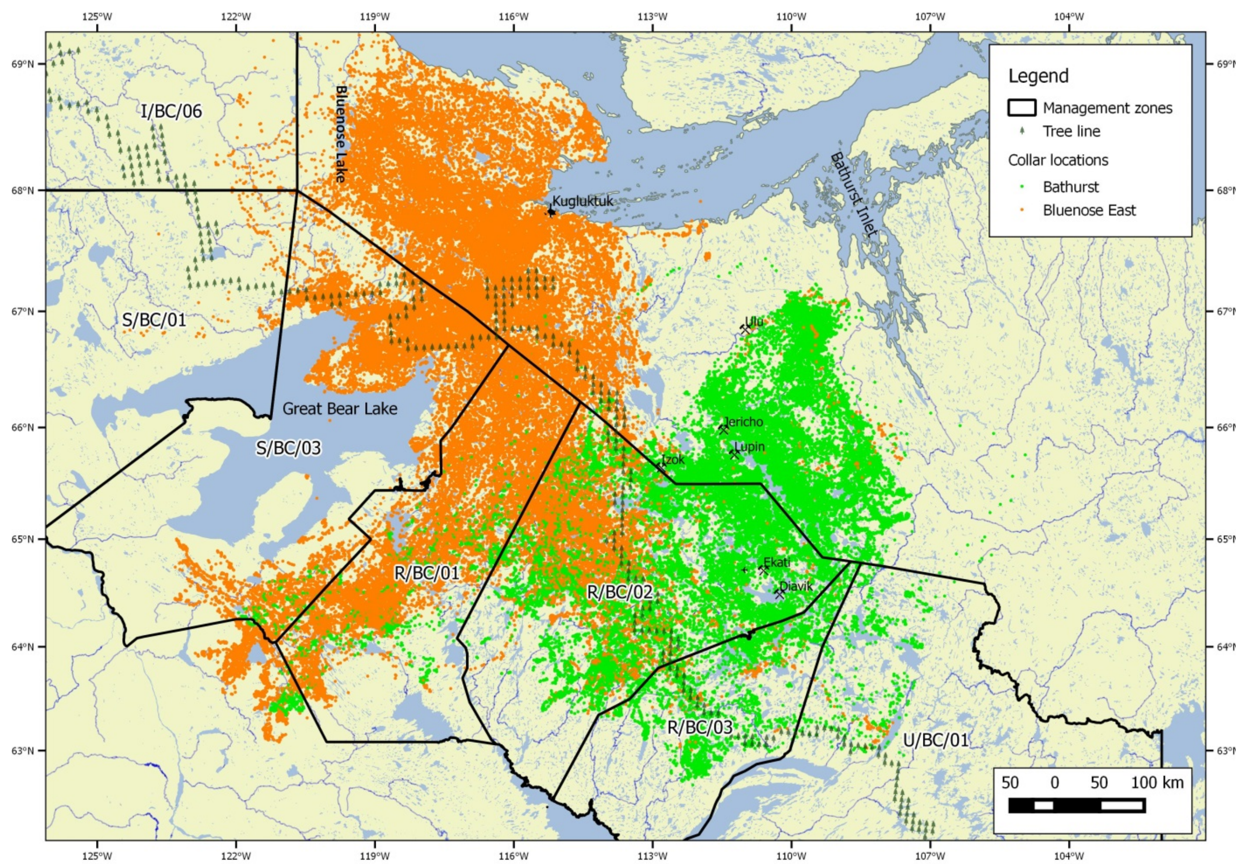


**Figure 1.** Caribou management areas with collar locations for Bluenose-East (orange dots) and Bathurst herds (green dots) for 2010-2013.

From this process a record of calving ground, fall management area residency and winter management area residency was compiled for each collared caribou in the data set. Caribou that were collared after calving in a given year were not used in the analysis unless the herd status of the caribou was known.

## Multi-strata Model Analysis

The resulting data sets were then analyzed using a multi-strata model (Hestbeck et al. 1991, Brownie et al. 1993, White et al. 2006) that estimated the probability of movement of collared caribou from the calving ground to each management area in the fall and then the probability of movement from each management area in the fall to a management area in the winter. The analysis therefore had a calving ground session, a fall session, and a winter session. For example, a caribou that was present on the Bathurst calving ground during calving then moved to R/BC/01 for the fall and then to R/BC/02 for the winter season would have this sequential record in the analysis. Management areas were pooled to three principal strata with the "north" strata defined as R/BC/01 and S/BC/03, the middle strata defined as R/BC/02, and the south strata defined as R/BC/03 and U/BC/01.

