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Population Estimates of Tuktoyaktuk Peninsula, Cape Bathurst and Bluenose-West Barren-ground Caribou Herds, using Post-Calving Photography, July 2018

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ABSTRACT

A post-calving photographic survey was conducted in 2018 to obtain population estimates for the Tuktoyaktuk peninsula, Cape Bathurst, and Bluenose-West barren-ground caribou herds in the Northwest Territories. A total of 103 collars were deployed on the three herds in March and April 2018 in anticipation of the survey.

Photos of the main aggregations of the Bluenose-West herd were taken on July 10, 2018 with additional peripheral groups photographed or counted between July 8-18, 2018. There were 61 collars available for the Bluenose-West herd and 55 of them were counted. The minimum count was 13,390 adult caribou and the population estimate was 21,011±4,602 (with ±95% confidence intervals). There is a non-significant population trend for this herd between 2005 and 2018 of -2% per year.

The main aggregations of the Cape Bathurst herd were photographed on July 16, 2018 and peripheral groups photographed or counted on July 14 and 18, 2018. There were 51 collars available for the Cape Bathurst herd and 50 were counted with a minimum count of 3,180 adult caribou. The resulting adult population estimate (with ±95% confidence intervals) was 4,521±875. This estimate may be affected by the large number of small groups detected but there was a non-significant population trend for this herd between 2005 and 2018 of 4% per year.

Photos were taken of the Tuktoyaktuk Peninsula herd on July 14, 2018. The Tuktoyaktuk Peninsula herd had 17 collars available and all of them were photographed, with the minimum count being 1,157 adult caribou resulting in a population estimate of 1,499±626 of non-calf caribou (with ±95% confidence intervals). The population trend between 2005 and 2018 for this herd is a decline with a rate of 6% per year.

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INTRODUCTION

The first photo surveys of barren-ground caribou post-calving aggregations within the range of the Cape Bathurst and Bluenose-West herds were accomplished in 1986 and 1987 by McLean and Russell (1992). These surveys were of the 'Bluenose' herd, which included barren-ground caribou east of the Mackenzie River to Kugluktuk (Coppermine), and south from the Arctic Coast to Great Bear Lake (McLean and Russell, 1992; Nagy et al., 1999). A review of historic survey data and the results of telemetry surveys, which incorporated data from a satellite tracking program started in 1996, indicated that there were three distinct herds using three calving grounds in the historical 'Bluenose' range (Nagy et al. 1999; Nagy, 2009a; Zittlau et al. 2003). From west to east, these herds are now referred to as the Cape Bathurst (CB), Bluenose-West (BW) and Bluenose-East (BE) herds. The first post-calving ground photo survey to estimate population size of these as distinct herds was conducted in 2000. These herds are regularly monitored as set out in the *Taking Care Of Caribou: The Cape Bathurst, Bluenose-West, and Bluenose-East Barren-ground Caribou Herds Management Plan* (Advisory Committee for Cooperation on Wildlife Management 2014).

The Tuktoyaktuk Peninsula herd (TP) was first identified to the Department of Environment and Natural Resources (ENR) during community consultations (ENR, 2005). Community members in Tuktoyaktuk believe that caribou returned to the peninsula after the domesticated reindeer herd was removed from Tuktoyaktuk Peninsula in 2001 (Nasogaluak, personal communication). It was first surveyed in September 2005 (ENR, internal report) and the first population photo survey was conducted in July 2006 (Nagy and Johnson, 2006). It is currently being managed as a separate herd by the Wildlife Management Advisory Council (NWT) (WMAC (NWT)) and ENR.

Post-calving photo survey results in 2005 and 2006 showed a significant decline in the CB and BW herds since they were surveyed in 2000 (Nagy and Johnson, 2006). Conservation concerns since 2006 have resulted in post-calving ground photo surveys conducted every three years for the TP, CB and BW herds. This report presents the results of the 2018 post-calving photo survey of the TP, CB and BW herds.

For this analysis, the estimator of Rivest et al. (1998) is used to calculate population size. The Rivest estimator is a two-phase estimator of post-calving population size that circumvents many of the issues with the Lincoln-Petersen estimator used previously (Boulanger et al. 2018). The main distinction of the Rivest estimator is that it more appropriately defines caribou groups rather than collared caribou as the sample unit for estimates. Using this approach allows for various models of how collared caribou represent aggregated groups to be considered and provides a more robust estimate of population size that better accounts for the effect of variation in groups sizes and the numbers of collared caribou on estimate precision. Until recently, this estimator was not readily applied given its complexity. However, in 2012 an R package of the estimator became available (Crepeau et al. 2012). The Rivest estimator was applied to past data from all Northwest Territories (NWT) barren-ground caribou post-calving photo surveys (Adamczewski et al. 2016, Boulanger et al. 2016;2018).

METHODS

Collar Deployment

The post-calving population estimate methodology requires a number of collars be active in the herd at the time of the survey. The target number of collars, based on an evaluation of simulations by Rettie (2008), is 30 for both the CB and TP herds and 60 collars for the BW herd. Any collars still functioning are considered and additional collars are deployed to meet the target numbers in March of the survey year. Just prior to deploying collars, a reconnaissance survey is conducted for all three herds to determine the distribution of caribou.

The reconnaissance survey flight lines are planned based on current collared caribou locations, seasonal range (Nagy et al. 2005), and feedback from the local Hunter and Trapper Committees or Renewable Resource Councils. All locations of observed caribou are recorded using a handheld Garmin GPS receiver. Flights are flown at an approximate survey altitude of 300 m AGL and average speed of 200 km/hr. Flight lines are spaced approximately 20 km apart (See Figure 1). The number of caribou observed and general composition of the group (cow/calves, bulls, mixed) is recorded and provided with location co-ordinates to the capture crew.

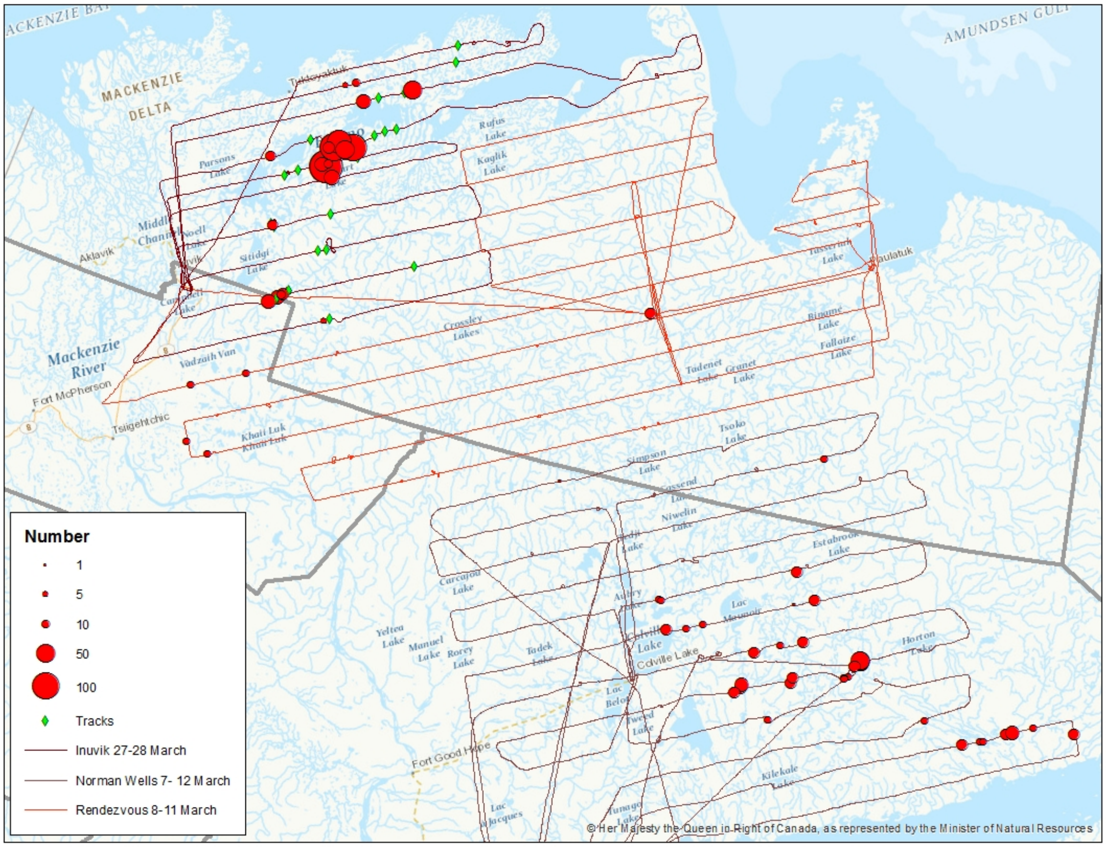

Figure 1. Flight lines and caribou observations during the March 2018 reconnaissance flights.

