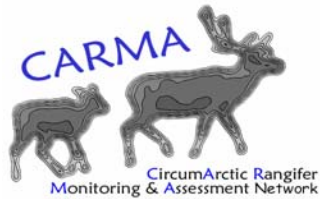


Monitoring *Rangifer* Herds (Population Dynamics)

MANUAL



CircumArctic *Rangifer* Monitoring and Assessment (**CARMA**) Network

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PROTOCOLS

1. RECORDING ESTIMATES of ABUNDANCE
2. RECORDING ESTIMATES of RATES OF INCREASE AND VITAL RATES
3. RECORDING ESTIMATES of DISPERSAL

INTRODUCTION

Across the circumpolar north, people are voicing concerns and questions about caribou and reindeer health and abundance. Many answers to those questions can come from herd-wide monitoring (routine gathering of information to measure, analyze and report on change) using both traditional and scientific knowledge. The CARMA Network¹ recognizes that, at present, knowledge about how environmental change can affect the Arctic's *Rangifer* herds is fragmentary and the relationship between *Rangifer* and the people's vulnerability to changes in caribou numbers is largely undocumented.

The CARMA Network proposes to:

- 1) provide baseline information on representative *Rangifer* herds and the human communities dependent upon them
- 2) standardize on-going monitoring and assessment of these *Rangifer* systems.

The CARMA Network² is a forum for documenting and assembling indicators to monitor caribou and their environment. CARMA is taking the lead in describing monitoring indicators and techniques to help biologists adequately collect, manage and report data in comparable ways³. CARMA's intent is to promote the use of standardized monitoring data to report the status and trends in barren-ground caribou (wild reindeer and caribou) in circumpolar regions.

Across the circumpolar caribou ranges, the environment varies considerably in topography, climate and vegetation. The herds are correspondingly diverse in the amplitudes of fluctuations in abundance. However, we are collectively uncertain about which demographic mechanisms underlying those changes are similar between herds and which differ. Studies have primarily focused on individual herds, and the type of data collected and methods used have differed between herds. This impedes and makes rare the integration or comparison of herd-specific data sets. CARMA, by encouraging the standardization of reporting and data collection, will stimulate the investigation of relationships between a changing environment and the different caribou herds.

Trend monitoring identifies both the current status and long-term changes in caribou herds, and will be used to evaluate possible human and natural factors causing those changes. CARMA is also encouraging model development and validation, in which a hierarchy or array of testable hypotheses or theories determined for one herd (a reference herd) are tested to see how they can be generalized and applied to other herds.

¹ In the context of this manual, we are referring to the migratory tundra caribou (Bergerud 1988).

² <http://www.carmanetwork.com/>

³ We do not intend the manual to detail procedures nor does the manual specify the method that any particular study should adopt.

This manual, the second in a series of three, focuses on caribou population demography⁴ at the herd level. CARMA's emphasis in this demographic manual is on monitoring techniques for the large migratory tundra herds. However, the methods are also relevant for monitoring caribou on arctic islands and mountain caribou. The first manual in the series describes the monitoring of health and condition of individual caribou. Monitoring caribou at the individual and population scales is linked, because caribou body condition affects population parameters, such as fecundity and population size. Additionally, monitoring the physical condition of caribou has both explanatory and predictive value for population parameters. Knowledge of population trends is needed to analyse circumpolar trends (for example, Thomas 1996) and to interpret effects of any trends in physical condition and environmental conditions. The third CARMA manual covers the monitoring of environmental changes through remote sensing.

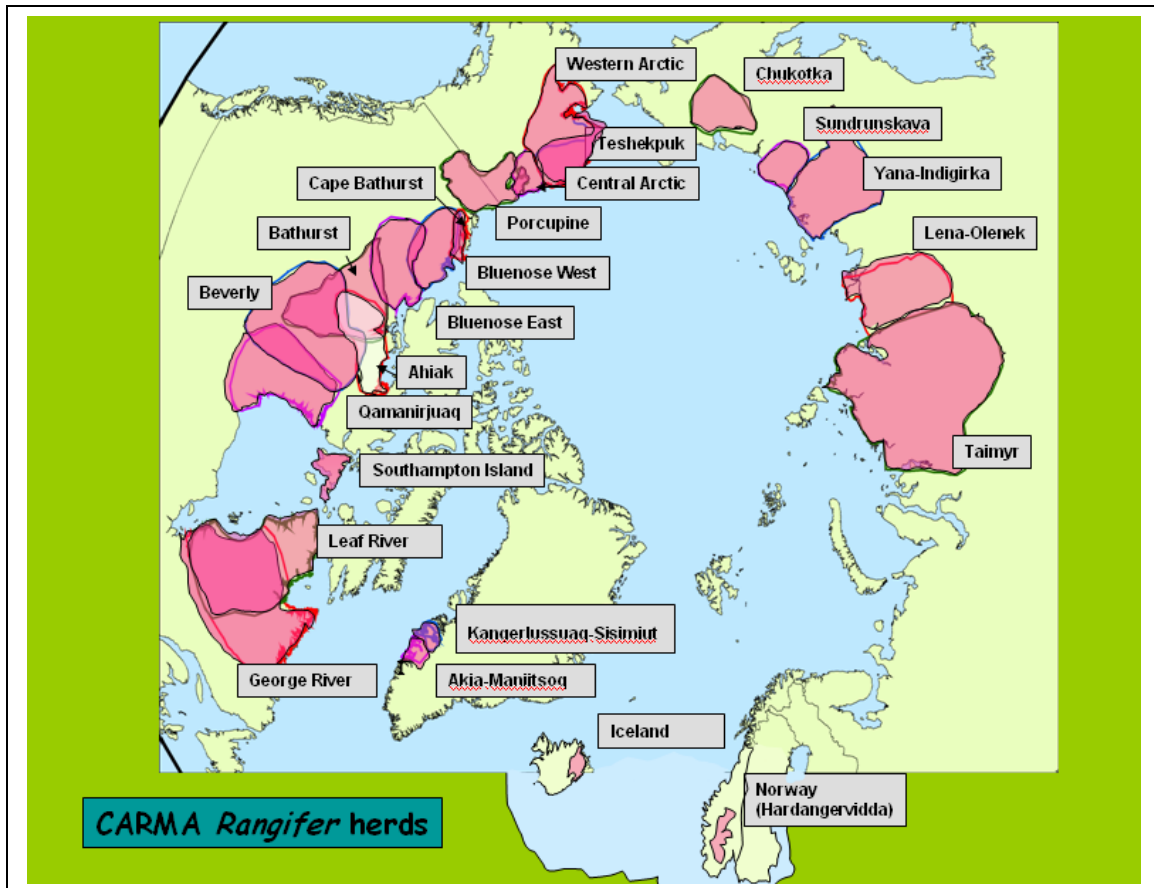
Monitoring demographic indicators is a large part of wildlife management, which means that there is experience and knowledge for other members of the deer family besides caribou. The indicators typically monitored are abundance, fecundity, mortality, recruitment, sex ratio, emigration and immigration. We recognize that agencies have historically taken different approaches for monitoring caribou herds in order to operate within constraints imposed by budgets, staffing, weather, day length, aircraft availability and remoteness of the caribou. We agree with Mason *et al.* (2006) that jurisdictions do not have to use the same methods to monitor wildlife. Even so, there are compelling arguments to "...employ fundamental statistical aspects of random sampling and bias corrections when developing new or applying previously published survey techniques". There has been a long history of monitoring techniques, including statistical design, being modified and developed for caribou, but in this manual, we have not reviewed the early efforts. Our emphasis is on current methods for caribou, and while this manual is not an exhaustive account, we have included information on how to describe the reliability (accuracy and precision) of indicators for monitoring demography. We also emphasize in this manual the information required in reporting indicators so that results generated by different monitoring techniques can be compared, and we mention newer techniques that have potential or are being introduced for caribou.

This manual offers an overview of monitoring methods applied to migratory tundra caribou. The protocols associated with this manual give details on how to report on the monitoring of demographic indices which differs from the approach used in the CARMA health and condition manual and protocols. In that manual, we describe the standardized measurements required to ensure that the same indicators are measured in the same way to minimize variation in the data (essentially Standard Operating Procedures). However for demographic indices, rather than specifying which method is to be applied, CARMA requests details about the methods used for the different herds or different regions, and rather than raw data (such as transect counts), mean values of indices and estimates

⁴ Demography is the study of birth rates, death rates, age distributions, and size of populations.

of precision are preferred. In the protocols, drop-down menus and column headings list the information required and the body of the protocols contains an explanation of the reporting requirements. In recognition of how busy field biologists tend to be, we have included some spreadsheet routines to facilitate calculating variance for sex and age ratios and rates of change.

Although this manual is skewed toward scientific approaches to monitoring caribou demography, this by no means suggests that expert opinion, specifically from experienced hunters who have lived close to caribou and the land, is inferior to quantitative data. We expect that, as we develop and foster a more unified approach using different bodies of knowledge to monitor caribou herds, the reliance on western scientific approaches will broaden. For the potential users of the manual, we caution that not all the monitoring techniques and approaches will be readily accepted by all those involved with caribou. People are sometimes concerned about over-flights, especially over calving grounds, but the greatest divergence of views is over handling caribou, as many indigenous people consider it disrespectful (for example, Byers 1999). Success in monitoring caribou comes with working within each herd's local context including respect for people's concerns.



Circumpolar herds

LEVELS OF DEMOGRAPHIC MONITORING

CARMA recognizes that monitoring of caribou demography varies considerably between herds, regions and countries. Methods vary and the amount of information collected and reported also varies. We can group the monitoring of indicators (abundance, vital rates and dispersal) into three sampling levels (Table 1).

Trend monitoring level 1: Knowing the rate of increase (or decrease) is the most useful attribute of *Rangifer* populations for circumpolar monitoring. For all herds the most basic monitoring involves estimating abundance with sufficient precision that moderate changes can be detected. Trend can be determined by measuring changes in abundance or by using expert opinion (usually aboriginal hunters).

Trend monitoring level 2: The next level of monitoring includes mechanisms for the observed rate of increase or decrease. Monitoring birth rates, calf survival and adult survival can indicate what is causing a caribou herd to increase or decrease. Monitoring the adult sex ratio is a useful adjunct to interpreting death rates, especially with regard to the effects of harvests.

Trend monitoring level 3 (Reference herds): CARMA identifies the most intensively monitored caribou herds as 'reference herds.' The more intensive monitoring fine-tunes our understanding of the mechanisms responsible for changes in demographic trends, such as abundance and age-specific rates of fecundity or mortality. Reference herds may also provide opportunities to propose and test relationships between demographic and body condition. Although we have data on those relationships, they are not consistent among herds or have only been established for a herd in a particular phase of increasing, stable or decreasing abundance. For example, April calf mass was correlated with fall calf-cow ratios in the Delta, but not in the Nelchina herd (Valkenburg *et al.* 2002). In the Fortymile herd, Boertje and Gardner (2000) concluded that extremes in pregnancy rates were useful in predicting trends in herd abundance while fall calf weights were not useful in predicting either pregnancy rates or trends in herd abundance. Reference herds can also be used to examine relationships among environmental factors, caribou body condition and demographic parameters. For example Griffith *et al.* (2002) related the amount of available forage, as indexed by NDVI (normalized difference vegetation index) satellite images, to calf survival on the Porcupine herd's calving ground – a relationship mediated by the cow's protein reserves and the amount of milk.

Table 1. The three sampling levels and their indicators for demographic monitoring of *Rangifer*.