Data were entered in the multi-strata model for each herd separately with years as grouping variables. Transition probabilities were only estimated for plausible transitions. For example, it was only plausible that caribou would move from the calving ground to a fall management area between the calving ground session and fall session. Other transition probabilities for the calving ground were set to zero. In some cases, caribou did not move to all the management areas in which case there were zero collars moving to a given area. In this case these transitions were also fixed at zero. The base multi-strata model assumed year-specific movements between all areas given that it was likely there would be yearly variation in movement and residency of herds in each area. The summation of transition probabilities from each strata were constrained to equal one using the multinomial logit link. Simulated annealing was used to assist in model convergence. Outputs from the analysis were a set of movement probabilities between the calving ground and management areas (calving ground to summer) and then movements between the various areas for the interval between fall and winter. All analyses were run in program MARK (White and Burnham 1999).

## Assessment of Calving Ground Population Size

Herd size was based on calving ground surveys that occurred for the Bathurst herd in 2009 and 2012 (Nishi et al. 2014, Boulanger et al. 2013) and Bluenose-East herd in 2010 and 2013 (Adamczewski et al. 2014, Boulanger et al. 2014). Population size was interpolated between the two years assuming constant population trends between surveys.

## Estimation of Bluenose-East and Bathurst Herd Sizes in Management Areas

Herd size was estimated for the fall season for management areas as the product of the calving ground survey herd estimates times the transition probabilities from the given calving ground to each of the management areas. The standard error of the estimate was then derived using the delta method which took into account variance in both the transition probability estimate and the herd size estimate (Buckland et al. 1993).

Herd size on the winter range was then estimated as the product of the fall estimate for each area times each of the transition probabilities for the given area and other areas where caribou could move between the fall and the winter. Included in the calculation was fidelity of caribou to the given area. For example, if the northern management area is denoted by N then the estimate of herd size for winter would be:

$$N_{winter} = \left(N_{fall} * NN + M_{fall} * MN + S_{fall} * SN\right) * Survival_{fall}$$

where $N_{fall}$, $M_{fall}$ and $S_{fall}$ would be estimates of herd size for the northern, middle, and south management areas and NN would be the estimate of fidelity of caribou to the N area from fall to winter, MN would be the movement probabilities of caribou from the middle (M) to the north (N) area and SN would be estimated movement probabilities from the south to the north area. Annual survival was set at 0.8 for both herds based upon OLS model-based survival estimates (Boulanger et al. 2011). Survival rates were then scaled for the time period of the actual seasonal interval. As discussed later these rates are approximate and could be estimated by the actual multi-state model in future analyses. This basic process was used for all the different areas to estimate size of each caribou herd in each area for the winter.

## Estimation of Harvest Risk for Each Herd and Management Area

The relative risk of harvest for each herd was then estimated as the herd estimate for a given area divided by the total number of caribou estimated to be in the area from each of the herds. This can be conceptualized as the probability that a caribou in each area belonged to either the Bluenose-East or Bathurst herds. Variances were again estimated using the delta method to allow an assessment of statistical certainty.

## Determination of Collar Sample Sizes Required to Measure Risk with Statistical Certainty

The precision of herd size estimates in management areas and harvest risk will depend on the precision of the calving ground estimate and the precision of each of the transition probabilities. The precision of the transition probabilities depends on sample sizes of collared caribou in each herd and how the herds move between the various management areas. I initially evaluated precision based upon the actual sample sizes of collared caribou in each herd. I then conducted simulations where sample sizes were increased for each herd and the resulting gains in precision were estimated. Criteria for acceptable precision for simulations was based upon a coefficient of variation (standard error of estimate divided by the estimate) of estimates of less than 20% which is considered acceptable for management (Pollock et al. 1990).

## RESULTS

Estimates of herd size reflected stability of the Bathurst herd and decrease of the Bluenose-East herd as documented in the calving ground survey reports (Boulanger et al. 2013, Boulanger et al. 2014).The precision of herd size estimates ranged from 13-16% based upon extrapolation. Collar sample sizes varied from 20-63 collars with generally fewer collars on the Bathurst herd (Table 1).

**Table 1:** Estimates of herd size on calving grounds based on calving ground estimates and interpolation between estimates. Numbers of collared caribou on calving grounds are also displayed.

| Year | Bathurst | | | | Bluenose-East | | | |
|---|---|---|---|---|---|---|---|---|
| | Collars | N | SE | CV | Collars | N | SE | CV |
| **2010** | 20 | 36,492 | 4,832.45 | 13.2% | 51 | 102,704. | 17,423.6 | 17.0% |
| **2011** | 18 | 35,973 | 4,791.45 | 13.3% | 25 | 89,764 | 15,228.2 | 17.0% |
| **2012** | 22 | 34,690 | 4,691.12 | 13.5% | 63 | 78,454 | 13,309.5 | 17.0% |

Sample sizes of collars on fall and winter range areas varied with the largest sample sizes on the northern R/BC/01-S/BC/03 range for the Bluenose herd (Table 2). Sample sizes of collared caribou on range areas for the Bathurst were low with the majority occurring on the middle R/BC/02 management area.