In March 2018, the collar deployment effort was planned to spread collars throughout the occupied range based on caribou locations obtained from the reconnaissance flights and active collars already deployed. Captures were conducted from late March to early April. Captures were planned to be completed prior to April 15 to reduce impact on pregnant females and a request from the Tuktoyaktuk Hunters and Trappers Committee to delay collaring on the Tuktoyaktuk Peninsula until after April 1. Capture crews consisted of a helicopter pilot, a net-gunner and an animal handler. Captures were conducted using an A-Star helicopter with a sliding door on the same side as the pilot for net gunning.

While conducting captures, operating procedures approved by the NWT Wildlife Care Committee (Wildlife Care Committee 2011) were used. As per these procedures, captures can only be conducted between temperatures of -5°C to -30°C with a pursuit time of less than one minute. The caribou were captured with a net gun and immobilized with leg hobbles. Blindfolds were used to help calm the animals. Each animal was initially examined to assess its condition and check for any capture-related injuries. Samples collected from each animal included: approximately 30 ml of blood (from the femoral vein in the foreleg), approximately 50 g of feces (either from the ground after defecation, or the rectum), and a sample of hair (with roots). Both eyes were checked for Besnoitia, and body measurements were taken (total body length, hind foot length, and neck circumference).

Global Positioning System (GPS) collars manufactured by Telonics, Inc. (Mesa, AZ) and Lotek Wireless Inc. (Newmarket, ON) were deployed on cow caribou. All cow caribou were fitted with collars such that collars were snug around the neck but allowing for an open-palmed hand to be moved freely between the neck and the collar material. As the necks of bull caribou expand during the rut, magnetic expandable GPS collars (Lotek Wireless Inc., Newmarket, ON) collars were deployed on bulls. GPS collar data were accessed either through the Argos or Iridium satellites.

Collar programming by manufacture and model is summarized in Table 1. Telonics collars (55 total) deployed on cow caribou were programed to take locations every eight hours (four locations a day). Lotek collars (48 total) were programmed to obtain locations every four hours (six locations a day). In addition, Iridium collars deployed on cows (six Lotek Iridium and 11 Telonics Iridium) had additional geo-fence programing that would initiate increased data collection (location every hour) when in the Inuvik–Tuktoyaktuk Highway (ITH) regional study area (15 km buffer around the road right of way) to monitor possible effects of the new highway on caribou movements. Each Telonics manufactured collar was equipped with an automatic release (Telonics CR-2A) set to drop-off August 1, 2021. Each Lotek manufactured collar was equipped with an automatic release (TRD) set to drop-off after 156 week from removal of the magnet; February 2021. All collars were also equipped with a VHF transmitter that allowed for tracking of the collar using a receiver and antenna. The very high frequency (VHF) schedule was: June and July on 16 hours starting at 15:00 UTC, and rest of year on ten hours starting at 15:00 UTC.

Table 1. Summary of collar programing.

Manufacture and Model	Number of collars	Deployed on	Herd	GPS schedule	Geo-fencing?	Scheduled Release Date
Lotek Iridium Iridiumtrack	6	Cows	CB/TP	Every 4hrs	Yes	February 2021
Lotek Iridium Lighttrack 420	42	Bulls	BW	Every 4hrs	No	February 2021
Telonics Argos TGW-4680-2/-3	44	Cows	CB/TP, BW	Every 8 hrs	No	August 2021
Telonics Iridium TGW-4677-3	11	Cows	CB/TP	Every 8hrs	Yes	August 2021

Post-calving Survey

Flights were flown in early July, with flight planned based on GPS/satellite (SAT) collar locations. All GPS and SAT collars deployed between 2015 (programed release date of August 1, 2018) and 2018 that were considered active were located using receiver and antenna affixed to the fixed-winged aircraft to ensure that the VHF transmitter was functioning. All collars with a malfunctioning GPS/SAT component were also scanned for to determine if the VHF component was functioning. Located collars with verified VHF functioning were compiled into a list of active collars for the post-calving photo survey.

The herds were monitored remotely using locations from GPS and SAT collars and periodic reconnaissance flights. Once weather and flying conditions were favourable and caribou formed large aggregations, collared caribou were located with a fixed-wing aircraft and high quality digital photos were taken. Photos were taken from the aircraft using a Nikon D3x digital camera. The photographer was seated behind the pilot and photographs were taken through an opening in the window. The collar frequencies, photo frame numbers and GPS waypoint for each aggregated group was recorded. Each aggregation was assigned a group number. The cameras were connected to a GPS receiver using a Nikon MC-35 GPS adapter cord so that a latitude and longitude were also recorded with the photographs. If the aggregation could not be captured in one photo, a series of overlapping photos were taken in one pass, to ensure minimal movement of caribou between frames.

The best photo (or best series of overlapping photos) for each group was selected. Digital photos were loaded into OziExplorer GPS Mapping Software (Version 3.95.4m, D&L Software Pty Ltd.) to create a photomap of each image. For large caribou groups covered by more than one photo, overlapping images were loaded side-by side on two computer screens and track lines were created in OziExplorer to delineate overlapping areas on the images. All adult caribou were counted on the photographs, and recounted independently by another preson, to test for counting error.

Incidental observations are not included in the Rivest estimate, however the proportion of counted animals from incidental observations was derived by calculating the percent of caribou associated with a non-radio collared group out of the total number of caribou counted.

Population Estimate

The Rivest estimator considers the sampling of post-calving aggregations as a two phase sampling process (Rivest et al. 1998). The first phase involves the distribution of collared caribou within the post-calving groups encountered during the survey. For this estimator, it is assumed that *n* caribou are collared and these caribou randomly distribute themselves into *m* groups during the post-calving period. In general, the probability of a group containing at least one collared caribou ($\hat{p}_{\geq 1 collar}$) increases with group size. The assumption in this case is that the radio collared caribou are randomly distributed within the groups and a test of this assumption is provided as part of the estimation procedure. Given that collared caribou are used to estimate detectability of groups, the Rivest estimator does not utilize data for groups of caribou sighted that contained no collared caribou.

The second phase of sampling involves the actual aerial search for groups. For this phase various models are proposed as to how groups with collared caribou are detected. Fundamental to this procedure is the estimation of detection probability of groups of caribou ($\hat{p}_{group}$). We summarized the sub-models as:

1. *The homogeneity model* - This model assumes that caribou groups (with collared caribou in the groups) are missed as a completely random event that is independent of the number of collared caribou in the group or other factors. Therefore, each group will have the same probability ($\hat{p}_{group}$) of being detected by the aerial survey.
2. *The independence model* - This model assumes that each collared caribou in the group has the same independent probability of being detected and therefore the overall probability of detecting a group ($\hat{p}_{group}$) increases as a function of the number of collared caribou in the group. An analogy would be the probability of detecting a group being equivalent to getting heads in a coin flip. As the number of coin flips (collared caribou) increases the probability of getting at least one heads (detection of the group) increases also. The assumption here is that the collared caribou are independent so that a simple probability model can be applied to detection of the group.
3. *Threshold model* - This model assumes that all groups with more than a threshold level of collared caribou (symbolized by B) have a detection probability of 1. For example, it might be that once more than three collared caribou occur in a group the group will always be detected whereas groups with one or two collars are not always detected. For this model, all groups with more caribou get a detection probability of 1 and detection probability ($\hat{p}_{group}$). is estimated for groups with one or two collars.

Each of these models can potentially describe detection probability variation in the data set. As part of the estimation procedure a log-likelihood score is produced and the model with the highest log-likelihood is considered to best fit the data. Threshold models are run across the range of observed sizes of collars in groups in the surveys we assessed.

