WINTER SURVEY OF BATHURST CARIBOU AND ASSOCIATED WOLF DISTRIBUTION AND ABUNDANCE

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Yellowknife, NT

2009

Manuscript Report No.185

ABSTRACT

With the current rate of decline for the Bathurst barren-ground caribou herd (*Rangifer tarandus groenlandicus*) estimated at 5% per year and with causes of the decline unknown, research on the winter dynamics of the herd and its main predator, the wolf (*Canis lupus*) is a priority. During February through March 2006, we conducted a stratified random survey of the Bathurst caribou winter range, a total area of 494,000 km^2. Survey cells were stratified as high or low caribou density, based on the current distribution of satellite-collared caribou. Those cells were further stratified by lichen occurrence and snow-water equivalence. Using those count data, we estimated the total number of caribou and wolves on the winter range. Also, we counted the number of caribou kills and related kill density to wolf and caribou density. The stratification protocol proved to be a novel and satisfactory desktop method. As expected, grid cells occupied by collared caribou contained a significantly higher mean number of caribou and displayed a trend towards increased mean numbers of wolves. Further stratification based on forage availability and snow-water equivalence was more problematic and future trials are required to refine these strata. Using the GeoSpatial Population Estimator and the stratified mean density of counted caribou, we estimated 41,004 ± 8,431 (Standard Error) and 36,077 ± 12,440, respectively. These values were much lower than the spring 2006 calving ground estimate for the same herd. Using the stratified mean density of counted wolves, the wolf population was estimated at 211 ± 66 wolves. We counted only 6

predated caribou. Given just one field season, the ecological significance of the caribou and wolf population density estimates are difficult to interpret. However, the stratified sampling design we employed appears to have some utility for counting caribou and wolves when they are found near or above the tree line during winter.

TABLE OF CONTENTS

Abstract iii
List of Tables vii
List of Figures ix
List of Appendices xi
Introduction 1
Study Area 4
  Methods 4
  Results 10
  Discussion 13
  Conclusions and Recommendations 18
Acknowledgements 20
Literature Cited 21

LIST OF TABLES

Table 1. Frequency of cells sampled for each strata (HC/LC=high/low caribou; HL/LL=high/low lichen; HS/LS=high/low snow) across the winter range of Bathurst caribou, February-March 2006. **.. 24**

LIST OF FIGURES

Figure 1. Spatial distribution of the Bathurst caribou winter range shaded in green (GNWT – ENR). **25**

Figure 2. Sample units (100 km^2) for surveying the Bathurst caribou winter range, February-March 2006. Boundaries of the winter range were defined using a 100% minimum convex polygon. **26**

Figure 3. Frequency distribution of numbers of individual caribou within discrete groups observed through aerial surveillance on the Bathurst winter range, February-March 2006. A group of caribou was considered discrete when they occurred approximately 100 m or more from the next nearest group. **27**

Figure 4. Snow-water equivalent (SWE) data collection sites (red dots) for the Northwest Territories. **28**

Figure 5. Mean number of caribou of the Bathurst herd (± 1SE) observed in the *a priori* designated High (HC) and Low (LC) caribou survey cells, February-March 2006. **29**

Figure 6. Mean number of wolves (± 1SE) on the Bathurst winter range observed in the *a priori* designated High (HC) and Low (LC) caribou survey cells, February-March 2006. **30**

Figure 7. Mean number of caribou of the Bathurst herd (± 1SE) observed in survey cells classified as high forage lichen abundance (HL) and low forage lichen abundance (LL), February-March 2006. **31**

Figure 8. Mean number of caribou of the Bathurst herd (± 1SE) observed in survey cells classified as high snow water equivalence (HS) and low snow water equivalence (LS), February-March 2006. **32**

Figure 9. Mean snow water equivalence (± 1SE) for each station within the Bathurst caribou winter range; number of years of snow data varied by station. **33**

Figure 10. Mean number of wolves (± 1SE) on the Bathurst winter range observed in survey cells classified as high caribou forage abundance (HL) and low caribou forage abundance (LL), February-March 2006. **34**

Figure 11. Mean number of wolves (± 1SE) on the Bathurst winter range observed in survey cells classified as high snow water equivalence (HS) and low snow water equivalence (LS), February-March 2006. **35**

Figure 12. Number of wolves observed per cell on the Bathurst winter range in relation to the number of observed caribou, February-March 2006. Solid lines represent the fit of the data to a linear regression fit (± 95% Confidence Intervals). The line with the slope near 0 represents the relationship following the removal of one cell where both a large number of caribou and wolves were recorded. **36**

Figure 13. Number of predated caribou observed on the Bathurst winter range in relation to the number of observed wolves per survey cell, February-March 2006. Solid lines represent the linear regression fit (± 95% Confidence Intervals). The

plot with the steepest slope represents the relationship following the removal of one cell where both a large number of caribou and wolves were recorded. **.......37**

LIST OF APPENDICES

Appendix A. Description of 10 x 10-km grid for NWT wildlife and fish surveys..**38**

Appendix B. Mean ±1SE SWE measurements across multiple years for all stations in the NWT. Sampling interval (i.e., number of years, *N*) varied among stations. **40**

INTRODUCTION

The Bathurst barren-ground caribou (*Rangifer tarandus groenlandicus*) herd is in a decline with numbers falling from 1996 levels of 349,000 ± 94,900 to the most current 2006 population count of 128,000 ± 27,343 (GNWT-ENR). The current rate of decline is estimated at 5% per year averaged over the last decade. Previous population estimates show a low in the late 1970s similar to the current situation. This dynamic appears cyclical, but the causative forces are not well understood. Current hypotheses for decline include range condition, disease, climate, weather, fire and predation by the caribou's primary predator, the wolf (*Canis lupus*). While these ideas are rooted in observation, few empirical studies have examined each potential interacting cause. The Bathurst Caribou Management Planning Committee (2004) recognises that the environment in the north is changing and that an understanding of trends in predator abundance and cause-specific mortality are important when herd numbers are low.

Winter can be a limiting season for caribou populations (Russell, 1993; Gerhart *et al.*, 1996). Deep snow conditions can negatively affect body condition of females, ultimately leading to low birth weights of calves (Chan-McLeod *et al.*, 1999). In addition to reduced reproductive potential and success, severe winter conditions can directly increase the risks of predation (Adams, 2005). Few studies have been conducted on the winter ranges of caribou in the Canadian central Arctic. In particular, we have little understanding of the interactions of density independent factors such as snow conditions and density dependent factors including predation and forage availability. Understanding winter dynamics is necessary for effective management, especially given the current consensus on global climate change (IPCC 2001).

During February and March 2006, we conducted a stratified random survey of caribou and wolves and caribou mortality sites on the late winter range of the Bathurst herd. The objectives of this pilot study were threefold:

1. Assess the utility of two survey techniques for estimating the winter range densities of caribou, wolves, and caribou mortalities;
2. Quantify the relationship between caribou and wolf density and various parameters that might be effective for stratifying winter ranges for further survey estimates; and
3. Provide an initial estimate of caribou and wolf densities on the late winter range and the relationship between the frequency of caribou mortality and caribou and predator densities.

We stratified the winter range into assumed high and low density survey cells based on the recent location of Bathurst caribou monitored with satellite collars. Using vegetation and snow data we also stratified the study area into high/low lichen and snow water equivalency cells. We employed the Sample Unit Probability Estimator (SUPE) to estimate wolf numbers. A SUPE is a robust form of stratified network, or snowball, sampling used to obtain density and population estimates where collaring of animals and mark-recapture designs are infeasible, where study animals are relatively scarce or fragmented, or are highly mobile over a large area (Becker *et al.*, 1998; Patterson *et al.*, 2004; Becker *et al.*, 2004).

In conjunction with the SUPE, we performed a simple stratified random survey of caribou and caribou mortalities. Poor snow conditions resulting from trampling by large groups of caribou and infrequent snowfall during the late winter of 2006 prevented us from back tracking wolves and applying the SUPE. Thus, we used the stratified random survey, as applied to caribou and caribou mortalities, to estimate wolf density on the winter range. Caribou density was calculated using the GeoSpatial Population Estimator (GSPE; Delong and Ver Hoef 2006) and the stratified mean density of counted caribou (Cochran, 1977). The observed clumped distribution of wolves and thus high zero count in many cells was unsuitable for the GSPE, thus, we estimated wolf density using the mean density of observed animals across strata. Results from this survey provide an initial estimate of caribou and wolf densities across a portion of the Bathurst winter range. Exploration of methods will aid in developing survey techniques for the Bathurst and other central Arctic barren-ground herds.

STUDY AREA

Research took place between February 21 and March 12, 2006, in the south-central Canadian Arctic within the assumed boundaries of the winter range of Bathurst caribou (Fig. 1). The survey covered 494,000 km^2 and occurred north and east of Great Slave Lake in the Northwest Territories, based out of Yellowknife and and Lutsel K'e (Fig. 2).

The survey region is characterized by forest tundra, and northern boreal forest, where the dominant tree species include black spruce (*Picea mariana*), white spruce, (*Picea glauca*), and jack pine (*Pinus banksiana*). The topography is gently rolling and typical of Canadian Shield with many small lakes, eskers, and rock outcrops (Walton 2000). Winter temperatures often fall below -30° C and the region receives a yearly average of 151 cm of snowfall (Environment Canada).