**Table 2:** Sample sizes of collared caribou for 2010-2013 as a function of management area, season, and herd.

| Season | Management Areas | | | | | |
|---|---|---|---|---|---|---|
| | North: R/BC/01-S/BC/03 | | Middle: R/BC/02 | | South: R/BC/03-U/BC/01 | |
| | **Bluenose-E** | **Bathurst** | **Bluenose-E** | **Bathurst** | **Bluenose-E** | **Bathurst** |
| **2010** | | | | | | |
| Fall | 28 | 0 | 14 | 10 | 0 | 1 |
| Winter | 20 | 0 | 12 | 16 | 0 | 1 |
| **2011** | | | | | | |
| Fall | 9 | 0 | 0 | 5 | 1 | 7 |
| Winter | 6 | 1 | 0 | 7 | 1 | 7 |
| **2012** | | | | | | |
| Fall | 44 | 0 | 8 | 14 | 0 | 2 |
| Winter | 39 | 6 | 11 | 7 | 0 | 4 |

Estimates of herd size for each season and area were based on both movements of collared caribou and estimates for each season (Table 3). In many cases estimates were imprecise (CV>20%) due to low collar sample sizes in management areas. If caribou remained in a management area from fall to winter then the CV of the estimate for the area changed little since fidelity of caribou was close to one for that area. If caribou moved from the area then often precision decreased from fall to winter. Given the complexity of estimates they are best viewed graphically. Figure 2 shows the total estimate of caribou for each management area with the relative numbers of each herd as sub-bars. From this it can be seen that the Bathurst herd was seldom in the S/BC/03-R/BC/01 area with the most intermixing in the R/BC/02 area. In 2010 and 2012 there were reasonable numbers of Bluenose-East and Bathurst collared caribou in this area.

**Table 3:** Estimates of herd size for each management area by season and year.

| Mgmt. Area(s) | Season | Bluenose | | | | Bathurst | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | | **N** | **SE** | **CI (±)** | **CV** | **N** | **SE** | **CI (±)** | **CV** |
| **North: R/BC/01-S/BC/03** | | | | | | | | | |
| **2010** | Fall | 65,591 | 13,068.2 | 25,614 | 19.9% | 0 | 0.0 | 0 | 0 |
| **2010** | Winter | 58,579 | 11,990.6 | 23,502 | 20.5% | 0 | 0.0 | 0 | 0 |
| **2011** | Fall | 77,005 | 15,164.4 | 29,722 | 19.7% | 0 | 0.0 | 0 | 0 |
| **2011** | Winter | 69,964 | 13,777.8 | 27,004 | 19.7% | 0 | 0.0 | 0 | 0 |
| **2012** | Fall | 63,564 | 11,413.3 | 22,370 | 18.0% | 0 | 0.0 | 0 | 0 |
| **2012** | Winter | 52,893 | 9,711.6 | 19,035 | 18.4% | 12,385 | 4279.0 | 8,387 | 34.6% |
| **Middle: R/BC/02** | | | | | | | | | |
| **2010** | Fall | 32,306 | 8,774.8 | 17,199 | 27.2% | 31,861 | 5,266.0 | 10,321 | 16.5% |
| **2010** | Winter | 30,366 | 8,621.6 | 16,898 | 28.4% | 29,328 | 4,847.4 | 9,501 | 16.5% |
| **2011** | Fall | 0 | 0.0 | 0 | | 12,425 | 5,435.2 | 10,653 | 43.7% |
| **2011** | Winter | 0 | . | 0 | | 11,437 | 5,003.2 | 9,806 | 43.7% |
| **2012** | Fall | 11,217 | 4,195.4 | 8,223 | 37.4% | 29,248 | 4,783.1 | 9,375 | 16.4% |
| **2012** | Winter | 15,049 | 4,819.7 | 9,447 | 32.0% | 8,346 | 3,756.8 | 7,363 | 45.0% |
| **South: R/BC/03-U/BC/01** | | | | | | | | | |
| **2010** | Fall | 0 | 0.0 | 0 | | 3,151 | 3,178.6 | 6,230 | 100.9% |
| **2010** | Winter | 0 | 0.0 | 0 | | 2,901 | 2,925.9 | 5,735 | 100.9% |
| **2011** | Fall | 8,556 | 7,836.1 | 15,359 | 91.6% | 22,089 | 5,954.7 | 11,671 | 27.0% |
| **2011** | Winter | 7,774 | 7,119.6 | 13,954 | 91.6% | 20,333 | 5,481.4 | 10,744 | 27.0% |
| **2012** | Fall | 0 | 0.0 | 0 | | 4,034 | 2,744.3 | 5,379 | 68.0% |
| **2012** | Winter | 0 | 0.0 | 0 | | 9,906 | 4,224.4 | 8,280 | 42.6% |