The estimate of herd size (symbolized by $\hat{T}$) is then basically the summation of each group size divided by the probability of the group being observed and having at least one collared animal included in it (which is estimated by the product of $\hat{p}_{group}$ and $\hat{p}_{\geq 1 collar}$).

$$\hat{T} = \sum_{i=1}^{n\ groups} \frac{group\ size}{\hat{p}_{group} * \hat{p}_{\geq 1 collar}}$$

It is through an iterative likelihood-based optimization procedure that each of these parameters is estimated to produce estimates of herd size.

An assumption of this method is that the collared caribou are randomly distributed within the separate caribou groups that are photographed. This assumption can be tested by assessing the number of collared caribou that are counted relative to group sizes. It is possible to test this assumption using a test for overdispersion of the Poisson probability distribution. Overdispersion applies to a case when non-independence of collared caribou produces a distribution of collared caribou relative to group sizes that is different from that if the caribou were randomly distributed. If overdispersion occurs then both estimates of population size and variance from the Rivest estimator will be negatively biased (Rivest et al. 1998).

All calculations were conducted using the R-package (R_Development_Core_Team 2009) entitled "caribou" (Crepeau et al. 2012). Confidence limits (CI) were based upon multiplication of the standard error (SE) of the estimate times 1.96. The lower limit of the CI was constrained to be equal or greater than the minimum number of caribou counted during the survey.

The Lincoln-Petersen method has been used in many historic post-calving studies to obtain estimates of herd size. We compared Rivest and Lincoln-Petersen estimates in terms of relative difference between estimates and overlap of confidence intervals as a function of sampling effort. The Lincoln-Petersen estimate of herd size was calculated using the total count of caribou observed during the survey (C), the number of collared caribou available (M), and the number of collared caribou that were observed in groups (R)(Russell et al. 1996, Patterson et al. 2004). Herd size is then estimated as:

$$\hat{N} = \left(\frac{(M+1)(C+1)}{R+1}\right) - 1$$

with variance estimated as:

$$Var(\hat{N}) = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)}$$

Some authors have suggested that only counts of groups with collars should be used with the Lincoln-Petersen estimator (Russell et al. 1996, Patterson et al. 2004) whereas other studies have included caribou from groups observed without collars (Nagy and Johnson 2006) under the assumption that groups without collars were often in close proximity to collared groups and therefore constituted part of the population represented by collared caribou. We calculated the estimate using both methods to assess the sensitivity of estimates to this assumption.

Note that if all of the collared caribou are observed in groups then the M and R terms in the herd size equation cancel each other out and the Lincoln-Petersen estimate equals the count of caribou observed. Also, the M-R term in the variance estimate becomes 0 leading to an estimate of 0 variance. In this case, it is assumed that a census of the herd has occurred with all individuals counted. Lincoln-Petersen estimates were calculated using the *caribou R* package.

Trend

Trends for each herd as indicated by Rivest estimates were modeled using weighted regression analysis (Brown and Rothery 1993). Each estimate of herd size was weighted by the inverse of its variance to account for unequal variances of surveys, and to give more weight to the more precise surveys. The more recent estimates from 2005-2018 were considered for this analysis. Earlier reports detail analyses of full data sets (Boulanger et al. 2016). Analyses were conducted with PROC GLM within SAS statistical package (SAS Institute 2000). Estimates were log transformed to partially account for the exponential nature of population change (Thompson et al. 1998). The rate of change could then be estimated as the exponent of the slope term in the regression model. The per capita growth rate (r) can be related to the population rate of change (λ) using the equation $\lambda = e^{r} = N_{t+1}/N_{t}$. If $\lambda=1$ then a population is stable; values > or <1 indicate increasing and declining populations. In addition, the halving time or doubling times for population were estimated as $0.693/r$ if a significant trend was detected. Halving or doubling time is the number of years before a population is half or double the current estimate under the assumption of a continued exponential rate of population change (Caswell 1989, Gunn and Russell 2008).

RESULTS

Collar Deployment

Reconnaissance flights over the late winter range of the BW herd were conducted March 7-12. Flights were conducted using a Cessna 185 fixed-wing aircraft (Simpson Air, Fort Simpson) based out of Rendezvous Lake and Cessna 206 fixed-wing aircraft (North-Wright Airways Ltd., Norman Wells, NWT) based out of Norman Wells. Reconnaissance flights over the late winter range of the TP and CB herds were conducted March 27-28. These flights were conducted using a Cessna 206 fixed-wing aircraft (North-Wright Airways Ltd., Norman Wells, NWT) based out of Inuvik. Other wildlife observations were also recorded during these flights. Flight lines and caribou locations marked during the survey are shown in Figure 1.

A total of 103 collars were deployed, 61 on cows and 42 on bulls (Figure 2). Collaring was conducted from Rendezvous Lake March 16-21 and from Norman Wells on April 3; this targeted the winter range of the BW herd. From April 4-11 collaring was conducted from Inuvik to target the winter range of the TP and CB herds. During the collaring period the TP and CB herds were mixed in the area around Husky lakes making identification of herd during deployment difficult in this area. However, several collars were also deployed on the TP herd present on the Tuktoyaktuk Peninsula during this time period. Final herd assignment was done in June, after newly collared caribou have returned to a calving ground.

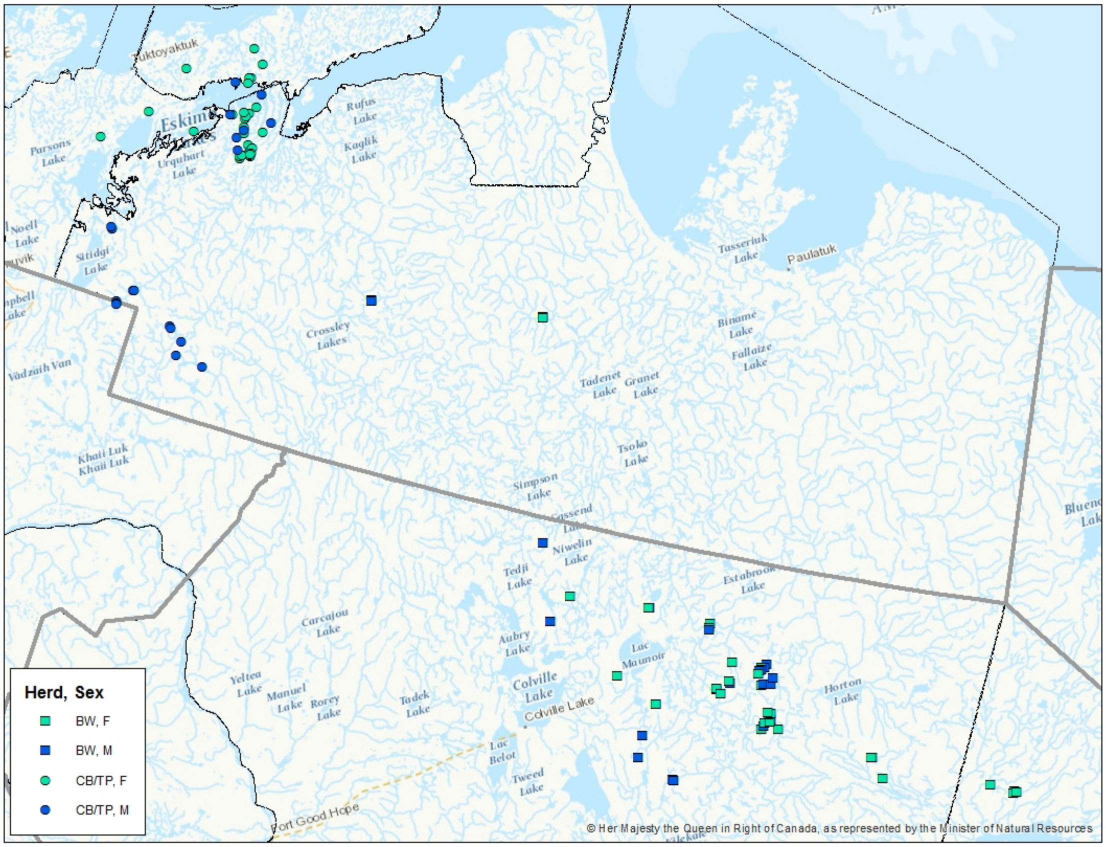

Figure 2. Location of deployed collars March and April 2018.

Average chase time during capture was <1 minute. Average handling time, from when the animal was first captured in the net to final release, was 14 minutes.