Indicator	Level 1	Level 2	Level 3 (Reference herd)
Abundance (direct)	Trend in herd size	Trend in herd size	Trend herd size
Abundance (indirect)	Trend in herd size		Long-term trend and climate patterns (hoof scars)
Vital rates		Birth rate	Age specific fecundity
		Annual calf survival	Seasonal calf survival
		Mortality – adult	Mortality – age specific
		Recruitment	Recruitment
		Sex ratio	Sex ratio
		Harvest rates	Harvest rates
			Predation rates
Dispersal		Natal and breeding dispersal	Natal and breeding dispersal

STANDARDIZED APPROACHES AND COMPARABILITY

The rationale for most agency-driven monitoring of caribou herds is the need to inform users about the caribou herds as well as for management decisions usually on harvesting. Methods for collecting data have varied from the more rigorously statistically designed approaches to “...convenience sampling with informal designs.” This quote is from Mason *et al.* (2006) who were describing monitoring of elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) in the western USA. The authors were describing the need for inter-jurisdictional cooperative survey design, data collection and analysis, and data sharing through a regional data archive. Mason *et al.*'s (2006) call for inter-jurisdictional coordination in standardizing data has parallels with CARMA's objectives.

In recent years, interest in standardized approaches to monitoring has grown and publications offer details on what is required. For example, Oakley *et al.* (2003) and Gibb *et al.* (1999) emphasized the need to articulate realistic and measurable objectives which in turn dictate the monitoring design. Three key elements to consider in designing wildlife monitoring programs are statistical power (the ability to detect change), precision, and accuracy. Statistical power is the probability of rejecting a null hypothesis that is false. It is the outcome of sample size, sample variance and effect size (Steidl *et al.* 1997). Power analyses can be used to determine whether sample size (for example, number of transects) will be sufficient to detect the desired effect, such as the difference between two estimates of population size. Steidl *et al.* (1997) provides details, as does Gerrodette (1987), on estimating sample size using statistical power, and

Seavy and Reynolds (2007) offer a cautionary note about balancing the use of statistical power with improving precision and reducing bias.

To compare among herds, we need consistent language for reporting estimates of demographic parameters and their reliability. By reliability, we mean the accuracy and precision of the estimate. Without reporting measures of bias and precision, indices of abundance are less useful and comparable (Anderson 2001, Yoccoz and Ims 2004). There is a considerable literature on survey design that includes seminal papers, such as Caughley's (1974a) in which bias and precision are succinctly described.

Accuracy (bias or measurement error) refers to how close the mean of a large number of repeated estimates of some parameter is to its actual value. A loss in accuracy can arise from any factor that causes a population estimate to differ from its actual value. There are many sources of low accuracy including: observer inexperience or fatigue; survey conditions, such as turbulence; misclassifying sex and age categories during aerial surveys (e.g., misidentifying young bulls as cows); misreading a measurement tool (e.g., latitude or longitude from a GPS unit); or errors in recording data on a data sheet. Bias is a systematic error that leads to either underestimation (negative bias) or overestimation (positive bias) of a parameter, such as caribou density.

Questions from the public about the accuracy of caribou counts are not uncommon. For example, Cuyler *et al.* (2002) recounts the loss of public credibility in estimates of caribou abundance in West Greenland when the magnitude of bias had not been determined or corrected for estimates of caribou abundance.

Precision (sampling error) refers to how close a set of repeated estimates are to each other; if a set of repeated estimates vary little from each other, the mean estimate is precise. A target is the common image offered to illustrate accuracy and precision: the closer arrows are to the bull's eye, the higher the accuracy; the closer arrows are to the same spot anywhere on the target, the higher the precision. Precision is measured by the variance about the mean and is usually expressed as the coefficient of variation (CV) (the ratio of the standard error to the mean). Usually, caribou biologists are most interested in tracking trends, in which case levels of precision determine the sensitivity of the measured trend to detect actual changes in caribou populations. A rule of thumb is that a survey estimate with a coefficient of variation of 10% or less is acceptable for management decisions, although it is worth noting that a 10% level of precision can only detect a 30% difference or greater between two estimates. The power of detecting changes in populations usually increases with the sample size of the parameter being measured.

INDICATORS FOR MONITORING DEMOGRAPHY

1. ABUNDANCE

Monitoring abundance is probably the most widespread wildlife management activity and the theory and practice is well-covered in books by Caughley (1977), Krebs (1998) and Caughley and Sinclair (1994). Another useful source is Gasaway *et al.*'s (1986) manual on moose surveys. Thompson *et al.* (1998) and Williams *et al.* (2002) have written detailed guides to the planning and analyses of surveys. The software program TRENDS (Gerrodette 1993) is a free interactive program that estimates power for a variety of monitoring designs. Heard (1985) gives a clear and concise account of potential sources of survey error specifically for caribou surveys. Although the theory behind survey designs is covered in the above mentioned reference books, the practical details as applied to caribou are often in unpublished reports. However, some reviews have been published notably in the proceedings of the Second North American Caribou Workshop held in 1985 and subsequent workshop proceedings. We have included for illustration, three examples of survey methods for barren-ground caribou currently in use (Text boxes 1 to 3).

Aircraft were first used for surveying in the late 1940s to try to obtain total counts over large areas (Banfield 1954). By the 1960s, the emphasis was shifting to aerial sample counts using strip transects and stratification, as well aerial photography (Parker 1972). As the use of aerial surveys grew, so did the realization of problems with the resulting estimates (Caughley 1974a). Even today, it is worth remembering Caughley's (1974a) comment that "aerial survey is, at best, a rough method of estimating the size of a population."

Counting all the individual caribou in a herd is rarely practical, although it is still attempted in Alaska for small mountain herds (100s of caribou) during the rut. Biologists in the Alaska Department of Fish and Game mostly estimate total minimum population size, although they are evaluating the feasibility of alternative population estimation approaches (J. Dau pers. comm. 2008). The aerial photo direct count extrapolation (photocensus) technique involves a combination of using radio tracking to locate post-calving aggregations so that they can be photographed, and using both radio telemetry and aerial visual searches to find caribou outside the large aggregations. For some herds in Canada, biologists use photography of post-calving aggregations; for other herds, sampled counts (either visual or photographic) are done over seasonal ranges and extrapolated to a population total. Reconnaissance surveys are used to determine survey areas by mapping the extent of caribou distribution (with the additional advantage that it can lead to allocating survey effort relative to caribou density to increase precision). Frequently, the locations of radio-collared caribou are used to define the survey area with the assumption that the collars are representative of the herd's seasonal distribution.

Before estimating population size, the herd (population) that is being sampled must be identified. Sometimes geography defines a herd through spatial isolation. Smaller islands are an obvious example and deeply incised coastal areas, such as the west coast of Greenland or mountainous regions of Norway, are other examples. In Norway, herds are confined (mostly) within natural borders (valleys, fjords) or highways/railroads that the reindeer no longer or very rarely cross (E. Reimers pers. comm. 2007).

In North America, typically, herds are defined on the basis of the annual return of the cows to their traditional calving ground (Skoog 1968, Thomas 1969). Satellite telemetry has reinforced the validity of defining herds based on the return to traditional calving grounds, confirming that cows together on the calving ground are together during the rut. As with any biological attribute, there is variation in calving fidelity (see the section on dispersal in this manual). Satellite telemetry also has revealed fidelity to post-calving and summer ranges. This fidelity supports surveying for abundance on calving, post-calving and summer ranges. Surveying abundance on winter ranges can be more problematic if neighboring herds are present and if their use of winter range overlaps in some years.

Technology is changing how monitoring is being undertaken. The use of global positioning systems (GPS) to record exact locations of caribou, flight pathways and elevation is already influencing how surveys are designed and how data are collected and presented. Other changes are occurring with the use of geographical information system (GIS) software for displaying and analyzing data. The relatively new field of geostatistics is at an early stage of development, but is already contributing new methods for analyzing distribution data (for example, see approaches to describing calving distribution in Kelleyhouse 2001 and Gunn *et al.* 2008).

1. a) Direct Estimates of Abundance

Sample counts

Sample counts in caribou monitoring to estimate abundance are typically indices of relative density. For example, caribou counted from an aircraft flying along a transect and the resulting extrapolation to an estimate of density is assumed to reflect the actual density of the entire herd. In caribou monitoring, the most common sample unit is a transect, although quadrats have occasionally been used. Fong *et al.* (1985) concluded that quadrats produced more accurate estimates than transects, although both types of estimates were imprecise at about 10% coverage. However, Caughley and Sinclair (1994) reported that transects, if correctly oriented with respect to landscape features, were more precise than quadrats.

Transect surveys may be bounded (strip) or unbounded (line). Strip transects require that all animals within the strip are counted. The strip does not include the area under the aircraft. For line transects, also called distance sampling

(Buckland *et al.* 1993), the perpendicular distance between the observer and the animals is measured or grouped into distance classes. The distances or distance categories are modeled using detection relationships and the best-fitting model is used to estimate densities. Successful application of line transects depends on accurately measuring the distance and Marques *et al.* (2006) describe a method using global positioning systems to measure distances for this survey method for relatively low densities.

One criticism of the strip transect technique is that it is inefficient when animal densities are very low and the individuals are aggregated. An alternative approach for low densities is adaptive sampling which intensifies survey effort in areas where most caribou occur (Thompson and Seber 1994, 1996). Adaptive sampling is not yet in use to monitor caribou, but has been applied successfully to pronghorn antelope (*Antilocapra Americana*) (Guenzel 1997). Adaptive sampling has been tested in the High Arctic for Peary caribou (D. Jenkins pers. comm. 2008) where caribou are at low densities dispersed across the landscape.

Accuracy: Typically, aerial transects are flown at low altitudes at slow speeds with narrow transects to increase the probability of detecting and counting caribou (for example, Cuyler *et al.* 2002). Alternatively, photography can be used instead of direct counts to minimize the problems of observer fatigue, boredom, difficulty of seeing and counting caribou depending on background contrast and light. Photography has the advantage of being a 'visual' record that can be re-checked by different people, but aerial photography has drawbacks as well: technical problems can occur with cameras or development of exposed film for film cameras; lenses may become clouded by dirt or oil (especially on cameras mounted outside of aircraft); and caribou may be difficult to count under some combinations of lighting and backgrounds. Nagy and Johnson (in press) outline an innovative use of mapping software to count caribou on digital photographs.

Besides designing survey methods to minimize bias, bias can also be measured and used to calculate a correction factor for a point estimate. However, bias may have several components that are likely specific to the survey type and situation. Bias can be estimated through modifying survey design and using linear regression analysis (Caughley 1974a). Care is needed when transposing estimates of bias between survey situations to correct population estimates. For example, Heard (1985) notes that a 'traditional' bias correction of 25% has been used, although he does not report a quantitative basis for the correction. Cuyler *et al.* (2007) describe double-counting to correct for bias in western Greenland. Double-counting depends on having more than one observer on the same side in the survey aircraft, comparing the number of animals counted by each observer, and then estimating the probability that an animal was seen.

Heard (1985) reported bias corrections for visual counts on calving grounds where caribou were aggregated in densities reaching 70 caribou/km². The corrections were based on a comparison of photographic and visual estimates,

and when applied, increased the visual estimate by 1.5 to 3.7 times. On calving grounds, bias in visual surveys occurs from observers having to count large groups and decide whether caribou groups are inside or outside the strip transect. In contrast, on other seasonal ranges where caribou densities are lower, the ability to detect animals is the probable source of error and, for example, Cuyler *et al.* (2002) explained how they calculated a correction factor for bias based on independent counts by three observers to estimate the probability that an observer would count (*i.e.*, detect) a caribou (0.82-0.92).

Experienced survey biologists acknowledge that under certain conditions caribou are extremely difficult to see regardless of what survey technique is employed. They have circled above a group of caribou that contained a radio-collared individual and could not see them under conditions of spotty snow and harsh, bright light – even out on open tundra with low vegetation (J. Dau pers. comm. 2008).

Precision: Estimates of abundance are based on a sampling count and, as such, the results are expressed as a mean value with its associated standard error. To compare between surveys, it is conventional to use the coefficient of variation (standard error/mean), usually reported as a percentage, as a measure of the estimate's precision. Precision becomes especially important when the survey objective is to determine trends in abundance (in contrast to cardinal estimates of actual population size). Precision is increased by standardizing survey techniques, increasing sample size (such as the number of transects – the rule of thumb is at least 10 transects), and increasing sampling intensity (coverage of the area, which depends on the number of transects, transect width and aircraft altitude). Cameron *et al.* (1985) describe the gain in precision from increasing survey coverage from 25% to 50% using higher numbers of transects.

