Barren-Ground Caribou Management in the Northwest Territories:

An Independent Peer Review

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Preface

This document represents the Alberta Research Council's independent peer-review of aspects of the Government of the Northwest Territories (NWT) Department of Environment and Natural Resources' (ENR) caribou research and management program. It encompasses our analyses of the methods and conclusions contained in key survey reports from ENR; raw data from surveys were not re-analysed. We place ENR reports in the context of published scientific literature and discussions with outfitters, caribou managers, and other scientists. The conclusions reflect the authors' assessment of ENR's caribou survey program. Our recommendations are geared toward helping provide ENR with the best possible caribou management program, as guided by accepted scientific principles and the latest ecological theory and research.

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Executive Summary

The Government of the Northwest Territories (NWT) Department of Environment and Natural Resources (ENR) long-term data on barren-ground caribou populations suggest declines since the 1990s. The Alberta Research Council's independent review generally supports the scientific validity of ENR's survey program and conclusions regarding population declines, based on the available data. We also suggest that some conclusions are subject to scientific debate in some areas. These issues are not necessarily limited to the ENR, but likely apply to many caribou jurisdictions.

1. Defining caribou herds by calving ground affiliation is consistent with current practice. However segregation and movement between herds can be only inferred in some cases, and this affects the certainty of conclusions based on existing data. Numbers of collared caribou should be increased in the Bluenose herds for demographic estimation; collars should be increased several-fold in the Bathurst and eastern herds. A more modern statistical assessment of caribou herd population dynamics across the NWT is recommended.
2. The ENR's caribou survey methods have been consistent with common practice. However, irregular survey frequency and methodology across herds hampers population comparisons across space and time. A sensitivity analysis of population estimates to survey assumptions (such as sightability correction factors, herd boundaries, stratification, survey timing) is required to better understand the inherent uncertainty in these estimates. Survey techniques should be updated following the results of this analysis. Much greater collection of data is required on adult (male and female) mortality, calf mortality, and birth rates, and should be incorporated into population models to validate population estimates from surveys.
3. The existing data better support a decline in Bathurst and Bluenose / Cape Bathurst herds (as defined by ENR) than alternative explanations, such as mass migration, herd splitting (biological or statistical), or a negative bias in population estimates that was compounded through time. Therefore, managing these herds on the basis of decline is a sound precautionary conservation measure and is justified by the existing data.

However, some interpretations of the data are scientifically debatable, and changes are required to make trend analyses more definitive and achieve public and scientific consensus on NWT caribou management. We additionally suggest the following recommendations, which are intended to help NWT achieve the most scientifically defensible caribou research and management program possible:

1. Substantially increase collaring efforts for all caribou herds.
2. Create a standardized, regularly scheduled monitoring program to improve long-term planning and reporting on caribou research.
3. Increase focus on obtaining demographic data on caribou herds.
4. Incorporate population modelling into caribou management programs.
5. Provide internal or external peer-reviews for all survey reports.
6. Publicly report survey and research results immediately and transparently.
7. Develop a Territory-wide, consistent and strategic approach to ENR's caribou research program with centralized coordination.
8. Formulate caribou management decisions within an adaptive management framework.
9. Form partnerships to increase resources dedicated to caribou research.

In summary, our review of the existing data did not reveal any evidence that the observed decline in some herds is an artefact of intent or neglect on the behalf of ENR biologists. The existing scientific evidence is subject to improvement but does tend to support a decline in the Bathurst and Bluenose / Cape Bathurst herds as defined by ENR. Therefore, until consistent and more comprehensive methods for multi-herd surveying and demographic research is employed, managing on the basis of a decline is indeed warranted based on existing data and the precautionary principle.

Introduction

The Government of the Northwest Territories (NWT) Department of Environment and Natural Resources (ENR) are responsible for collecting long-term data on barren-ground caribou populations to guide management decisions. Based on these data, ENR suggests that caribou populations in the Bathurst and Bluenose East herds have declined since a peak in the 1990s, and continue to decline (see Appendix 2 for population estimates through time for all NWT herds). In response to these apparent declines, ENR has recommended management actions to aid herd recovery in the NWT Caribou Management Plan (ENR 2006) and the Bathurst Caribou Management Plan (ENR 2004). These actions include (among others) managing human impacts on caribou herds, such as monitoring the effects of industrial development on caribou, and reducing harvest quotas to commercial outfitters.

In response to this quota adjustment, some commercial outfitters have questioned the validity of ENR's evidence for a caribou decline and ENR's caribou research and management techniques in general. The contention is that the purported caribou decline is instead an artefact of a combination of inaccurate caribou surveying techniques, statistical analysis, and a misinterpretation of the data (Andre 2007). A subsequent external review of some of ENR's caribou survey reports was commissioned by the outfitters, and supported the outfitters' claims (Fraker 2007, 2008). Fraker concluded that mathematical errors in ENR reports could contribute to erroneous interpretation of the evidence for a caribou decline in the NWT.

The Minister of ENR subsequently requested that the Alberta Research Council (Appendix 1) conduct an independent peer-review of ENR's caribou survey methodology and interpretation of long-term caribou population trends. The review has three main objectives:

1. Assess whether ENR's application of herd-based management is scientifically valid, and comparable to management employed by other North American jurisdictions responsible for caribou management;

2. Assess whether ENR's caribou survey methods - notably photography of post-calving aggregations and photographic transect surveys of calving grounds - are scientifically

valid and reliable ways of estimating herd size of barren-ground caribou, comparable to other jurisdictions;

3. Evaluate ENR's existing caribou research, and determine whether the data and analyses from population surveys and other related information provide sufficient evidence to support a decline in barren-ground caribou populations.

We have based this review on our past experience in caribou management and wildlife research, statistical expertise in experimental design and data analysis, current scientific and government literature, and discussions with other wildlife biologists. This is primarily a literature review. We did not re-analyse raw survey data to test assumptions or validate results. We did conduct some statistical analysis of trend information. We see the key objective - weighing evidence for or against a decline - as strategic and coarse-scale rather than an issue of fine-scale detail. Distilled into simple terms, this review evaluates whether evidence suggests that enough caribou were missed, miscounted, mis-assigned to herds, or moved between herds, to account for an alleged decline in caribou over the last decades; or instead that the data support an actual decline in caribou populations.

I. Herd-based management

The definition of *caribou herd* sits at the heart of the NWT caribou controversy. Caribou are seasonally gregarious, sometimes forming groups that can number in the tens or hundreds of thousands. Virtually all herds in North America are identified and managed on the basis of calving ground fidelity (*sensu* Skoog 1968). Parturient (pregnant) females that aggregate together at calving, together with other females and their associated males and juveniles, constitute a herd. A herd is assumed to exhibit generally similar pregnancy, birth, and survival rates, as well as immigration and emigration rates. These demographic rates tend to differ among herds, so different herds can be considered different populations (or subpopulations; Skoog 1968).

Managing and researching populations as basic ecological units is well justified. Berryman (2002) suggests "...it no longer makes sense to consider population dynamics as a particular way to view ecology - it's the only way". However, a common problem with *population* (or *herd*) is its casual definition. Population is generally described as "a group of individuals of the same species living together in a particular place" (Berryman 2002), but the definition of *place* is at the heart of controversy (Camus and Lima 2002). This controversy has been hotly debated by ecologists (*e.g.* Camus and Lima 2002; Baguette and Stevens 2003; Schaefer 2006), so it is not surprising that it is likewise debated by wildlife harvesters (*e.g.* Andre 2007) and other laypeople. This is particularly problematic when the *place* of a population tends to change through time, as is the case with barren-ground caribou (*e.g.* Bathurst herd; Gunn *et al.* 2008a,b). This problem can be negated by focussing on population *dynamics* rather than *place*. Berryman (2002 p.441) suggests that a population be defined as "a group of individuals of the same species that live together in an area of sufficient size to permit normal dispersal and/or migration behaviour and in which numerical changes are largely determined by birth and death processes".

ENR assigns herds on the basis of calving ground fidelity: a common calving area, and similar demographic characteristics, are the conceptual benchmarks for caribou herd identification. As herds are typically geographically separate from one another, at least for calving and post-calving, herd-based management is the basis for NWT's caribou management program. In doing so, management actions may be applied appropriately for each herd, given its particular set of demographic variables. Defining and managing herds by calving grounds is common among caribou jurisdictions (*e.g.* Alaska; Valkenburg 1998). In fact this definition is standardized across North American jurisdictions (Russell *et al.* 2002), and NWT adheres to these standards (Gunn *et al.* 2008c). Our analysis supports the rationale for herd-based management outlined in Gunn *et al.* (2008) and yields two additional conclusions.

First, ENR uses a herd definition that has been commonly employed in the past (Skoog 1968) and present, and is generally operationally feasible. The alternative - identifying the entirety of barren-ground caribou as a single herd - violates all ecological assumptions about populations, as different herds have different demographic rates and different dispersal patterns. Defining herds based on calving grounds has been the most reasonable biologically justified approach to management. Though Skoog (1968) developed the herd concept, the NWT has helped advance the definition of calving grounds (Gunn and Miller 1986). This standard definition has been adopted by other jurisdictions (Russell *et al.* 2002; Hinkes *et al.* 2005).

However, defining a herd by its calving grounds does not solve the issues inherent in *delineating* the boundaries of a herd's annual range. The great degree of overlap among herds outside the calving grounds (Gunn 2008; and Appendix 3), and the known geographic shifts in calving ground locations (*e.g.* Bathurst herd; Gunn *et al.* 2008b) makes the delineation of *herd* a moving target, literally and figuratively. This is illustrated by the ongoing definition of new herds, such as the Ahiak and various Bluenose herds. New herd definition is a product of constantly accumulating information, new technology, further research, and changes in caribou herd dynamics over time. This is not solely an NWT phenomenon; for instance Valkenburg (1998) describes the assignment of new Alaska herds with additional information. Though the definition of new herds on the basis of newly discovered calving grounds is sound, the issue of herd delineation still exists. Overlapping herds may share similar sources and rates of mortality, particularly since overlap occurs during harvesting seasons. Inter-herd exchange of individuals is also possible, and these rates are poorly understood.