Methods

Stratifying the winter landscape

We used recent location data from 14 caribou to identify the boundaries and strata for the survey area broadly focussed on the late winter range of the Bathurst herd. Caribou in the Bathurst and surrounding herds are collared by the Government of the Northwest Territories with doppler-shift (Argos) satellite transmitters for continual monitoring (GNWT-ENR). Our sampling area was set prior to surveillance and we used the most recently available location data (data collected on Feb 16, 2006, two weeks prior to commencement of the survey) to calculate a 95% Minimum Convex Polygon (MCP). MCPs do not have underlying assumptions of distribution, are not affected by autocorrelation and are one of the most common methods for estimating use areas, such as home ranges (Seaman *et al.*, 1999; Kenward, 1992). We set the MCP as the boundary for an aerial survey of the Bathurst herd and associated wolves. This boundary was then superimposed on a grid of 10 × 10 km cells (Fig. 2, and see Appendix A) developed for wildlife surveys by the Government of the Northwest Territories (GNWT) .

We stratified the study area into cells of potentially high caribou concentration (HC cells) and cells of potentially low caribou concentration (LC cells) based on the most recent locations of collared Bathurst caribou. Cells containing the collared caribou and all directly adjacent cells were classified as HC cells. All other cells within the survey area were classed as LC cells. This method assumed that the collared caribou were representative of the entire herd. Reduced movement by caribou during the winter season facilitates this type of stratification that would otherwise be affected by a highly mobile animal. The HC and LC cells were then assigned landscape-level forage availability and snow characteristics according to satellite land cover classification maps from the NWT government and snow-water equivalence (SWE) data from Environment Canada (GNWR-ENR, Meteorological Service of Canada – Climate Research Branch).

From the satellite land cover data, we extracted the vegetation types, *lichen dominant* and *spruce-lichen boreal forest*. The *lichen dominant* class is defined as polygons with ≥ 50% land cover of foliose or fruticose lichen, while the *spruce-lichen boreal forest* class is comprised of greater than 10% canopy cover of which 75% is spruce-lichen dominant (GNWT – FMD 2002). These two vegetation types are considered 75-80% accurate by the Forest Management Division of the Environment and Natural Resources Department of the Government of the Northwest Territories (GNWT – FMD 2002). We assumed that a 10 × 10 km survey cell containing ≥ 50% of the *lichen dominant* and/or *spruce-lichen boreal forest* land cover types, by area, had abundant lichen and thus winter forage (HL cell). The remaining cells were then stratified as low forage availability (LL cells).

The second landscape-level classification used in this study, SWE, is an indicator of combined snow depth and density. The SWE data consisted of mean SWE measurements from 57 collection sites located throughout the Northwest Territories (Fig 3). Time of collection for these sites ranged from 2 to 39 years ($\bar{X}$ = 25 years) (Meteorological Service of Canada – Climate Research Branch). The most current data for this study were collected from the winter of 2004-2005. An interpolated map of SWE was generated for the survey area using ArcMap 9.0 (ESRI, 2005). We applied the average SWE from stations within or near the survey area to the inverse weighted distance (IDW) technique. This technique interpolates values based on a series of sample data. Interpolated values are more strongly influenced by data, or in this case stations, that are relatively closer in geographic space. All default settings were used in the creation of the SWE IDW interpolated map.

The mean of all SWE measurements was 101.7 mm; thus, this value served as the midpoint for stratifying each survey cell. If the majority of a 10 × 10 km cell had SWE measurements above the mean of 101.7 mm, then the cell was classified as having high SWE (HS cell). If the majority of a cell had SWE measurements below the mean, then the cell was classed as low SWE (LS cell).

As survey efforts were constrained by flying time and funding, we identified four strata/treatments: 1) high SWE-abundant forage (HS-HL cells); 2) high SWE-sparse forage (HS-LL cells); 3) low SWE-abundant forage (LS-HL cells); and 4) low SWE-sparse forage (LS-LL cells). We assumed that areas of high SWE correlated with high snow depth and/or density resulting in increased energy expenditure for cratering and a lower likelihood of finding caribou and wolves. Areas of abundant forage lichens should correspond to areas of high caribou usage, and thus increased likelihood of encountering caribou and wolves.

Aerial Surveillance

Sampling took place from February 23 to March 12 and flying was possible on 13 of the 18 days. Weather conditions were excellent on all days spent flying and did not reduce sightability. We randomly selected cells for survey during each day of the study. Using a 4-seat Maule fixed-wing aircraft, we flew between 90 and 180 m above ground, at a speed of 100 to 130 km/h. Each survey cell was flown 10° east of true north to account for the angle of the 10 × 10 km cell grid. Flight lines ran north-south approximately 2.2 km apart. The distance between each line flown within a cell depended on the sightability for that particular cell. To increase the number of cells surveyed, large open expanses, such as lakes or tundra, were flown with greater distance between flight lines providing that the researcher, spotter, and pilot were confident the area was fully visible and no animals were being missed.

During the survey, caribou, wolves, and predated caribou were located and circled to ascertain exact number of animals as well as take a GPS (GARMIN GPSmap 76CS) location for geospatial reference. The activity (i.e. bedded or foraging) and general location (i.e. on a lake or in the trees) of the animals were also recorded. All flight route plans, waypoints taken and tracks flown were developed and recorded using OziExplorer software v.3.96.1c (D & L Software Pty Ltd., 2006).

Statistical Analysis

We used a *t*-test to determine if the stratification technique based on caribou abundance (HC and LC cells) was effective. Here, we tested for a significant difference in the mean number of caribou between cell types. Caribou, wolf, and predated caribou counts were also analyzed using ANOVA. For this analysis, we compared mean numbers of observed animals among the habitat-level classification of lichen abundance (HL and LL cells) and SWE (HS and LS cells). Simple linear regression tested for a relationship between caribou and wolf occurrence and the frequency of predated caribou within each survey cell.

We used the GSPE, a new software program designed for moose surveys in Alaska and northern Canada, to estimate the number of caribou across the winter range survey area. The software uses an autocorrelation function developed from animal numbers in adjacent and more distant cells to construct a population estimate (Delong and Ver Hoef, 2006). We also used the simple mean density of counted caribou across strata to extrapolate a population estimate (Cochran, 1977). Observed wolf distribution was unsuitable for the GSPE, thus, like our second estimation technique for caribou, we used the mean density of observed wolves across strata to determine a population estimate. Standard errors for the density estimators were corrected for variation in sample sizes across strata (Cochran, 1977).

All analyses were performed using STATISTICA v. 6 (Statsoft, 2001), except the estimate of caribou population size, which was calculated using the GeoSpatial Population Estimator (GSPE) Moose Survey software v. 1.0 (Delong and Ver Hoef, 2006). We considered results with P-values < 0.05 significant, and all parameter estimates are given as the mean ± 1 standard error.

Results

In total, we surveyed 19.1% of the winter range study area (94 surveyed cells of a total 494 available cells; Fig 2). We randomly selected and surveyed 35.7% of the possible HC (high caribou concentration) survey cells, and 15.7% of all available LC (low caribou concentration) survey cells. The number of cells sampled within each habitat-level classification was uneven (Table 1). Habitat combinations with small numbers of sampled cells (< 10) were the result of low availability across the study area.

We counted 8,681 caribou, 51 wolves, and 6 predated caribou within all the randomly selected survey cells. The mean number of caribou across all cells, where caribou were observed, was 174 ± 67. Comparing HC to LC cells, on average we counted 319 ± 191 and 99 ± 23, respectively. The mean number of wolves per sampled cell, where at least one wolf was observed, was 5 ± 2. The mean number of wolves observed in HC cells was 6 ± 4 and LC cells was 3 ± 1. Within a cell, caribou and wolves were often observed segregated into smaller groups, and we recorded numbers based on the smallest observable division. Groups were identified as collections of animals separated by approximately 100 m or more. Mean observed groups size for caribou and wolves (within cells) was 33 ± 4 and 3 ± 1 animals, respectively. The majority of groups of caribou consisted of 1–23 individuals (Fig. 3).

Using the GSPE moose survey software, we estimated 41,005 ± 8,431 caribou across the surveyed portion of the Bathurst caribou winter range. Comparing this method to a simple extrapolation of the mean density by strata we produced a second estimate of 36,077 ± 8,970. This estimate was based on 180.57 caribou/100 km^2 within HC cells and 51.0 caribou/100 km^2 in LC cells.

Thirty-two of the 51 observed wolves were in 5 HC cells, and the remainder were sighted in 6 LC cells. Based on the limited wolf data, we estimated 90 ± 24 wolves in high caribou concentration areas (a total area of 8,400 km^2) and 122 ± 42 wolves in low caribou concentration areas (a total area of 410,000 km^2) for a total of 211 ± 48 wolves across the survey area. On average, we observed 0.01 ± 0.004 and 0.003 ± 0.001 wolves/km^2 in HC and LC cells, respectively.

We found significantly more caribou in survey cells defined as high caribou abundance (Fig. 4; t = -3.474, df = 276, P < 0.001). There was no significant difference in the number of wolves observed in cells surveyed as high or low caribou abundance (t = 0.589, df = 17, P=0.564). Although, there was a trend towards a higher mean number of wolves in the cells designated as high caribou abundance (Fig. 6).

The abundance of observed caribou was significantly greater in cells with high forage abundance (Fig. 7; F = 4.049, df = (1,275), P = 0.045). We note that the high lichen cells had a greater range of variation in caribou numbers relative to the low lichen cells (Fig. 7). There was a significant difference between the number of caribou found in cells with high versus low SWE measurements (Fig. 8; F = 8.514, df = (1,275), P = 0.004). Contradicting our working hypothesis, the cells designated as high SWE had a higher mean number of caribou and a greater range of variation in the numbers of caribou observed (Fig. 8). Observed results might be a product of highly variable SWE measurements across year within stations (SE = 4 to 11 mm; Fig. 9).