Most survey designs use systematically placed transects which are orientated perpendicular to large-scale topographic features to minimize variation between transects. However, Cuyler *et al.* (2002) used fixed length randomly placed transects to sample caribou densities in West Greenland.

Precision may also be increased by stratifying the survey area into blocks (strata) of similar caribou density. The strata with the highest variability in density are then sampled most intensively. Of course, this approach requires that information about caribou density be available before the actual sampling surveys are initiated to allocate sampling effort between strata. Typically, sampling effort should be allocated between strata relative to the variance of each stratum's sampled counts, but this information is often obtained by aerial reconnaissance survey and reconnaissance can be expensive. Alternatively, previous density estimates can be used for stratification purposes. Cuyler *et al.* (2003) provides details on a simulation model using densities from previous surveys to estimate the number of transects required for desired confidence intervals. Tamstorf *et al.*

(2005) suggest that stratification could be based on habitat mapped through remote sensing.

Precision is less commonly reported for estimates of demographic rates, such as calf survival. Yet, variance provides important biological information, as well as being essential for measuring trends. For example, Griffith *et al.* (2002) did not find a significant difference in net calf production during an increase and a decrease phase in the Porcupine herd, but the coefficient of variation during the decrease phase was twice the coefficient of variation during the increase phase. Total variance includes both biological variance (sometimes called process variance) and measurement error.

Box 1 - Estimates of breeding female densities on caribou calving grounds

Estimating the density of breeding females on calving grounds is commonly done in Canada. The advantages of counting caribou on traditional calving grounds were recognized during the 1960s (Parker 1972) and Heard (1985) describes the rationale for the censuses of breeding female caribou on calving grounds. The location and the timing are relatively predictable and all the breeding cows are concentrated in one area (the calving ground).

Objective: In the Northwest Territories, the objective is to estimate the number of breeding females with high precision (coefficient of variation < 10%).

Design and methods: The following is summarized from Gunn *et al.*'s (2005a) description of a recent census of the Bathurst herd. The census began with a systematic aerial strip transect survey to delineate the boundaries of the calving ground using predefined criteria to determine the length of the transects. Counts of caribou along the transect lines were used to estimate caribou densities across the calving ground and the densities were used to allocate sampling effort for the photographic survey. From the photographic count of caribou, the number of caribou on the calving ground was estimated. Immediately after the photography was finished, the proportion of breeding females on the calving ground was estimated during a classification survey.

The classification survey was designed so that all caribou had an equal chance of being sampled and the sampling effort was proportional to density. The sampling points were at the centres of consecutive 10 km x 10 km segments where a fixed number of groups were sampled and or a fixed duration of sampling time was spent at each site. A helicopter was used for either aerial observations or to position observers on the ground.

Caribou were classified as breeding females, non breeding females, yearlings or bulls. Breeding females (pregnant and post-partum) were identified by the presence of a distended udder or at least 1 hard antler; cows with distended udders and no hard antlers were probably breeding cows that had lost their calves, and cows with hard antlers but without a visible udder or calf may have either lost their calf or not yet given birth. Non-breeding cows had no visible udder and either new antler growth or no antlers. Yearlings were identified by their shorter face and smaller body size, while bulls were easily identified by their relatively large antlers in velvet or a penis.

Precision: Over the years, precision has been variable, which caused Thomas (1996) to question the technique's ability to detect trends in the numbers of breeding females. Gunn *et al.* (2005a) reported that the precision of previous calving ground photographic surveys for the Bathurst herd expressed as a coefficient of variation ranged from 6.2% to 23%. Solutions for increasing precision, implemented since the mid-1990s, have included: 1) higher coverage for the photographic survey, 2) fewer and larger strata to reduce the risks of movements between strata, 3) allocation of effort based on mean density and standard error, and 4) monitoring trends over several surveys rather than between pairs of surveys.

Implementing these solutions, biologists used a systematic strip transect survey with about 10% coverage to determine the pattern of caribou density as a basis for allocating sampling effort (number of photographs and survey transects) to different sample blocks (strata). The densities were ascribed to relative density classes that were mapped and then strata delineated to enclose similar densities. In delineating these strata, biologists considered the variance of observed density classes within each stratum and the presence of calves and breeding females, and ensured that the strata were large enough to accommodate possible movements of caribou between the reconnaissance and photographic surveys. The stratum baseline had to be long enough to allow for a minimum of 10 transects and the transect lines had to be of relatively similar length. The survey design oriented the transects to parallel the gradient in density and to be perpendicular to the long axis of the stratum.

Box 1 - Estimates of breeding female densities on caribou calving grounds (continued)

Accuracy: Aerial photography was more accurate than visual counts according to Heard (1985), who described the rationale for applying aerial photography to a strip transect survey approach. The photography involved a specialized large-format (23 x 23 cm) camera taking overlapping photos at an altitude of 1000 m above ground level. The photo-plane was an Aero-commander equipped with a radar altimeter. The GPS navigation system on the survey aircraft was linked to a belly-mounted Wilde RC30 camera equipped with forward motion compensation. The printed photos were scrutinized and caribou counted – double counting between observers was used to verify accuracy for a sub-sample of photos.

Data Analyses: Estimates of caribou numbers for each stratum were calculated using the Jolly 2 Method for unequal sample units (Jolly 1969) in the program AERIAL (Krebs 1998, Program 3.5). Cochran's (1977) Jackknife method was used to calculate the mean proportion of breeding females in each stratum. The proportion of breeding females in each stratum was multiplied by the population mean estimate for that stratum to estimate the number of breeding females on the calving ground. The variances of the number of breeding females and the total herd estimate were calculated as suggested by Heard (1987b).

Gunn *et al.* (2005a) used two analytical methods to estimate the trend in numbers of breeding females: a) weighted least squares regression (Brown and Rothery 1993), which weighted each population estimate by the inverse of its variance (to account for unequal variances of surveys and to give more weight in the estimation to the more precise surveys) – the population size was log transformed and linear regression was used to estimate the rate of increase (r) (Caughley 1977); and b) Monte Carlo simulation, which allowed another estimate of the variance in trend that resulted from the individual variances of each of the surveys (Manly 1997).

Advantages/disadvantages: The calving grounds are a relatively small area to survey and their location is more predictable than any other seasonal range. Use of satellite telemetry has increased our confidence that breeding females have a strong fidelity to their traditional calving grounds except in years when snow conditions delay spring migration.

The specialized photo aircraft, however, is expensive (about 40% of the budget) and the window of opportunity for the aerial photography is tied to cloud ceilings being greater than 1000 m above ground level within two to five days of the peak of calving. After five days, cows aggregate and can rapidly move, which confounds stratification.

Variations: For the George River herd in Quebec and Labrador, Couturier *et al.* (1996) described three approaches to compare estimates of herd size in 1993. On the calving grounds, radio-telemetry was used to locate caribou, then a systematic strip transect survey was used to delimit strata for a helicopter-borne 35 mm photographic survey. Caribou in the individual photographs were counted by two people and the numbers were used to estimate density. Composition data were used to determine the number of breeding females. An alternative approach used the calf count from the photos and the cow/calf ratio from the composition data to estimate the number of breeding females. The two estimates from the calving ground were compared to a minimum herd count based on photography of post-calving aggregations located through radio telemetry. The photographic count was corrected for missing radio collars and stochastic modeling was used to account for biases caused by less aggregated groups and missed groups. The authors concluded that the calving ground estimate might have been influenced by a biased female/adult ratio.

Box 2 - Late winter sample counts using strip transects

This example is from the coast of West Greenland where the caribou ranges are squeezed between a rugged mountainous coast and the ice cap, and aircraft are prohibitively expensive. Previously, researchers monitored abundance with variations on sample counts using strip transects, however, those strip transect surveys were found to underestimate total population size. To reduce this bias, Cuyler *et al.* (2002, 2003, 2004, 2005 and 2007) recently made changes to the survey design.

Objective: To estimate herd abundance in mountainous terrain using helicopters.

Design: The design is a stratified sample count using strip transects.

Precision: The extreme expense of using helicopters for surveying in Western Greenland restricted flying time. Although the survey design included a relatively high number of fixed-length transects evenly dispersed across the strata, total coverage was low (<5% of the total annual range). The number of transects was determined by using the highest density recorded in a previous survey and a binomial simulation to estimate the confidence limits with differing numbers of transects. Effort (number of transects) was then allocated among the strata based on the previous survey's relative densities.

Accuracy: Fixed-wing aircraft were replaced by helicopters (guided by Global Positioning System navigation) that could maintain a slow speed and constant altitude when flying transects over mountainous terrain. Flight speed (45-65 km/hr) and altitude (15 m above ground level) were low and strip width was narrow (0.6 km). Caribou detectability was increased by flying short transects (7.5 km) oriented to reduce the amount of time that an observer would be looking into the sun and to reduce solar glare reflecting off the snow surface. Transects of random location and heading were possible because in late winter (March-April) caribou group sizes averaged fewer than 6 animals and variability was low which reduced sampling error and aided precision.

Besides all the steps to increase accuracy, Cuyler *et al.* (2002, 2004 and 2007) also corrected the estimates based on a double counting method where three people within the helicopter independently counted caribou. However, the surveys might still have underestimated caribou numbers, because the low flight altitude (15 m) often created "dead-ground", *i.e.* areas where terrain features hid some of the strip width.

Analyses: The counts from the transects were extrapolated over the entire survey area to estimate total population size. A bias correction was estimated from comparing the counts of the two observers on the same side of the helicopter and the variance of the correction factor was calculated using a bootstrap method.

Advantages/disadvantages: The survey design (number of sampling units and allocation of sampling effort) was dependent on the relative densities from previous surveys, but those densities could vary with abundance.

Box 3 - Post-calving aggregation photography

The application of aerial photography to count caribou in post-calving aggregations started in Alaska in 1961 (Lent 1966 in Davis *et al.* 1979). Refinements followed quickly as assumptions were questioned and solutions tried (Davis *et al.* 1979). The method is sometimes described as a total count, although in reality, when dealing with 10s to 100s of thousands of caribou, this is unlikely. More realistically, it is a minimum estimate with extrapolations to a total population size. In Alaska, until the 1980s, transects were flown to locate caribou, but since then, VHF radio- and satellite-collared caribou have been tracked to find the aggregations. Post-calving photography has become the most commonly used technique for monitoring abundance in Alaska and for some herds in Canada. In Russia, it was used to estimate wild reindeer numbers on Taimyr after it was found that visually estimating the size of aggregations over-estimated reindeer numbers (L. Baskin unpubl. report 2007).

Objective: To estimate herd abundance with minimum bias and maximum precision.

Design and methods: In the NWT, Nagy and Johnson (in press) applied post-calving photography to the Bluenose West herd in 2006 when it numbered 18 000 caribou. The biologists used a single fixed-wing aircraft to track VHF radio-collared cows and bulls along systematically spaced transect lines (20-40 km apart) while flying at altitudes ranging from 440 to 1320 m above ground level. Aggregations were photographed from the radio-tracking aircraft with a handheld digital camera. The aircraft flew between 110 and 330 m above and parallel to each group when the photos were taken. The photographer sat in the rear seat and attempted to photograph each aggregation in a single pass to minimize movement of caribou between frames and to allow for approximately 20% overlap between successive frames. Nagy and Johnson (in press) used OziExplorer GPS Mapping Software (Version 3.95.4m, D & L Software Pty Ltd) to create a digital photomap of each digital image. They then searched the digital photomaps on a computer screen and marked each caribou with a waypoint.

Post-calving photography has also been used to census the Western Arctic herd in Alaska since 1970. Three to five airplanes are used to radio-track caribou and photographs are taken using a large format (23 cm X 23 cm) mapping camera mounted in the belly port of a De Havilland Beaver airplane. Photographs are taken during the peak of insect harassment (1-12 July). An onboard laptop computer linked to a GPS receiver and radar altimeter help determine flight lines and record the area covered by each photograph. Black and white film is used and caribou on contact prints are counted by hand after identifying areas of end and side lap.

