Survival Rate Estimates for adult female caribou in four herds of barren-ground caribou using radio-collared individuals, Northwest Territories and Nunavat DRAFT

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Introduction

The survival rate of adult female herbivores in general, and caribou *Rangifer tarandus* in particular, is a key component in population dynamics. In long-lived large mammals, adult survival rates tend to be relatively high and vary little between years (Caughley 1977). However, it does not take a large change in adult survival rates to influence the rate of population change (for example, Gaillard *et al.* 2000, Walsh et al. 1995). Walsh *et al.* (1995) modeled the potential changes in size of the Porcupine caribou herd based on measured survival and reproductive rates. Walsh *et al.* (1995) determined that a reduction in adult female survival from 0.871 to 0.847 would lead to a decline in herd size (assuming other variables did not change).

Before the popularity of radio-telemetry, survival rates were either estimated from measuring trend in herd size, recruitment and harvest mortality (Bergerud 1980, 1983) or estimated from life-tables (Thomas and Barry 1990). However, with the increasing use of radio-telemetry, survival rates are now more frequently estimated from the survival of radio-collared individuals (for example, Hearn *et al.* 1990, Fancy et al. 1994, McLoughlin et al 2003). The use of radio-telemetry is often characterized by relatively small sample sizes.

In this report we use newer analysis methods as part of program MARK to compare survival rate estimates in four herds of barren-ground caribou.

We applied the "Known Fates" model in program MARK (White and Burnham 1999) to estimate survival rates. This is a parametric model that assumes the survival events can be described using the binomial distribution. This contrasts with the Kaplan Meir method used with many caribou studies (Fancy et al. 1994, McLoughlin et al 2003) that estimates survival as one minus the proportion of vulnerable animal that died for a given sampling period. Previous analyses (Boulanger 2003) suggest that the MARK known fate model produce similar estimates to the Kaplan-Meir (Pollock et al. 1989) method of survival rate estimation. However, the advantage of the binomial model is that survival rates can be described as a function of individual and group covariates allowing testing of factors that influence survival. In addition, use of the binomial model allowed the pooling of seasonal survival events that increased sample sizes of collars for estimates.

A secondary objective of the analysis is to determine if there are seasonal differences or temporal trends in survival rates and whether these difference are universal across four herds considered in the analysis

1. Methods

1.1. Data screening

We divided the radio-telemetry data were individuals assumed to be alive (from changing locations) and those assumed to be dead (either stationary conseqcuitive locations or confirmed deaths from finding a dead caribou). To estimate time of death, the last location in which the caribou was moving was used as the time of death. This grouped death dates into weekly periods given that the duration between fixes was 5 to 7 days for most of the study.

Data was then compiled to a "live-dead" x-matrix format for survival rate estimation. Some caribou had their collars removed while the caribou was still alive so that the fate of the caribou was unknown. These caribou were included in the data set with the records being right-censored to denote that the caribou was alive upon release (Pollock et al. 1989).

1.2. Survival rate analyses

Program MARK can accommodate sessions of varying lengths and therefore each year of the analysis was divided up into calving, post-calving and summer (June to August), fall and rut (September to October), winter (December to April) and spring migration (May). This allowed testing of whether survival rates were similar between seasons of the year. This similarity of survival rates for each season and herd was also tested. In addition, models that assumed linear trends in survival rates were considered to test for negative or positive trends in survival over time.

One issue with the analyses was that the Qamanirjuaq and Bathurst herds were monitored from 1993 to 2003 and 1996 to 2003 whereas the Lorillard and Wager Bay were only monitored from 2000 to 2003. Given this, analysis of trends of overall survival rates was conducted using only the Qamanirjuaq and Bathurst herds given the similar periods of monitoring. An additional analysis that using only data from 2000-3 was used to compare survival rates for the Qamanirjuaq Bathurst, Lorillard, and Wager Bay herds

Models were evaluated using the sample-size-corrected Akaike Information Criterion (AICc) index of model fit. The model with the lowest AICc score was considered the most parsimonious, thus optimizing the tradeoff between bias and precision (Burnham and Anderson 1998). The difference between any given model and the most supported (ΔAICc) was used to evaluate the relative fit of models when their AICc scores were close. In general, any model with an ΔAICc score of ≤ 2 was most supported by the data.