We observed a positive trend between number of wolves and cells with high caribou forage abundance, but the result was not statistically significant (Fig. 10; F = 1.032, df = (1,16), P = 0.325). As with forage lichens, the observed number of wolves was not significantly related to the SWE stratification (Fig. 9; F = 0.221, df = (1,16), P = 0.644). The mean number of wolves observed in cells with high SWE measurements was highly variable, while very few wolves were observed in the low SWE cells (Fig. 11).

Linear regression suggested that the number of wolves observed was positively related to the number of caribou in each cell (Fig. 12; F = 213.083, df = (1,92), R^2_{ADJ} = 0.695, P < 0.001). Our review of the data, however, suggested that one cell, where caribou and wolf numbers were much higher, was highly influential on the results of this comparison. After removing the influential cell, the number of wolves was no longer related to the number of caribou (Fig. 12; F = 0.122, df = (1,91), R^2_{ADJ} < 0.001, P = 0.727).

The number of predated caribou was significantly related to the number of wolves observed per surveyed cell, although the amount of explained variation was small (Fig. 13 ; F = 4.945, df = (1,92), R^2_{ADJ} =0.041, P = 0.029). Again there was one cell with a high wolf count that influenced results. Repeating the analysis after removing that cell, improved the observed relationship (Fig. 13; F = 29.543, df = (1,91), R^2_{ADJ} = 0.237, P < 0.001).

Discussion

Stratifying the winter landscape

We observed significantly more caribou in cells we stratified as high caribou concentration. Thus, our survey results suggested that the *a priori* stratification of the study area based on collared caribou locations was appropriate. Since the cell type (HC or LC) was set approximately two weeks prior to sampling, this result also indicated that caribou moved little prior to and during the survey period. This finding concurs with our visual observations of the biweekly movements of collared caribou during the winter of 2005/2006 and Kelsall (1968) who reported that barren-ground caribou herds remain relatively stationary during the winter months. Although stratification based on direct field observation of animal distribution is generally preferred (Delong and Ver Hoef, 2006), funding, staffing and time constraints may limit this approach. In our case, the “desktop” stratification appeared to be a satisfactory substitute.

Determining the effectiveness of the stratification protocol for wolf surveys was more problematic. Our results did not support a strong relationship between wolf and caribou abundance. However, a small and variable sample might have confounded the expected relationship; we observed only a total of 51 wolves in 11 cells. Further sampling over more years may confirm the observed trend of greater wolf numbers within cells classified *a priori* as having high densities of caribou. Becker *et al*. (1998 and 2004) noted that stratification for secretive, low density, highly mobile species, such as wolves, should be based on knowledge of harvest patterns, abundance, and distribution of prey. However, other studies that lacked knowledge of wolf distribution also relied on prey habitat as a proxy for wolf density (Patterson *et al*., 2004). As wolf abundance on the Bathurst caribou winter range is poorly understood, a combination of density indicators, such as harvest patterns and caribou distribution may increase the effectiveness of a stratification and survey protocol.

In addition to caribou distribution, we also stratified the survey area according to habitat attributes. As expected, we observed a higher number of caribou within cells containing a majority of lichen-bearing habitat classes. Forage abundance was not effective for classifying wolf density, but this is not unexpected given the poor relationship in our survey between caribou and wolf abundance. The SWE classification produced counter-intuitive results as we observed a larger number of caribou in cells with high SWE measurements. One might expect caribou to select areas with low snow depth/density in an effort to reduce the energetic costs of foraging and locomotion. Furthermore, wolf kill rates on ungulates typically increase with greater snow depths (Peterson and Allen, 1974; Huggard, 1993; Chan-Mcleod *et al.*, 1999; Jedrzejewski *et al.*, 2002; Adams, 2005).

Problems with the original SWE classification may account for our counterintuitive finding. Because we were working at large spatial scales and current SWE data were not available for the entire survey area, we developed our index using an averaged SWE measurement from a number of years and stations. However, SWE measurements show fairly large inter-year variation that may render the mean relatively inaccurate for one particular year. Unfortunately, Meteorological Services of Canada only take SWE measures at the end of each winter prior to spring melt (Meteorological Service of Canada – Climate Research Branch). This prevents application of contemporary SWE data to winter surveys for caribou or wolves. Alternatively, SWE measures could be taken by the researcher periodically throughout the winter at select locations and an IDW interpolated map could be created based on direct and current field measurements. Unless these data could be collected in conjunction with other studies, we expect that such an initiative would be prohibitively expensive.

Problems with the interpolation of the SWE averages may also have influenced the observed relationships. Poor results can be obtained from IDW maps when sampling is not dense in relation to the interpolated phenomenon. Furthermore, if the sampling of input data is sparse or uneven, the results may not sufficiently represent the desired surface (Watson and Philip, 1985). The 57 stations used to calculate the SWE interpolated map were clumped in some areas and sparse in others, perhaps leading to insufficient representation of the local variation in snow depth and density. As a crude ground truth of the SWE map, a visual account of snow depth was attempted during aerial surveillance. Snowfall appeared low in all sampled areas and visual differentiation was problematic.

Observations of Wolf and caribou dynamics

The observed relationship between caribou and wolf density was highly dependent on one sampled cell where we recorded large numbers of both caribou and wolves. When this cell was considered an outlier, and removed from analysis, the relationship became statistically nonsignificant. However, we suspect that removing the influential cell may misrepresent the true dynamics of the system. The territoriality of barren-ground wolves is less prevalent during the winter season (Walton, 2001), thus allowing for superpacks to congregate in single cells with large numbers of caribou.

The number of kill sites, where we assumed caribou had been predated, was related to wolf density. Removal of the high-density wolf cell, as discussed above, resulted in a stronger, more highly significant relationship. Again, whether the influential cell should be removed from the analysis is debatable, and increased sampling over multiple years would help confirm and possibly strengthen the suspected relationship. The low numbers of kills and wolves, observed in only a few cells, did reduce the precision of our analysis and the strength of inference from this survey.

Intensive tracking of GPS and/or radio-collared wolves and sampling over multiple years would increase sample sizes and provide much greater insight into kill rates, rates of consumption, and pack size. Wolves can consume a large proportion of prey quickly, with 65-90% of the kill being totally consumed within two feedings for larger packs of approximately 15 individuals (Mech, 1970; Potvin and Jolecoeurm 1988). Rapid consumption may make kills older than a couple of days difficult to detect from an aerial survey.

Density Estimates

Using the GSPE moose survey software, we obtained an estimate of the Bathurst herd on the winter range that is much lower than the recent estimate of breeding females on the calving ground (GNWT – ENR). Confirmation using a simple stratified density estimator (Jolly, 1969) suggested that the GSPE was reliable. Identifying the focal landscape and strata according to the distribution of only 14 collared caribou may have misrepresented the placement or size of the winter range for the entire herd. As well, sightability, although not an issue obvious during field work, may have affected the estimate as some caribou in treed grid cells may have been missed or undercounted. We acknowledge that counting large groups of caribou was difficult leading to possible error in cell counts. However, reviewing the frequency distribution of observed group sizes, we counted few groups (> 100 m apart) larger than 50 individuals.

The estimate of wolf density was crude. Our attempts to extrapolate the observed wolf numbers to the larger study site, a magnification of over fivefold, is imprecise but reveals numbers that are not unreasonable. For example, Cluff (manuscript in prep.) reported estimates of 1 wolf per 150 km^2 for a summer denning census in areas considered to be high wolf density. Within our study area, we observed approximately 1 wolf per 94 km^2 in cells delineated as high caribou density (HC). Densities as low as 1 wolf per 200 km^2 have been reported for other wolf populations that follow migratory caribou (Ballard *et al*., 1997). Our density estimates may be inflated by a failure to consider the influence of pack territoriality on area calculations; although, past research on barren-ground wolves indicated a general lack of territoriality during winter (Walton, 2001).

Originally, we had planned to conduct a SUPE for wolves in the study area. The high density of caribou, obliterated wolf tracks in most areas, making it impossible to backtrack wolves, as is required by the SUPE technique. The SUPE also relies on at least one substantial snowfall prior to beginning the survey and low snowfall plagued the research period.

Conclusions and Recommendations

Our stratification technique based on the distribution of a sample of animals appears to be useful for barren-ground caribou herds that contain collared individuals. Small delays between collecting the distribution data and conducting the survey do not appear to be problematic for winter range counts. For barren-ground populations with no collared animals, our data suggest that lichen abundance is a reliable indicator of caribou density. Vegetation maps might be a suitable proxy for true distribution or abundance data and allow for an adequate desktop stratification of survey cells. Estimating population numbers using the GSPE moose survey software is relatively simple and appears effective for barren-ground caribou on tundra landscapes. However, estimates are dependent on the autocorrelation function developed for the survey population. This suggests that the technique may not be suitable for low-density populations relative to habitat availability or landscapes with patchy resources and boundaries to animal distribution. Thoughtful application of this method is necessary and further testing for barren-ground caribou is warranted.

Preliminary attempts at conducting a SUPE for wolves indicated that this method may not be useful where predators follow and interact with high densities of prey. If a SUPE were to be attempted again on this landscape, a smaller plane or helicopter, allowing lower and slower flight, would aid in track detection. Fresh deep snow is also essential. More experience in tracking, and landing to verify tracks may also be necessary to complete a SUPE survey across the winter range of large migratory caribou herds.

Aerial surveillance provides a restricted view of the dynamics of complex ecosystems. Backtracking collared wolves for kill frequency, and ground work such as kill-site investigations would provide more insight into the behavioural and ecological mechanisms driving the wolf-caribou relationship. The results of this study do indicate that the potential for simultaneous sampling of wolf and caribou populations exists in the near treeline and barren-ground winter landscape, however more research is needed to develop protocols with increased accuracy and precision.

