



DEMOGRAPHY AND POPULATION VIABILITY OF POLAR BEARS IN
THE GULF OF BOOTHIA, NUNAVUT

Mitchell K. Taylor¹
Jeff Laake²
Philip D. McLoughlin³
H. Dean Cluff⁴
François Messier³

¹Wildlife Research Section, Department of the Environment, Government of Nunavut,
P.O. Box 209, Igloolik, NU X0A 0L0, Canada

²National Marine Mammal Laboratory, Alaska Fisheries Science Center,
National Marine Fisheries Service, Seattle, WA 98115, USA

³Department of Biology, University of Saskatchewan, 112 Science Place,
Saskatoon, SK S7N 5E2, Canada

⁴Department of Resources, Wildlife, and Economic Development, Government of the
Northwest Territories, Yellowknife, NT X1A 2P9, Canada

2006

Final Wildlife Report, No. 8

Taylor, M.K., J.L. Laake, P.D. McLoughlin, H.D. Cluff, and F. Messier. 2006. Demography and population viability of polar bears in the Gulf of Boothia, Nunavut. Government of Nunavut, Department of Environment, Final Wildlife Report: 8, Iqaluit, 29 pp.

Abstract: We estimated demographic parameters and harvest risks for a population of polar bears (*Ursus maritimus*) inhabiting the Gulf of Boothia, Nunavut, from 1976 to 2000. We constructed estimates of survival and abundance from capture-recapture and harvest recovery data (630 marks-at-risk) using a Burnham Cormack-Jolly-Seber model formulation implemented in program MARK. Total abundance in the last three years of study averaged 1528 ± 285 (SE) bears. Model selection based on ΔQAIC_c suggested survival rates did not require stratification by sex. We estimated total annual survival as 0.817 ± 0.201 for cubs (age 0), 0.875 ± 0.085 for subadults (ages 1–4), and 0.935 ± 0.040 for adults (ages 5+). Mean size of newborn litters was 1.648 ± 0.098 cubs. The proportion of available females (i.e., unencumbered or possessed 2-year-old cubs in the year previous) that subsequently had litters at time of census was 0.19 ± 0.18 for age 5, 0.47 ± 0.17 for age 6, and 0.965 ± 0.30 for ages 7+. We incorporated demographic parameters and their variances into a harvest risk analysis designed to consider demographic, process, and sampling uncertainty in generating likelihoods of persistence (i.e., a stochastic, harvested Population Viability Analysis [PVA]). Our results suggest that past harvest in the Gulf of Boothia has been below the maximum sustainable yield and the population is currently growing ($\delta = 1.046 \pm 0.020$). Our simulations suggest that a legislated increase in harvest rate to 74 bears/year will likely be sustainable.

Key Words: demography, mark-recapture, polar bear, Population Viability Analysis (PVA), program MARK, harvest

Nomenclature: Wilson & Reeder, 1993

Introduction

Polar bears (*Ursus maritimus*) have recently gained attention as a species vulnerable to pollution (Born, Renzoni & Dietz, 1991; Norstrom & Muir, 1994; Bernhoft, Wiig & Skaare, 1996; Durner, Amstrup & McDonald 2001; Wolkers *et al.*, 2004) and habitat change in response to global warming (Derocher, Lunn & Stirling, 2004). While we do not disagree that risks of these impacts to polar bears are of potential, long-term significance, it is clear that the most important human impact to the species is currently direct, human-caused mortality in the form of hunting. All historical declines in polar bear populations in North America can be attributed to unsustainable harvesting (e.g., Beaufort Sea and Chukchi [Amstrup, Stirling & Lentfer, 1986]; Western Hudson Bay [Derocher & Stirling, 1995]; Viscount-Melville Sound [Taylor *et al.*, 2002]; M'Clintock Channel [Taylor *et al.*, 2006]), and where data suggest that climate change is currently impacting survival rates (i.e., Western Hudson Bay), the observed population decline may likely be reversed through a reduction in harvest (Minutes of the 14th Working Group Meeting of the IUCN/SSC Polar Bear Specialist Group, June 20–24, 2005, Seattle, WA). Since the hunting of polar bears is of major cultural and economic importance to many northern residents (Freeman & Wenzel, 2006), we believe human-caused mortality will continue to play the major role in determining trends of polar bear populations.