2. Results

For the Bathurst herd, 60 caribou were fitted with UHF collars transmitting locations through a satellite over the course of the study. Of these, 18 are still active, 22 are dead (1 grizzly, 3 shot, 3 wolf, 15 unknown cause of death), 5 were collared then eventually released, 12 collars failed (6 unknown cause, 6 premature drop-off), and 3 had unknown fates (which were right censored). For the 83 satellite collars in the other herds, 5 caribou died in the Wagar Bay herd (4 unknown, 1 wolf kill), 6 in the Lorillard herd (4 unknown, 1 hunter kill, 1 wolf kill), and 19 in the Qamanirjuaq herd (15 unknown,4 hunter kill) (Table 1).

Table 1: Descriptive statistics for collaring efforts

Herd	Total collared	Mortalities	Mean (std) collars on	Collar failure
Bathurst, NWT	60	22	13.24 (4.086)	6
Qamanirjuaq	36	19	7.11 (2.46)	2
Lorillard	25	5	9.5 (2.68)	4
Wager Bay	22	5	8.93 (3.6)	0

2.1. Analysis of Bathurst and Qamanirjuaq herd trends 1993-2003

AICc model selections results suggested that a model with constant survival properties was most supported by the data. A model that assumed herd-specific survival rates, and a model with linear yearly trends in survival were also partially supported as indicated by ΔAICc values of less than 2.

Table 2: AICc model selection results for Qamanirjuaq and Bathurst herds; 1993-2003

Model	AICc	Delta AICc	AICc Weights	K[1]	Deviance
constant	309.3	0.000	0.414	1	66.7
herd	311.0	1.653	0.181	2	66.4
linear trend	311.0	1.715	0.176	2	66.4
herd+linear trend	312.5	3.156	0.085	3	65.9
season	313.4	4.049	0.055	4	64.7
herd*linear trend	314.4	5.070	0.033	4	65.8
herd+season	315.1	5.765	0.023	5	64.4
season+linear trend	315.1	5.814	0.023	5	64.5
seasonXlinear trend	318.0	8.686	0.005	8	61.2
herd*season	318.1	8.799	0.005	8	61.3
time	356.7	47.358	0.000	44	22.4
herd*time	402.9	93.531	0.000	73	0.0

[1]The number of parameters in the model

Survival rate estimates for the most supported model that assumed survival rates were temporally constant and equal for herds was 0.805 (std= 0.027, CI=0.746 to 0.853). Herd-specific survival rates for the other supported model were 0.786 (std= 0.043, CI= 0.689 to 0.859) for the Qamanirjuaq herd and S= 0.819 (std= 0.034 CI= 0.74 to 0.878) for the Bathurst herd. Trends in estimates are best considered using model-averaged estimates given the relatively low support for a model that had herd-specific trends.