ACKNOWLEDGEMENTS

We would like to thank Drs. Kathy Parker and Mike Gillingham for comments and suggestions on the initial survey design. Bruno Croft provided invaluable operational assistance during the survey and continued to work with us to relate these results to the current knowledge of the Bathurst herd. Pilots Blair Jenson of Ursus Aviation in Yellowknife, and Nick Hawes of Prince George, ensured safe and successful flights.

We would also like to thank the Lutsel K’e Dene, Yellowknives Dene, and the North Slave Metis Alliance, as well as all residents who participated in the aerial surveillance, including Charlie Catholique, Sam Boucher, and Baptiste Catholique from Lutsel K’e, Lawrence Goulet of N’Dilo, and Ed Jones of Yellowknife. Karl Mattson provided invaluable moral and flight support during the first half of the survey.

The accommodation of Mike Phelan and roommate Sied as well as Stephen Ellis and Tracey Williams in the communities of Yellowknife and Lutsel K’e was greatly appreciated. Stephen Ellis was always helpful in providing local contacts and information. We are thankful for the kindness and accommodation that was shown to I-JM at the Lutsel K’e Wildlife Office by the Wildlife Committee and Monica Kreiger, and by the community of Lutsel K’e as a whole, including Clint at the Lutsel K’e remote airport and Brian at the local Co-op.

Funding for this work was generously provided by the Department of Indian Affairs and Northern Development, the Natural Sciences and Engineering Research Council, and the University of Northern British Columbia.

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TABLES

Table 1. Frequency of cells sampled for each strata (HC/LC=high/low caribou; HL/LL=high/low lichen; HS/LS=high/low snow) across the winter range of Bathurst caribou, February-March 2006.

Cell classification	Number of sampled cells
HC+HL+HS	9
HC+HL+LS	1
HC+LL+HS	14
HC+LL+LS	6
LC+LL+LS	26
LC+LL+HS	25
LC+HL+LS	6
LC+HL+HS	7

FIGURES

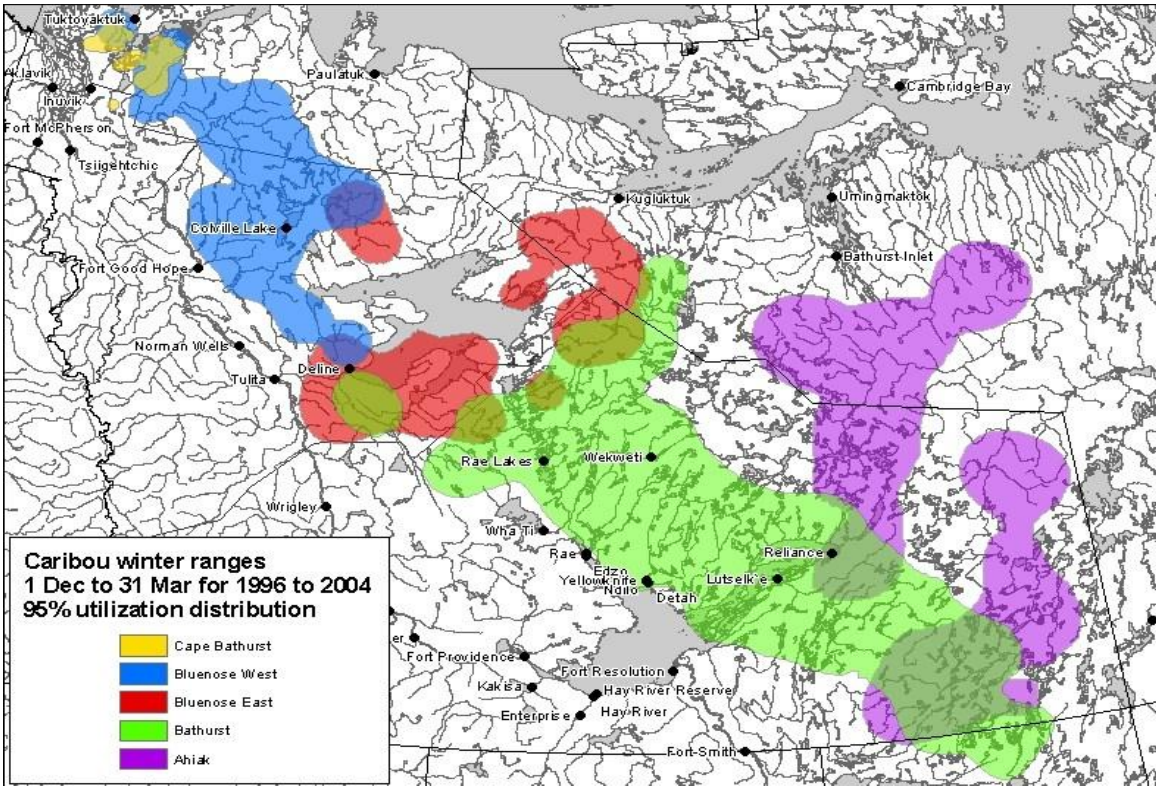

Figure 1. Spatial distribution of the Bathurst caribou winter range shaded in green (GNWT – ENR).

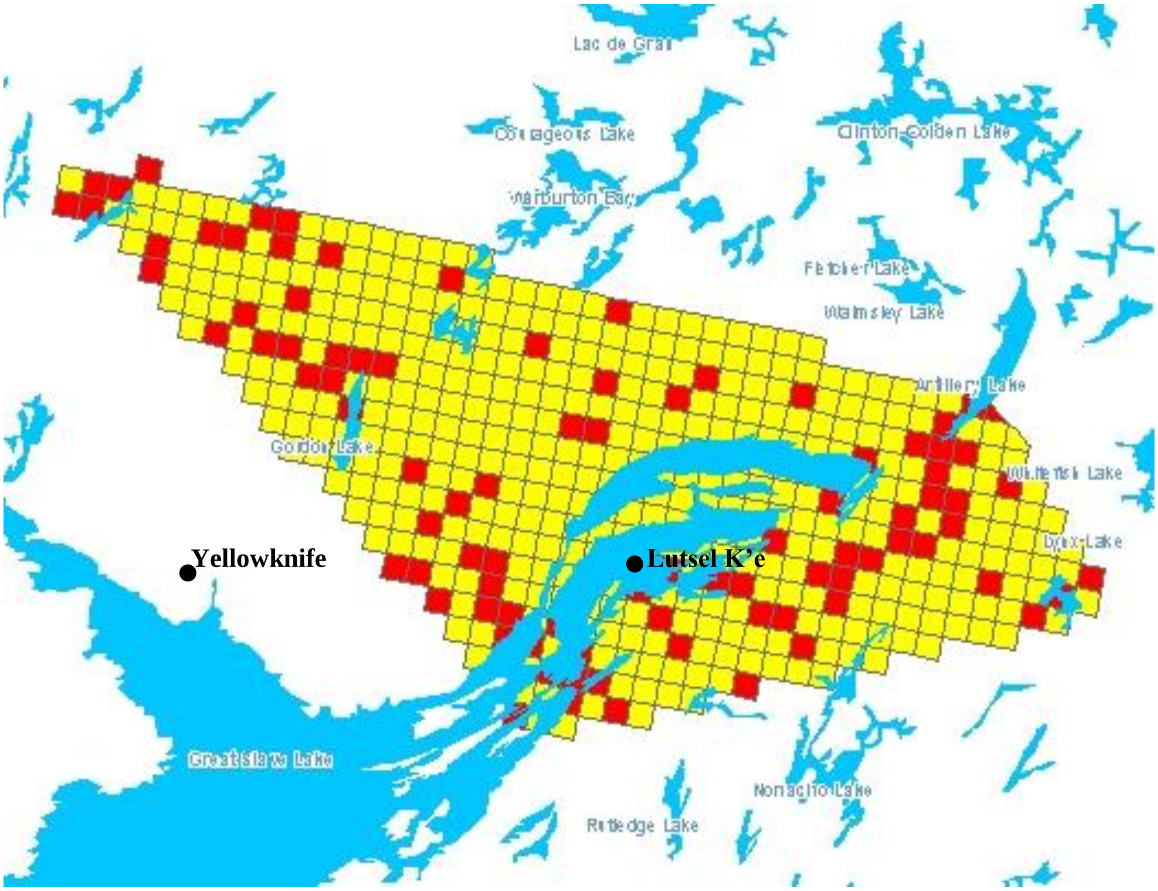

Figure 2. Sample units (100 km^2) for surveying the Bathurst caribou winter range, February-March 2006. Boundaries of the winter range were defined using a 100% minimum convex polygon.