This leads to our second conclusion: ENR's operational application of herd-based management generates ambiguity in data interpretation. The ambiguity primarily surrounds estimates of population closure - the degree to which exchange occurs among populations, in this case herds. A population, once defined as such, is assumed to experience a minimal amount of immigration or emigration compared with births and deaths (Berryman 2002; Camus and Lima 2002). The key question can be summed up as: *once an individual is born into a herd, does it always stay with that herd?*

The NWT's position is that herds are relatively discrete, without significant immigration or emigration between them (Gunn *et al.* 2008c) - significant meaning in numbers large enough to affect population estimates between surveys. This position reflects statements made in reports on collaring studies (Heard and Stenhouse 1992 in Gunn *et al.* 2008c; Heard and Williams 1990, 1991). Gunn (2008) and Gunn *et al.* (2008a) report no movement of Bathurst females to other calving grounds. This position also reflects ENR's original interpretation of Zittlau's (2004) genetic analysis of herd differentiation (*e.g.* Gunn and D'Hont 2002) which was that genetic evidence suggest herds are quite discrete (but see Gunn *et al.* 2008c for a more recent interpretation). Andre (2007) suggests an alternative hypothesis - that caribou populations are radically indiscrete, and that the caribou declines in the Bathurst herd are instead the result of mass emigration, or splitting of the Bathurst herd, to the neighbouring Ahiak herd. This hypothesis was based in part on the fact that the calving grounds of the two herds spatially (but not temporally) overlapped (Gunn and D'Hont 2002).

In fact, herd fidelity is likewise debated among some caribou biologists. Hinkes *et al.* (2005) illustrate that although herd infidelity is strongly contested by many caribou researchers, it can happen. In Alaska, collars deployed on the expanding Mulchatna caribou herd (MCH) and the adjacent Kilbuck caribou herd (KCH) showed that the MCH herd displayed range expansion, shifts in calving grounds, and a decreased calving ground fidelity. This phenomenon was predicted by Skoog (1968, in Hinkes *et al.* 2005) and others in response to increasing caribou densities. Hinkes *et al.* (2005) suggested that calving ground fidelity, and indeed herd fidelity, decreased during periods of high caribou density, akin to a metapopulation dynamic (Levin 1970). *Metapopulation* refers to a "population of populations", wherein individuals sporadically but frequently move between otherwise discrete populations in response to local conditions.

The hypothesis that *it is possible* that caribou change herds and calving grounds is supported by theory, but there is no empirical evidence that exchange is widespread or that exchange rates are high. Though exchange has been empirically demonstrated in the Alaskan KCH, with a peak of 11 of 13 collared animals shifting grounds (Hinkes *et al.* 2005), this was an unusual occurrence, and overall calving ground switching rates are extremely low. The ENR argues that their data suggest major movements of caribou between herds (and hence calving grounds) has not occurred in the NWT (Gunn 2008; Gunn *et al.* 2000; Gunn *et al.* 2008a; Gunn *et al.* 2008c). Our analysis suggests that this is the best available inference based on existing data.

However, it *is* an inference, as the data are neither abundant nor rigorous enough to yield reliable conclusions. Very few examples of inter-herd movement exist; for example, Johnson *et al.* (2008)'s Ahiak survey reported a number of cases where collared cows switched calving grounds between years. Other data (see Gunn 2008; Gunn *et al.* 2008a) represent equivocal evaluations of the extent of calving-ground switching (see below). Additionally, contrary to ENR's original interpretation of Zittlau's (2004) analysis of genetic differentiation between herds, it is apparent that Zittlau did not find genetic differences between herds to suggest they are discrete from one another (see *Gunn et al.* 2008c for further discussion). Overall, the degree of closure among caribou herds in the NWT is not well defined. This problem is linked with issues of herd identity, range boundaries, seasonal movements, and demography, and is primarily due to three main issues:

1. Sample size of collared animals.- *Collars* refers collectively to VHF collars, GPS collars, and/or satellite collars, all of which provide information on individual movement. ENR relies on collars to provide information on calving grounds, herd delineation, seasonal movement, and to guide post-calving photography (PCP) surveys. Barren-ground caribou herds in the NWT are defined based on calving-ground fidelity of often very small numbers of collared female caribou. For example, Table 1 (from Gunn *et al.* 2008a) shows the numbers of satellite collars deployed on the Bathurst herd by year from 1996-2005. Table 2 (from Nagy 2008a) shows similar information for the Bluenose herds. Table 3 (compiled from Nagy 2008b and Rettie 2008) shows the number of all collared caribou in the Bluenose herds at the time that post-calving photography surveys were conducted.

Table 1. Sample sizes of satellite-collared cows, Bathurst caribou herd, April 1996 - May 2005. From Gunn *et al.* (2008a).

Season	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
winter	9	8	6	19	14	15	15	15	8	20
spring migration	10	7	14	16	13	14	12	13	7	17
calving	9	7	3	14	13	13	11	12	6	
post-calving	10	7	9	12	13	13	11	11	6	
early summer	9	7	8	12	12	12	11	10	5	
mid-late summer	10	8	8	13	13	13	11	10	5	
fall migration	10	7	6	14	12	11	9	10	6	
rut and late fall	9	7	21	14	13	9	10	9	10	

Table 2. Sample sizes of satellite-collared cows used for demographic data and movement data: Cape Bathurst, Bluenose-West, and Bluenose-East herds, 1996 to 2006. From Nagy (2008a).

	Herd				
Year	Bluenose-East	Bluenose-West	Cape Bathurst	Unknown	Total
1995-1996	5	5	4	1	15
1996-1997	3	2	-	-	5
1997-1998	5	-	-	-	5
1998-1999	-	13	2	-	15
1999-2000	-	-	-	-	-
2000-2001	-	-	-	-	-
2001-2002	-	8	10	1	19
2002-2003	3	1	-	-	4
2003-2004	-	-	-	-	-
2004-2005	7	9	8	4	28
2005-2006	8	8	7	4	27
Total	31	46	31	10	118

Table 3. Sample sizes of satellite- and VHF-collared cows combined by survey year, used for PCP survey caribou aggregate identification: Cape Bathurst, Bluenose-West, and Bluenose-East herds. Adapted from Nagy (2008b).

Herd	2000	2005	2006	Sample size recommended by Rettie (2008)	Planned sample sizes in 2009*
Bluenose West	47	63	66	60	70
Cape Bathurst	17	32	33	30	33
Bluenose East	33	43	51	40-60	60

* data from Jan Adamczewski, NWT ENR

Based on Bathurst population estimates (Nishi *et al.* 2007), percentages of the Bathurst population sampled thus ranged from 0.01% in 1996, to 0.03% in 2003. In other words, conclusions about population movement are based on 1-3 individuals in 10,000. Small sample sizes make estimates of any measured parameter much less reliable (Hurlbert 1984; Skalski *et al.* 2005; Whitlock and Schluter 2008); this is particularly true when measuring individual-level phenomena (*e.g.* Turchin 1998). Movement rates, fidelity, fecundity, birth, and survival rates for the entire population are being based on sample sizes that are far too low to reliably infer to the greater population. Sample sizes are further decreased by mortality, collar failures, and unknown herd affiliation prior to collaring

(Gunn 2008). This issue is recognized by ENR biologists (Gunn 2008 p. 4). As such, for these eastern herds (Bathurst, Beverly, Qamanirjuaq), collar data are currently used as ancillary information, not as primary information. For the western (Bluenose) herds, which rely on PCP surveys for population estimates, collaring data are more important.

Rettie (2008) performed a power analysis to determine the sample sizes of collared caribou required to reliably detect trends in female survival, and determined that 80 or more collared females per herd would be required to detect moderate (6% - 7% per year for >3 years) changes in female survival. This number is far less than the number of collars currently deployed for the Bathurst herd (Table 1), the Bluenose herds (Table 2), or the Ahiak herd (36 as of November 2008; J. Adamczewski, ENR, pers. comm.). Rettie (2008) likewise performed a power analysis to determine the sample sizes of collared caribou required to reliably assign herd identity for the Bluenose herds, as the basis of PCP surveys. Based on his analysis, Rettie recommended sample sizes for each herd: Bluenose-East, 40-60; Bluenose-West, 60; Cape Bathurst, 30; and Upper Tuktoyaktuk Peninsula, 30 (Table 3). These recommended sample sizes are larger than the numbers deployed for the 2000 survey, but equivalent to numbers used in the 2005 and 2006 surveys, and the number planned for the upcoming 2009 survey (J. Adamczewski, ENR, pers. comm.).

Based on Rettie's (2008) power analysis and our own assessment, ENR collar numbers are currently sufficient to produce reliable population estimates from PCP surveys of the Bluenose herds (see *Caribou Survey Methods*), but not adequate to reliably estimate demographic rates. We strongly suggest a several-fold increase in the sample size of collars for Bathurst herds, and a 30%-100% increase in satellite collars for Bluenose herds, is required to produce reliable demographic estimates for barren-ground caribou monitoring. Most collars should be placed on females, but collars should be placed on males as well to assess inter-herd movement and bull mortality. Overall, more location data are needed to provide better information about herd distribution, movement, demography, and overlaps between caribou herd ranges.