Caribou were generally in good shape. On a scale of one to four, the average condition was 2.4 (range one to 3.5). However, many of the caribou captured in the TP/CB herds had patches of worn hair on legs and some also on their nose. There was a visible ice layer in the snow in this area. Thirteen of the 103 (12.6%) captured caribou had Besnoitia, a parasite that can be detected by small white bumps present in one or both eyes.

During the capture effort, there were two caribou mortalities on the BW range and two on the TP/CB range. In three of these four incidences, the caribou suffered broken legs and were put down by the capture crew. The capture team did an assessment of the capture events and could not find any changes to the capture procedure that could reduce the chances of this happening again. The other mortality occurred when the net tangled on the antlers of a bull caribou and the caribou continued to run. While two more nets were deployed on the bull to capture it, the caribou sustained a chest injury from one of the weights and the capture crew put the caribou down. An assessment of the event determined that larger sized nets should be used for all captures to help ensure that all caribou, including antlered animals, are better tangled. Larger nets were secured for use before more captures proceeded. In all cases, the crew field butchered the caribou and the meat was distributed to local communities.

Post-calving survey

Surveys to verify the number and frequency of collars with functioning VHF components commenced June 30.

There were 32 collars from 2015 deployment and four collars from 2017 deployment still active on the three herds. Of the 103 collars deployed in 2018, one collar malfunctioned and seven collars went stationary prior to the survey, leaving 95 collars still active. After observing the collar movements, two of the deployments turned out to be cows that calved on the Bluenose-East calving ground. The location of where collared caribou were photographed in July compared to location collared in March is shown in Figure 3. The total number of collars found active and available for the photo survey was 61 for BW, 51 for CB and 17 for TP (Table 2).

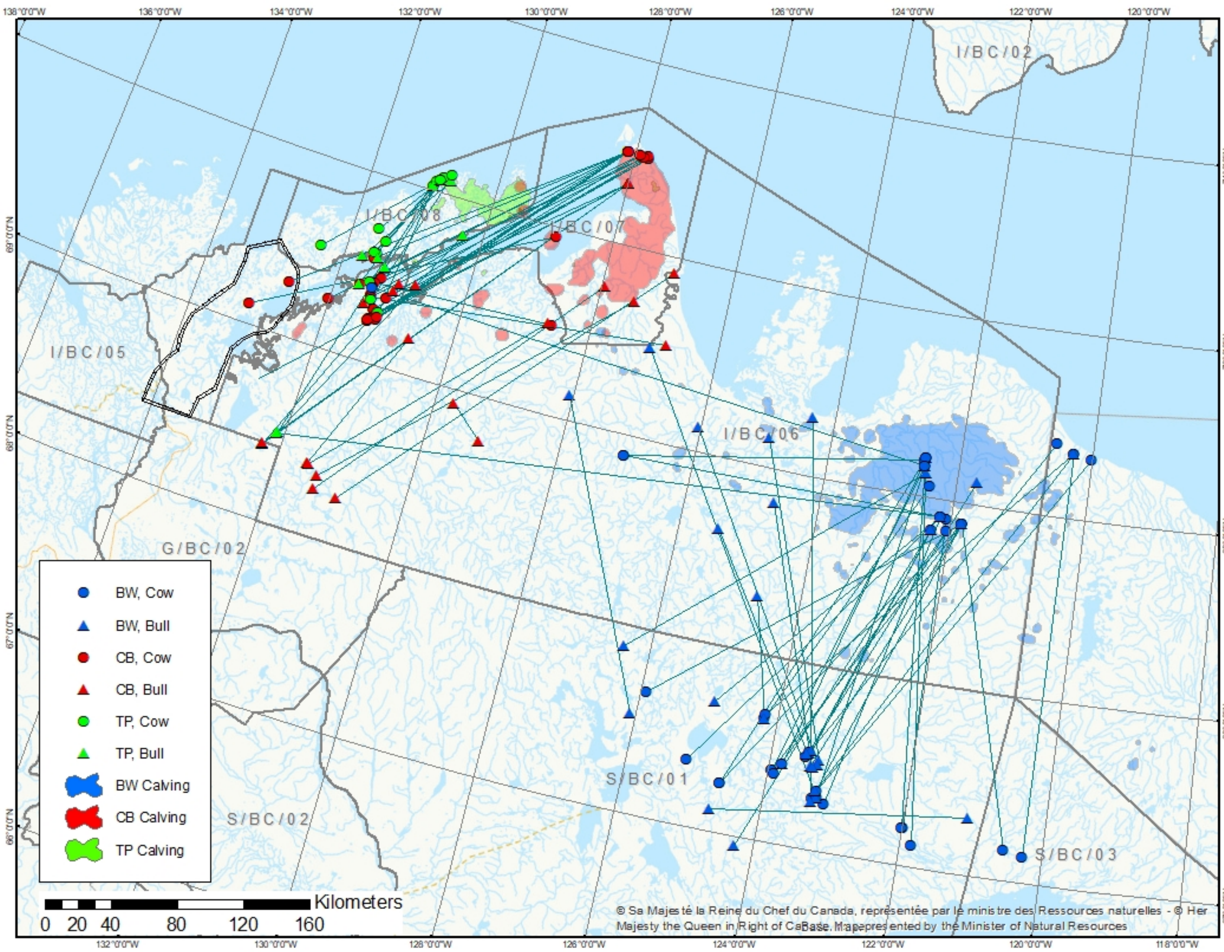

Figure 3. Location where caribou were collared in March/April vs where they were photographed in July 2018, symbolized by herd and sex. (Calving area are 90% kernel densities from collar locations 2009-2016 also show for comparison, ENR unpublished Data)

Table 2. Collars available for the 2018 post-calving photo survey by sex and deployment year.

	Bluenose-West		Cape Bathurst		Tuktoyaktuk Peninsula		
Deployment Year	Cow	Bull	Cow	Bull	Cow	Bull	Total
2015	14	2	8	4	2	2	32
2017			4				4
2018	24	21	20	15	8	5	93
Total Available	38	23	32	19	10	7	
	61		51		17		129

The main aggregations of the BW herd were photographed on July 10. On July 8, 11, 13 and 18 some additional bull groups were located and included in the analysis. All but one of these groups was single bulls, with the one exception being a pair. These groups never aggregated and were geographically distinct from the main herd which aggregated (Table 3, Figure 4). Ten groups were found that did not have collared caribou in them, and 447 caribou were counted in those groups, therefore 3.3% of the caribou counted were incidental observations.

Table 3. Survey data for the 2018 BW survey.

Date	Group	Collars	Sex of collared caribou	Caribou
08-Jul	0	1	Male	1
10-Jul	1	5	Male & Female	1,796
10-Jul	2	5	Male & Female	1,949
10-Jul	3	1	Female	430
10-Jul	4	4	Male & Female	1,637
10-Jul	6	1	Female	1
10-Jul	7	0	n/a	1
10-Jul	8	0	n/a	108
10-Jul	9	6	Male & Female	2,403
10-Jul	10	0	n/a	36
10-Jul	11	0	n/a	130
10-Jul	12	1	Female	5
10-Jul	13	1	Female	220

Date	Group	Collars	Sex of collared caribou	Caribou
10-Jul	14	0	n/a	1
10-Jul	16	0	n/a	1
10-Jul	17	1	Female	67
10-Jul	18	2	Female	506
10-Jul	19	4	Male & Female	1,327
10-Jul	20	4	Female	717
10-Jul	22	5	Male & Female	1,451
10-Jul	23	1	Male	12
10-Jul	24	3	Male & Female	376
10-Jul	25	0	n/a	102
10-Jul	26	0	n/a	66
10-Jul	28	1	Female	35
10-Jul	29	0	n/a	1
10-Jul	30	1	Male	1
11-Jul	31	1	Male	1
11-Jul	32	1	Male	1
11-Jul	33	0	n/a	1
11-Jul	34	1	Male	2
11-Jul	35	1	Male	1
11-Jul	36	1	Male	1
13-Jul	37	1	Male	1
18-Jul	38	1	Male	1
18-Jul	39	1	Male	1
Total		55		13,390