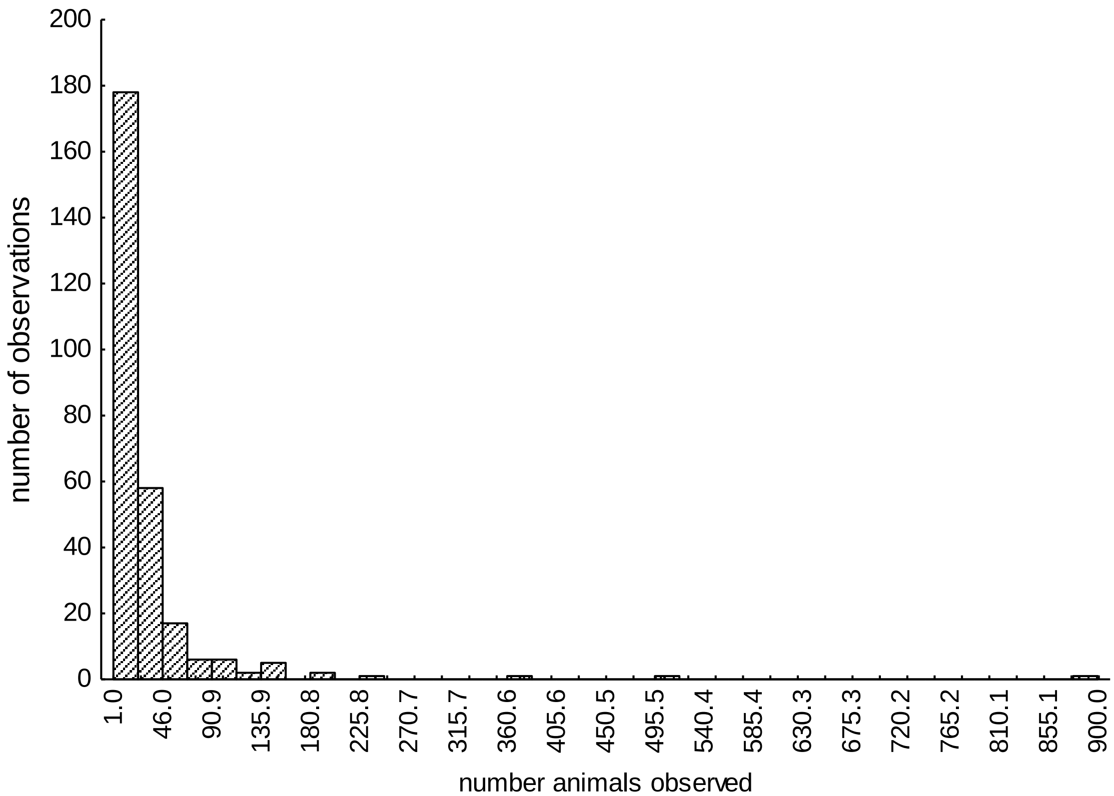

Figure 3. Frequency distribution of numbers of individual caribou within discrete groups observed through aerial surveillance on the Bathurst winter range, February-March 2006. A group of caribou was considered discrete when they occurred approximately 100 m or more from the next nearest group.

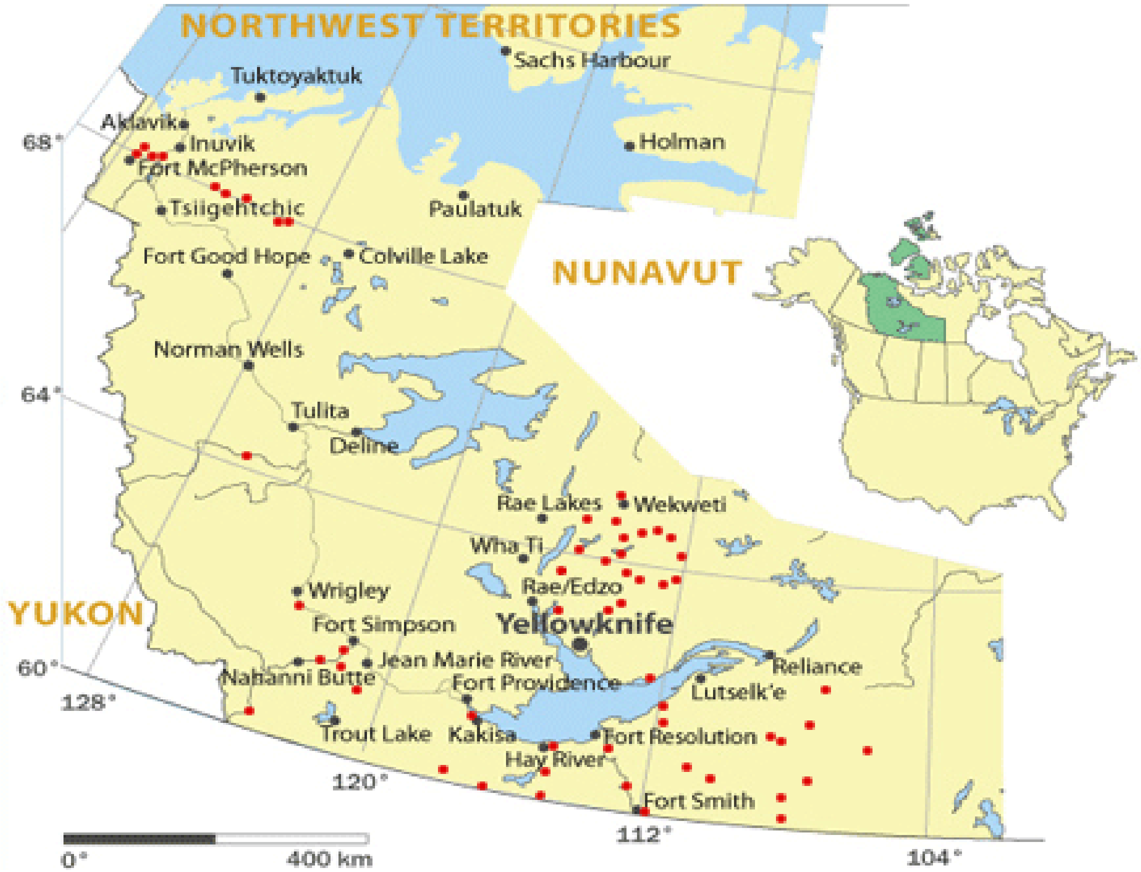

Figure 4. Snow-water equivalent (SWE) data collection sites (red dots) for the Northwest Territories.

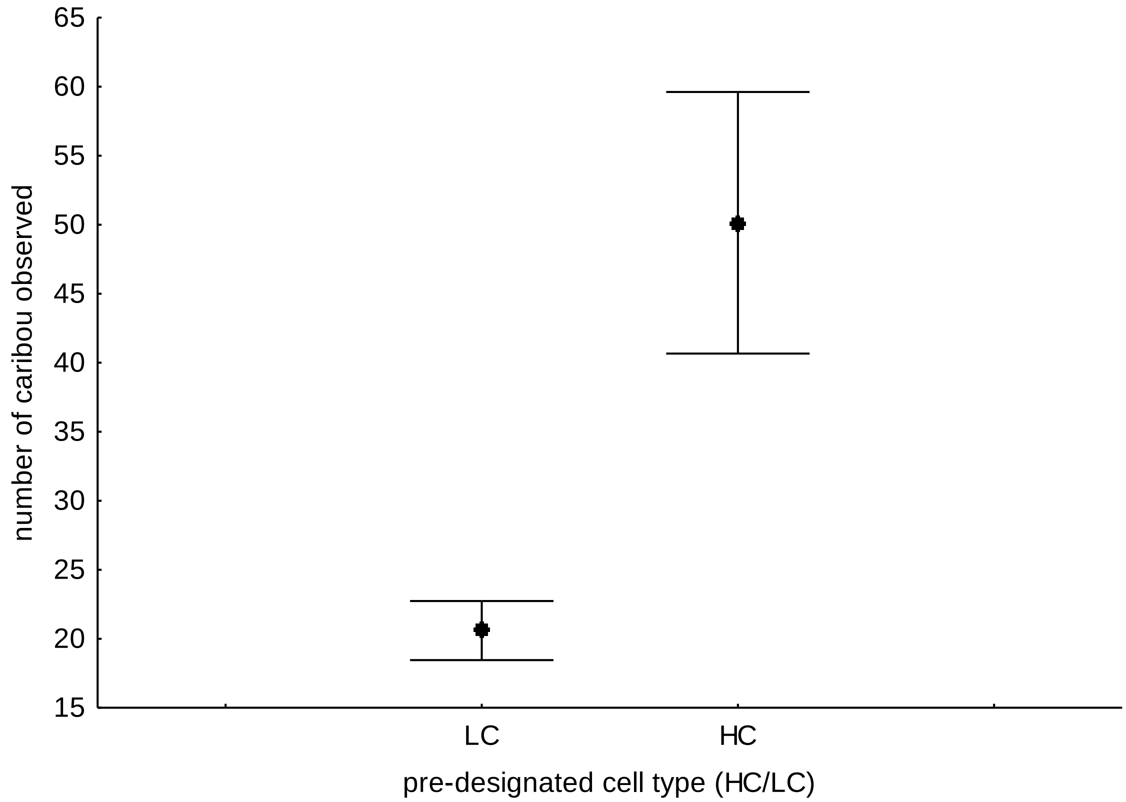

Figure 5. Mean number of caribou of the Bathurst herd (± 1SE) observed in the *a priori* designated High (HC) and Low (LC) caribou survey cells, February-March 2006.