We recognize that ENR biologists do not always decide collar sample size. Low collar sample sizes are due, in large part, to limited financial resources and to social pressure against collaring from local First Nations people (Byers 1999). In 2008 the Dene

Nation resolved that satellite collars are not to be used to monitor caribou (A. Gunn, pers. comm.). Political and social demands are obvious priorities for any responsible government. Nevertheless, the trade-off in rejecting collaring is accepting inadequate scientific information about caribou movement and population dynamics. In an area the size of NWT, in herds as large as the NWT caribou herds, the apparent alternative to collars - frequent and routine flights to survey caribou locations - is not feasible, and cannot be used to obtain key demographic data (see *Recommendations*). In fact, many demographic parameters critical to population estimation and modelling cannot be obtained without collaring. Constraints on collar sample sizes leave the results of studies that depend on collars open to scientific and statistical scrutiny, and lessen the credibility of conclusions based on these data, except in cases where the statistical requirements for sample sizes can be demonstrably met (*e.g.* Table 3). This is also true of population estimates that rely on assumed demographic parameters weakly supported by sparse collaring data.

2. Experimental design of collaring surveys.- Some sampling techniques used for selecting individual females for collaring may bias evidence of calving ground fidelity. Collars are typically deployed on winter ranges (*e.g.* Gunn 2008) away from the calving grounds (Gunn *et al.* 2008b). The subsequent calving destination of these collared females serves as the basis for their herd affiliation. Repeated returns to that same calving ground is ENR's evidence for calving ground fidelity (Gunn and D'Hont 2002; Gunn 2008). We suggest that these data may be rendered somewhat equivocal by experimental design problems.

Initial selection of females for collars is often based on locations from existing collared caribou (*e.g.* Gunn 2008 p.14). This problem is common in caribou collaring studies across jurisdictions, as caribou cannot be collared if they cannot be found. Nonetheless this is biased sampling. If those females displaying calving-ground fidelity group together outside the calving grounds, then selecting females in proximity to one another will bias evidence in favour of fidelity; the opposite is also true. Selecting animals from the same group ensures that observations are *not* independent, and cannot be reliably extrapolated to the whole herd. Females should be selected randomly from a candidate pool established by reconnaissance transects. In some cases, such transects are flown and used as a basis for collar deployment, and this is the preferred approach.

However, even with collars deployed *via* reconnaissance, there are several instances where collars are deployed in clusters or uniformly, not randomly (Gunn and D'Hont 2002; Gunn 2008; Gunn *et al.* 2008a; Nagy 2008a,b). Nagy (2008b) reviews several criteria for deployment of collars prior to a PCP survey, notably over-dispersion (non-random selection) of sampled caribou. Nagy describes in detail the justification for these criteria, and we agree that these criteria must be considered given the demands for collar dispersion in PCP surveys. However it must be recognized that any non-random sampling generates the potential for bias.

Uniform (and hence non-random) deployment of collars for PCP surveys is necessary to ensure that collars are represented in all aggregations, and that is the objective of these surveys. In non-PCP sampling (such as sampling for demographic rates, herd movements, calving ground fidelity), the use of randomization in collar deployment would strengthen the weight of ENR's evidence considerably. For example, Gunn *et al.* (2008) sought to assess whether collared animals were representative of the herd. However, they focussed their assessment on whether the herd avoided collared caribou; they found no effect, so assumed collared animals were adequately representative of the population. Other measures of sample representation (*e.g.* Hurlbert 1984) were not tested, simply because they are extremely difficult, if not impossible, to field-test. Randomization is a key feature of statistically rigorous analyses (Skalski *et al.* 2005; Whitlock and Schluter 2008). Randomization is necessary to prevent pseudoreplication (Hurlbert 1984), wherein inappropriate inferences about a population are made from samples. Randomizing the selection of individuals allows the assumption that individual variability in relation to the population is also random, and therefore without bias, curtailing the unrealistic requirement that each sampled individual is truly representative of the population. We recommend that (exclusive of PCP survey collar deployments) sampling regimes for collared caribou be re-examined, and a practical and financially feasible compromise approach be devised for which possible biases are acknowledged and statistically managed.

3. Lack of data on demographic rates for herds.- Population size is the result of births, deaths, immigration, and emigration. We have described that immigration and emigration rates are not well known for barren-ground herds. Birth data - including parturition (birth rates) and recruitment (rate of calf survival to yearling age) are estimated from classification, or composition, surveys. Classification surveys are conducted in the fall and winter and in our experience can be very difficult to undertake. Survival rates based on these surveys are likewise difficult to reliably estimate (Skalski *et al.* 2005).

NWT deals with this difficulty by estimating survival as the change in the relative number of calves per cow (Gunn *et al.* 1997; Gunn *et al.* 2005; Gunn *et al.* 2008c). This estimation is the best available, given the limited data. However, this estimation assumes that the change in cow survival is also known, but it is not; it is assumed without empirical data. Therefore the calf survival estimates based on this change in cow survival are likewise assumed.

It must be made clear that the problems we have identified *do not* constitute supporting evidence for the opposing hypothesis that caribou numbers are stable or increasing. It is entirely possible that sampling biases and assumptions of key demographic rates operate to underestimate population sizes, making the decline even more precipitous than ENR suggests. ENR has used the best data available to produce the most reasonable estimates possible. However, the lack of reliable demographic data makes these estimates scientifically debatable, and ENR is aware of these shortcomings.

Conclusions.- The consequence of low sample sizes and non-random sampling designs is that inferences made about caribou movements and demography are less robust. For example, no data exist on movements of sex-age classes other than adult females, leaving the question of caribou movements by these other classes unanswered. However, in a logistically limited system - common to all scientific inquiry (Collins and Pinch 1998) - collaring the adult female (breeding) component of the population is the most reasonable course of action. Ideally, many more females, and some males, would be collared and movement and survival data collected.

The existing low sample sizes of collared animals on adjacent herds preclude a conclusive test of the degree of inter-herd movement. In fact, even within low sample sizes, some variability in individual movement and calving ground fidelity does exist. The magnitude of this fidelity is unknown. This is a pivot point, as Andre (2007) suggests animals have moved (or split) from Bathurst calving grounds to Ahiak grounds, mixing the herds, and obscuring the population estimates from each herd. There are no data to support Andre's supposition, and the data to the contrary are not definitive. We concur with ENR that in the absence of better data, existing data tend to suggest that major movements would be extremely rare. This is a reasonable conclusion - on an interim basis. The data need future improvement to definitively test this conclusion. Our first key recommendation is that variability in individual movement and fidelity be tested more conclusively with a several-fold increase in collaring intensity.

It is unlikely that the populations are as discrete as is currently assumed. New definitions of populations should be considered for use in herd-based management. Treating the NWT's caribou as a metapopulation, as has been suggested for some Alaskan groups (Hinkes *et al.* 2005), might be more appropriate. In this model, currently defined herds are considered subpopulations within a metapopulation, and the degree of movement between the subpopulations becomes an ecologically important area of focus. There are more statistical models than the metapopulation model available for analysis of adjacent populations without clear boundaries. Fuzzy structures (Schaefer and Wilson 2002; Schaefer 2006) may prove more feasible for future caribou research and management. Fuzzy structures account for among-group movement, individuals on the edges of groups, and cross-scale problems associated with estimating densities of very patchily distributed organisms. They do not assume rigid herd assignments, but rather probabilities of herd affiliation, a much more likely ecological scenario (Schaefer 2006). Fuzzy structure analysis has been conducted on other caribou herds to assign herd affiliation, to good effect (Schaefer *et al.* 2001).

The implication for management is that herds, although surveyed, modelled, and managed as separate units, should additionally be integrated and demographically modelled as interacting components of a whole population. To this end a Territory-wide system to temporally and spatially allocate survey effort should be implemented. This has been suggested to some degree in the NWT Caribou Management Strategy (2006). This is a start, but the analysis of the survey data for each herd should be integrated within a metapopulation or some other integrative population framework.

Finally, we acknowledge that all scientists must work with imperfect data, make the best conclusions possible based on those data, and try to improve the data for the next set of conclusions (Collins and Pinch 1998). ENR has applied these principles, and their inferences and conclusions are the best available. In contrast, no data support the competing hypotheses that all caribou should be treated as one herd, nor that mass movements between herds have demonstrably occurred. Though there is no indication that the existing evidence definitively opposes the ENR's conclusions, additional evidence is needed to provide a more definitive test of ENR's conclusions.

II. Caribou survey and monitoring methods

The reliability of population estimates is weighed by the validity of survey methods. Surveys are observational experiments, designed to test hypotheses about population sizes. Experimental design is one of the most difficult and controversial aspects of scientific endeavour (*e.g.* Hurlbert 1984). Experimental design is made remarkably more difficult in uncontrolled field conditions, over large areas, when the study animal typically moves thousands of kilometres over its lifespan, as is the case for ungulate surveys (see Skalski *et al.* 2005 for some discussion). Bergerud (1963) outlined a technique for caribou aerial surveys, and some of the difficulties inherent in conducting them. In the NWT, Heard (1985, 1987) outlined methods for caribou aerial surveys, and these have served as the basis for subsequent aerial calving-ground surveys of the Bathurst, Beverly, and Qamanirjuaq herds (ENR, 2008). Other herds, such as the Porcupine, Bluenose-West, -East and Cape Bathurst herds, are enumerated *via* photographic surveys of post-calving aggregations (Williams 1994; Nagy 2007). Regarding the ENR's application of survey methods, we have identified the following issues.