To avoid hunting unsustainably, but yet maximize offtake, the general approach has been to develop deterministic models of abundance and yield. If some individuals are harvested from a population, survival and reproduction of remaining individuals are expected to increase to compensate for the losses. If the rate of harvest is excessive, the

population will be unable to maintain its numbers. If the rate of harvest is too low the population will increase until density-dependent reductions in birth, death, or both cause the population to stabilize at a higher number. From a deterministic perspective there is only one rate of harvest that will stabilize a population at its current number and be sustainable indefinitely. Determining harvests that are sustainable depends upon a number of factors, including abundance, natural rates of birth and death, and the sex and age composition of the harvest (Caughley & Sinclair, 1994). Unfortunately, since population size and vital rates are almost always obtained with some degree of error, either through sampling error or observations of process (e.g., environmental) variation, deterministic attempts to calculate sustainable yields are only rarely of value for managing real populations.

Rather than relying on deterministic models to establish sustainable yields, an alternative approach may be to manage for harvests that provide for some reasonable likelihood of population persistence some time into the future. Models of probability of persistence, such as stochastic Population Viability Analysis (PVA [review in White, 2000]), are ideal for incorporating uncertainty of input parameters into harvest models. When information is uncertain, theoretically any harvest level poses some risk to a population. PVA has the flexibility to provide managers and stakeholders with harvest compositions that are sustainable with an associated probability, but also consequences should a harvest later be deemed too severe (e.g., required length of moratorium to restore the population [Taylor *et al.*, 2002]).

We used mark-recapture data collected from 1976 to 2000 to estimate demographic rates and their variances for polar bears inhabiting the Gulf of Boothia, Nunavut (Figure 1), and harvest risks for the population at estimated size. Our demographic analysis included a

detailed assessment of age- and sex-specific survival and recruitment from 630 marked polar bears, using information contained within the standing age distribution of captures and survival and abundance estimates from mark-recapture analysis. We incorporated demographic parameters and their variances into a harvest risk analysis designed to consider demographic, process (e.g., environmental), and sampling uncertainty in generating likelihoods of persistence (i.e., a stochastic, harvested PVA).

Methods

STUDY AREA

The geographic bounds of the Gulf of Boothia polar bear population (Figure 1) has also been previously evaluated using movements of marked and recaptured (or harvested) individuals (Taylor & Lee, 1995), DNA analysis (Paetkau *et al.*, 1999), and movements of radio-collared adult females (Taylor *et al.*, 2001a). Our study area in this paper corresponds to the Gulf of Boothia polar bear population identified in Taylor *et al.* (2001a).

CAPTURES, RECAPTURES, AND RECOVERIES

There have been three main capture programs in the Gulf of Boothia yielding data for use in this study (Table I). The first effort (1976–1978) was part of a general arctic polar bear study conducted in the mid-1970's (Schweinsburg, Furnell & Miller, 1981; Schweinsburg, Lee & Latour, 1982; Furnell & Schweinsburg, 1984). For a brief period from 1986 to 1987 a limited number of polar bears ($n = 5$) were captured along coastal

areas in the study area (Table I). The most recent capture program was staged from 1994–2000, whereupon capture effort was directed evenly across the entire study area, with every bear encountered captured.

We chemically immobilized all bears and their dependent cubs for capture and marking according to procedures described by Stirling, Spencer & Andriashek (1989), following Animal Care Protocol No. 950005 of the University of Saskatchewan and under guidance of the Canadian Council on Animal Care. Bears captured from 1976 to 1987 were primarily immobilized with Sernylan (Furnell & Schweinsburg, 1984); bears captured in later years were immobilized with Telazol (Stirling, Spencer & Andriashek, 1989). Upon initial capture, we assigned a unique identification number to each bear and marked the animals accordingly using a plastic ear tag and permanent lip tattoo. We also marked each bear with a wax crayon on the fur to ensure that they were not captured more than once per year. We considered a bear's age as 'known' if the bear was captured as a cub-of-the-year (cub) or yearling, or its age was estimated by counting annular rings of an extracted vestigial premolar (Calvert & Ramsay, 1998). The sex, age, family status, and location of all polar bears killed by hunters, killed as problem bears, or found dead from any cause were recorded.