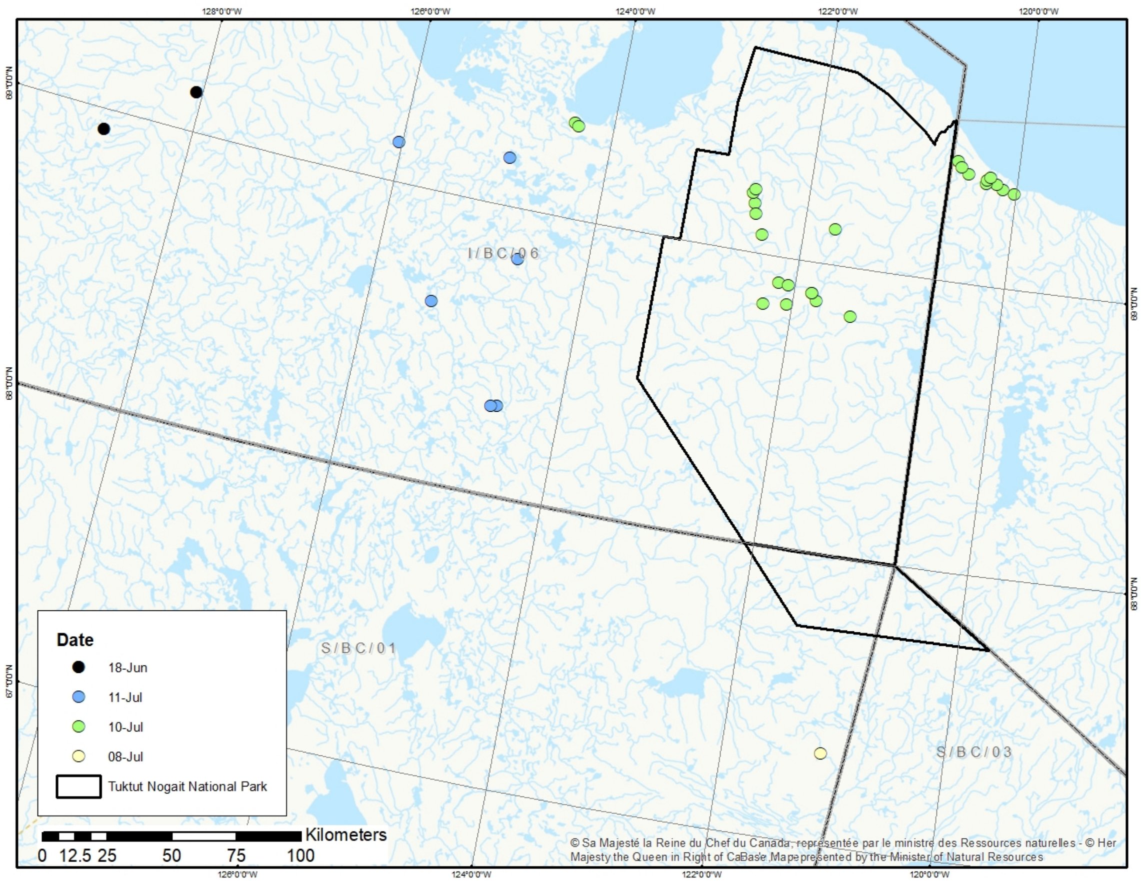

Figure 4. Location of groups counted during the July BW post-calving survey.

The main aggregations of the CB herd were photographed July 16. On 14 of July one group (group 0), located at Nicolson Point, was aggregated and photographed. Localized fog made locating it again on the 16th impossible however it was geographically isolated from the main aggregations. Additionally some small groups, which never aggregated, were located on July 18 and included in the analysis (Table 4, Figure 5). These were all small groups with many being single bulls and were geographically distinct. All groups located for CB had collared caribou in them.

Table 4. Survey data for the 2018 CB herd.

Date	Group	Collars	Sex of collared caribou	Caribou
14-Jul	0	1	Female	111
16-Jul	1	18	Female	1,311
16-Jul	2	4	Female	266
16-Jul	3	4	Female	324
16-Jul	4	2	Female	273
16-Jul	5	1	Female	259
16-Jul	6	7	Male	615
16-Jul	7	1	Male	1
16-Jul	8	1	Male	1
16-Jul	9	1	Male	1
16-Jul	10	1	Male	2
16-Jul	11	1	Male	1
18-Jul	12	1	Female	2
18-Jul	13	1	Female	1
18-Jul	14	1	Male	1
18-Jul	15	1	Male	1
18-Jul	16	1	Male	1
18-Jul	17	1	Male	6
18-Jul	18	1	Male	2
18-Jul	19	1	Male	1
Total:		50		3,180

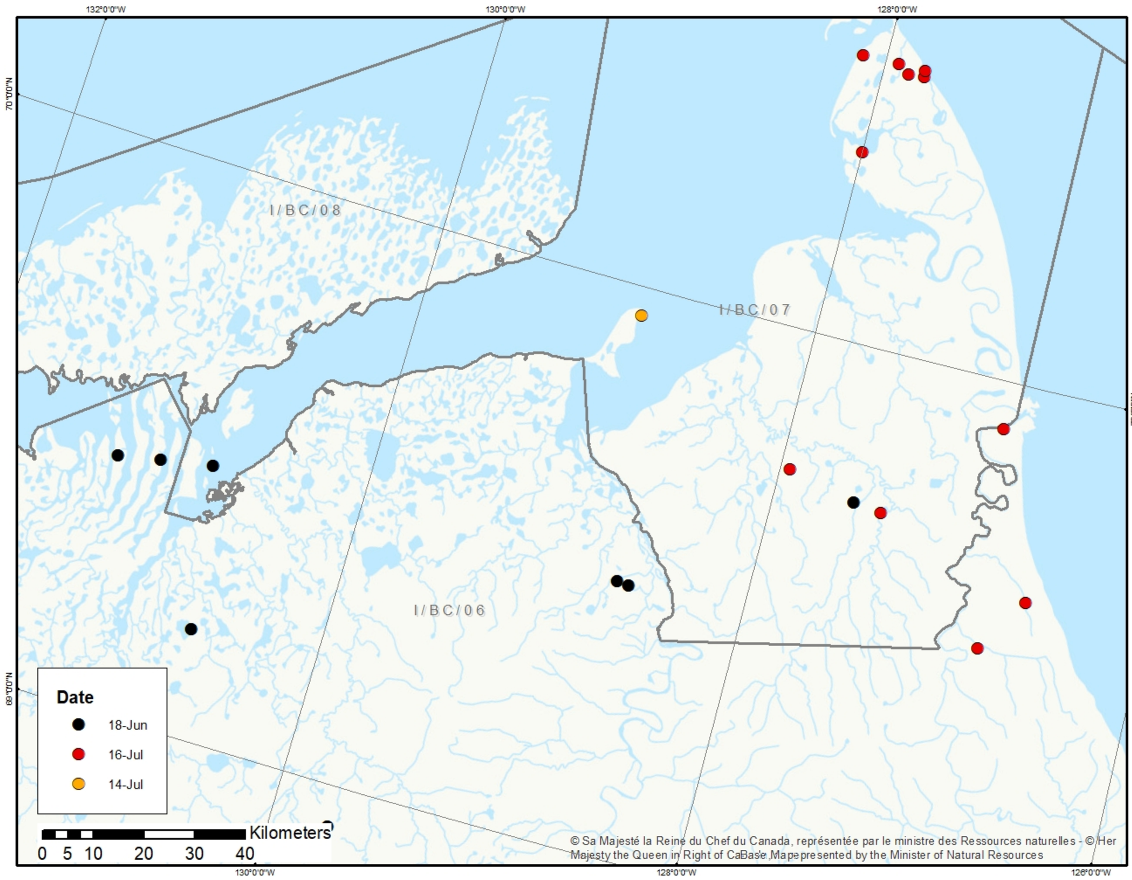

Figure 5. Location of groups counted during the July CB post-calving survey.

The TP herd was aggregated and photographed on July 14 (Table 5, Figure 6). Three groups were found without collared cariobu in them and 94 caribou were counted in those groups. Therefore 8.1% of the caribou counted were incidental observations.

Table 5. Survey data for the 2018 TP herd.