1. Experimental design of caribou calving-ground population surveys.- Calving-ground surveys are conducted by ENR on the Bathurst, Beverly, and Qamanirjuaq herds (Gunn *et al.* 1996; 1997; 2000; 2001; 2002; 2005). The objective of calving-ground surveys is to provide an estimate of breeding females in the herd, to produce data on trends through time. Calving-ground surveys are aerial surveys conducted on annual calving grounds - the area occupied by parturient caribou from birth to first foraging by calves, about 3 weeks after birth (Russell *et al.* 2002; Gunn *et al.* 2008). Ideally these surveys are conducted as close to the peak of calving as possible. In the NWT, calving ground surveys start with a systematic reconnaissance flight to delineate the annual calving ground and stratify the area into high, medium, and low-density strata to increase precision of population estimates (e.g. Gunn *et al.* 2005). Each stratum is sampled, from aerial strip transects, according to its caribou density. The total number of mature (greater than 1 year old) individuals counted in strip transects is used to estimate total numbers of mature caribou on the annual calving grounds. As the objective of calving ground surveys is to estimate numbers of breeding females, the proportion of individuals counted that are breeding females is estimated from composition surveys – surveys of age and sex classes. These ideally (but not always) occur in conjunction with aerial population surveys. The proportion of breeding females on the calving grounds, multiplied by the number of caribou counted, provides estimates of breeding females (*e.g.* Gunn *et al.* 2005).

Any survey is only as rigorous as its experimental design and the validity of its assumptions. Calving ground aerial surveys in general are particularly prone to the following experimental design parameters:

Site selection - Calving ground locations shift through time (Gunn *et al.* 2005; Gunn *et al.* 2008b), so identifying the appropriate location to survey is critical. Locations of calving grounds are first identified by the ENR through analysis of locations of collared cows during the peak calving season (late May to early June; Gunn *et al.* 2008). Aerial reconnaissance surveys are flown in the vicinity of these collared cows to establish the location of caribou and stratify the grounds for surveys (*e.g.* Nishi *et al.* 2007). This two-pronged approach is quite suitable and effective with two caveats. (i) As site selection relies on collared females as the first experimental design criterion, it is sensitive to both the number of collars deployed and the experimental design of their deployment, both of which require improvement. (ii) Site selection is subject to potential error associated with survey timing.

Survey timing - Calving ground aerial surveys are timed to coincide with peak of calving, which changes slightly from year to year; in the last few years peak calving has occurred the first week of June (Gunn *et al.* 2008b). Bad weather can delay flying a few days; in this short time caribou can markedly redistribute, requiring a repeated reconnaissance and re-stratification (*e.g.* Nishi *et al.* 2007). This redistribution makes calving-ground surveys very sensitive to survey timing. To account for this, the ENR has undertaken considerable work in establishing estimates of peak calving times using clearly defined criteria. Peak of calving is defined as the 7-day period when 50% of the cows had calved; the peak calving ground is defined as the area used by parturient cows during the 7-day period centred on the peak of calving (Gunn *et al.* 2008b). This definition aligns with that of other caribou jurisdictions (Russell *et al.* 2002). ENR has shown diligence in its assessment of peak calving times for calving-ground surveys, and in the distribution of caribou on the grounds around this period. An additional safeguard ENR might consider is a sensitivity analysis to examine potential changes in estimates derived from surveys staggered a few days apart. To our knowledge this analysis does not exist from NWT or other jurisdictions, and without it, it is not possible to judge the degree to which slight changes in survey timing might affect the population estimate and its precision. An estimate of time-sensitivity is particularly important when establishing survey boundaries.

Survey boundaries - Delineating the boundaries of the survey area is one of the most critical experimental design parameters of a survey. If boundaries are delineated incorrectly and animals are missed, then population estimates will be biased downward. If areas without caribou are included, variance increases and the precision of the estimate drops, making trend analysis less reliable (see *Evidence for Declines*). If boundary delineations are inappropriate, then survey data cannot be reliably compared across years. Gunn *et al.* (2005) describe their methods for survey boundary delineation. Systematic reconnaissance flights are used to survey groups of breeding females in transects parallel to the calving grounds. In addition to recon flights, survey transects are flown 10 km past the last observed groups of breeding females. This procedure appears to be consistently and reliably applied, and we could find no evidence of >10 km spacing of breeding females on the calving grounds that might cause surveys to miss large numbers of breeding females.

Consistency of survey methods including delineation and stratification of survey lines - Aerial calving surveys are based on methods described by Heard (1985, in Gunn *et al.* 2005). Since that time, the ENR has endeavoured to keep their survey methods as consistent as possible across years to permit comparison of population estimates across time (Gunn *et al.* 2005). The ENR has recognized that technological and statistical developments allow for greater survey accuracy and precision, and have also endeavoured to incorporate these into their surveys. For example, the advent of GPS technology allows for greater accuracy in planning and following flight lines; this was introduced in the 2003 survey. Other changes were made in that survey, following a workshop hosted by the ENR (Gunn *et al.* 2005; compare to Gunn and D'Hont 2002, Gunn *et al.* 1997):

- Allocation effort between strata was improved by considering variance within strata as well as density when allocating survey effort;
- Sampling effort was verified by using a spotter plane to check strata boundaries just before photo flights were done to correct for major movements of large aggregations;
- Locations of the satellite-collared cows were used to plan the reconnaissance survey of the annual calving ground and delineate strata boundaries;
- A small number of relatively large non-rectangular strata to were used help minimize the effects of within-strata movements and ensure that transects are orientated against the density gradient;
- Precision of the estimate was improved by increasing photographic coverage for high density strata, and using the less costly line transect sampling with visual observers for lower density strata.

We fully agree that these upgrades benefited the surveys greatly, as reflected in the much greater precision (lower variance) of the 2003 and subsequent estimates (Figure 1, and Nishi *et al.* 2007). It is difficult to judge how the population estimates from surveys prior to these upgrades compare to population estimates after these upgrades. We can weigh two non-mutually exclusive hypotheses: (i) that the upgrades may have eliminated a unidirectional bias in previous surveys that were inflating previous estimates, making the observed decline in recent surveys fallacious; and (ii) the upgrades increased survey precision. Evidence for hypothesis (ii) is offered in Figure 1 and Nishi *et al.* (2007). Evidence for, or against, hypothesis (i) is not apparent. Theoretically, unidirectional bias could have been eliminated with the upgrades if previous surveys had inflated the numbers of caribou estimated in low-density strata, relative to the numbers estimated in high-strata. However, we found no evidence that this was the case. We did not examine the raw data from previous and recent surveys to determine how estimates may have changed with the upgrades to strata allocation and survey effort per stratum. Without this analysis, there is no evidence that there was any unidirectional bias eliminated or introduced by changes to survey methods through the years.

We recommend that the ENR consider such an analysis, to investigate the reliability of comparing surveys across years. As it stands, we are left with the conclusion that changes to survey methods have increased precision, are therefore valuable and should be continued in the future; however some analysis of potential differences between past and present surveys incurred by methodological upgrades should be conducted.

Our assessment of survey techniques is not new; Thomas (1998) reviewed several issues with caribou surveys that question their reliability. Thomas (1998) called for "less counting and more ecology"; while we agree more ecological research needs to be conducted, we must emphasize the need for precise, accurate surveys repeated frequently through time to assess population trend.

2. Post-calving ground photography (PCP) surveys *versus* calving-ground surveys.- Post-calving photography (PCP) surveys are conducted by ENR on the Bluenose and Cape Bathurst herds (McLean and Russell 1992; Patterson *et al.* 2004; Nagy and Johnson 2006; Nagy *et al.* 2006) and the Porcupine herd (ENR 2008). PCP surveys capitalise on aggregation behaviour by caribou that often (but not always) occurs post-calving (Patterson *et al.* 2004). The objective of PCP surveys is to estimate the total number of animals in the herd. Collars are deployed prior to surveys in a design aimed to achieve uniform dispersion of collared caribou throughout the entire herd. Locations of collared animals are used to locate and then photograph aggregations. Caribou are enumerated from photographs, which represent a minimum population size. Total population size is estimated using a modification of the Lincoln-Peterson Estimator (*e.g.* Nagy and Fraser 2007).

PCP surveys rely on locating radio-collared animals to estimate the size of the herd, and generally require large numbers of collars to be effective (Heard and Williams 1990). There is considerable potential for under-estimation of herd size from missing groups without or not detected radio-collared animals (Rivest *et al.* 1998). The distribution of collared animals among the groups within the herd is critical to the accuracy of the population estimates based on this approach. There are also issues around the inability to detect calves that are eclipsed by larger adults. The benefit of PCP surveys is that they allow for observation of a large percentage of the population. Rivest *et al.* (1998) showed by way of an example that population estimates based on post-calving ground surveys may be close to those of calving ground surveys, but with much lower variability. The notable problem with PCP surveys that there is no way to measure bias (missed animals), and this bias is not expected to be consistent across years, making trend comparisons relatively unreliable. Population estimates from PCP surveys tend to increase with increasing collar deployment (Rivest *et al.* 1998). PCP surveys using relatively few collars tend to yield population underestimates, making comparisons across years difficult if collar sample sizes fluctuate (*e.g.* Table 3).

The ENR uses PCP surveys on western herds, and calving ground surveys on eastern herds. Heard and Williams (1990, 1991) outlined the rationale for using different survey techniques for different herds. This dichotomy stems from historically different objectives for each group of herds: trends in numbers of breeding females for eastern herds, and overall population size for western herds. More importantly, the dichotomy also stems from a social pressure against collar use in the east (required for PCP surveys, thus necessitating calving ground surveys) that is less prevalent in the west.