Analyses: Nagy and Johnson (in press) obtained a minimum population size from caribou counted on the digital photographs. The minimum population estimate was extrapolated to an estimated mean total herd size (and variance) based on Russell *et al.*'s (1996) modification of White and Garrott's (1990) use of the Lincoln-Petersen Index as applied to radio telemetry. Not all aggregations photographed contained a radio-collared caribou, but they were typically found in close proximity to aggregations with radio-collared caribou. Nagy and Johnson (in press) assumed that these groups formed a general aggregation of caribou that under more favorable conditions would have formed one group. This extrapolation took into account groups found without a radio-collared caribou and radio-collared caribou known to be alive, but not located. Alternatively, Rivest *et al.* (1998) increased the extrapolation by 12% to account for missing groups by using a stochastic model for the 1993 census of the George River caribou herd.

Precision: Estimates of precision were calculated from the total number of radio-collared caribou available, and the number of caribou and number of radio-collared caribou in all aggregations observed during the survey (Nagy and Johnson in press).

Box 3 - Post-calving aggregation photography (continued)

Accuracy: The use of photography is assumed to reduce bias. However, problems can arise in counting caribou on the photographs. Dau (2005) commented that the 1999 post-calving census of the Western Arctic herd was an underestimate. The caribou had not aggregated until the last days of the survey period and the photographs were taken from a higher altitude than usual (because of fog). The result was that calves were missed on the photos. Variation in counting caribou on the photos is also a potential source of bias. Griffith *et al.* (2002) described the bias from several observers counting caribou in photographs as $\pm 2\%$, but reported that it was ignored in rounding the census estimate to the nearest 1000 for the Porcupine herd.

The level of accuracy depends on conditions during the photography and accounting for all radio-collared caribou and groups without radio-collared caribou. For example in 2003, the Alaska Fish and Game Department had 106 collars on cows and 16 collars on bulls in the Western Arctic herd. Based on the radio-collars, 98% of the caribou were in 37 aggregations that were photographed, and 455 012 caribou were counted on the large format photos. Two radio-collared caribou with 14 small groups totaling 5000 caribou were found close to, but were not part of, the aggregations (equates to 1250 caribou per collar) and three collared caribou were known to be alive and not found (extrapolates to $3 \times 1250 = c. 4000$ caribou). In addition, 26 300 caribou were visually estimated during flights at 800 to 1500 ft (240 to 460 m) above the ground as the groups were too small and dispersed to photograph (Dau 2003).

Advantages/disadvantages: Shortcomings in the accuracy of this technique have caused rates of change to be underestimated. For example, the Mulchatna herd's high rate of increase from 1992 to 1994 was attributed in part to a more accurate count during the latter census (Woolington 2005). Aircraft availability, especially the photo aircraft, and weather suitable for the caribou to aggregate have caused some censuses to be skipped in Alaska. A disadvantage in some areas is not the method itself, but the inability to estimate accuracy and precision, and the need for radio-collared caribou to locate aggregations). In some regions, the public has reservations about handling caribou and fitting radio-collars. An advantage of this technique is that it minimizes uncertainty associated with sampling error by essentially counting the entire herd. Also, the technique provides mid-summer data on sex and age class composition.

Variations: In Alaska, variations included floor-mounted vertical photography or hand-held cameras (film or digital) used to laterally photograph the aggregations. For the Western Arctic herd, biologists do not take lateral 35 mm or digital photographs as caribou in the images are difficult to count. They either directly count small groups or call in the photo airplane. Another variation involves flying the survey in the fall and photographing or directly counting the aggregations during the rut. Direct visual counts of aggregations are still in use for some herds such as the Nelchina (Valkenburg *et al.* 2002). The July count is also extrapolated to a fall population estimate using fall composition; a variation that may cause confusion unless it is specified whether the reported total caribou number includes calves or not.

1. b) Indirect Estimates of Abundance

In monitoring caribou population abundance, there is relatively little use of non-linear indices based on caribou signs, at least for migratory tundra caribou. Those indirect ways to estimate abundance include mark and recapture methods used, for example, to estimate caribou numbers during post-calving photography. However, the application of mark-recapture for estimating caribou abundance is scarce, as it requires a relatively high proportion of the population to be marked and depends on the assumption of equal catchability which is difficult in practice.

A potential alternate approach for caribou is to use molecular genetic techniques to 'mark' (identify) individuals, 'recapture' them by sampling fecal pellets, and use mark-recapture models for estimating population size. However, caution is needed as accuracy depends on population size and the rate of recapture of sampling pellets (for example, Waits and Leberg 2000, Lukacs and Burnham 2005, White *et al.* 1982).

Aerial surveys index current density while density of fecal pellets or tracks in the snow are a cumulative index over a period of time. Although counting fecal pellets should be more accurate than counting caribou during aerial surveys (easier to standardize between observers and less subject to survey conditions), the relationship between fecal pellet counts and absolute density is not linear; using pellet counts requires the estimation of defecation rate which is variable (Freddy and Bowden 1983). The accuracy of estimating population size using single visit pellet counts has been disputed in the literature (Fuller 1991).

Caribou tracks on snow may also be used as an index of abundance. In Russia, in each regional hunting management unit, staff count tracks on snow and the data are used to estimate reindeer density and abundance. The results are an approximation, but do reveal general trends (Baskin 1989).

Another indirect approach to indexing abundance is using dendrochronology to age hoof scars on spruce roots. The frequency of occurrence of known-age scars has been used to index longer-term increases and decreases in caribou abundance for the Bathurst and George River herds (Morneau and Payette 1998, 2000, Boudreau 2003, Zalatan *et al.* 2006). The advantage of this approach was that the annual growth ring widths of the roots correlated with July-August mean temperatures and with the phases of the Arctic Oscillation (Zalatan *et al.* 2006). Thus, there is a means to test relationships between caribou abundance and large-scale climate phenomena over large areas and over timescales reaching centuries.

2. RATES OF CHANGE AND VITAL RATES

Rate of change (increase or decrease) is a useful and integrative indicator to monitor for a population in the context of management and conservation. The

frequent objective for monitoring abundance is to determine rates of change and to use those rates to compare populations on a common basis.

Vital rates (also called demographic rates) are those components that collectively determine the rates of change – in other words, the mechanisms for why populations change in size. The rate of change is the outcome of how many animals are born (birth rate), how many die (death rate) and how many disperse from their birth population (egress or ingress). As such, they can be useful adjunct data to support whether a population is changing in size as well as indicating the mechanism.

Typically, vital rates are estimated from marked individuals (most often with radio telemetry) or from ratio data, such as number of calves per 100 females. Ratios are used to monitor calf survival and productivity, and to compare male and female survival. The dangers of using ratios that compound changes in either the numerator or denominator are known (Caughley 1974b, McCullough 1994). The difficulty in using ratios is that the reference class (for example, cows in calf:cow ratios) is unlikely to be constant. For calf:cow ratios, an estimate of adult female mortality is needed (Caughley 1977, McCullough 1994). Harris *et al.* (2008) used modeling and data from elk to examine how variation in individual vital rates influenced age ratios and how well the ratios indexed population dynamics. As adult female mortality is annually less variable than calf mortality, Harris *et al.* (2008) argued through modeling that calf:cow ratios did track calf survival. They also cautioned that age ratios alone should not be used to track trends in population size.

Although ratios are used as a standard monitoring technique for migratory tundra caribou, relatively little has been published on testing sampling design to achieve appropriate levels of precision or bias. In an unpublished review of caribou monitoring in the Northwest Territories, Heard and Williams (1990) examined precision for late spring calf to cow ratios. The basis for the sampling was that all caribou had a chance of being sampled and that sampling effort was allocated according to relative densities (although due to logistical and budget constraints, this is rarely achieved). Resampling techniques have been used for analyses – either Jackknife (Heard and Williams 1990) or bootstrapping (Gunn *et al.* 2005b) – and the recommended level of precision (coefficient of variation of 10%) has usually been achieved by sampling at least 18 groups (Heard and Williams 1990).

Reducing bias includes assigning calves and cows to the correct sex and age classes and ensuring the sampling is representative of the herd's distribution. In caribou monitoring, however, relatively little effort has been invested in examining the sources of bias in collecting ratio data. Misclassification as a source of bias for caribou sex and age ratios has not been assessed, such as by double counting by different observers although some observers have commented that it is possible. Confusion is most likely between classifying male short-yearlings as

2-year old females and conversely, 2-year old females as short-yearlings (Dau 2005). In other species such as pronghorns (*Antilocapra Americana*), Woolley and Lindzey (1997) found differences in bias and precision between observers and methods (ground or aerial surveys). Bonenfant *et al.* (2005) also reported seasonal bias in calf:cow ratios for red deer (*Cervus elaphus*); as the cow-calf bond changed, the calf was not always seen with the cow especially in more densely vegetated habitat.

A likely source of bias for caribou ratios is unrepresentative distribution of sampling, as distribution of the sexes is likely not random even during the rut. For example, Dau (2007) commented that unrepresentative sampling may contribute more variability to the sex ratio than biological variation in the Western Arctic herd. In the Bathurst herd, sampling the sex ratio during the rut revealed marked geographic differences in both the sex ratio and the calf to cow ratio, although conventional thinking is that segregation is lowest during the rut. During late winter, sex- and age-biased distribution is common and the problem is compounded if the count is delayed until the onset of spring migration. For some Alaskan herds, such as the Nelchina, Delta and Fortymile herds, this is the reason that calf:cow ratios are not determined during late winter (Valkenburg *et al.* 2002).

Systematic testing or modeling of sampling design to ensure representative sampling is lacking. Current approaches are to sample in the vicinity of radio-collared caribou (assuming that they are a random sample of the overall distribution). A cautionary note is sounded, however, as McLean and Heard (1991) found differences between the calf:cow ratio in groups sampled with a radio-tracked individual and groups found without radio tracking, although the reasons were not obvious.

Another approach to ensure representative sampling is to allocate sampling effort based on relative densities from reconnaissance aerial surveys. In Greenland, sex and age composition is determined during aerial surveys to estimate abundance. Observers classify all caribou seen while ferrying to or from transects or while searching areas with high numbers of caribou, given the objective is to sample as many caribou as possible.

Occasionally, recruitment rate is incorrectly used interchangeably with rate of increase. Recruitment rate is estimated by the number of 1-year-old animals (usually measured in late winter composition counts so they may be 9- to 10-month-old calves) and can be used to index the potential rate of increase (not the actual observed rate). Confusion is also possible unless recruitment is clearly reported as calves per 100 cows, or calves relative to the total population, *i.e.*, calves per 100 non-calves (“adults”).

2. a) Finite and Exponential Rates of Increase

The observed rate of increase is either expressed as a finite or an exponential rate (they are a re-statement of each other, but the exponential is preferred). The finite rate of increase (λ) is often expressed as a percentage ($\lambda = 1.2$ indicates 20% growth; $\lambda = 0.90$ indicates a 10% decline).

$$\lambda = N_{t+1}/N_t \quad \text{where } N=\text{number and } t=\text{time}$$

λ can also be written as $\lambda=e^r$, where e is a constant (base of Natural logs) and r is the exponential rate of increase. The finite rate converts to the exponential rate as:

$$\log_e e^r = r$$

The exponential rate, r , is more useful than the finite rate e^r (Caughley 1977) because:

- r is easy to calculate;
- r is centered at zero which helps comparing rates of increase and decrease;
- r is easily converted from one unit of time to another; and
- from r it is easy to calculate doubling or halving time ($0.6931/r$).

Population estimates are converted to natural logs and a linear regression, $Y=a+rX$, is fitted with Y (the dependent variable) being the estimate, X (the independent variable) being time, r (the slope of the regression) is the exponential rate and a (a constant) is the intercept of the Y axis.