SURVIVAL AND ABUNDANCE

Estimates of survival and abundance were constructed from analysis of capture-recapture data using the Burnham Cormack-Jolly-Seber (CJS) model formulation implemented in program MARK (White & Burnham, 1999). The Burnham model also

incorporates harvest recoveries of tagged animals into a CJS model framework for capture-recapture data. The CJS likelihood for capture-recapture data is conditioned on initial capture events (i.e., the initial capture is treated as a release). The likelihood is based solely on recapture events of marked (i.e., previously caught) animals, and is defined by user-specified models for survival (S) and recapture probabilities (p) that may be expressed as functions of covariates such as sex, age, and time. The Burnham model extends the CJS model to include a model for reporting probabilities (r) that may also include covariates (i.e., the probability that a dead bear is reported [recovered] in a given year). Here we fixed the fidelity parameter, F , at 1.0; that is, we assumed no permanent emigration from the Gulf of Boothia population.

We used program MARK to analyze the Gulf of Boothia capture-recapture and harvest data collected from 1976 to 2000. Captures of bears from 1976 to 1987 were used as initial captures, but the population estimate was restricted to recaptures from 1994 to 2000 because captures were geographically non-random and non-uniform in the 1976–1987 capture programs. Recapture probability for 1976–1993 was set to zero.

For 1994–2000 data, we examined a series of models for capture probability that incorporated potential covariates. We expected that capture probability would vary by year because capture teams were different each year. Therefore, we considered a model that allowed capture probability to vary for each year and another model in which capture probability was the same for all years. Within the area searched in a given day, bears were located by visual observation and tracking from a helicopter. Successful location and eventual capture were likely to be affected by the number of bears in a group, their reaction to the helicopter, movement patterns, and fidelity to known areas of high use. Because

these factors were likely to vary for different ages and sexes, we categorized bears by sex and age (cubs [0 years], subadults [1–4 years], and adults [5+ years]), and considered models in which capture probability varied for these classes.

For survival and recovery probabilities, we also considered models that included covariates of sex, age, and year: males were expected to be harvested at a higher rate than females; we expected cubs to have lower survival than non-cubs; and annual differences in environmental conditions were likely to create temporal variation in survival.

We fitted a series of Burnham-CJS models using each capture probability model with each survival and recovery probability model (White & Burnham, 1999). We considered additive models with main effects (e.g., sex + year) and some limited interactions (e.g., age \times sex, year \times sex), but did not consider models with higher order interactions because there were too few data to support the additional complexity. We used Akaike's Information Criterion adjusted for sample size and over-dispersion ($QAIC_c$) as a guide for model selection (Burnham & Anderson, 2002). The data were likely to be over-dispersed (i.e., greater than binomial variation) because survival and capture events of family groups (e.g., females with cubs or yearlings) were not independent. We estimated the overdispersion coefficient, \hat{c} , based on the number of dependent cub captures relative to all captures (Taylor *et al.*, 2002). We ranked the model with the lowest $QAIC_c$ as best, and we used differences in $QAIC_c$ between the best-fitting model and every other model ($\Delta QAIC_c$) to identify other likely models. We followed Burnham & Anderson (2002) in selecting likely models, where $\Delta QAIC_c < 2.0$, 2.0–4.0, 4.0–7.0, and >7.0 can be said to exhibit strong, some, little, or no support, respectively. We also used program MARK to calculate the $\Delta QAIC_c$ weight for each candidate model; these weights sum to 1.0 and

represent the relative likelihood of each model (Burnham & Anderson, 2002). For models with $\Delta\text{QAIC}_c < 2.0$ we used model averaging, weighted according to ΔQAIC_c weights, to present parameter estimates (Burnham & Anderson, 2002).

Because the Burnham-CJS model likelihood did not include the probability distribution for unmarked animals, it was not likely to have the best precision for estimating abundance when survival and capture probabilities are not time dependent (i.e., constrained Jolly-Seber model). Thus, although we used the Burnham-CJS model formulation to estimate survival rates, we used the Jolly-Seber approach to estimate abundance. We used estimated re-capture probabilities (p) from marked animals in the CJS portion of the Burnham-CJS likelihood and used it as the capture probability for both previously marked and unmarked animals to estimate abundance (N) for each year i (Taylor *et al.*, 2002). We computed variance estimates for N_i using a Taylor series approximation that contains a component of variance for the number of marks observed and another for estimation of p (Thompson, 1992:165).