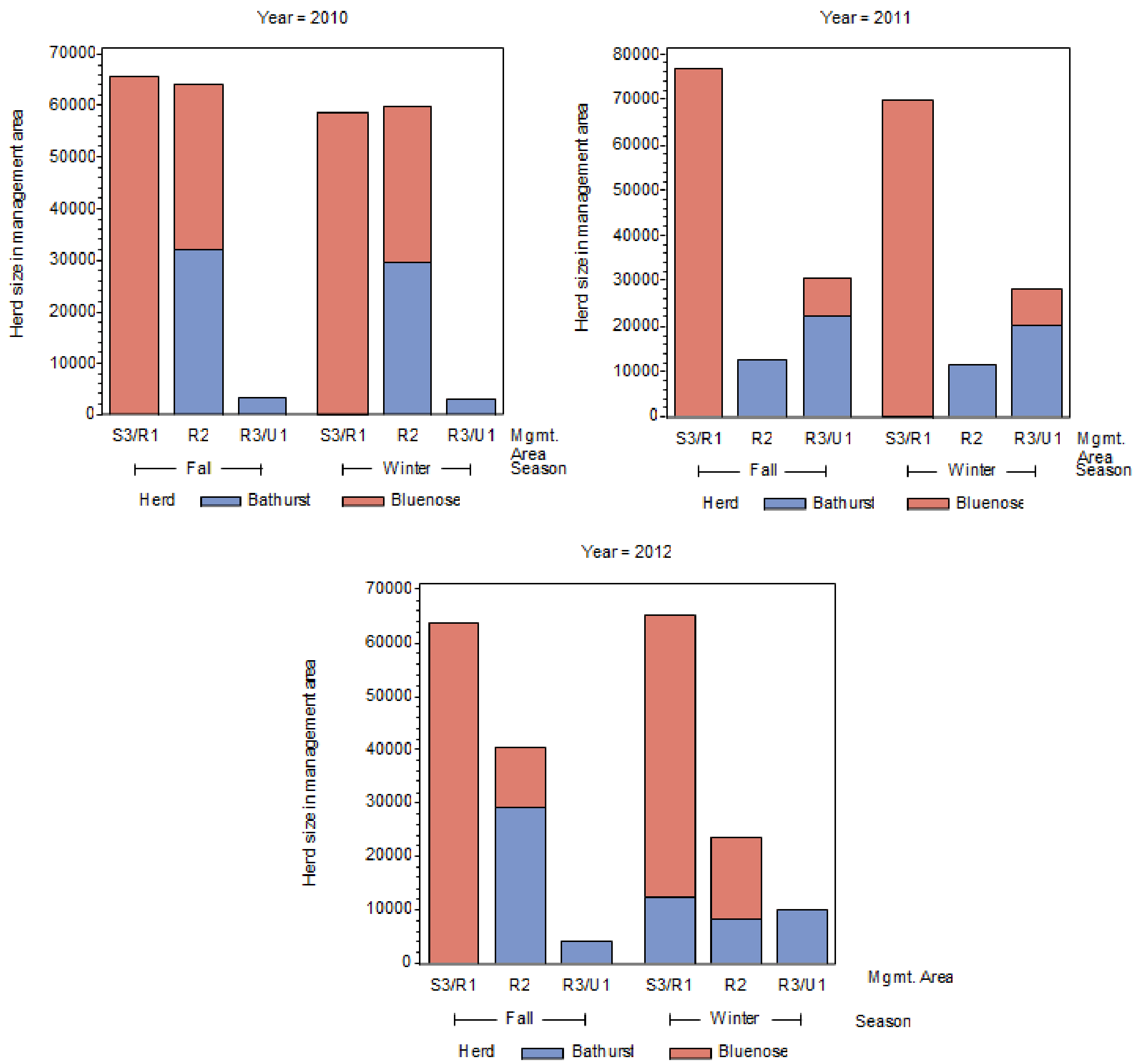


**Figure 2.** Total estimated numbers of caribou on each winter range with relative numbers of each herd indicated by sub-bars.

If the estimates are viewed with confidence limits it can be seen that there is relatively high uncertainty in estimates for some of the management areas (Figure 3). Confidence limits will be determined by the original confidence limit of the calving ground estimate but also the number of collared caribou in the management area.