Population rate of change can also be estimated with Hatter and Bergerud's (1991) method using estimated female recruitment (R) from calf:cow ratios and survival rate based on radio-collared caribou. Other rates of increase, such as the intrinsic rate of increase r_m (see Caughley 1997 and Caughley and Sinclair 1994), are not included in this manual on monitoring populations.

2. b) Birth Rate (Fecundity, Pregnancy, Parturition)

Birth rate (natality) can be measured as **fecundity rate**, which is the mean number of live births per female per year expressed by age class (fecundity table). Fecundity tables are derived from harvested animals whose age class and pregnancy status are determined and fetal sex ratio is measured or assumed to be 1:1. Thomas and Barry (1990a) provide an example of an age-specific fecundity table from harvested caribou of the Beverly herd.

More often in monitoring *Rangifer* demography, **pregnancy rate** is used as an index for birth rate. Pregnancy rates can be determined from harvested caribou and should be expressed as the percentage of pregnant females per year by age class (for example, 75% of females 3 years or older). **Parturition** means giving birth and is measured by the number of females about to give birth or with

newborn calves. Maternal status is usually determined by direct visual observation of females; however, for some herds (e.g. the Teshekpuk herd in Alaska), parturition rates have been deduced through remote sensing by a period of lower movement during the calving season (Carroll *et al.* 2005). Breeding females may be referred to as **parous**, which means they have given birth at least once during their life; **primiparous** is used to denote a cow giving birth for the first time.

When it is not practical to harvest females, there are other ways to estimate pregnancy rates. During the calving period, parturient females (pregnant and post-partum) are identifiable by the presence of at least one hard antler and/or a distended udder (Bergerud 1964, Whitten 1995). Most parturient cows retain their hard antlers until two to three days after the birth of their calf, although Whitten (1995) cautions that on exceptionally good ranges, cows may drop their antlers before birth. Jenkins and Barten (2005) compared parturition rates from aerial observations on the calving grounds with observations of radio-collared cows. The mean estimates of parturition from aerial surveys averaged 5-10% lower than from radio-collared females, possibly because non-parturient females aggregated in larger groups and were more visible than parturient females, and the radio-collared sample likely was skewed towards older females. Cows with velvet buds on the calving grounds are barren cows that shed their antlers in spring and in the Alaskan Western Arctic herd, the proportion of cows with velvet antlers is inversely related to the calf:cow ratio (Dau 1997).

Precision of the proportion of parturient cows (breeding females) is measured by a systematic and stratified sampling design. For example, Gunn *et al.* (2005a) reported sampling composition on the calving ground within 10 x 10 km grids, with the number of grids sampled being relative to caribou density. Cochran's (1977) Jackknife method was used to calculate the mean proportion and variance of the breeding females in each stratum. Precision varied 10-fold between the high and low density strata in 2003 on the Bathurst herd's calving ground.

In the 1990s, the ability to track the reproductive performance of individual females using radio collars led to the realization that pregnancy rates are not annually constant, but vary as individual females undergo reproductive pauses. In a poor year, there may be a high number of cows without sufficient body reserves to conceive and this proportion of cows may be enough to change the population's pregnancy rate (Cameron 1994). The implication is that pregnancy rates need to be annually monitored especially to determine whether any changes in the ratio of calves to cows reflect changes in pregnancy rates, calf survival and adult female survival.

Other terms: The term **net calf production** is sometimes used to represent the product of pregnancy rate and calf survival. It takes into account calf mortality, so when the term is used, the time period to which it is being applied should be

reported. For example, Griffith *et al.* (2002) calculated net calf production for June (the product of June calf survival and parturition rate). Annual calf production is often reported, but is based on measuring calf:cow ratios in late winter, so more accurately, it is net calf production for 10 months.

Conception rate is the number of females that conceive per year. In practice, it is usually considered to be the same as pregnancy rate if levels of intrauterine mortality are very low; this is common, but there are exceptions. In the Porcupine herd, for example, if cows are in very poor shape during the rut, the fertilized egg may implant and then be lost within two to three weeks (Russell *et al.* 2002).

Peak of calving: Monitoring the timing of the peak of calving is potentially useful, as changes in timing may reveal information about the cows' condition during the rut or a change in breeding behaviour if cows are being bred in their second estrus. Typically, caribou biologists refer to peak of calving as being when 50% of cows have given birth to their calves (Reimers 1997). The proportion of calves born can be determined during sequential aerial surveys. More frequently obtained data (daily), such as through radio tracking, allows estimating median birth dates, as well as the spread and synchrony of birth dates. Sample size and representation of the age structure of cows can be a potential problem in radio tracking, however, Adams and Dale (1998) ensured that, by annually collaring 1-year-old females based on fall composition data, their sample of radio-collared cows was a good representation of the age structure of the herd.

2. c) Sex Ratio

Monitoring the sex ratio is based on assigning caribou into sex and age classes either from the ground or from the air. Caribou are classified as females, males or calves based on their appearance and external sex characteristics. Females are reliably indicated, when seen from the rear, by the presence of a vulva (as a dark spot) and a urine patch below the tail. Antlers should not be used to classify cows, as young males sometimes have similar form and conversely, herds differ in the proportion of naturally polled (antlerless) females. Males are recognizable by not having a vulva and, when viewed from the side, the penis is usually visible. Prime bulls are large bodied with conspicuously convex facial profiles and have either large antlers in fall or no antlers in late winter. In contrast, young bulls have antlers that are, roughly, less than shoulder height from the ground in fall or still have antlers in late winter. Calves are small-bodied with relatively short faces. Calves at the end of their first winter are also known as short-yearlings. In the Northwest Territories, biologists do not consistently classify yearlings as they suspect that classification errors between 22- and 34-month-old caribou are likely. They record cows with no antlers (probably genetically polled) as this varies between herds.

In Alaska, to determine sex and age counts, biologists conduct composition surveys during the rut in late October, because sexual segregation is usually considered minimal at that time of year. Biologists locate radio-collared caribou

using fixed-wing planes to allocate sampling effort throughout the herd. The tracking plane calls in a helicopter from which they classify ~200 individuals within 5 km of each collared caribou. The biologists classify caribou as bulls, cows or calves.

Sex ratios are expressed as the proportion of females in the total sample or as males per 100 females, or simply the ratio of males to females. Monitoring the sex ratio provides insight into relative mortality of the two sexes and, if the trend of the population is known, the ratios can be corrected to estimate mortality for either sex from ratio data (Bender 2006). The bull:cow ratio is also an important parameter for management of heavily hunted herds, especially when recreational harvests comprise a substantial portion of the total harvest. Monitoring the sex ratio also has explanatory and predictive power when the ratio becomes heavily skewed. For example, a strong bias toward females may have an effect on the timing of breeding, parturition and calf survival (Myserud *et al.* 2002, 2003).

2. d) Mortality

Even small changes in adult survival can have a large influence on trends in herd population size (Gaillard *et al.* 1998). Mason *et al.* (2006) recommended collecting survival rate estimates for adult and juvenile ungulates. Gaillard *et al.* (2000) and Coulson *et al.* (2005) suggested that while herbivore populations can tolerate random variation in calf survival, persistent low recruitment and calf survival may influence population trends. Calf survival is a product of the calf's fitness as well as that of its mother. Calf survival is likely less buffered against environmental variation than adult survival (for example, Russell and White 2000). Calf survival may vary substantially from year to year, which necessitates long term data sets to detect temporal trends. For example, the coefficient of variation for calf survival in the Bathurst herd was 37% over 1985-95 and 2001-06. On the other hand, monitoring adult mortality requires sufficient precision and accuracy to detect relatively small changes in rates of a few percentage points. This is difficult because of the large sample size required.

The importance of monitoring mortality was realized early in caribou studies. Bergerud (1980) proposed using estimated population size, estimated harvest level and recruitment to calculate mortality. However, it proved difficult to obtain sufficiently accurate estimates of abundance and harvest (Martell and Russell 1983, Davis and Valkenburg 1985). Instead, Martell and Russell (1983) advocated the use of radio collars to estimate mortality. Mortality can be directly estimated in populations with marked (radio-collared) individuals whose fate (alive or dead) is known either by using a mortality sensor on a radio collar or sighting a carcass. Software programs to analyze telemetry data are readily available, for example, the binomial known fate models in program MARK (White and Burnham 1999) or Kaplan-Mier (Pollock *et al.* 1995). Program MARK models allow the testing of trends, incorporation of covariates, and direct testing of survival rate differences between groups of caribou with resulting gains in

precision and inference (Boulanger *et al.* 2003). If a time series of data exists, there are methods available to separate process variance and sampling variation (Thompson *et al.* 1998). For example, Boulanger and Gunn (2007) used random effects modeling in program MARK (White and Burnham 1999), to estimate biological (process) variance from survival estimates of the Bathurst caribou herd from 1996 to 2006. Approximately 68% of the variance of the estimate was process variance, and 32% was sampling variation.

Survival rate estimates from field data include estimates of precision, but accuracy is less easily described. Three assumptions underlie the accurate use of marked individuals to estimate mortality. The first assumption is that marking a caribou does not affect its likelihood of dying. This has two components. First, capturing and processing the caribou does not affect its survival. For example, Boertje and Gardner (2000) reported lower calf survival when both the calf and its dam were captured by chemical immobilization from a helicopter, as the pairs were less likely to reunite. Goudreault and Luttich (1985) reported that capture and radio collaring from a boat while caribou were swimming severed the cow-calf bond in 18% of the 39 pairs handled and subsequently monitored, although it is not known if this affected the survival of those calves that were separated from their mothers. Currently, the most common method of capturing caribou is by net-gunning from a helicopter, which is usually assumed to be associated with a low rate of deaths or conspicuous injuries. Although a comprehensive review of net-gunning for caribou has not been undertaken, Webb *et al.* (2008) summarized 3350 white-tailed deer captures by helicopter-based net-gunning. Excluding broken antlers, 6.1% of deer were injured and 0.6% died. A subset of 51 male yearlings was radio collared and monitored for two years and capture-related deaths were 1% (Webb *et al.* 2008).

The second component of the assumption that marking a caribou does not affect its likelihood of dying is that the collar does not increase a caribou's vulnerability to predation or hunting or other effects. The effect of collars is relatively unexamined, although improvements made to collar design and fitting, including reducing transmitter weight, have reduced injuries in other species (Krausman *et al.* 2004). Effects of collars may be subtle and have been missed previously because data have not been analyzed to document effects. Brooks *et al.* (2008) found that a GPS collar weighing 0.6% of body mass in zebras (*Equus burchelli antiquorum*) reduced foraging movement rates compared to a GPS collar weighing 0.4% total body mass. Haskell and Ballard (2007) speculated that satellite collars reduced productivity in the Western Arctic herd, as their model using survival rates from radio-collared females from 1984-89 did not match the herd's actual rate of growth. Their comment about the effect of collars was referenced back to a statement that an earlier design of collars may have contributed to increased mortality (Dau 2003). Haskell and Ballard's (2007) speculation about the effect of satellite collars was also based on comparing pregnancy rates for yearlings from various herds without reference to range conditions or any environmental factors that influence condition.

The second assumption underlying the accurate use of marked individuals to estimate mortality is that censoring caribou records is independent of the caribou's fate. Biases can result if censored records (*i.e.* the collar signal was lost and therefore the record was censored) are actually deaths and not collar failures (that should be censored). For this reason, precise and timely determination of fates is essential for unbiased estimates. If fates of caribou are not known accurately for each survey period, or the actual time of mortality is unknown, then alternative analyses should be considered to estimate the probability of a caribou that died being reported as dead (the reporting rate), and the probability of a caribou fate being recorded each survey period (Williams *et al.* 2002).

The third assumption is that individuals are representative of a population and this is sometimes problematic. Depending on the study objectives, specific age and sex classes may be selected. For example, Dau (2003) explains the rationale for selecting prime-aged bulls and healthy cows for fitting radio collars in Alaska's Western Arctic herd.