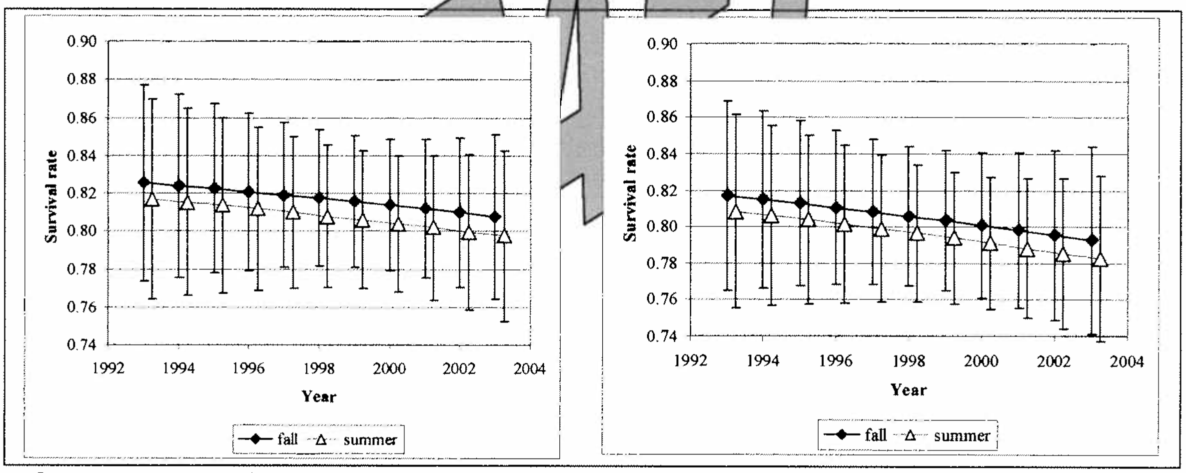

Figure 1: Model averaged estimates of survival rate trends for the Qamanirjuaq (left) and Bathurst herds (right) from MARK known fates analysis. Estimates are given for the fall and summer seasons. Survival rate estimates for winter and migration were inbetween the fall and summer estimates.

A slight negative trend in survival rates can be seen for both herds. However, the low precision of estimates limits the interpretation of trends.

2.2. Comparison of seasonal and herd survival rates for the four herds

Survival rates were compared for herds and seasons using each of the data sets. One issue with this analysis was the relatively short monitoring period for the Lorilard and Wager Bay herds (2000-03). This short time period therefore precluded models of temporal trend in survival since reliable trend information probably could not be inferred from 3 years of data. Instead, the analysis focused on season and herd-specific analyses.

AICc results suggested that a model that pooled data for the longer term data sets (Qamanirjuaq and Bathurst herds) and shorter term data sets (Lorillard and Wager Bay herds) was most supported suggesting that there may be a difference in survival rates caused by the differences in monitoring periods or potentially different survival rates between these groups of herds. A model with constant survival rates for all herds and season specific estimates was also supported (Table 3).

Table 3: AIC model selection results for comparison of 4 herds

Survival model	AICc	Delta AICc	AICc Weights	K	Deviance
BH QM and LR WB	410.99	0.00	0.38	2	102.44
constant	411.40	0.41	0.31	1	104.86
season	412.40	1.41	0.19	4	99.83
herd	414.09	3.10	0.08	4	101.52
herd+season	415.04	4.05	0.05	7	96.40

[1]This model pooled survival rates for Bathurst/Qamanirjuaq and Lorillard/Wagar Bay herds

Estimates of seasonal survival rates suggested that the lowest survival rates were for the migration season whereas the highest survival rates were for the fall (Table 4). These survival rates were averaged across herds considered in the analysis. Herd-specific survival rates suggested the the Lorillard and Wager Bay herds had higher survival rates than the Qamanirjuaq and Bathurst herds.

Table 4: Survival rate estimates for seasons and herds

Parameter	Time period	Estimate	SE	Confidence Interval	
Season					
migration		0.713	0.091	0.509	0.856
summer		0.806	0.048	0.694	0.883
fall		0.903	0.038	0.800	0.956
winter		0.823	0.031	0.752	0.876
Herds					
Lorillard	2000-03	0.901	0.042	0.784	0.958
Wager Bay	2000-03	0.844	0.058	0.694	0.928
Qamanirjuaq	1993-2003	0.786	0.043	0.689	0.859
Bathurst, NWT	1993-2003	0.819	0.035	0.741	0.878

One potential issue was the effect of time period of monitoring on survival rates. Therefore, the analysis was run only for data collected between 2000-2003 to see if survival rates of the Bathurst and Qamanirjuaq herds changed. Survival rates for most herds were relatively similar with the exception of the Qamanirjuaq herd that displayed a reduced survival rate of 0.669 (SE=0.078, CI=0.51 to 0.80). This reduced rate could have been an artifact of the relatively low number of collars on caribou for this herd combined with the short time period of monitoring.

3. Discussion

3.1. Assumptions of survival rate estimation

This analysis has several assumptions that should be considered when interpreting estimates.