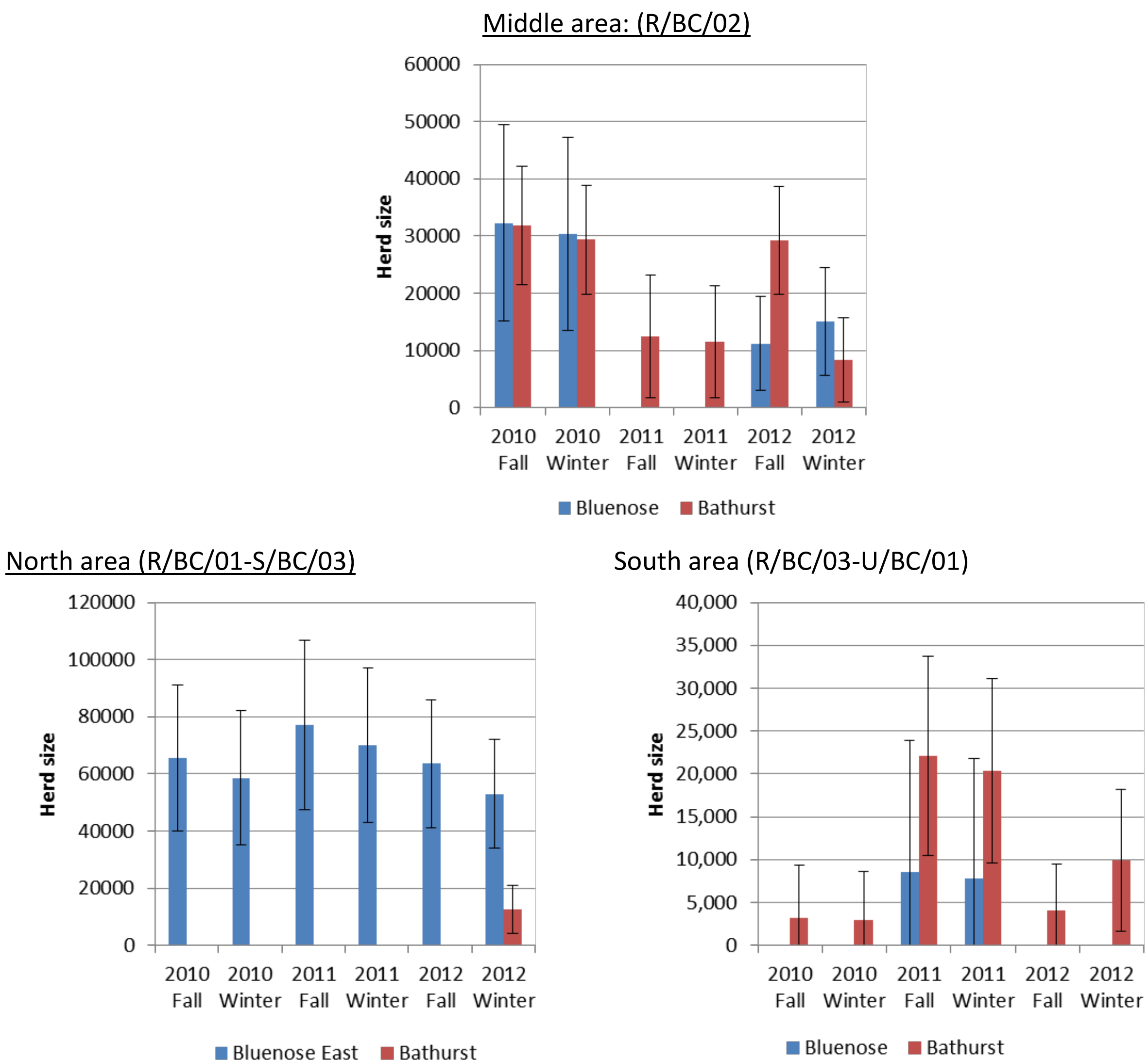


**Figure 3.** Herd estimates with confidence limits for each management area and year.

The harvest risk was estimated as the proportion of Bathurst caribou on each winter range (Figure 4). The estimates indicated the highest risk in the southern R/BC/02-U/BC/01 area in comparison to other areas. However, the relative risk in the R/BC/02 area varied yearly. As discussed later, inclusion of the Beverly, Ahiak, and Qamanirijuaq herds would probably reduce harvest risk for the Bathurst herd in the R/BC/03-U/BC/01 area since these herds do overlap the Bathurst occasionally in these areas (particularly U/BC/01).