Sample sizes (number of marked individuals) are usually low relative to population size, increasing the likelihood that the sample of marked individuals may not be representative of the population's sex and age structure. Small sample sizes usually restrict the estimates of mortality to combined age classes such as 'adult'. Sample size in practice is usually dictated by budget. However, if individuals are being marked to estimate mortality (or other objectives such as life-time fitness or dispersal), a statistically adequate sample size is essential. The program MARK (White and Burnham 1999) has a simulation module for the known fate binomial model that can be used to simulate a survival study and provide estimates of the precision of survival rate estimates as a function of the number of caribou collared for each sampling period and assumed survival rates of individuals. Alternatively, the precision of survival rate estimates can be approximated using the binomial distribution (Williams *et al.* 2002). However, this method is somewhat restrictive in terms of incorporating specific details of a particular study. Formulas for power and precision for the binomial distribution can be found in Agresti (1990) and Williams *et al.* (2002). Another method for estimating either sample size or levels of power, bias and precision is using the capture-recapture software M-SURGE (Devineau *et al.* 2006).

Efforts should be undertaken to ensure that the sample of collared caribou is representative throughout a collaring program. Adding new individuals annually to maintain a target sample size will reduce the likelihood that the sample of marked individuals will be skewed or biased with regard to age or fitness. If re-collaring of new caribou does not occur at frequent intervals, the sample of collared caribou can potentially over-represent individuals with higher survival rates (Zens and Peart 2003). This creates a potential source of process variation.

However, for reference herds where a more detailed understanding of the mechanisms driving changes in abundance is needed, age-specific survival rates may be required. Festa-Bianchet *et al.* (2003) concluded that understanding age-specific survival rates was essential to avoid erroneous diagnosis of density-dependent effects on adult mortality. Age-specific death rates can be estimated from a large sample of harvested caribou through constructing a life-table (for example, Thomas and Barry 1990b and Leader-Williams 1988). Thomas and Barry (1990b) sampled 856 female caribou from 1980-87 to construct their life-table. The details and pitfalls of constructing life tables have been documented by Caughley (1977), Caughley and Sinclair (1994) and Taylor (1991). To interpret life-tables, other essential information is needed, specifically, the trend in population size. As an alternative to life-tables, a large sample of radio-collared known-age individuals can be used to follow individual cohorts. This requires radio collaring of calves and ensuring adequate sample sizes to detect age-specific changes in survival rates.

As calves are an easily recognized age class, **calf survival** is frequently monitored, and thus, calf survival rates can be estimated. If calves have been radio collared, survival rates can be estimated directly. Calf survival rates can also be monitored through changes in successive calf:cow ratios, which reflects the proportion of calves that have died per 100 cows. Estimating birth to spring survival (an index to annual survival, although more correctly it is survival to 10 months) requires an estimate of the birth calf:cow ratio.

In many Alaskan herds, the reproductive status of radio-collared cows is monitored on the calving ground, which provides an estimate of the birth calf:cow ratio if tracking flights cover the period of calving. In Canada, calf:cow ratios are estimated during calving ground censuses. Both approaches may include early calf (perinatal) mortality.

To estimate calf survival from calf:cow ratios, a correction for adult female mortality is necessary. The annual adult female survival rate must be adjusted for the interval between birth and the timing of the composition survey (fall or late winter) to estimate calf survival rates. To detect trends in yearly calf:cow ratios and associated variance estimates, Gunn *et al.* (2005b) used weighted least squares regression (Kleinbaum and Kupper 1978 in Gunn *et al.* (2005b).

About half of calf mortality occurs on the calving ground (references in Griffith *et al.* 2002), which emphasizes the importance of monitoring calf survival in June (perinatal and neonatal mortality). Although measuring the proportion of cows with distended udders and no calves may reflect early calf mortality on the calving ground, Whitten (1995) suggested that it was not a reliable index. Three approaches to estimating neonatal calf mortality have been tried. Miller *et al.* (1988) used helicopter searches for dead calves and necropsied the calves to determine the cause of death. This approach can return large sample sizes,

provide an approximation of calf age in days, and detect changes in the rate and causes of mortality during calving (perinatal) and early post-calving (neonatal).

A second approach is to catch and radio collar newborn calves and to monitor calves by radio tracking to determine their fate (for example, Jenkins and Barten 2005). Potential biases arise from the effects of capture, as some calves are abandoned, and from still births and perinatal mortality that may be underestimated (Whitten *et al.* 1992). However, Jenkins and Barten (2005) took precautions to reduce calf abandonment. A third approach is to radio track cows and to monitor the fate of their calves on the calving ground (Whitten *et al.* 1992). A combination of approaches is also used; for example, Adams *et al.* (1995) tracked newborn radio-collared calves as well as collared cows in the Alaskan Denali herd and Jenkins and Barten (2005) applied both techniques to the Mentasta herd in Alaska. The approach chosen should reflect the exact objectives which should specify the age class of the calf that is of most interest (Table 2).

Table 2. Mortality terms for different ages of fetuses and calves

Age of calf	< 1 month after conception	> 1 month after conception	Birth to 2 days	2 days to 1 month	1 month to 10 months	10 month to 12 month
Mortality Terms	Early embryonic loss	Fetal mortality				
		Perinatal mortality				
			Neonatal mortality			
			10-month mortality			
			Annual calf mortality			

In summary, the three approaches measure different things:

1. Searching for dead calves: measures still births, perinatal and early neonatal mortality;
2. Capturing and tracking newborn calves: measures some perinatal mortality, and neonatal and post neonatal mortality; and
3. Radio-tracking cows: measures stillborn, perinatal, neonatal and postnatal mortality until the cow:calf bond breaks.

Harvest: Monitoring harvest is useful because harvest can influence population size, trend and sex-age composition, and because it emphasises the importance of caribou to people. Systems for collecting harvest data are highly variable between jurisdictions. Generally, certain classes of hunters are regulated through a permit system with compulsory or voluntary reporting. For aboriginal users, harvest monitoring has changed from a government-based

reporting to interview-based hunter-recall extrapolations. Usher and Wenzel (1987) provide a detailed history of collecting harvest statistics in northern Canada. The estimates of harvest are usually based on sampling (questioning) hunters with an attendant need to report bias and precision. Usher and Wenzel (1987) provide detail on biases in harvest data and describe some solutions.

Sutherland (2005) describes an alternative approach using a model in which the community harvest is recorded through interviews and weighted by the number of people in a village and a categorical rating for how close the Western Arctic herd was to the village during the winter. In some years, herds overlap on their winter ranges which means that hunters may be harvesting from two herds. Satellite-collared caribou distribution is used to allocate harvest levels, for example, between the Western Arctic, Teshekpuk and Central Arctic herds in Alaska (Sutherland 2005). An alternative approach applied to other species but not yet to caribou is to use microsatellite analyses to discriminate harvested caribou between populations (Selkoe and Toonen 2006).

Predation and disease rates: A detailed account of monitoring predators is outside the scope of this manual. However, while monitoring caribou herds, there is the opportunity to index predator abundance. Those indices, to be comparable between years or areas, should be standardized and include numbers of wolves, bears or other predators seen per km of aerial survey or per unit area. Monitoring for diseases at the herd scale is a relatively recent consideration in *Rangifer* monitoring. As with most aspects of monitoring, it depends on applying adequate sampling design and some of the pitfalls are described in Nusser *et al.* (2008). The techniques used to monitor diseases and parasites for individual caribou are described in CARMA's condition and health manual. At the herd scale, the key to effective monitoring will be to determine appropriate sample size and sample design.

3. DISPERSAL

Dispersal is the movement of an individual from its place of birth to where it reproduces (Howard 1960, Bullock *et al.* 2002). Dispersal can be innate or driven by environmental changes (Howard 1960). The movement of a juvenile from its birth place to its place of reproduction is termed natal dispersion and the movement of adults between breeding places is breeding dispersal (Greenwood and Harvey 1982). Immigration, transience and emigration are the three parts of dispersal (Wolff 1994). Emigration is the individual's departure from its group (population) and immigration is the individual's arrival into the new population. Transience is the presumed risky crossing of unfamiliar ranges.

Understanding dispersal is as important as describing birth or death rates in population dynamics. Interpreting trends in caribou abundance could be confounded if many caribou dispersed between herds and, conversely, understanding synchrony in abundance between herds requires information on dispersal. Despite recent technical advances, such as telemetry and the ability to

measure fine-scale genetic variation, monitoring dispersal has lagged far behind reporting birth and death rates, especially as a designed sampling strategy versus ad hoc observations.

Currently, the application of telemetry and genetics is focused on defining management units, such as herds that are identified based on dispersal. The current consensus from telemetry data is that herds are not completely closed populations, but they are adequate as management units over the shorter-term (Hinkes *et al.* 2005, Couturier *et al.* in press). The conventional definition of a barren-ground caribou 'population' is a matrilineal definition based on the fidelity of cows to a specific calving ground. The implicit assumption that cows that calve together are also together during the rut is supported by satellite telemetry data. Infrequently, overlap in range between collared cows from two neighbouring calving grounds is seen during the rut (for example, Boulet *et al.* 2005), but what this overlap during the rut means for male and female dispersion between herds is an unresolved question that will likely require a combination of behavioural observations as well as spatial genetic analyses. On the basis of defining a caribou population, evidence for breeding dispersal between herds is observed when cows calving on one calving ground emigrate and calve on another herd's calving ground. Likewise, individuals that calve and rut with one herd, then immigrate and rut with a different herd provide additional evidence for dispersal assuming the immigrant breeds.

Although satellite telemetry is relatively common, its use in monitoring emigration/ immigration is limited by sample design and sample size. Some information on dispersal has been accumulated as an adjunct to monitoring movements. Yet despite the lack of designed studies, dispersal is sometimes invoked to explain changes in abundance and instability in estimated population sizes. Monitoring immigration and emigration is attained through demonstrating movement of individual cows between calving grounds. Telemetry reveals the timing and extent (number of individuals) of immigration and emigration, but the individual has to be sighted to reveal whether it bred outside its natal population. Telemetry is often limited to small sample sizes (the number of collared caribou is low relative to population size) which would impede detecting a relatively infrequent event. For example, in the Teshekpuk Herd, Person *et al.* (2007) documented annual apparent emigration rate of 0.07 cows per year \pm 0.03 (SD) (5 cows in 73 caribou years). The selection of individuals that are collared may introduce a bias for monitoring dispersal and distinguishing between innate (natal) and breeding (environmental) dispersal. Typically in large mammals, it is juveniles that disperse and adult cows that are fitted with radio collars. However, for some Alaskan herds, males, calves and yearlings are being collared, so once the data are compiled, a better understanding of natal dispersal will accrue.

A second technique for monitoring dispersal is using genetics, which has the advantage of being able to reveal whether an immigrant successfully bred. Genetics, compared to ecology, uses different terminology for dispersal, which

can cause confusion. Migration in a genetics context refers to the movements of a few individuals per generation (for example, Mills and Allendorf 1996). Genetic evidence to monitor dispersal is cumulative over a much longer timescale and larger spatial scale than evidence collected using satellite telemetry (Scribner *et al.* 2005). Interpreting genetic similarities as evidence for dispersal between two populations is difficult if effective population size is large. In large populations (100s-1000s), genetic drift is slow and differences between populations can require many generations to appear. Similarities can be the result of a common origin for two populations or dispersal between the populations. Additionally, measuring immigration and emigration between populations is problematic because the traditional genetic approach to understanding movement rates between populations (herds) involves a standardized measure of variance in allele frequencies between populations (F_{ST}) and its relationship to the number of 'migrants' a population receives per generation (Nm , where N is the genetic effective population size and m is the effective migration rate): $F_{ST} = 1/(1 + 4Nm)$ (Wright 1931). The relationship between F_{ST} and Nm is based on a model that is so highly idealized that it renders the relationship meaningless to the student of demographics (Whitlock and McCauley 1999). Perhaps most importantly, the relationship only holds at equilibrium, and equilibrium is expected to take $> N$ generations to be achieved in the typical range of Nm that one considers. Thus, if N is in the thousands and generation time (mean age difference between offspring and parents of both sexes) is five or more years, F_{ST} could still be influenced by population configurations that were in place at a time during the Wisconsin ice age. Even in the unrealistic event that equilibrium is ever achieved, radically different demographic scenarios can lead to the same value of F_{ST} ; for example, episodic interbreeding between members of different populations without any animals actually switching their population of residence versus a regular, long-term, low level of individuals dispersing to and breeding in a population other than their natal population. The dismissive tone of this paragraph is in reference to measuring immigration and emigration at the demographic scale. However, measurements of F_{ST} can be useful for assessing gene flow among herds, and even temporal changes in connectivity in much smaller populations.