1. *The collared caribou are a random and representative sample of all adult female caribou from the each herd.* The collared caribou should be distributed throughout the herd so that mortality factors affecting collared caribou represent the same mortality factors affecting all the adult females in the herd. This is especially critical in the case of this study where a small number of caribou were collared relative to the overall herd size. In this case, samples will be highly sensitive to any differences between collared caribou and uncollared adult females within the herd

2. *Collaring, and the presence of collars does not affect an individual collared caribou's survival.* The process of collaring should not affect survival and collared caribou should not be more vulnerable to predation or hunting. An analysis with the Bathurst data suggested that survival rate was not significantly different for caribou immediately after collaring suggesting that the effect of capture on survival was minimal. All the caribou were collared using the same method: brief chase with a helicopter (standardized to 1 minute or less); capture with a net fired from a modified rifle and then blind-folded while the net is removed and the collar fitted. No tranquillizing drugs are used. The collars used in the Bathurst herd were Telionics ST3 from 1996-98 when we switched to St10s [*I am looking for collar weights*]

3. *It is assumed that the censoring of records due to radio failure or loss of signal is independent of fate.* Basically, it is assumed that collar failure or signal loss is due entirely to radio failure and not mortality of the caribou (Williams et al. 2002). Biases can results if caribou that died are censored since the mortality events would not be used in the estimation of survival.

4. *Survival and mortality events of collared caribou are independent.* It is assumed that the death or survival of one caribou does not affect the death or survival of another caribou. The general result of violation of this assumption is an underestimation of the variance of survival rates.

3.2. Robustness of analysis to low sample sizes of collared caribou

One issue with this analysis is that the number of caribou collared at any one time is very small relative to the actual number of caribou in each of the herds. In 1996 the Bathurst herd was estimated have 360 000 caribou of which about 60% would be adult females. [*Mitch to add herd sizes*] Given this, it could be argued that any mortality event has relatively large impact on estimates. This was partially confronted by pooling data into larger seasonal time periods therefore increasing sample sizes of collars for any one point in time. In addition, using the binomial model allowed the pooling of seasonal survival events which increased sample sizes of collars for estimates. For example, the sample size of collars used for herd-specific survival estimates was the cumulative number of caribou collared as listed in Table 1. This differs from methods such as the Kaplan Meir that estimate survival rate as the product of monthly or yearly survival events (Pollock et al. 1989) which potentially cause estimates to be biased by low numbers of caribou during any one sampling period.

This analysis will still be sensitive to the assumption that collared caribou are representative of the overall caribou herd. Because sample sizes are small, any difference in survival rates between collared and non-collared caribou will potentially bias estimates compared to study designs where a larger proportion of the population is collared. In addition, the lower number of caribou collared affects the power of the AIC model selection to detect trends in the data, as evidenced by support for the constant survival models.

The survival rates of themselves do not identify a trend in herd size. Other vital rates (calf survival, pregnancy rates) would also be necessary additional input to a stochastic model. However, we do have independently determined estimate of the trend in herd size for at least the Bathurst herd based on photographic counts of caribou on the calving grounds. Between 1986 and 2003, the Bathurst herd has declined by an average annual rate of 5%.

The survival rates are similar to those estimated from radio-telemetry in other large herds of caribou seasonally migrating between the tundra and taiga. In the George River herd in Quebec and Labrador, survival rates for adult females were lower in summer than winter and decreased during the 1980s during a period when the herd was starting to decline in size (Hearn *et al.* 1990). In 1984-85, survival as 0.895-1.00 (95% CI) compared to 0.846-0.971 in 1986-87. Annual survival of Porcupine caribou herd adult females was about 84% between 1982 and 1988 (Fancy et al. 1994, Walsh et al. 1995) during a period when the herd was increasing in size. However, estimates of adult female survival are not available after 1989 when the herd started to decrease. In other Alaska herds, for example the Nelchina, annual survival for radio-collared adult cows was 82% (1999-2000) during a period when the herd was declining (ADFG 2001). In the Western Arctic herd, survival for adult females during the period when the herd was increasing (1984-1990), annual survival averaged 87% compared to 85% when the herd was stable to slowly declining 1990-2000.

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