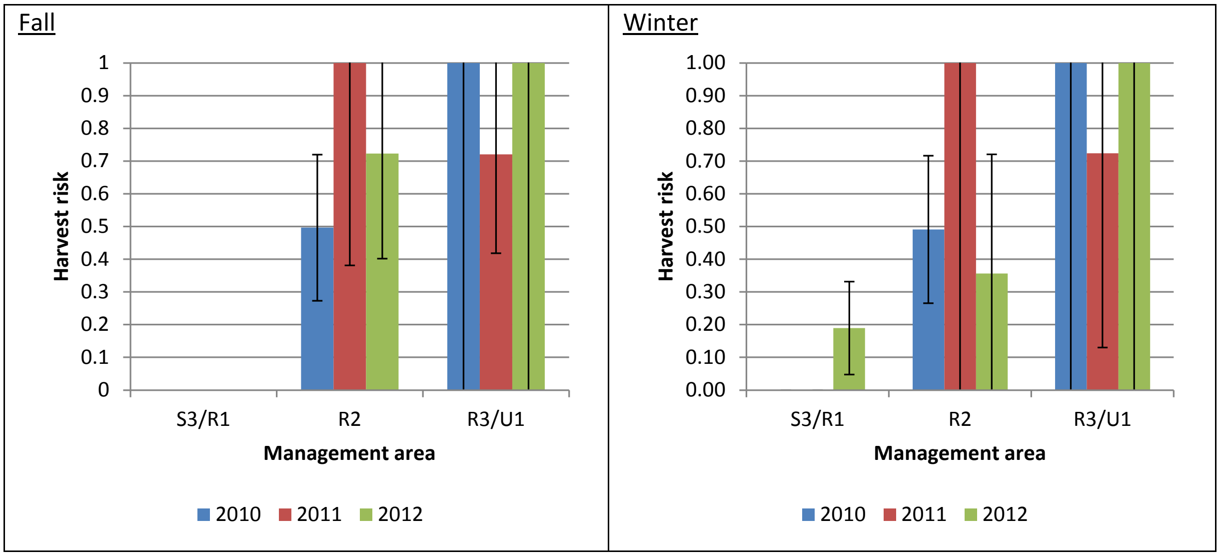


**Figure 4.** Harvest risk for fall and winter for each management area for the Bathurst herd.

## Sample Size of Collars to Obtain Precise Estimates of Management Area Herd Sizes

A plot of the estimates of herd size for the fall and winter ranges for the Bathurst and Bluenose-East herd reveals a pattern where the only estimates that had acceptable precision (CV<20%) were for areas that had 20 or more collars. In some cases precision was reasonable with lower collar numbers however these cases were limited usually to fall and not winter range areas. When collar numbers were <10 the precision of estimates was very low with CVs up to 100% (Figure 5). In general, no estimates had CVs below about 18% due to limitations imposed by the precision of the initial calving ground estimates (Table 1).

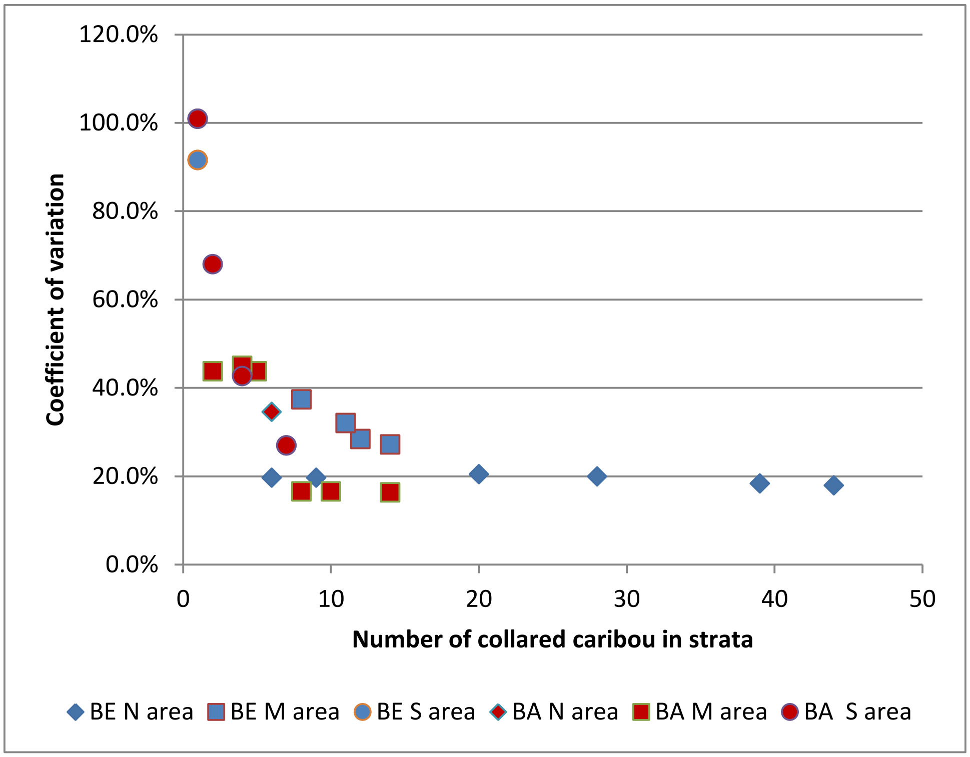


**Figure 5.** Precision of herd size estimates for Bluenose and Bathurst herds based upon the number of collared caribou present in the management area for fall and winter range estimates.