Heard and Williams (1990) debated the relative merits of these two survey methods almost 20 years ago, and the issue remains today. Calving-ground surveys are weather-dependent, as slight weather delays can result in marked shifts in survey-area boundaries. PCP surveys are also highly dependent on weather, as caribou aggregation is limited to a fixed time window when temperatures are warm enough. Sometimes caribou do not aggregate in a given year, making regular PCP surveys impossible. Lack of aggregations precluded PCP surveys of the Bluenose herds in 1991 and 2001, a problem shared with other jurisdictions (Patterson *et al.* 2004). In contrast, females have a strong evolutionary drive to aggregate on calving grounds, making regular calving-ground surveys more feasible.

Similar to PCP surveys, calving ground surveys also use radio-collared animals to help define areas of focus. Calving-ground surveys are based on the premise that breeding females have fidelity to their traditional herd calving ground, and this premise is grounded in caribou's strong evolutionary predisposition to calve in familiar territory. However, the degree of departure from this premise is unknown (*e.g.* Johnson *et al.* 2008). Further research on the degree of fidelity or infidelity of breeding females to calving grounds is warranted (see *Herd-based Management*).

Calving-ground surveys require data on several demographic parameters for extrapolation to estimate population sizes, whereas PCP surveys do not. In contrast, calving ground surveys rely less heavily on collars and more heavily on reconnaissance flights for boundary delineation and stratification. The stratification used in calving-ground surveys can have a major impact on the precision of the population estimate. The end result is that calving-ground survey estimates can be imprecise relative to PCP surveys. However, any bias introduced in calving ground surveys (such as estimated demographic ratios for extrapolations) can be documented, and is likely to be consistent across years. This is an advantage over PCP surveys, where the major assumptions (number of caribou groups missed) may not be consistent across years, and is difficult to estimate and document.

In summary, each technique has benefits and drawbacks, and preferences for each technique vary widely among caribou biologists (Anne Gunn, John Nagy, Ray Cameron, Don Russell, pers. comm.). Regardless, this dichotomous survey system is potentially problematic. The different techniques make herd comparisons difficult, if not impossible, and prevent an integrative approach to Territorial caribou management using metapopulation or fuzzy structure models. We see this strategic integration of survey information as critical to the success of NWT's program (see *Recommendations*). We recommend that ENR consider the implementation of a single survey method for all herds. We agree with Heard and Williams' (1990) suggestion that establishing trend be an objective for all caribou herds. Given the current constraints on collaring in the east, the relative consistency of potential sources of bias in calving ground surveys, and the reliability of calving-ground aggregation, the ENR may wish to consider calving-ground surveys for all herds. At the very least, a correction factor should be devised to allow comparison of calving-ground survey estimates with PCP herd estimates. We recommend this issue of reconciling PCP survey results with calving-ground survey results from neighbouring herds be pursued further based on consultation with other caribou biologists from other jurisdictions.

3. Integration of survey data with demographic data and population models data for herd management.- Survey estimates rely on estimated values for demographic parameters, including calf survival, and cow:calf ratios. Cow:calf ratios and calf survival rates are assessed *via* classification surveys (Nagy and Johnson 2007a,b; Gunn *et al.* 2005b). This is standard practice across jurisdictions. However, calf survival estimates rely on assumed, untested values for cow mortality, rendering calf survival estimates potentially unreliable. On the whole, the demography of NWT's caribou herds requires more research.

Demographic data are needed to produce rigorous population models. Population models provide forecasts of population growth (or decline) through time, based on empirically estimated birth and death rates (as well as immigration and emigration). Radio-collaring with intensive relocations would provide data on parturition rates, calf survival, and estimates of adult survival. These estimates, together with survey-derived population estimates, can be used in a population model to project population trajectories, and thus verify the validity of population estimates from subsequent surveys. The combination of population modelling and survey estimation is the backbone of caribou management programs for many caribou jurisdictions (*e.g.* Newfoundland –Mahoney and Schaefer 2002a; Quebec – Couturier *et al.* 2004; Alaska – Jenkins and Barten 2005; *etc.*).

In of themselves, demographic data such as birth rates and calf survival are key to validating population increases and decreases. The NWT has recently embarked on some retrospective demographic modelling for the Bathurst herd to assess whether or not existing demographic data support the evidence for a herd decline derived from surveys

(Boulanger and Gunn 2007). Their analysis suggested that the demographic evidence best supported a population model with constant male and female survivorship, and declining fecundity and calf survival. These results are similar to results from models of other declining caribou herds (*e.g.* Mcloughlin *et al.* 2003; Jenkins and Barton 2005). However, Boulanger and Gunn (2007) also recognized that the low numbers of collared caribou reduced the precision of survival estimates, thus reducing the power to detect trends in survival. Simulation models likewise suggested that increasing adult survivorship would not curtail a decline; rather increased fecundity and calf survival were required to stabilize population trends (Boulanger and Gunn 2007).

Boulanger and Gunn's (2007) modelling exercise is statistically sound and rigorous. They exercise due diligence in highlighting the need for better, and more, demographic data. Unfortunately, they had to rely on inferences from demographic studies from the Porcupine herd (Fancy *et al.* 1989; Fancy *et al.* 1994; Walsh *et al.* 1995) to derive their own estimates for the Bathurst herd model (Boulanger and Gunn 2007). This lack of mortality, fecundity, and recruitment data for NWT herds hampers ENR's ability to conduct the rigorous population modelling key to a caribou management program.

In particular, research should be undertaken to estimate mortality rates for each of the herds through well-replicated long-term collaring research. For example, herd overlap on the winter ranges is considerable, at a time when much resident harvest and all commercial harvest occurs. Accurately allocating harvest mortality to each herd (differentiating between harvesting bulls and cows), and estimating the compensatory or additive effect of natural predation, is key to estimating mortality rates for population modelling. Combined with the lack of birth, immigration, and emigration data (see *Herd-based Management*), the end result is that the ENR has had to make population and trend estimates based on incomplete information.

Conclusions.- Our analysis suggests that existing survey and demographic data - though in need of improvement - tend to support ENR's conclusions. Where demographic assumptions have been necessary, these have been based on data from other herds, and are reasonable interim assumptions. There is no evidence that these interim assumptions have biased the results to yield a false decline. Nor did we find any evidence that existing demographic data conflicted with the decline indicated by survey estimates; the different sources of data corroborate the ENR's conclusions. However the assumed demographic parameters, upon which conclusions have been based, must be treated as interim. We strongly recommend the ENR focus on obtaining empirical demographic data for each herd, including estimates of harvest mortality. We likewise recommend that they conduct population modelling for each herd, to corroborate (or refute) trend analyses from surveys. Finally, it is extremely difficult to compare the population estimates from PCP surveys to aerial calving ground surveys, and it is apparent that a more integrative (but still herd-based) approach to caribou management for the NWT is preferable given herd overlap and questions of emigration and demographic rates. We recommend that the NWT either adopt of standardized survey protocol for all herds, or that some work be devoted to developing a correction factor to allow ENR to compare population estimates from PCP surveys to those obtained from aerial calving ground surveys.

III. Evidence for caribou population declines

1. Bathurst herd.- There are several methods by which trends may be analysed. They are not equally valid, and each may yield a different result. The analysis for the Bathurst herd is the most detailed statistical trend analysis conducted by the ENR, and the Bathurst herd decline sits at the heart of the controversy. We have examined in-depth the analysis of trend in estimates breeding females in the caribou herd conducted by Nishi *et al.* (2007) to assess the rigour of ENR's conclusions of caribou declines.

Nishi *et al.* (2007) conducted a trend analysis of estimates of numbers of breeding females in the Bathurst caribou herd between 1986 and 2006 (Table 4). Nishi *et al.* (2007) employed a weighted least squares (WLS) approach to estimate the trend. This approach is appropriate considering the large differences in the accuracy of the population estimates for the 5 years. The most common weight to use is the inverse proportion of the variance ($1/SD^2 = 1/Variance$; Draper and Smith 1981), which Nishi *et al.* used. Therefore, in this case, the population estimate from 1996 will be weighted much less than the population estimates in 1986, 2003 and 2006 since the estimate from 1996 is less accurate (large SE).

Table 4. Estimates of numbers of breeding females in the Bathurst caribou herd 1986 – 2006, derived from calving ground surveys. From Nishi *et al.* (2007)

Year	N	Variance (x 10^7)	SE	CV	Degrees of freedom
2006	55,593	7.76	8,813	0.16	19
2003	80,756	17.337	13,167	0.16	17
1996	151,393	123.510	35,144	0.23	13
1990	151,927	66.59	25,805	0.17	10
1986	203,800	16.118	12,696	0.06	43

Weighted least squares assumes the weights are known, however since this is rarely the case in real applications, the next best situation is having weights that are equally accurate (*i.e.* based on a similar large number of observations and estimation procedure). It is also important to be cautious of outlying observations as they can have a large impact of the results of the WLS, especially if they are points that are given large weighting. If outliers exist, data should be analyzed both including and excluding these values to determine what influence they have on the results. Figure 1 shows the WLS linear (dotted line) and natural log (solid line) fits. Both provided reasonably good fits. Nishi *et al.* presented the natural log fit and accompanying exponential rate of change of -0.059. As a rule of thumb, the use of the exponential rate of change is preferred and given that the fit is good, it is a reasonable approach. The linear fit actually shows a steeper decline than the log fit.

Before estimating the rate of change, it is important to determine whether the initial and final population estimates differ statistically. Nishi *et al.* used a t-test to compare the 2003 and 2006 breeding female estimates. The t-test is an acceptable technique to use in this case. It is not clear why the t-test was only used to compare 2006 and 2003, but not to compare 1986 and 2006 in terms of the population estimates for breeding females. The 2006 estimate was significantly lower than the 1986 estimate ($p<0.001$).