In the last 20 years, geneticists have gained access to large numbers of highly variable markers (microsatellites). Potentially, this means a shift from the indirect, population-level approach described above to a direct, individual-level approach. This has been fostered by recent advances in laboratory and analytical techniques. Currently, a large number of individuals can be sampled for microsatellites efficiently and relatively cheaply (Selkoe and Toonen 2006). Non-invasive techniques, such as extracting DNA from fecal pellets or shed antler pedicels, allow large numbers of individuals to be sampled which can increase the resolution and power of genetic analyses to partition genetic variation between individuals, social units, populations and groupings of populations (Scribner *et al.* 2005). Selkoe and Toonen (2006) list sampling considerations, such as deciding on the number of loci and which loci to use.

Paetkau (pers. comm., 2007) described an application of microsatellites for recovery planning in BC's Southern Mountain caribou. In this direct approach, detailed genotypic data were used to identify each individual's natal population, which was then compared to capture location to deduce movements between birth and capture. This approach has proven practical in specific contexts where small, isolated populations that have experienced rapid genetic drift – generating the strong differences between populations that allow assignment of natal origin – are brought back into contact through habitat restoration or dispersal. In a specialized context like this, genetic methods can provide data that are comparable to direct movement studies, and can do so for the majority of individuals in a population spanning their entire lifetime and achieving this in a single field season without ever handling a single animal (for example, Dixon *et al.* 2006). Genetic drift can be rapid and over a small spatial scale when effective population size is only relatively few individuals. This was the case for Svalbard reindeer from two sites about 45 km apart that were genetically different based on microsatellite differentiation (Côté *et al.* 2002).

Unfortunately, direct methods depend upon an ability to assign individuals to their natal population with confidence, and large populations at equilibrium tend not to be sufficiently differentiated for this to be feasible (Paetkau *et al.* 2004, Zittlau 2004). It is important to remember that genetic differentiation between populations accumulates in proportion to Nm , not m alone, so small populations accumulate much greater differences at a given migration rate than do larger populations. Thus, direct genetic methods could have considerable utility in monitoring post-recovery movement between currently small, isolated populations of boreal caribou, or for identifying native versus introduced animals in the years following population augmentation, but may not be practical in the context of large northern herds.

Another possibility for using population genetics in northern caribou is in population identification at different times of the annual movement cycle, or following harvest. This approach has been used in such diverse applications as relating breeding and over-wintering populations of migratory birds (Clegg *et al.* 2003), apportioning catches of anadromous fish species by spawning stock (Shaklee *et al.* 1999) and assigning poached ivory to source elephant populations (Wasser *et al.* 2004). Ideally, such studies would be able to assign individual animals to source populations, as described above, but even if the power to do this is lacking, one could draw useful inference using groups of animals. To the extent that questions remain about the movement patterns of specific herds, or about harvest patterns, such an approach may have practical utility. However, feasibility studies to follow-up on earlier studies (such as Zittlau 2004) are needed using more loci and large samples (30-40 individuals). The sampling strategy has to be designed relative to the objective: for herd differentiation, samples such as shed cow antlers from calving grounds would be appropriate.

THE PROTOCOLS

The Protocols are a separate document and have two sections. The first section is an example of how to report demographic monitoring for CARMA. It is a spreadsheet with the explanation for the entries. The second part is examples of Excel tools to help with data entry. Examples of Tools (in Microsoft Excel) for Calculating Indicator Values

The following three spreadsheets were developed to assist Users with data analysis approaches:

- 1) Population rate of increase
- 2) t-test of aerial surveys and power analysis
- 3) Precision of composition estimates

DISCLAIMER: These tools are provided to facilitate further discussion and promote consistent methods for baseline data analysis. Although we have no reason to believe there are errors in the spreadsheet calculations or analyses, Users should refer to primary references to ensure that analytical methods and assumptions are valid. Users are encouraged to provide any feedback to CARMA. CARMA is not responsible for any errors that may exist in the calculations and methods.

Population rate of increase

Rate of Increase (RateIncrease.xls)

A population's rate of increase is described as either a finite or exponential rate. The purpose of this spreadsheet is to help the user understand the difference between the two descriptors and their derivations. The text below is based largely on Caughley 1977 (Chapter 5 Rate of Increase, p. 51).

The **finite rate of increase** (also termed the growth multiplier) is the simplest measure of a population's rate of increase; it is the ratio of numbers in two successive years. The Greek symbol lambda (λ) is used to represent the finite rate of increase. Thus

$$\lambda = N_{t+1} / N_t$$

When λ is equal to 1, a population is stable. A value of λ greater than 1 indicates that the population has increased between successive years, whereas a value less than 1 indicates that the population has declined.

The exponent (r) is the power to which e (the base of natural "Naperian" logs, taking the value of 2.71828) is raised such that $e^r = \lambda$; r is the exponential rate of increase. A population that exhibits exponential change grows or declines at a constant rate, i.e., the number of animals added or lost varies among time periods, but that number, as a percentage of population size is constant (Gasaway et al. 1986, p. 66).

Thus

$$\lambda = N_{t+1} / N_t = e^r$$

According to Caughley (1977), the exponential rate of increase (r) is a more useful expression of population increase than λ for three reasons:

- 1) r is centered at zero, hence a rate of increase measured as r has the same value as an equivalent rate of decrease, apart from reversal of sign;
- 2) r converts easily from one unit of time to another, i.e., when r per year equals x , r per day equals $x / 365$; and
- 3) doubling time of a population can be easily calculated from r by $0.6931 / r$. For example $0.6931 / -0.059$ equals a halving time of 11.8 years.

1) In the Excel spreadsheet titled "RateIncrease.xls", the tab labelled "**Estimating RateIncrease.xls**" shows how to quickly calculate the finite and exponential rates of increase. The tab has been preloaded with hypothetical data for an introduced ungulate population (with an initially biased sex ratio for females). The user can enter their own data in to the green shaded cells. Pink shading indicates cells that have formulas and should not be changed.

Step 1 shows the straightforward calculation for finite rate of increase, which is N_{t+1} / N_t .

Step 2 shows that the exponential rate of increase between subsequent surveys is calculated from the natural logs of the population estimates using the following formula: $r = \log_e (N_{t+1}) - \log_e (N_t) / (t+1) - (t)$

Step 3 allows the user to convert values between λ and r . It also calculates the doubling time if the value of $r > 0$, and the halving time if $r < 0$.

2) The tab labelled "**Precision of r**" is based on the methods outlined by Gasaway et al. 1996 and shows how the precision for r can be estimated from survey data from two population estimates. The two population estimates used in this example are the estimate of breeding females on the Bathurst calving ground in June 2003 (Gunn et al. 2005) and 2006 (Nishi et al. 2007).

3) The tab labelled "**RateIncrease-LinRegress**" demonstrates how linear regression techniques may be used to estimate the exponential rate of increase (r) from a series of population estimates based on the same data as presented in the first tab. The linear regression is calculated on the natural logs of the respective population estimates/counts, and r is represented by the slope of the regression.

23 November 2007

J.S. Nishi

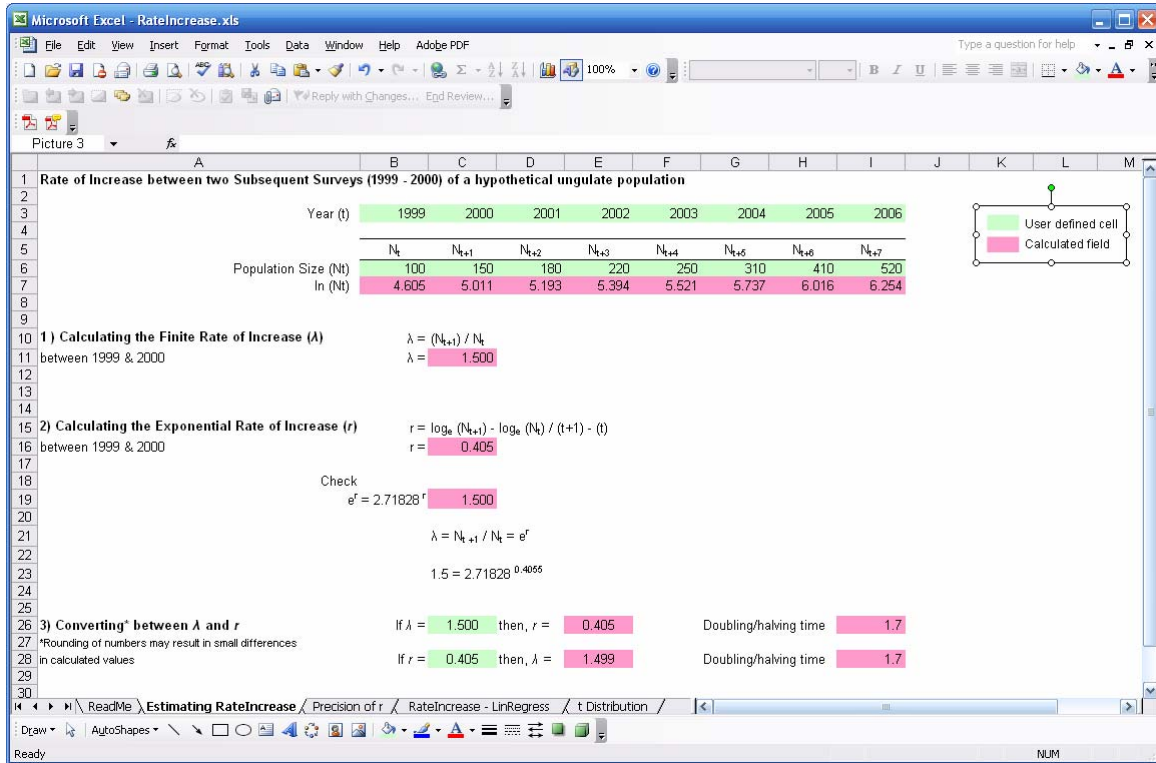
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Download "RateIncrease.xls" from CARMA website

<http://carmanetwork.com/display/public/Population+Monitoring>

t-test of aerial surveys and power analysis

Detecting Numerical Changes from Subsequent Aerial Surveys of Ungulates (GasawayTtestAerialSurveys.xls)

I designed this spreadsheet to understand the implications of survey precision on power to detect numerical changes in estimates from aerial strip-transect surveys. The specific application of this spreadsheet was to compare data from subsequent estimates of breeding females from calving ground surveys of barren-ground caribou in the Bathurst herd, but it has been modified here for general comparisons of aerial survey data using t-tests and power analyses.

Data Entry

The spreadsheet allows the user to enter data for the two subsequent aerial surveys in to separate tabs labelled "Survey 1" and "Survey 2" respectively. The green shading indicates cells that require data input for the respective surveys that the user is preparing to analyse. The pink shading indicates cells in which formulas have been entered to automate the calculations and do not require user entry. As a working example, the spreadsheet has been preloaded with aerial survey results of 1+-yr-old caribou on the annual calving ground of the Bathurst caribou herd in 2003 (Gunn et al. 2005) and 2006 (Nishi et al. 2007) respectively.

The User should update the values in the green shaded cells in the "**Survey 1**" and "**Survey 2**" tabs with their data to use the spreadsheet. The data required for an aerial survey include the number of transects sampled within a stratum, as well as the respective population estimates and variances for each stratum (step 1). As these data are entered, the spreadsheet automatically summarizes the survey results and calculates the overall variance, standard deviation, and CV for the estimate. The spreadsheet uses these data to calculate the degrees of freedom (step 3) that are associated with the survey.