## Simulation Study of Sample Sizes Needed for Adequate Precision

The Bluenose-East and Bathurst caribou 2012 distribution of collared caribou was used as a basis for simulations. Collar numbers in various areas were modified by either changing the number of collared caribou at the initial calving ground or by changing the movement probabilities of caribou into areas. Winter range was considered separately from fall range estimates since winter range involves a separate set of movements from the initial movements from the calving ground. The general trend in all simulations was that acceptable precision of estimates could only be obtained if there were at least 30 collared caribou in a given management area.

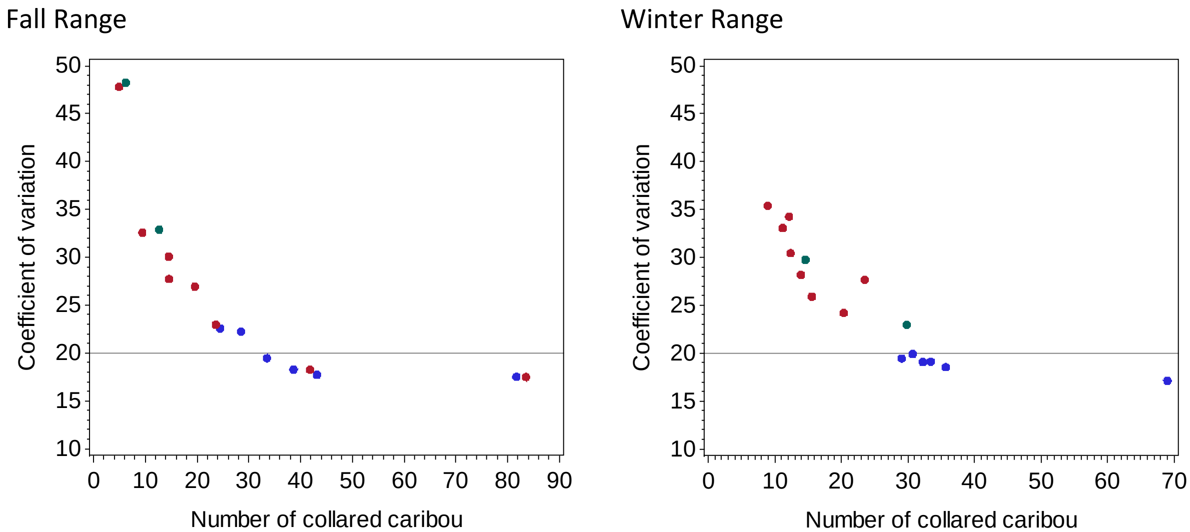


**Figure 6.** Simulation results assuming initial calving ground estimate has a CV of 0.17. The red dots are for the middle strata and the blue dots are for the northern strata and the green dots for the southern strata. Number of collared caribou is for each management area. Coefficient of variation is for the herd size estimates in each management area. Simulation results were pooled given similarities in trends between simulations.

The precision of the calving ground estimate of herd size can also affect the subsequent precision of herd size in management areas and as a result the number of collared caribou needed to obtain adequate precision. To explore this I ran a set of simulations in which the CV of the herd size estimate was 0.13 which is similar to the Bathurst herd in 2010 (Table 2). Using this CV, the number of collars needed for adequate precision is closer to 20 collars per management area for fall estimates but closer to 30 collars for winter estimates.