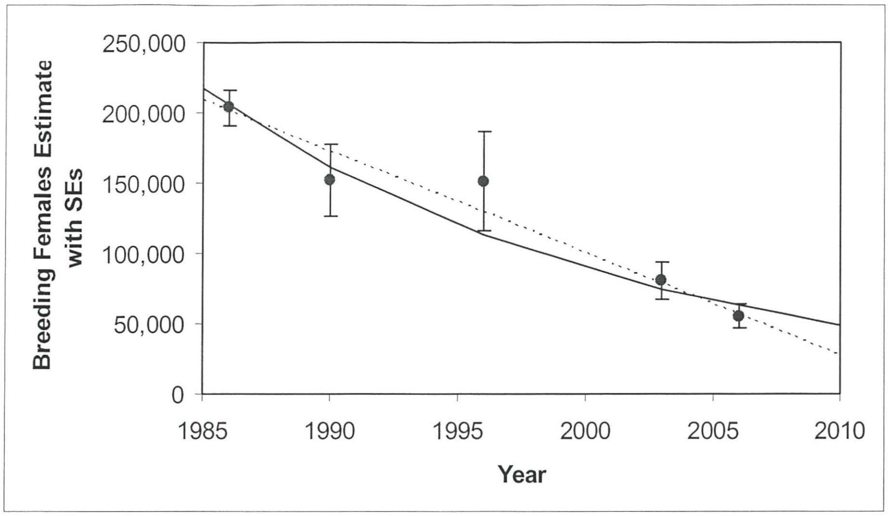

Figure 1: Breeding female population estimates over time for the Bathurst caribou herd, fitted with weighted least squares linear (dotted line) and natural log (solid line) trend lines.

Data from Nishi *et al.* (2007).

Linear equation: N = 14,587,862 - 7243.8509*Year; $R^2 = 0.99$; $p<0.001$.

Log equation: N = exp (129.99141 - 0.059295596*Year); $R^2 = 0.98$; $p<0.01$.

As Nishi *et al.* (2007) reported, the population estimates from 2006 and 2003 did not differ significantly. It is also important to note that the power of the t-test comparing 2006 and 2003 was low (<0.80), however the pairwise comparisons between 2006 and 1986 had acceptable power (*i.e.* > 80%). The application of the Monte Carlo simulation by Nishi *et al.* (2007) also seems reasonable.

Finally, based on this trend analysis a mean annual rate of decline of 5% per year in the Bathurst herd has been suggested by ENR (Gunn *et al.* 2005b; Nishi et al. 2007; Gunn *et al.* 2008c). This has been challenged by Andre (2007) and Fraker (2007). ENR's description of this 5% decline tends to suggest a steady decline in caribou numbers through time. Populations do not decline in this manner, but rather in stepped pulses; the appearance of a steady decline is an artefact of linear regression and has no biological significance. We suspect the ENR is well aware of this, and suggest they clarify the issue of the actual biological rate of caribou decline.

2. Bluenose herds.- Prior to 2000, the caribou in the vicinity of Bluenose Lake were surveyed as a single herd (in 1986 and 1987; McLean and Russell 1992). Since then, several different calving grounds have been identified, and this herd was separated into the Bluenose-East, Bluenose-West, and Cape Bathurst herds (Nagy and Johnson 2006; Nagy 2008a). Population estimates were obtained for each separate herd (*e.g.* Patterson 2004). Nagy and Johnson (2006) retrospectively analysed the old data and derived separate population estimates for each herd from the 1986 and 1987 surveys. Our analysis suggests that because the older surveys were not designed to detect distinct herds, these retrospective data are not suitable for inclusion in trend analysis. The remaining estimates are derived from surveys in 2000, 2005, and 2006 (Patterson *et al.* 2004; Nagy and Johnson 2006). These three represent too few data points collected over a relatively short period of time (7 years) upon which to base a regression model or other long-term trend analysis.

The precision of the 2000 population estimate was low, making comparisons with the 2005 and 2006 estimates more difficult (Table 5). It is unlikely that a significant change in the population estimate for the Bluenose East herd could be detected based on these estimates. The differences through time in population estimates for Cape Bathurst and Bluenose-West surveys (see Appendix 2) are much more marked (Nagy and Johnson 2006; Nagy *et al.* 2006).

Table 5. Estimates of numbers of breeding females in the Bluenose East caribou herd derived from PCP surveys. Compiled from ENR caribou survey data.

Year	N	SE
2000	103,974	22,101
2005	68,284	7,131
2006	65,119	3,504

As with the Bathurst herd, the data may be improved. During the PCP surveys, ENR staff exercised diligence by searching for potentially undetected groups of caribou. Searching indeed yielded undetected groups, adding to the rigour of the survey estimates, but also providing evidence that there were groups to be missed. The undetected component of a population cannot be known in PCP surveys. Though this does not negate the utility of these surveys, it does suggest that more surveys are required to validate each result, and improve tests of population declines. Surveys must be more frequent (with frequency guided by power analysis), and a statistical trend analysis must be conducted before definitive conclusions can be made.

However, though PCP surveys are subject to the error that we have outlined, and calving ground surveys require more caribou demographic data to test the inherent assumptions, there is no indication that either set of surveys have been subject to unidirectional bias (*e.g.* consistently underestimating herd size) that has compounded through time to produce a false decline. Though changes have been made to design through the years (with collar numbers, and herd delineation), and there are few data points through time, the existing data do suggest a decline is occurring for the Bluenose herds. In fact, as the number of collars deployed have increased through time (and PCP estimates tend to decline with fewer collars), the fact that fewer caribou have nonetheless been detected is further evidence that populations are indeed in decline. This is the best supported hypothesis and ENR has managed on that basis, a responsible application of the precautionary principle.

3. All herds.- It is difficult to judge the putative declines of other barren-ground caribou herds, as population estimates were not collected consistently enough to reliably monitor trend in all herds. The population trends over the last 30 years for all NWT herds are illustrated in Figure 2. Trends for each herd, with associated standard errors, are given in Appendix 2. No power analysis has been conducted by ENR to determine the survey frequency required to detect changes in each herd, given the variance of population estimates and the desired change to be detected; we suggest this needs to be done.

Data for the Beverly and Qamanirjuaq are truncated at a population high, and calving ground distribution data for the Ahiak herd has been collected only recently (Johnson *et al.* 2008). Data acquisition has been infrequent and irregular for all herds. As mentioned, survey data resolution issues exist for the Bathurst and Bluenose herds. These issues include trend interpretation and historical context. The Bathurst is an extreme case, where the population peak is quite large and the negative slope of the decline quite steep when measured from that population peak. However, the population appears to be returning to early 1980s estimates (though, it should be noted, has shown no evidence of remaining stable at 1980s numbers). Caribou population cycling is an important issue, and ENR should be transparent in couching the latest decline in the historical context of population cycles.

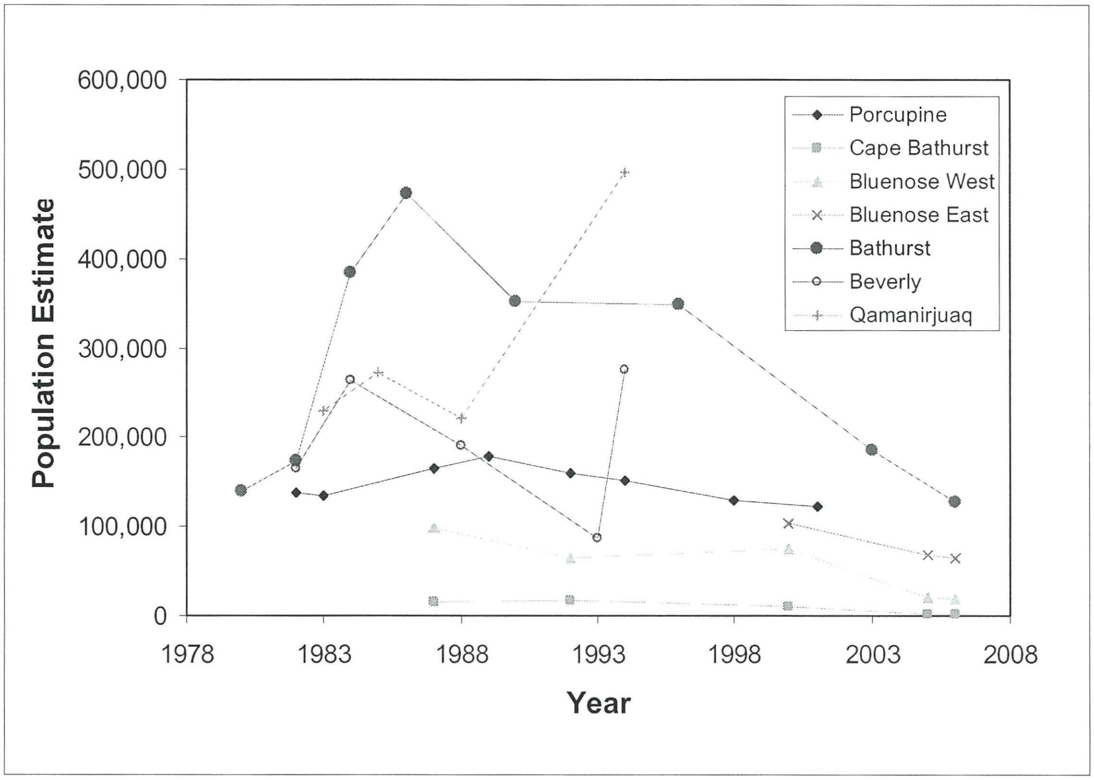

Figure 2: Population estimates over time for the NWT herds, compiled from ENR caribou survey data. Ahiak and Dolphin Union herds are not shown.