Comparison and Power Analysis

The comparisons of the two surveys are based on t-test analyses and formulas described by Gasaway et al. 1986 in Chapter 4 of their monograph on moose survey analyses; power analyses are also based upon Chapter 4.

The "**Comparison**" tab takes the user through 5 steps to compare the two surveys, and to evaluate the power of the test.

Step 1, summarizes the degrees of freedom for each respective survey.

Step 2 calculates the total degrees of freedom for the t-test between the two surveys.

Step 3 requires that the user enter the population estimates and CV's for the respective aerial surveys. Upon entering these data, the spreadsheet calculates the variance for the respective surveys. This step also requires the user to enter a percentage value (of the 1st survey) for the Consequential Difference of interest (CD) for subsequent power analyses (step 5).

Step 4 calculates the t-value and provides the critical values (at the appropriate degrees of freedom from the tab "**t Distribution**") at varying levels of alpha for two-tailed and one-tailed t-tests.

Step 5 allows the user to determine the power of the t-test if she rejected the null hypothesis in step 4 (above). The parameter that requires entry at this step is the t-value to the corresponding value for alpha (Type I error rate). Since the parameters that are used to calculate the critical value for beta (Type II error rate) also include the CV's for the respective population surveys, and the Consequential Difference of interest (CD), the user can iteratively explore post hoc power analyses by changing those parameters singly or in combination. This exploratory analysis can also be used in an a priori fashion to consider how the variance of a future survey may affect power to detect change in a subsequent survey.

22 November 2007
J.S. Nishi

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Microsoft Excel - GasawayTtestAerialSurveys.xls

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Type a question for help

Picture 4

TITLE FOR DATASET		Aerial Survey #1				
Date						
1) Population Estimate						
Stratum	# Transects	1+-Yr-Old Caribou				
		Pop Est	Variance	SE	CV	
1	17	83959	236816435.0	15388.8	0.18329	
2	10	23385	18529666.0	4304.6	0.18408	
3	14	2639	338116.0	581.5	0.22034	
4				0.0	-	
5				0.0	-	
6				0.0	-	
7				0.0	-	
8				0.0	-	
9				0.0	-	
10				0.0	-	
SUM	41	109983	255684217.0	15990.1	0.14539	
2) Summary of Population Estimate						
Estimate		109983				
Variance		255684217.0				
SE		15990.1				
CV		0.1454				
3) Degrees of Freedom (df) for the survey estimate (Gasaway et al. 1986, Section 3.7.2.3; pg 39)						
		18				

Legend: User defined cell (green), Calculated field (pink)

Ready NUM

Download "GasawayTtestAerialSurveys.xls" from CARMA website
<http://carmanetwork.com/display/public/Population+Monitoring>

Precision of composition estimates

Tukey's Jackknife Method for Proportional Data (JackknifeComposition.xls)

I developed this spreadsheet to calculate variances for composition data using Tukey's Jackknife method (Cochran 1977, p. 178; Krebs 1989, p. 464; Sokal & Rohlf 1981, p. 796). The data entry format was designed specifically for use during composition surveys of caribou on a calving ground, but an additional tab has been included to accommodate composition data from fall or spring composition surveys. A useful aspect of the spreadsheet is that the User can enter composition data in the field and know immediately whether additional data should be collected in order to achieve their objectives for survey precision.

There are two Data Entry tabs where the user can enter their field data: these are labelled "**Calving Grnd**" and "**Fall Spring Comp**". Choose the appropriate tab and enter descriptive information and composition data in the light green shaded columns in the appropriate tab labelled. Note that the green shading indicates cells that can be changed by the user. Conversely, rose shading indicates cells that have formula entries and should not be modified.

The **Calving Ground** tab has been designed to accommodate up to 200 observations within a stratum. As an example, it has been pre-loaded with 43 observations collected during a composition survey of Bathurst caribou in a high density stratum in June 2006 (Appendix H in Nishi et al. 2007). These data should be deleted prior to actual data entry.

The **Fall - Spring Composition** tab has been designed to accommodate up to 400 observations, and has been pre-loaded with 148 observations from a fall composition survey of the Bathurst herd in November 2001 (Appendix F in Gunn et al. 2005). These data should be deleted prior to use of the tab.

****Note:** For data on fall or spring composition surveys, there may be observations of bachelor groups comprising of bulls only. Since the calculation of a ratio with zero as a denominator (i.e., no cows observed in a group) results in an calculation error, the bachelor groups that had zero cows observed could either be i) excluded from the Jackknife calculation, or ii) adjusted by adding a single cow to the groups where no cows were observed. The first approach under estimates the bull to cow ratio because it ignores bachelor groups. The second approach involves calculating an 'adjusted' bull to cow ratio, by including the observations of bachelor groups and adding one cow to the composition of the group. This adjusted approach allows the bachelor groups to contribute to the overall calculation of the bull to cow ratio. I have not explored the bias introduced by the arbitrary addition of a single cow to a bachelor group, which may become an issue if the composition sample comprises a large number of small bachelor groups. However, the underlying principle is that the sample should be representative of the population for the ratios of interest.

Results are displayed in the tab labelled "**Data Summary**."

22 November 2007
J.S. Nishi

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Microsoft Excel - JackKnifeComposition.xls

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A1 TITLE FOR DATASET

1	TITLE FOR DATASET																Br
2	DATE				BREEDING FEMALES			NON-BREEDERS									
3			Waypoint	Lat	Long	Antlered	Antlerless	Antlered	Antlerless	Calves	Yearlings	Bulls	Sum All	Sum Breeding	Sum 1+ Yr		
4	Date	Stratum	(Obs #)			Wrth Udder	Wrth Udder	No Udder	No Udder					Females	Old Caribou		
5	11-Jun-06	1	1	66.86667	-110.88333	0	2	0	14	2	1	0	19	2	17	0	
6	11-Jun-06	1	2	66.86667	-110.88333	0	4	0	13	0	0	0	17	4	17	0	
7	11-Jun-06	1	3	66.86667	-110.88333	13	36	0	13	46	0	0	108	49	62	0	
8	11-Jun-06	1	4	66.86667	-110.88333	48	108	3	0	117	0	0	276	159	159	1	
9	11-Jun-06	1	5	66.86667	-110.88333	9	29	3	12	33	1	4	91	41	58	0	
10	11-Jun-06	1	6	66.86667	-110.88333	3	19	1	12	15	13	0	63	23	48	0	
11	11-Jun-06	1	7	66.86667	-110.88333	29	65	0	16	57	2	0	169	94	112	0	
12	11-Jun-06	1	8	66.86667	-110.88333	1	37	0	4	12	1	5	60	38	48	0	
13	11-Jun-06	1	9	66.86667	-110.88333	23	231	0	6	114	6	0	380	254	266	0	
14	11-Jun-06	1	10	66.86667	-110.88333	7	84	0	11	61	0	0	163	91	102	0	
15	11-Jun-06	1	11	66.86667	-110.88333	10	209	0	0	92	0	6	317	219	225	0	
16	11-Jun-06	1	12	66.86667	-110.88333	0	0	0	23	0	2	3	28	0	28	0	
17	11-Jun-06	1	13	66.86667	-110.88333	5	75	0	18	18	1	0	117	80	99	0	
18	11-Jun-06	1	14	66.86667	-110.88333	15	166	0	0	136	0	0	317	181	181	1	
19	11-Jun-06	1	15	66.86667	-110.88333	21	144	1	3	103	0	0	272	166	169	0	
20	11-Jun-06	1	16	66.86667	-110.88333	16	118	0	0	74	0	0	208	134	134	1	
21	11-Jun-06	1	17	66.86667	-110.88333	22	203	0	0	146	0	0	371	225	225	1	
22	11-Jun-06	1	18	66.86667	-110.88333	13	191	0	4	95	0	0	303	204	208	0	
23	11-Jun-06	1	19	66.86667	-110.88333	0	9	0	1	1	0	0	11	9	10	0	
24	11-Jun-06	1	20	66.86667	-110.88333	0	14	0	0	14	0	0	28	14	14	1	
25	11-Jun-06	1	21	66.86667	-110.88333	0	1	0	10	0	2	0	13	1	13	0	
26	11-Jun-06	1	22	66.86667	-110.88333	11	126	0	0	72	0	0	209	137	137	1	
27	11-Jun-06	1	23	66.86667	-110.88333	4	25	0	2	11	1	1	44	29	33	0	
28	11-Jun-06	1	24	66.86667	-110.88333	3	21	0	12	3	1	2	42	24	39	0	
29	11-Jun-06	1	25	66.86667	-110.88333	6	41	6	5	0	0	6	64	53	64	0	
30	11-Jun-06	1	26	66.86667	-110.88333	2	43	0	11	6	0	0	82	45	56	0	
31	11-Jun-06	1	27	66.86667	-110.88333	9	43	1	41	40	6	0	140	53	100	0	
32	11-Jun-06	1	28	66.86667	-110.88333	15	70	0	10	72	3	0	170	85	98	0	
33	11-Jun-06	1	29	66.86667	-110.88333	16	101	1	14	99	1	0	232	118	133	0	
34	11-Jun-06	1	30	66.86667	-110.88333	15	26	0	3	39	0	0	83	41	44	0	
35	11-Jun-06	1	31	66.86667	-110.88333	29	85	0	1	114	1	0	230	114	116	0	
36	11-Jun-06	1	32	66.86667	-110.88333	1	13	0	41	3	2	3	63	14	60	0	
37	11-Jun-06	1	33	66.86667	-110.88333	22	83	0	13	65	2	0	185	105	120	0	
38	11-Jun-06	1	34	66.86667	-110.88333	12	28	0	4	35	0	0	79	40	44	0	
39	11-Jun-06	1	35	66.86667	-110.88333	45	65	0	7	90	1	0	208	110	118	0	
40	11-Jun-06	1	36	66.86667	-110.88333	30	57	0	13	55	0	0	155	87	100	0	
41	11-Jun-06	1	37	66.86667	-110.88333	21	90	0	4	102	0	0	217	111	115	0	
42	11-Jun-06	1	38	66.86667	-110.88333	9	43	1	41	40	6	0	140	53	100	0	
43	11-Jun-06	1	39	66.86667	-110.88333	14	93	3	3	95	1	0	208	107	111	0	
44	11-Jun-06	1	40	66.86667	-110.88333	5	26	0	7	0	21	0	59	31	59	0	
45	11-Jun-06	1	41	66.86667	-110.88333	6	16	0	24	2	0	0	49	23	47	0	
46	11-Jun-06	1	42	66.86667	-110.88333	1	7	0	1	5	0	0	14	8	9	0	
47	11-Jun-06	1	43	66.86667	-110.88333	5	109	0	108	0	0	0	222	113	114	0	
48	11-Jun-06	1	44			0	0	0	0	0	0	0	0	0	0	0	
49	11-Jun-06	1	45			0	0	0	0	0	0	0	0	0	0	0	
50	11-Jun-06	1	46			0	0	0	0	0	0	0	0	0	0	0	
51	11-Jun-06	1	47			0	0	0	0	0	0	0	0	0	0	0	
52	11-Jun-06	1	48			0	0	0	0	0	0	0	0	0	0	0	
53	11-Jun-06	1	49			0	0	0	0	0	0	0	0	0	0	0	
54	11-Jun-06	1	50			0	0	0	0	0	0	0	0	0	0	0	
55	11-Jun-06	1	51			0	0	0	0	0	0	0	0	0	0	0	
56	11-Jun-06	1	52			0	0	0	0	0	0	0	0	0	0	0	
57	11-Jun-06	1	53			0	0	0	0	0	0	0	0	0	0	0	
58	11-Jun-06	1	54			0	0	0	0	0	0	0	0	0	0	0	
59	11-Jun-06	1	55			0	0	0	0	0	0	0	0	0	0	0	
60	11-Jun-06	1	56			0	0	0	0	0	0	0	0	0	0	0	
61	11-Jun-06	1	57			0	0	0	0	0	0	0	0	0	0	0	

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