Date	Group	Collars	Sex of collared caribou	Caribou
14-Jul	1	1	Male	3
14-Jul	2	3	Male & Female	147
14-Jul	3	1	Female	86
14-Jul	4	5	Male & Female	378
14-Jul	5	2	Male & Female	67
14-Jul	6	0	n/a	57
14-Jul	7	1	Male	80
14-Jul	8	0	n/a	36
14-Jul	9	1	Female	66
14-Jul	10	2	Male & Female	232
14-Jul	11	0	n/a	1
14-Jul	12	1	Male	4
Total:		17		1,157

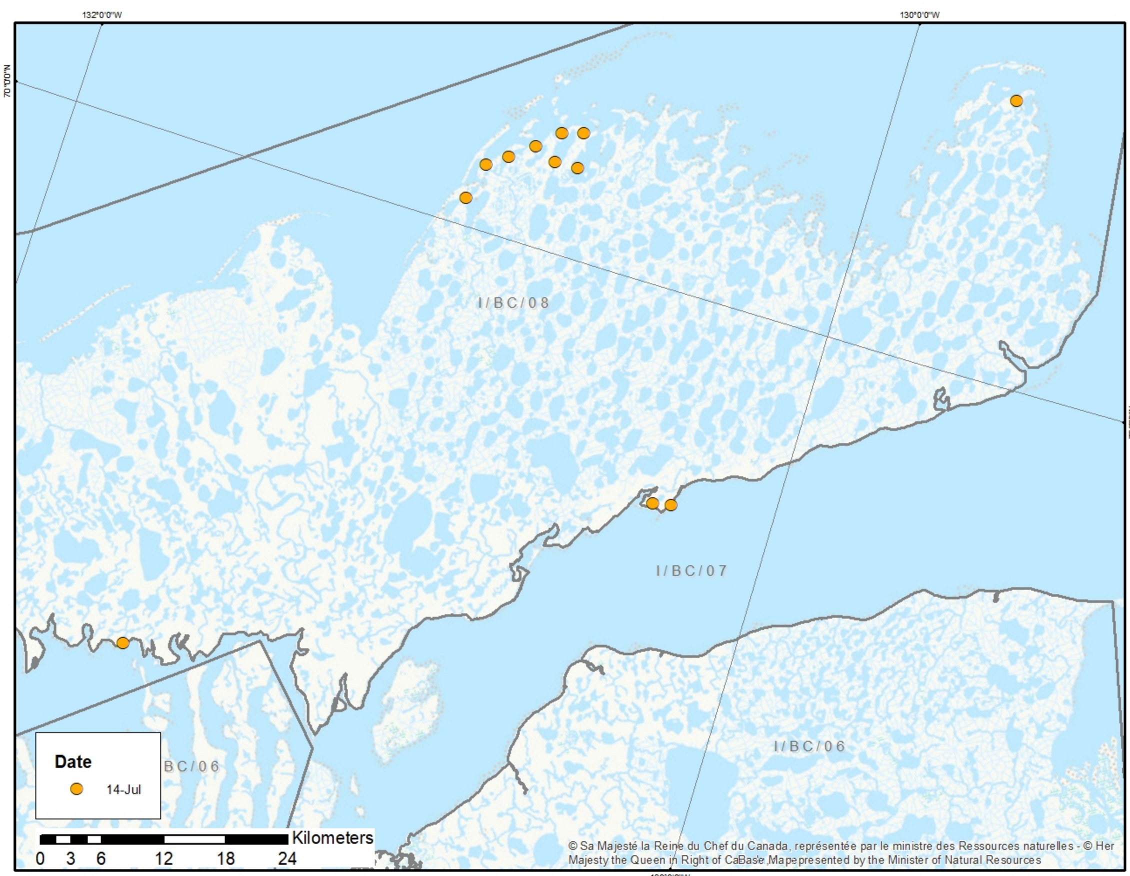

Figure 6. Location of groups counted during the July TP post-calving survey.

Population Estimate and Trend: Bluenose-West

Overall, 61 collars were active in the BW heard at the time of the survey, of which 55 were detected. Groups were reasonably aggregated as indicated by the negative binomial aggregation index of 0.24 (SE=0.044) (Table 6). A threshold model with groups of four or more caribou having detection probabilities of one had the highest likelihood. Therefore the best population estimate for the BW herd is 21,011±4,602 (95% CI) adult caribou. However, resulting estimates were similar between models with reasonable levels of precision. Tests for randomness suggested that this assumption was met in all applicable models.

Table 6. Detection models ranked by log-likelihood with estimates of detection probabilities and herd size for the BW data. The Lincoln-Petersen estimate is given for comparison. Lower confidence limits were constrained to be equal to the total count of caribou during the survey

Detection Model	Log-likelihood	Detection Probabilities		Estimate of Herd Size				
		Estimate	SE	$\hat{T}$	SE ($\hat{T}$)	Confidence Limit		CV
Threshold (B=4)	16.20	0.79	0.09	21,011	2347.8	16,409	25,613	11.2%
Threshold (B=3)	16.14	0.76	0.09	21,264	2376.2	16,607	25,921	11.2%
Independence	15.90	0.25	0.09	21,282	2398.9	16,580	25,984	11.3%
Threshold (B=2)	15.80	0.74	0.09	21,315	2413.7	16,584	26,046	11.3%
Threshold (B=5)	15.75	0.85	0.09	20,929	2232.2	16,554	25,304	10.7%
Homogeneity	15.70	0.90	0.07	21,042	2134.1	16,859	25,225	10.1%
Threshold (B=6)	15.52	0.89	0.07	20,976	2145.1	16,772	25,181	10.2%
LP (collars)				14,330	589.2			4.1%
LP (all)				14,825	609.6			4.1%

Population Estimate and Trend: Cape Bathurst

Of the 51 active collars in the CB herd during the time of the survey, 50 were detected. All groups detected, had collared caribou within them. Groups were reasonably aggregated as indicated by a negative binomial coefficient of 0.23 (SE=0.057) (Table 7), however, the lack of groups with no collars may have influenced this estimate.

A threshold model with groups that had four or more collars having a detection probability of one had the highest likelihood score. Therefore the best population estimate for the CB herd is 4,521±875 adult caribou (95%CI). Estimates from all Rivest models were reasonably similar with adequate levels of precision. Lincoln-Petersen estimates were same for groups with and without collars since all groups contained collared caribou. Tests for randomness suggested that this assumption had been met for all models considered.

Table 7. Detection models ranked by log-likelihood with estimates of detection probabilities and herd size for the full CB data set. The Lincoln-Petersen estimate is given for comparison. Lower confidence limits were constrained to be equal to the total count of caribou during the survey.

Detection Model	Log-likelihood	Detection probabilities		Estimate of herd size				
		Estimate	SE	$\hat{T}$	SE ($\hat{T}$)	Confidence limit		CV
Threshold (B=4)	40.0	0.94	0.06	4,521	446.8	3,646	5,397	9.9%
Threshold (B=7)	39.9	0.96	0.05	4,505	440.4	3,642	5,369	9.8%
Homogeneity	39.9	0.98	0.06	4,489	432.8	3,641	5,338	9.6%
Independence	39.9	0.06	0.06	4,516	447.9	3,638	5,393	9.9%
Threshold (B=2)	39.9	0.94	0.06	4,515	447.9	3,637	5,393	9.9%
LP (collared groups)				3,242	61.9	3,121	3,364	1.9%
LP (all groups)				3,242	61.9	3,121	3,364	1.9%

The estimate for the CB herd was 42% higher than the total count of caribou during the survey. Plots of the components of the estimation process were generated to further explore this difference (Figure 6). In review, the Rivest model estimates herd size as summation of the count of caribou in each group divided by the probability that the group has at least one collar in it and the probability that group was detected. In the case of the threshold model groups that had <4 caribou in them had a detection probability of 0.94 with groups that had more than four caribou having a detection probability of 1. The probability of groups having at least one collar was dependent on group size with group sizes of one having a probability of 0.01 of containing at least one collar. As a result, larger group sizes (above 200) contributed relatively little to the overall estimate with single collar groups contributing the most. The main assumption in this case is that there were many small groups (without collars) not detected in surveys therefore leading to an estimate that is much larger than the number of caribou counted. If for some reason this was not the case (small groups were over represented by collars and therefore there were relatively few small groups not detected) then the estimate would be biased high. As discussed later, the effects of factors such as sex-specific segregation and aggregation could be explored further via simulation modelling to assess the relative robustness of the Rivest estimator to these issues.