Declines in other herds are less apparent, and no statistical analysis (such as Nishi *et al.*'s for the Bathurst) has been conducted for these herds. Without these statistical analyses and associated power analyses, we cannot definitively state whether a decline has occurred in other herds. Nonetheless, trend lines for a number of the herds tend to support, rather than refute, declines for some herds. ENR has managed on this basis. As mentioned previously, a strategic cross-herd large-scale approach to data collection and population modeling should be undertaken by ENR to better understand herd growth and decline. The NWT Caribou Management Strategy (ENR, 2006) illustrates that ENR is moving toward a more strategic large scale approach to the NWT barren-ground caribou management, and we strongly support this and encourage the ENR to develop this policy further.

A note on mechanisms of decline.- There are myriad potential mechanisms that might cause a decline in caribou populations. Density-dependent population cycling is likely common in caribou (Gunn 2003). Predators have been identified as primary mechanisms for caribou decline in some regions (*e.g.* McLoughlin *et al.* 2003). Industrial development has also been shown to adversely affect caribou (Dyer *et al.* 2001; Mahoney and Schaefer 2002b); cumulative effects of petroleum development on caribou demographic rates, movement patterns, and calving ground selection have been demonstrated (National Research Council 2003; Cameron *et al.* 2005). Over-harvest and adverse weather are two additional potential mechanisms. Gunn *et al.* (2005) identified fly infestations as a possible cause of decline in the NWT, and examined possible environmental correlations that might help test this hypothesis, but this was a preliminary attempt. If there is a decline occurring in NWT caribou herds as existing data suggest, the identification of the mechanism should be a primary research focus for ENR. In this respect the ENR is lagging behind other jurisdictions such as Alaska (Valkenburg *et al.* 2002), and Newfoundland & Labrador, who are launching major research studies in partnership with Universities to identify the mechanisms of decline in their herds (W. Barney, NL Fish & Wildlife, pers. comm.). A focused research program to test explicit hypotheses about potential mechanisms is needed if these mechanisms are to be mitigated and caribou declines curtailed.

General Conclusions

The existing evidence from PCP surveys, calving ground surveys, and classification surveys, backed by demographic data, tend to support the hypothesis that the Bathurst and Bluenose / Cape Bathurst herds, as defined by ENR, are likely in decline. There is no evidence to support the competing hypothesis - that caribou were consistently and cumulatively missed, miscounted, mis-assigned to herds - to suggest that trend data are in error. The telemetry data are too few to definitively test the hypothesis that caribou movement between herds accounted for the observed decreases in the Bluenose herds, or Bathurst and adjacent herds. The precautionary principle requires that caribou management decisions should be based on the existing evidence suggesting a decline, until such time that more and better data are available to make definitive conclusions regarding barren-ground caribou populations.

We suggest that a number of factors have combined to make some evidence ambiguous. The ambiguity in NWT data stems from a lack of strategic, Territory-wide management of multiple overlapping herds in the absence of robust data. Herd delineation is problematic; the identification of new herds based on new information makes determining the relative contribution of these individuals to past surveys difficult. The paucity of collaring data makes questions of herd identity, herd fidelity, and inter-herd movement extremely difficult to answer. Likewise, a paucity of demographic data renders assumptions inherent in survey estimates difficult to test. There exist several opportunities to improve data collection for NWT caribou herds, and we identify these in the *Recommendations*.

In summary, though data require improvement, our review of the existing data did not reveal any evidence that the observed decline in some herds is an artefact of intent or neglect on the behalf of ENR biologists. The existing scientific evidence is subject to improvement but does tend to support a decline in the Bathurst and Bluenose / Cape Bathurst herds as defined by ENR. Therefore, until improved methods for multi-herd surveying and demographic research is employed, managing on the basis of a decline is certainly warranted based on existing data and the precautionary principle.

Recommendations

Opportunities exist to improve the ENR's caribou research and management program. Some of the following recommendations have been already identified by ENR staff in the NWT Caribou Management Plan (2006). Some are not. We view all of these as important recommendations that should be adopted to improve NWT's knowledge of caribou populations, guide management, and improve communications with the scientific community and with NWT residents. It must be noted that our recommendations do not necessarily imply that NWT has failed to reach to minimum standard. On the contrary, our recommendations are geared toward providing ENR with the best possible caribou research and management program, as guided by accepted scientific principles and the latest ecological theory and research. Some are specific to ENR, but many could likely apply to other caribou jurisdictions. We recognize that these recommendations will be tempered by logistical, financial, and political considerations; however all of these considerations incur a trade-off in scientific rigour, and this must be acknowledged and managed appropriately.

1. Substantially increase collaring efforts for all caribou herds.

Location data from collars are integral to any caribou management program. The sample sizes of collars currently employed by ENR are inadequate to provide empirical evidence strong enough to support many assumptions key to ENR's caribou management policies. This is due in large part to reticence by Co-Management Boards and communities to allow collaring. Education, public relations, and active engagement of communities geared towards illustrating the importance of collars to safeguarding of NWT's caribou heritage may be required. The low number of collars deployed represents one of the most serious flaws in the ENR's caribou management program; the need to increase collaring cannot be overstated. All collars need not be expensive satellite collars; a mix of satellite collars for fine-scale movement and demographic data, and less expensive VHF collars for large-scale movement and fidelity data would suffice.

2. Create a standardized, regularly scheduled monitoring program to improve long-term planning and reporting on caribou research.

Consistency among surveys is a fundamental principle in long-term monitoring. To reliably detect trends in population size survey methods must be kept as consistent as possible across years. If the survey methods are consistent, then error (in terms of precision) will be similar, and results should be comparable. We recommend that either calving ground surveys or PCP surveys be applied to all herds consistently. Calving ground surveys are subject to the same statistical error in repeated years, and this error is to some degree measurable. This is not necessarily true of PCP surveys. Regardless of the option selected, we recommend if survey methods are changed, that ENR create a correction, or translation, factor to guide integration across NWT herds.

The frequency of calving ground surveys is currently politically, not statistically, decided (NWT Caribou Management Plan 2006). Heard and Williams (1990) recognized this as an issue almost 20 years ago, and recommended that power analyses be conducted on existing data to determine data requirements to reliably detect trends in caribou abundance for each herd. Currently, more (and better) data exist to inform a power analysis. While we cannot at this time recommend a frequency for regularly scheduled surveys, we highly recommend that the ENR undertake a power analysis to determine this frequency, and weigh this analysis very heavily against political and financial considerations to justify or amend the schedule in the NWT Caribou Management Plan (2006).

We recommend that the good work currently being done to simultaneously map calving ground distributions for each herd (Appendix 3) be continued periodically to provide information on calving ground location and segregation. As calving grounds provide the basis for NWT caribou management, data on these grounds should be updated often. Additionally, the ENR may wish to consider periodically conducting simultaneous (or nearly so) aerial surveys of some immediately adjacent herds. Currently, the suggestion of large-scale dispersal between herds (Andre 2007) cannot be empirically tested, as surveys on adjacent herds are not performed concurrently to determine if large decreases in one herd coincide with comparable increases in other herds. Although it is not possible to fully survey all herds within the same year, we recommend that a high priority be placed on obtaining population estimates for the Bathurst and Ahiak herds in the same year, and the Qamanirjuaq and Beverly herds in the same year.

For other herds, reconnaissance surveys describing the distribution of adjacent herds would inform metapopulation and fuzzy structure analysis, and provide better tests of hypotheses about herd delineation and inter-herd movement. Recon surveys would not need to be as frequent as calving ground or PCP surveys, but could be staggered and rotated through the survey schedule. These may help ENR with the difficult tasking of delineating herd affiliation and distribution of caribou across a 1,346,000 km^2 landscape.

3. Increase focus on obtaining demographic data on caribou herds.

Currently the ENR collects some demographic data from classifications, estimates some parameters from classifications and surveys, and infers other parameters from caribou studies in other jurisdictions. As such the quality and quantity of the data needed to corroborate population trend data or inform population modelling require improvement. Conducting research on adult (male and female) mortality rates, calf mortality rates, parturition rates, and additive mortality (harvest) rates are a key requisite for well-supported conclusions from a caribou management program. We very strongly recommend that the ENR considerably increase their research on caribou demography; they lag behind other jurisdictions in this regard.

4. Incorporate population modelling into caribou management programs.

Currently the ENR relies on field data to provide estimates of caribou population trajectories, without the benefit of population forecast models. Modelling is a key tool for evaluating the validity of field evidence. Comparison of field data with population forecasts produced by models can help scientists validate both field data and model parameters, critical components of any caribou management program. Population models also provide objective triggers and thresholds for harvest, as a basis for management decisions. The creation of population forecast models for each herd - and integration with other jurisdictions sharing herds - should be a high priority for ENR.

5. Provide internal or external peer-reviews for all survey reports.

This necessarily includes review of experimental design, data analysis, and report content. The mathematical inconsistencies found by Fraker (2007, 2008) illustrate that simple changes in calculations can dramatically change population estimates derived from a survey. If the mathematical inconsistencies identified in a few survey reports by Fraker (2007, 2008) represent errors, it is not obvious whether these errors are likewise found in other reports, nor if they constitute a fundamental flaw in the conclusions drawn from caribou surveys and research. We spent considerable time extracting key information from lengthy survey reports. Though these contained much detail, indicative of due diligence, the presentation of these details sometimes obscured evidentiary support for conclusions. Errors are made by all humans, including scientists (Collins and Pinch 1998). Such errors do, however, weaken the credibility of the reports, and leave ENR open to criticism. A standard independent peer-review process for surveys and classifications - by independent ENR biologists, or undertaken on a contract basis, or through publishing in *Rangifer* or other journals - would strengthen the validity and increase the value of survey reports (*e.g.* Patterson *et al.* 2004). Independent peer-reviews are more than proofreads; they require that a manuscript may be rejected for revision if inadequate. Peer-review of surveys would catch potential errors and inevitable inconsistencies in data collection and analysis, force clarity and brevity, make report contents more accessible to other scientists and the public, boost the credibility of ENR's survey results, and encourage the incorporation of new field and statistical techniques.