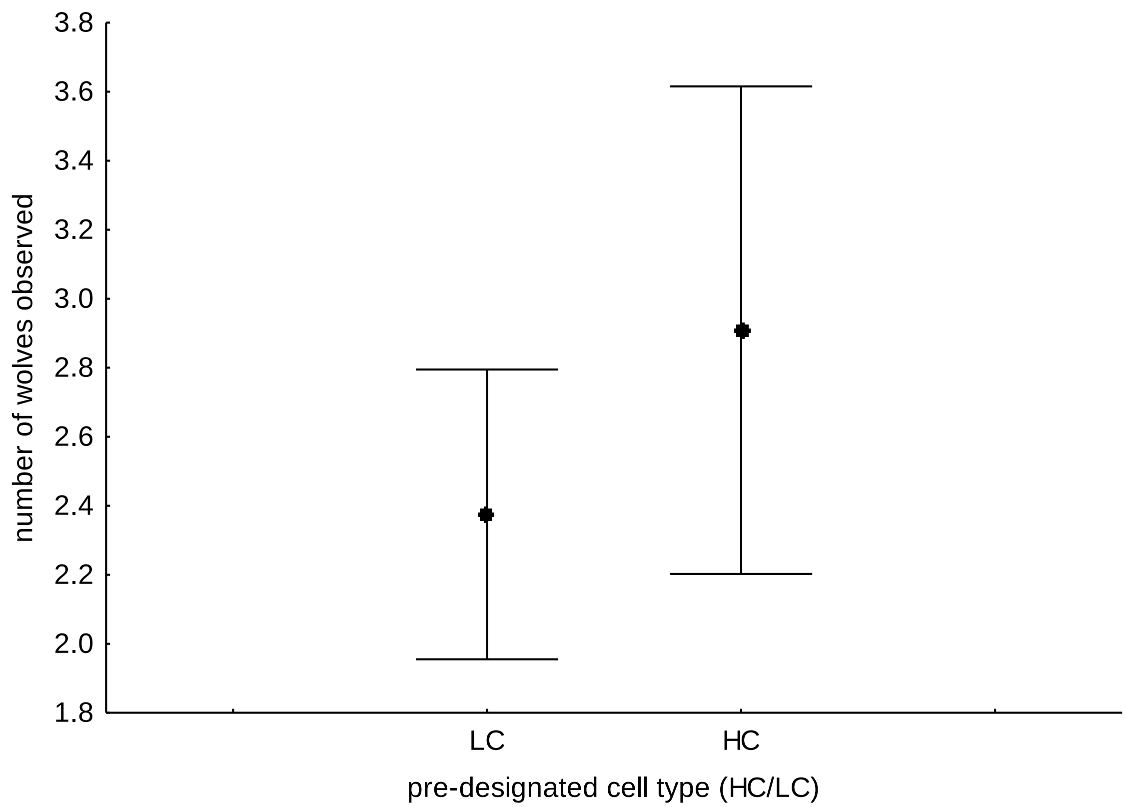

Figure 6. Mean number of wolves (± 1SE) on the Bathurst winter range observed in the *a priori* designated High (HC) and Low (LC) caribou survey cells, February-March 2006.

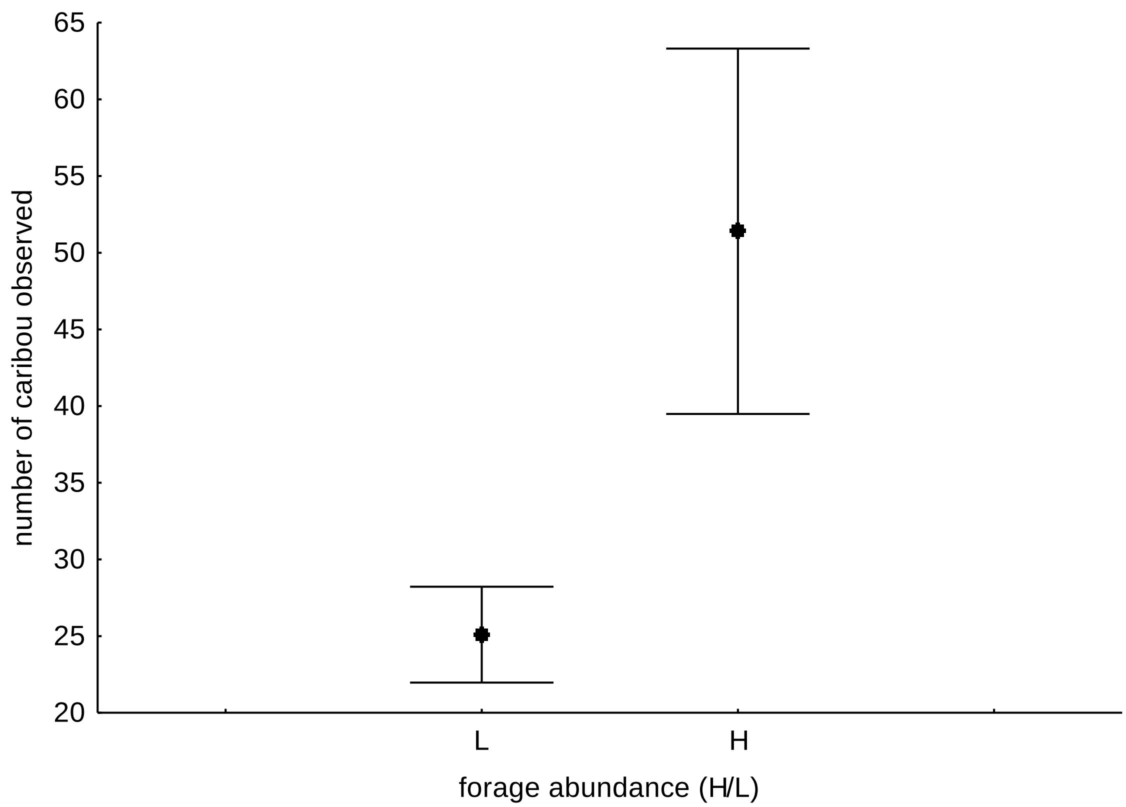

Figure 7. Mean number of caribou of the Bathurst herd (± 1SE) observed in survey cells classified as high forage lichen abundance (HL) and low forage lichen abundance (LL), February-March 2006.

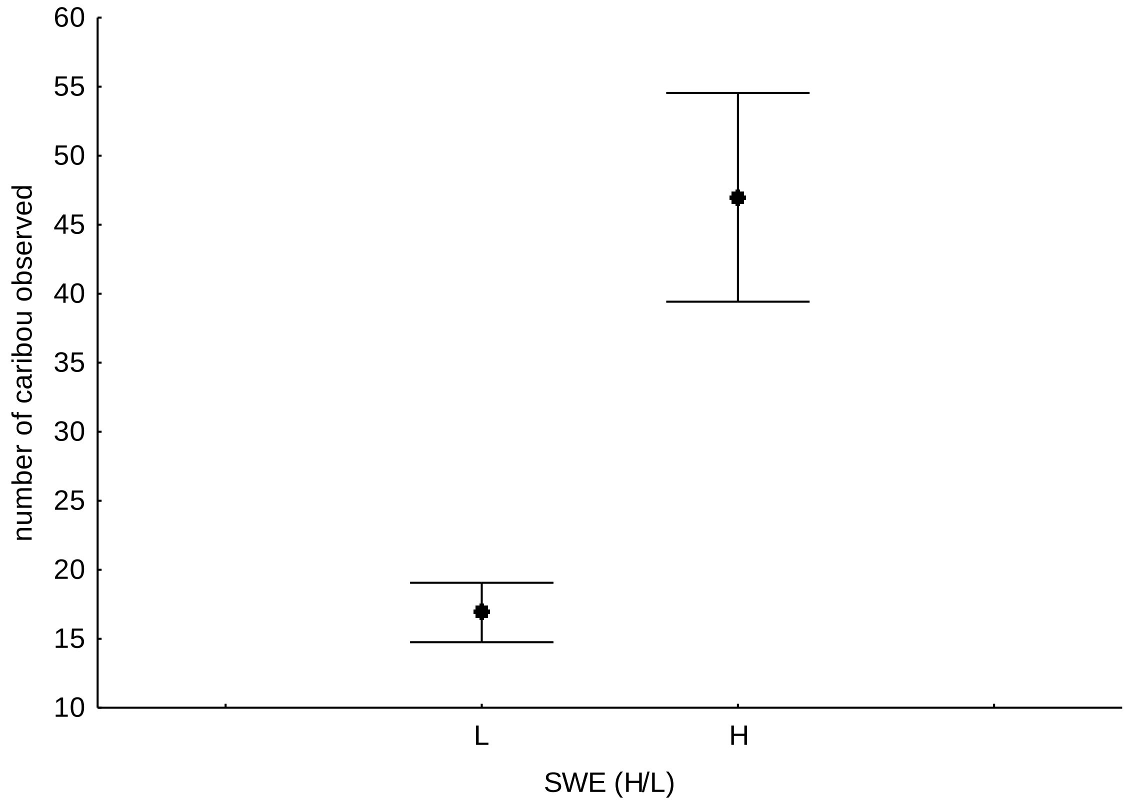

Figure 8. Mean number of caribou of the Bathurst herd (± 1SE) observed in survey cells classified as high snow water equivalence (HS) and low snow water equivalence (LS), February-March 2006.