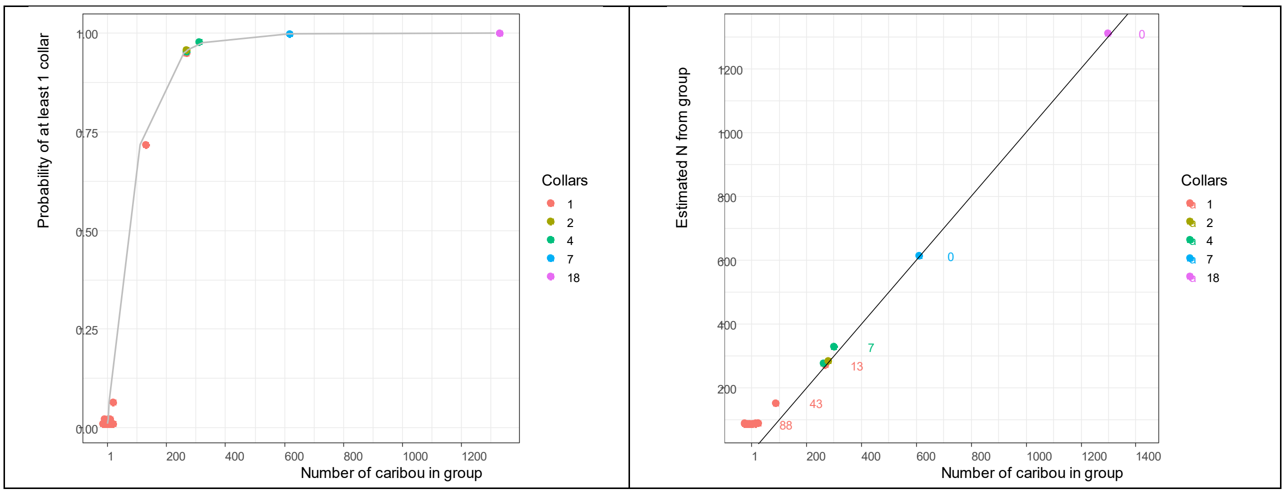

Figure 7. The probability of a group containing at least one collar as a function of group size for the CB herd (left graph). The right graph illustrates the relative contribution of each group observed to the overall estimate (the numbers near each data point). Points are staggered given that there were many observations of single caribou during the survey (Table 4). Estimates are from the threshold (group size=4) model.

The fundamental assumption of the Rivest estimator is that the groups that contain collared caribou are a random sample of overall groups available during the survey of the CB herd. A relatively large percentage (23%: 12 of 51 collars) were single caribou. The Rivest estimator therefore assumes that there were also a lot of uncollared single or small group caribou present that were not detected. Given that the sightability of small groups without collars is lower it is plausible that these groups were present. The fact that no groups without collars were observed further suggests that either groups without collars were not present or more likely were hard to detect.

An analysis that excluded data from July 18 was conducted to further explore sensitivity of estimates to inclusion of the small non-aggregated and spatially segregated groups counted on July 18 (Table 8). In this case, the total collars available during the main survey (which occurred on July 16) was 43 which was the number of collars in the area surveyed on July 14 and 16. Aggregation of this group, as estimated by theta, was higher (0.31. SE=0.10) than the full data set.

Table 8. Detection models ranked by log-likelihood with estimates of detection probabilities and herd size for the CB data set with July 18 data excluded. Forty-three collars were available during July 14 and 16. The Lincoln-Petersen estimate is given for comparison. Lower CI were constrained to be equal to the total count of caribou during the survey.

Detection Model	Log-likelihood	Detection Probabilities		Estimate of Herd Size				
		Estimate	SE	$\hat{T}$	SE ($\hat{T}$)	Confidence limit		CV
Threshold (B=4)	40.06	0.90	0.10	3,824	297.9	3,241	4,408	7.8%
Threshold (B=7)	40.04	0.94	0.09	3,794	289.1	3,227	4,361	7.6%
Homogeneity	40.02	0.98	0.07	3,774	279.5	3,227	4,322	7.4%
Independence	39.90	0.12	0.11	3,820	302.7	3,227	4,413	7.9%
Threshold (B=2)	39.89	0.88	0.12	3,820	303.5	3,225	4,414	7.9%
Lincoln-Petersen				3,239	73.1	3,095	3,382	2.3%

For this reduced data set the estimate from the threshold (B=4) model is 3,824±583 (CI). This estimate now corresponds to the northern area surveyed as opposed to the full extent of the survey area. Therefore, it is likely negatively biased given that collared caribou were detected in the southern area. More exactly, approximately 700 caribou (the difference between the full estimate and estimate excluding the southern area surveyed on July 18) were estimated to occur in the southern area.

Population Estimate and Trend: Tuktoyaktuk

All 17 collars of the collars for the TP herd that were monitored were located on July 14.

The degree of aggregation of caribou was marginal as indicated by a negative binomial theta of 0.67 (SE=0.24) (Table 9). As discussed later, theta for most post-calving caribou surveys was less than 0.4 with higher values suggesting lower levels of aggregation.

All of the Rivest models returned similar estimates of herd size as well as log-likelihood scores. This was due to the fact that all 17 collars were located in groups suggesting high probabilities of detection of groups with collared caribou. Rivest estimates had marginal precision potentially due to issues with aggregation. Estimates from the Lincoln-Petersen estimator equaled caribou counted since all collars were detected which also precluded an estimate of SE. Tests of randomness for all models suggested this assumption had been met. The best population estimate for the TP herd was 1,499±626 (95%CI) adult caribou.

Table 9. Detection models ranked by log-likelihood with estimates of detection probabilities and herd size for the TP dataset. The Lincoln-Petersen estimate is given for comparison. Lower CI were constrained to be equal to the total count of caribou during the survey.

Detection Model	Log-likelihood	Detection probabilities		Estimate of herd size				
		Estimate	SE	$\hat{T}$	SE ($\hat{T}$)	CI		CV
Homogeneity	0.328	1	0	1,499	312.9	886	2,113	20.9%
Independence	0.328	1	0.004	1,500	312.9	886	2,113	20.9%
Threshold (B=2)	0.328	1	0	1,499	312.9	886	2,113	20.9%
Threshold (B=3)	0.328	1	0	1,499	312.9	886	2,113	20.9%
Threshold (B=5)	0.328	1	0	1,499	312.9	886	2,113	20.9%
LP (collar groups)				1,063				
LP (all groups)				1,157				

[A] This estimate applies to a group with at least one collared caribou. Detection probabilities will increase as a function of group size for this model.

Trend

The regression analysis presented in earlier reports (Boulanger et al. 2016) was updated with the 2018 data sets (Table 10). Trends were not significant in the BW and CB, however, a significant decline was detected in the TP herd. Non-significant estimates of trend suggested a slow decline in the BW herd (-2% (CI=-4 to 1%) per year), and an increase (4% (CI=-3 to 10%)) in the CB herd. The Tuktoyaktuk Peninsula herd decreased at a rate of -6% (CI=-7 to -3%) per year.

Table 10. Weighted regression analysis of the 2005-2018 data sets for the three herds considered in the analysis.

Parameter	Estimate	SE	t-statistic	Pr>|t|	95% CI	
Bluenose-West						
Intercept	10.55	0.25	41.94	<.0001	9.85	11.25
Year (*r*)	-0.02	0.01	-1.92	0.13	-0.04	0.01
Trend (λ)	0.98				0.96	1.01
Cape Bathurst						
Intercept	6.90	0.63	10.97	0.00	5.16	8.65
Year (*r*)	0.04	0.02	1.56	0.19	-0.03	0.10
Trend (λ)	1.04				0.97	1.10
Tuk Peninsula						
Intercept	8.18	0.03	290.51	<.0001	8.09	8.27
Year (*r*)	-0.06	0.00	-16.42	0.00	-0.08	-0.05
Trend (λ)	0.94				0.93	0.95

A plot of estimates shows a large degree of spread in both the BW and CB herds (Figure 8). For example, most estimates from the BW herd suggest a declining trend with the exception of the 2012 estimate which was less precise. The clearest trend is for the TP herd as indicated by the continuously declining estimates.