6. Publicly report survey and research results immediately and transparently.

A regular reporting schedule should accompany the regular surveying schedule, and should be consistently enforced. ENR conducts extensive consultation with Co-Management Boards (J. Adamczewski, pers. comm.), and this is vital. Expansion of this consultation to the general public is recommended. For example, Alaska reports on all their surveys and places the information on their website for public access (*e.g.* Harper 2007). This regular reporting helps the public better understand the government research program, including the science and the politics. Public engagement is crucial to obtaining support for a management program, and would prevent future misinterpretations of data. For example, the rationale for not having population surveys done on the Ahiak herd should have been immediately established, considering the existing information on Bathurst range shifts and the nominal collaring data. The extensive work of Nagy (2008a) in justifying the delineation of Bluenose herds should be condenses and formatted for laypeople and made publicly accessible. To defray future criticism, clearly defined research plans and accompanying rationale should be made public well in advance of surveys.

7. Develop a Territory-wide, consistent and strategic approach to ENR's caribou research program with centralized coordination.

ENR has had several people involved in caribou research and management, with a few key people providing consistency for different herds (*e.g.* Gunn *et al.* 1996; 1997; 2000; 2001; 2002; 2005; and Nagy *et al.*; 2006; 2007; 2008). ENR has shown due diligence in contracting reputable biologists and statisticians to aid in design and analysis of some surveys (*i.e.* John Boulanger and John Nishi), and our statistical appraisal of the data concurs with their analyses. However, we conclude that the regional governance model employed by NWT may inhibit coordination of the caribou research and management program. A more centralized management and reporting structure would help provide consistency in experimental designs, data analysis, and ensure the use of standard methods in all research and surveys. The herds surveyed, the years they are surveyed, the methods employed, should all be made the purview of a centralized management with a complete understanding of the entire NWT caribou management program. A more centralized management can balance statistical requirements of surveys with logistical requirements and cost to develop a strategic, systematic plan for herd surveys, as well as set research priorities (such as demographic and movement data). Implementing this recommendation within the current co-management board system – which is vital to the NWT – will improve consistency across the program, and across time.

The ENR's program also needs to integrate across political and territorial boundaries to a greater degree, and include Nunavut, Yukon, and Alaska in surveys and management of cross-boundary herds – though we recognize that their survey and research programs are out of NWT's control. A strategic approach to herd surveying was recommended in the NWT's Caribou Management Plan (2006), but needs to be extended to encompass all aspects of caribou research including estimating population closure, survival rates, fecundity rates, and potential ecological or other mechanisms behind caribou declines.

8. Formulate caribou management decisions within an adaptive management framework.

Management decisions regarding caribou are currently made without defined criteria. Though it lays outside the purview of this Review to comment on license allocations, we can recommend that the caribou population and demographic thresholds that will trigger a license change (and other management decision) be specified. This will demand an increase in data quality as we have described. It will also require that ENR set priorities for surveys and research, and therefore explicitly consider the objectives for each of its surveys and research programs. The results of these studies will feed back into the management framework to help gauge the efficacy of management decisions, evaluate the state of herd size and demographics relative to established thresholds, and alter management decisions accordingly. This recommendation obviously integrates, and illustrates the needs for, the scheduled and published surveys, standardized monitoring, population modelling, and strategic research approach we have advocated in previous recommendations.

9. Form partnerships to increase resources dedicated to caribou research.

Caribou declines are common across Canada (CARMA 2008). NWT houses a tremendous number of Canada's caribou, and as such is a steward of a national resource. This resource appears to be declining, and may decline further with industrial development and climate change. ENR's budget should not be expected to maintain the weight of this responsibility. Federal assistance should be sought and secured. Additional research funding should be obtained through partnerships with researchers at government research organisations and Universities, who are privy to the latest conceptual and statistical advances in population estimation and modelling, and who have access to NSERC and other institutional research funding. Academic research can capitalise on existing survey efforts to provide advanced, peer-reviewed, published research. This model has been used to great effect in other caribou jurisdictions such as Newfoundland (*e.g.* Mahoney and Schaefer 2002a,b) and Alberta (*e.g.* McLoughlin *et al.* 2003).

Research should focus on testing potential mechanisms effecting caribou declines. Correlative studies are a start, but rigorous field experiments are needed to test explicitly formulated hypotheses about potential mechanisms. Additionally, NWT can make an important contribution to caribou management by facilitating the use of population genetic analysis. Although the NWT was a major participant in earlier genetic work (*e.g.* Zittlau 2004), they should take advantage of the rapidly improving techniques available to better refine our understanding of genetic differentiation between herds. Population genetic, ecological, and demographic research is necessary to inform management decisions designed to protect the barren-ground caribou population. The formation of academic partnerships would dramatically enhance the research capacity of NWT's caribou research program and be a benefit to NWT and its people.

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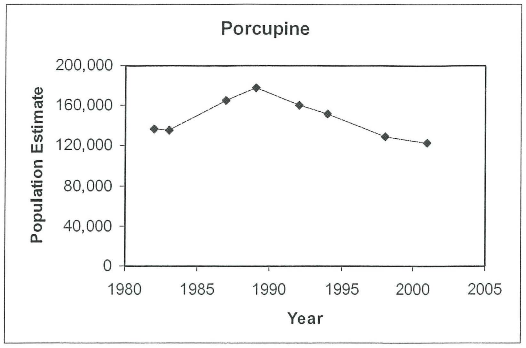
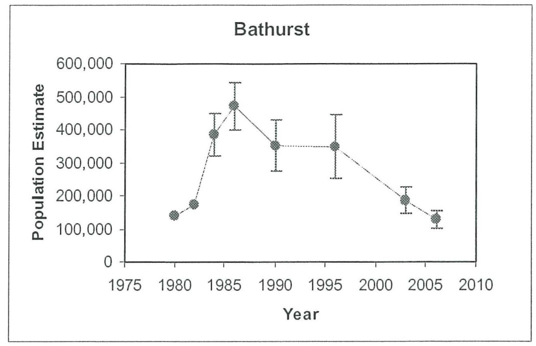
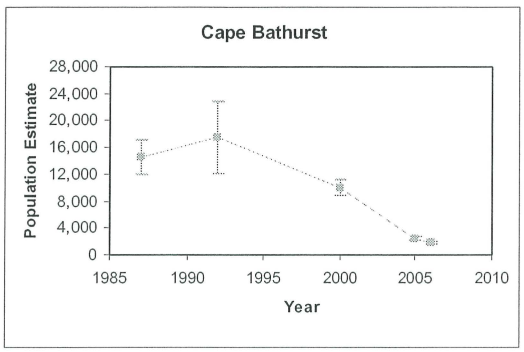
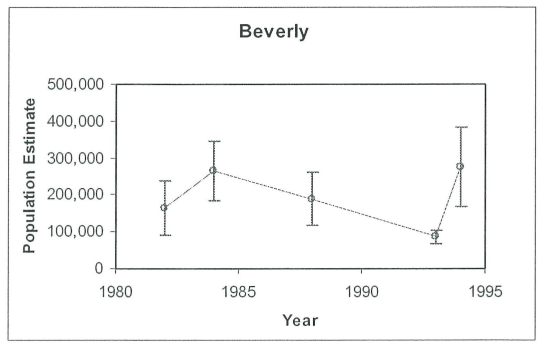
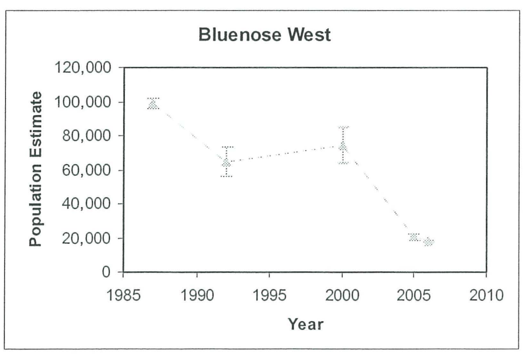
Appendix 2: Caribou population estimates through time for all NWT herds (ENR data).

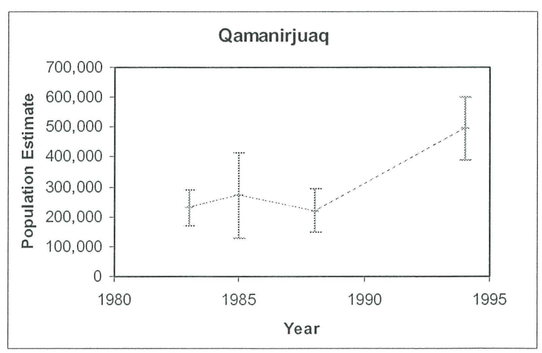


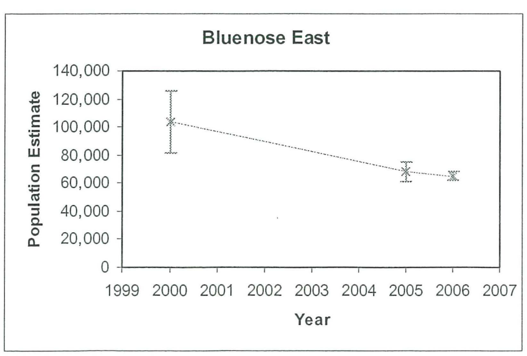












Appendix 3: NWT caribou annual and calving ground range maps. Provided by NWT ENR.

NWT Barren-ground Caribou Herd Ranges and Calving Grounds