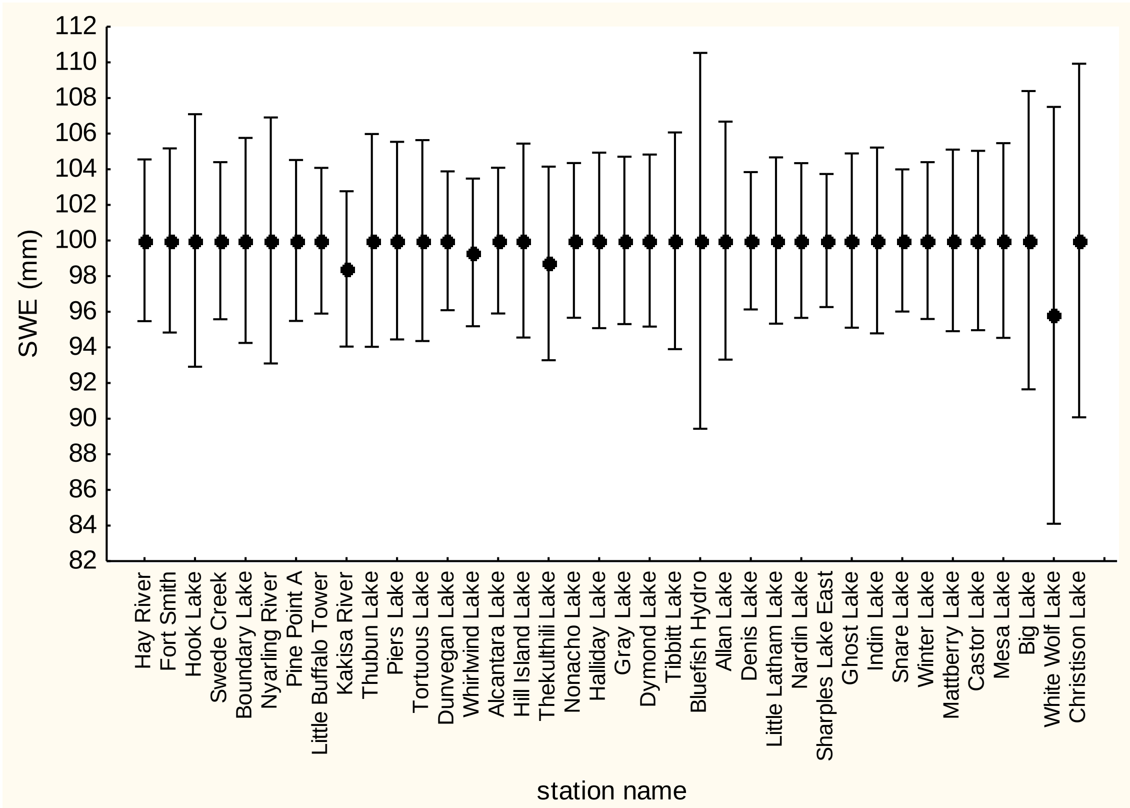

Figure 9. Mean snow water equivalence (± 1SE) for each station within the Bathurst caribou winter range; number of years of snow data varied by station.

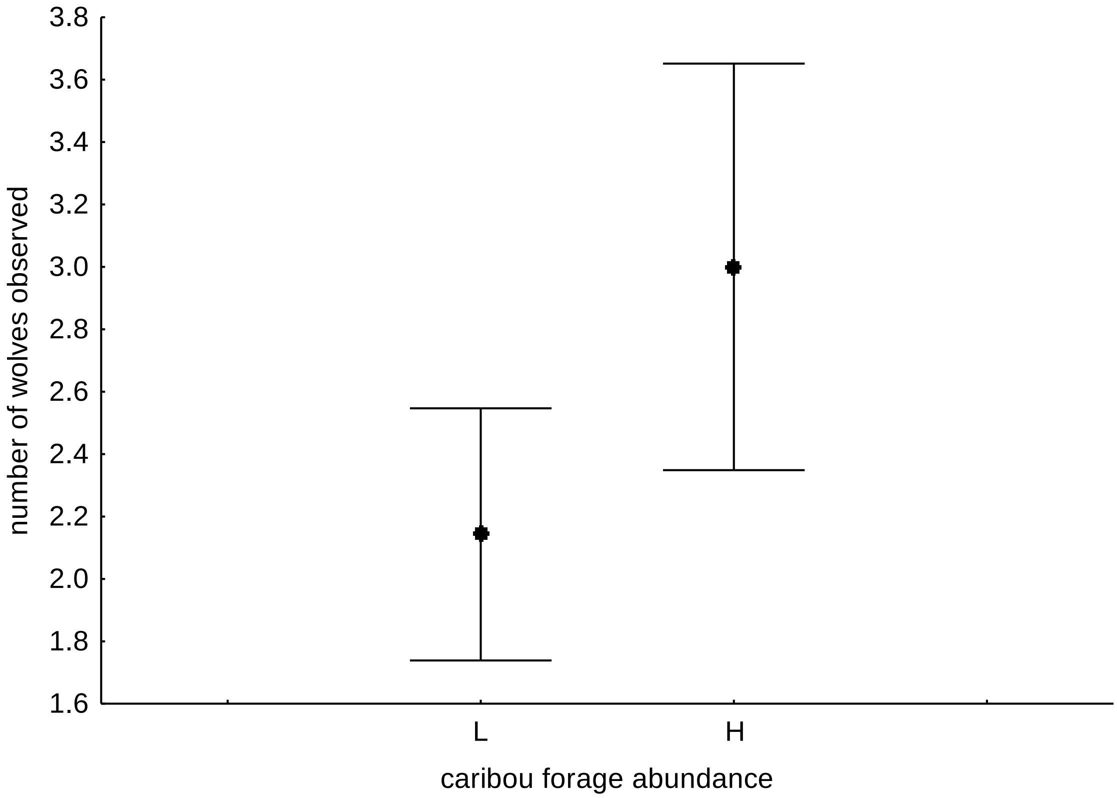

Figure 10. Mean number of wolves (± 1SE) on the Bathurst winter range observed in survey cells classified as high caribou forage abundance (HL) and low caribou forage abundance (LL), February-March 2006.

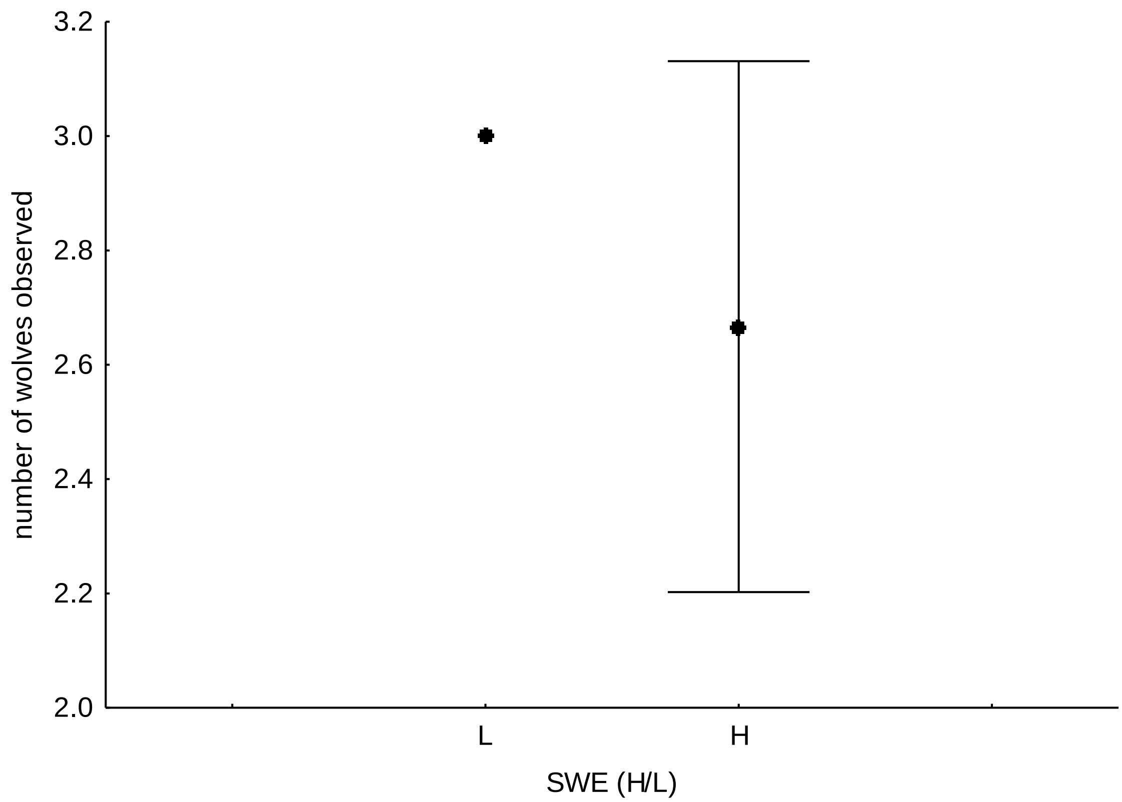

Figure 11. Mean number of wolves (± 1SE) on the Bathurst winter range observed in survey cells classified as high snow water equivalence (HS) and low snow water equivalence (LS), February-March 2006.