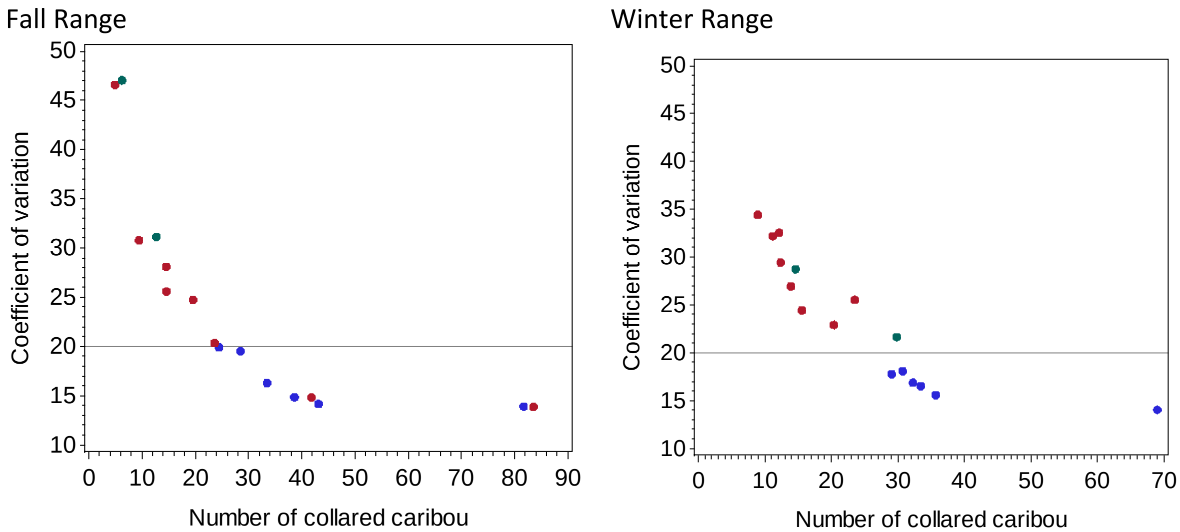


**Figure 7.** Simulation results for assuming initial calving ground estimate has a CV of 0.13. The red dots are for the middle strata and the blue dots are for the northern strata and the green dots for the southern strata. Coefficient of variation is for the herd size estimates in the management area. Simulation results were pooled given similarities in trends between simulations.

## DISCUSSION

The analyses in this manuscript are aimed at providing managers with another tool to assess harvest risk and estimate the proportion of each herd that was harvested in management areas, using collar locations and relative herd sizes. One of the main challenges in recent Northwest Territories caribou management is that numbers are estimated on calving grounds whereas actual management-based decisions for herds usually occur in the fall and winter range areas. This method takes into account the movements of caribou from calving ground areas to management areas in both the fall and the winter. If collar sample sizes are adequate it allows estimates of herd size in each management area. This method is most useful for herds such as the Bluenose-East and Bathurst that intermingle in some of the management areas.

The results of these analyses suggest that management areas should ideally be placed to ensure overlap of the majority of the winter range of each herd. If herds are subdivided between multiple management areas then the uncertainty in the actual number of caribou will increase. For example, empirical and simulation analyses suggest that at least 20 collared caribou are needed per area to allow estimates of adequate precision. If caribou are primarily in two areas then the optimal sample size becomes 40-60 collared caribou. If there are three areas then the optimal sample size becomes 60-90 caribou. A study by Otto et al. (2003) for the George River herd used different analyses but concluded similarly that 64 collars were needed to define the herd's winter distribution with 95% probability and 49 collars with 75% probability.

This method assumes that collared caribou are randomly placed within the herd so that proportions of collared caribou are indicative of the overall distribution of the caribou herd. Using this logic, it also makes sense that sample sizes of caribou need to be reasonable (>30 caribou) to help meet this assumption. It is also assumed that caribou are collared prior to calving so that their herd membership is known. In its present formulation it also assumes that there is no difference in cows or bulls in terms of movement between range areas. This assumption could be tested by adding sex as a covariate to movement transitions.

This method is flexible to different formulations of management areas and sampling intervals, as well as to additional sources of data such as mortality information. In fact, it is possible to add in mortality estimates to get survival rate estimates for each management area, which would enhance the estimates for each area compared to the current approach that assumes equal annual survival rates across all areas and herds. In that context, estimation of survival rates from collared caribou as part of the multi-strata analysis may be useful to better understand spatial causes of mortality. It is also possible to examine factors influencing switching of calving grounds based upon locations of winter ranges. This approach was initially considered for this analysis however sample sizes of switching caribou between the two herds were too low for estimation.

The seasonal sampling periods in this analysis assumed that caribou would show fidelity to a given management area for an entire season (fall or winter). In some cases this did not occur so residency was categorized as the management area where the most locations occurred. It would be possible to use monthly or bi-monthly sampling intervals to provide a finer time scale of caribou movements and herd size estimates. The key limiting factor is sample sizes of collars which would need to be 20-30 caribou per area per herd to allow estimates of fidelity and movement for each sampling period.

One factor that should be considered in evaluation of risk from this analysis is that Beverly, Ahiak, and Qamanirijuaq caribou were not factored in the analysis. This probably would affect the southern management area (R/BC/03-U/BC/01, but mostly U/BC/01) where Beverly, Ahiak, and Qamanirijuaq caribou occur on the winter range. It would be possible to add Beverly, Ahiak, and Qamanirijuaq collar data into the analysis to better estimate risk for these areas.

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