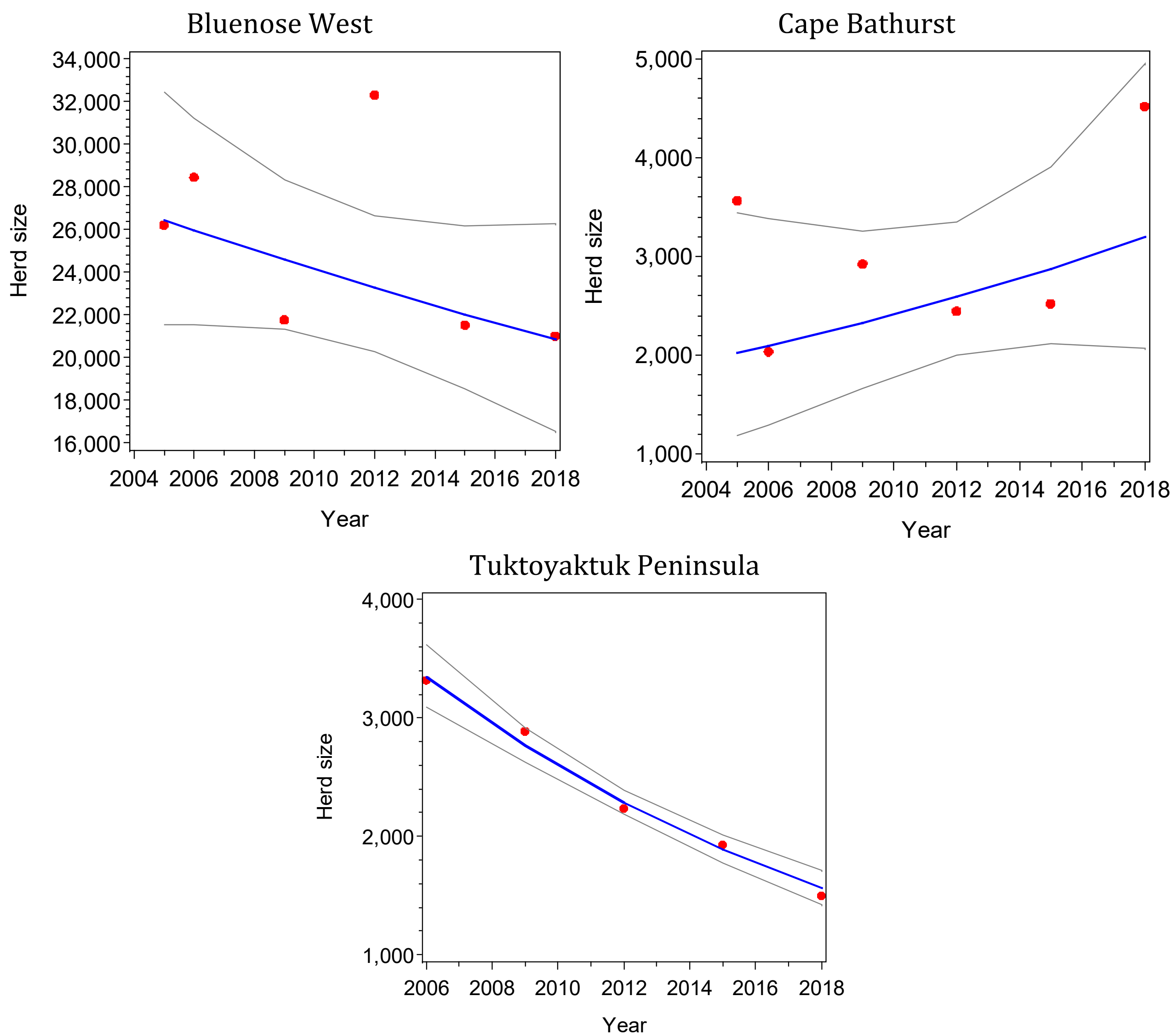

Figure 8. Regression analysis prediction of trends for the BW, CB and TP herd in Table 10.

DISCUSSION

Overall, post-calving surveys were successful in 2018 with reasonably precise estimates from Rivest models. The TP herd estimate was the least precise (CV=21%) which was potentially due to lower aggregation of groups in this herd along with lower samples sizes of groups encountered. The effect of lower aggregation (Θ), as indicated by the negative binomial dispersion parameter, can be seen in Figure 9 which also shows data from historic surveys. The Tuktoyaktuk Peninsula survey had a higher aggregation index suggesting lower aggregation which was associated in lower precision (higher coefficient of variation) in other surveys.

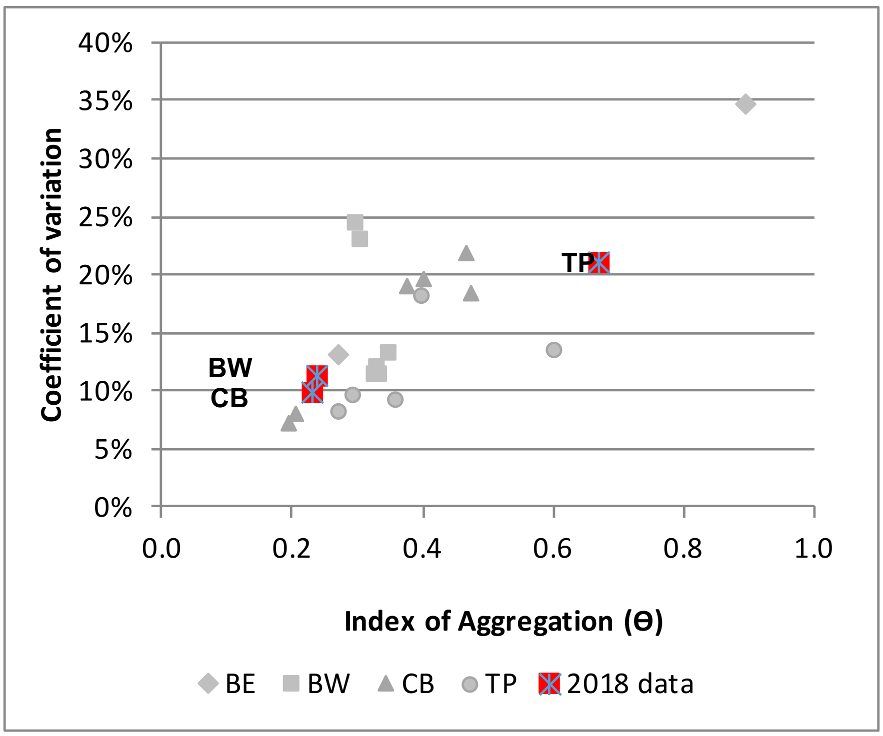

Figure 9. Relationship between aggregation (as indexed by negative binomial theta) and estimate precision, coefficient of variation, from 2018 surveys and past surveys (Boulanger et al. 2018).

Compared to previous data sets, few groups without collars were present in the input data sets. This is potentially due to the focus of search efforts on locating GPS collars which can be accurately located compared to previous VHF collars. Therefore, it is less likely that non-collared groups will be detected. Since the Rivest estimator does not utilize non-collared groups, this difference in methodologies will not affect estimates. However, exclusion of non-collared groups will affect the estimates of negative binomial dispersion, show in Figure 9 as an index of aggregation, as it utilize non-collared groups in the estimate. In addition, it can increase the difference in estimates between the Rivest estimator and the Lincoln-Petersen estimator, as the Lincoln-Peterson estimator can include non-collared groups.

A fundamental assumption of the Rivest estimator is that the collared caribou intermix with non-collared caribou so that the distribution of collared groups that are observed represent the overall distribution of caribou including groups that are not observed. This assumption is partially tested using the test for overdispersion which is part of the Rivest estimation procedure. In addition, various submodels are available to test for the relationship between the number of collars in a group and detection probability. Main potential factors that might influence the Rivest estimator is if there are differences in relationships between collared caribou and groups due to geographic or sex-specific levels of aggregation especially if proportions of bull and cow collars are not proportional to the bull cow ratio of the herd. This may be a factor in this year's Cape Bathurst population estimate results, as there may be a segregation of bull and cow caribou based on the collars. Therefore, the Cape Bathurst estimate should be taken with caution. Simulation modelling could be used to further explore the robustness of the Rivest estimator to these potential issues.

The 2018 population trends for the three herds give mixed results with the Tuktoyaktuk peninsula herd continuing to decline, the Bluenose-West's trend not being statistically significant and the results for the Cape Bathurst herd is positive, indicating an increasing trend. The results of this survey is provided to the Advisory Committee for Cooperation on Wildlife Management and used for the designation of the herd statuses and action plans as set out in the *Taking Care Of Caribou: The Cape Bathurst, Bluenose-West, and Bluenose-East Barren-ground Caribou Herds Management Plan* (Advisory Committee for Cooperation on

Wildlife Management 2014). Monitoring of these herds will continue as outlined in the plan.

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PERSONAL COMMUNICATIONS

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