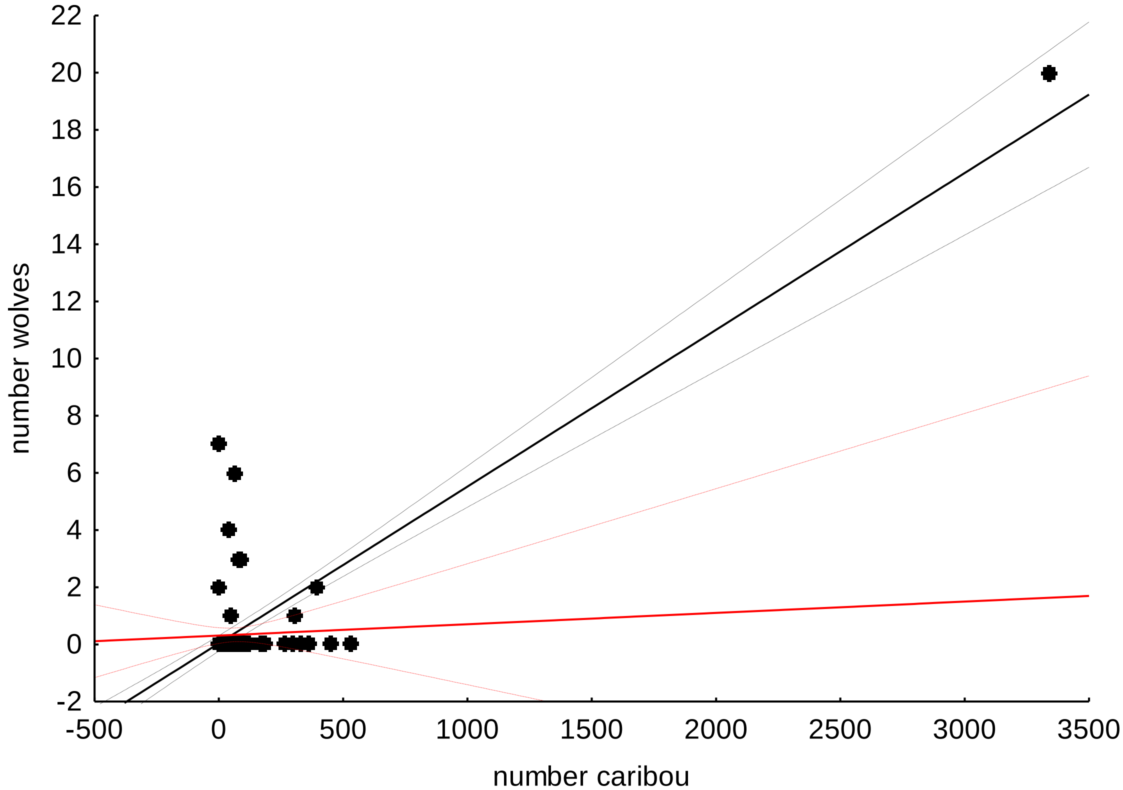

Figure 12. Number of wolves observed per cell on the Bathurst winter range in relation to the number of observed caribou, February-March 2006. Solid lines represent the fit of the data to a linear regression fit (± 95% Confidence Intervals). The line with the slope near 0 represents the relationship following the removal of one cell where both a large number of caribou and wolves were recorded.

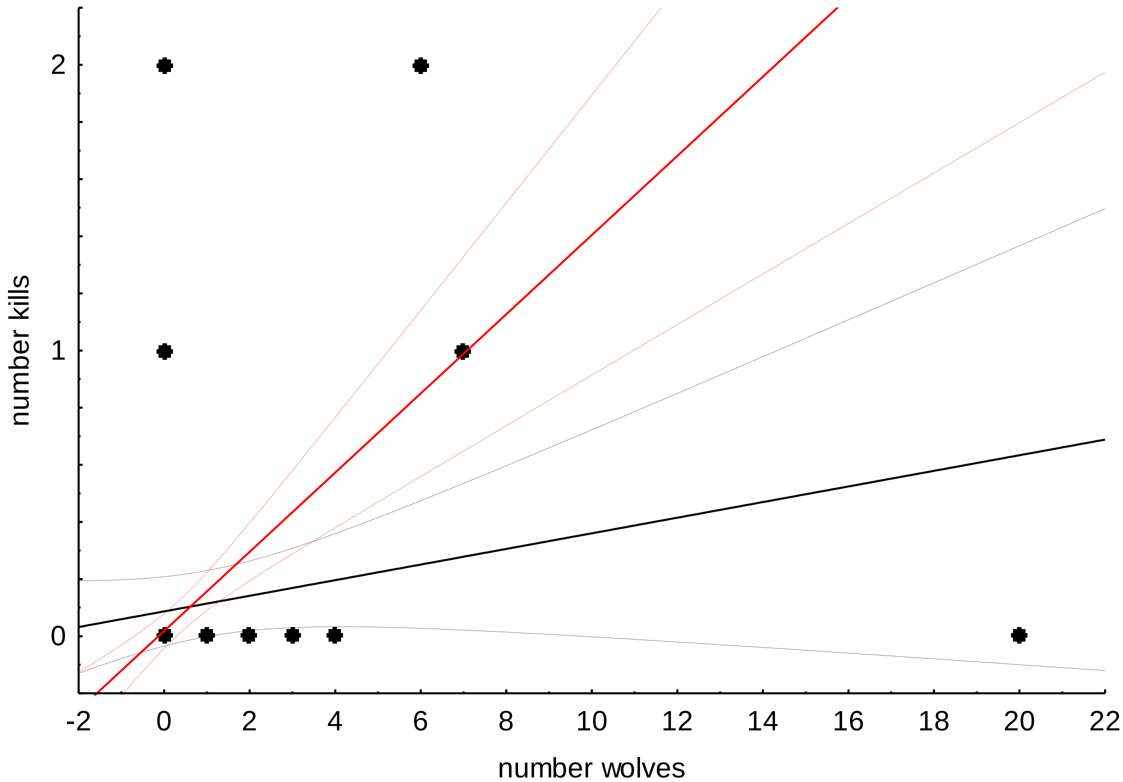

Figure 13. Number of predated caribou observed on the Bathurst winter range in relation to the number of observed wolves per survey cell, February-March 2006. Solid lines represent the linear regression fit (± 95% Confidence Intervals). The plot with the steepest slope represents the relationship following the removal of one cell where both a large number of caribou and wolves were recorded.

Appendix A. Description of 10 x 10-km grid for NWT wildlife and fish surveys.

A 10 km grid has been developed for the NWT for use as part of wildlife and fish surveys or other projects where a general location is required. It has been based on a grid originally created by the Sahtu GIS project for the Sahtu area. This grid has been expanded and used by Wildlife and Fish, Inuvik and Forest Management in Fort Smith. It was not until this grid was generated that the entire NWT was included. Additionally to ensure that each cell was uniquely identified to help with the general visual location of each cell, a systematic label was created for each cell. It is anticipated that all data collected using the various earlier versions based on the Sahtu grid be related to this label system so that there is a unique label for each cell that is consistent across the NWT. This should also permit similar data collected in different parts of the NWT to be compiled for territory-wide analysis.

The final product was two layers a 100 km by 100 km grid with unique MAPCODE values. The second layer is the 10 km grid, which has for each cell a unique INDEX. Each 100 km by 100 km block has 10 km by 10 km cells inside.

The original Sahtu 10 km grid was based on a Lambert Conformal Conic projection with the following parameters: central meridian –127, first and second standard parallels 62 and 68 respectively, reference latitude 0 and no false easting or northing.

It was created using the ARC/INFO GENERATE command with the FISHNET option. The FISHNET parameters were: origin coordinate –574968.375, 8068461, y-axis coordinate –574968.375, 8100000, cell size 10000, 10000, 0 for the number of rows and columns and 675032.25 9258461 as the upper right corner.

To create the Wildlife and Fish 10 km grid with a unique labeling that could assist with general cell location, the process started with a 100 km by 100 km grid. The parameters were the same except that the cell size was 100000 by 100000 and the upper right corner coordinates were 1470000, 10370000.

A program was written to generate a unique two digit MAPCODE for each major cell, with each cell coded from A to W in the y-direction and A to T in the x-direction, starting from the lower left corner.

The 10 km minor grid was generated based on the Sahtu coordinates except that the upper right corner coordinates were 1470000, 10370000. Both grids were joined together and another program was written to create a unique INDEX based on additions to the MAPCODE values

The NWT Wildlife and Fish 10 km grid cell identification system is based on the Archaeological Site Identification System developed by Dr. Charles Borden in 1952.

W																			
V																			
U																			
T																			
S																			
R																			
Q																			
P																			
O																			
N																			
M																			
L																			
K																			
J																			
I																			
H																			
G																			
F																			
E																			
D							x												
C																			
B																			
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T

In block ‘x’, the MAPCODE is DH

Within block DH are 100 10 km by 10 km cells:

j									
i									
h									
g									
e					x				
e									
d									
c									
b									
a	b	c	d	e	f	g	h	i	j

So the complete individual cell code for ‘x’ is DeHf

Appendix B. Mean ±1SE SWE measurements across multiple years for all stations in the NWT. Sampling interval (i.e., number of years, *N*) varied among stations.

Station	*N*	Mean	Standard Error
Hay River	25	100.01	4.54
Fort Smith	24	100.00	5.17
Hook Lake	18	100.01	7.09
Swede Creek	25	99.99	4.41
Boundary Lake	19	100.01	5.76
Nyarling River	24	100.00	6.91
Pine Point A	25	100.00	4.52
Little Buffalo Tower	25	99.99	4.09
Kakisa River	24	98.41	4.36
Thubun Lake	24	100.01	5.97
Piers Lake	24	100.00	5.55
Tortuous Lake	38	100.00	5.64
Dunvegan Lake	40	99.99	3.90
Whirlwind Lake	37	99.33	4.14
Alcantara Lake	38	100.00	4.09
Hill Island Lake	40	100.00	5.44
Thekulthili Lake	37	98.71	5.44
Nonacho Lake	40	100.01	4.34
Halliday Lake	40	100.01	4.93
Gray Lake	40	100.01	4.70
Dymond Lake	39	100.00	4.83
Tibbitt Lake	26	99.99	6.08
Bluefish Hydro	12	99.98	10.55
Allan Lake	18	99.99	6.68
Denis Lake	19	99.99	3.86
Little Latham Lake	19	100.00	4.66
Nardin Lake	19	100.00	4.35
Sharples Lake East	19	100.00	3.73
Fort Simpson	18	99.99	5.27
Fort Liard	15	99.99	8.22
Jean Marie Creek	13	100.00	8.12
Blackstone River	13	99.99	8.73
Shale Creek	12	100.00	6.95
Rengleng River	18	99.53	6.75
Caribou Creek	18	99.41	5.24
Big Spruce Lake	26	100.01	6.00
Ghost Lake	29	100.00	4.89
Indin Lake	29	100.00	5.22
Snare Lake	29	100.00	3.99
Winter Lake	28	100.00	4.40
Mattberry Lake	28	100.01	5.10

Castor Lake	28	100.00	5.03
Mesa Lake	28	100.00	5.46
Big Lake	10	100.02	8.37
White Wolf Lake	10	95.80	11.70
Christison Lake	12	100.00	9.92