For cases where we stratified the population into k strata (e.g., sex), the total estimated population was the sum of stratum estimates and the variance estimator was extended to include covariances between estimated capture probabilities in the k strata (see Taylor *et al.*, 2002). We used a similar estimator to construct a variance estimate for the average population size over several years.

Our estimates of total survival derived from capture-recapture data, S , included losses from harvest. We were interested in estimating natural survival, S_N , to investigate potential impacts of alternative harvest strategies. As the total harvest of Gulf of Boothia polar bears was known, we used the approach presented in Taylor *et al.* (2002) to estimate

natural survival, S_N , from the average annual harvested population size and total survival (S), which assumes that harvest and natural mortality occur in two separate time periods. Here, we also used a Taylor series approximation for the variance of natural survival.

REPRODUCTION

We estimated reproductive parameters from the standing age distribution based on captures and recaptures from 1994 to 2000. Each individual or family group was recorded by age as a male, solitary female, female with a cub, female with 2 cubs, female with a yearling, female with 2 yearlings, female with a 2-year-old, or female with 2 2-year-old cubs. One female with 3 offspring was observed and was treated as an observation of a female with 2 offspring for analysis.

Our methods for estimating litter size, age-specific litter production rates (for females aged 4, 5, 6 and 7+ years), and sex ratio at birth from the standing age distribution are described in Taylor *et al.* (1987) and Taylor, Carley & Bunnell (1987), and available as the software package ‘Vital Rates’ (Taylor, Kuc & Abraham, 2000). Variances of summary reproductive parameters were determined from Monte Carlo simulations with 1,200 iterations available in program Vital Rates (Taylor, Kuc & Abraham, 2000).

POPULATION GROWTH RATE

The geometric mean, zero-harvest population growth rate (λ_N) and harvested (i.e., total) population growth rate (λ_H) at stable-age distribution were calculated according to Taylor *et al.* (1987, 2001b). We ran 1,200 Monte Carlo simulations to estimate the

geometric mean of λ using the life table-based (Caughley, 1977), Visual Basic program 'RISKMAN' (Taylor *et al.*, 2001*b*; see Eastridge & Clark, 2001, Howe, 2002, Taylor *et al.*, 2002, 2005, 2006). We described variability about λ by presenting the bootstrapped standard deviation (SD) of λ (Manly, 1997).

HARVEST RISK ANALYSIS

We also used RISKMAN to model risks of future declines in the Gulf of Boothia polar bear population given population parameters and uncertainty in data (i.e., population viability). RISKMAN can incorporate stochasticity into its population model at several levels, including sampling error in initial population size, variance about vital rates due to sample size and annual environmental variation (survival, reproduction, sex ratio), and demographic stochasticity. RISKMAN uses Monte Carlo techniques to generate a distribution of results (Manly, 1997), and then uses this distribution to estimate population size at a future time, population growth rate, and proportion of runs that result in a population decline set at a predetermined level by the user. We adopted the latter to estimate persistence probability.

Our approach to variance in this simulation was to pool sampling and environmental variances for survival and reproduction. We did this because: 1) our estimator of variances for reproductive parameters did not lend itself well to separating the sampling component of variance from environmental variance, and 2) we were interested in quantifying the risks of population decline including all sources of uncertainty in the data.

For each simulation, the frequency of occurrence of unacceptable outcomes (based on a threshold value of decline that was >20% of initial population size) was monitored and reported as the cumulative proportion of total runs over the threshold after 15 years. We chose to conduct model projections using these criteria because: 1) the population inventory cycle for this population is currently planned to be 15 years in duration, 2) we do not advocate using PVA over long time periods in view of potential significant changes to habitat regarding climate change in the Arctic, and 3) we felt most readers would appreciate a >20% decline in population size over 15 years as an unacceptable outcome. For comparison, we also present the probability of any decline over the period of simulation (in which case 1 minus this value represents the likelihood of population increase). Individual runs could recover from 'depletion', but not from a condition where all males or all females or both were lost. Required population parameter estimates and standard error inputs included: annual natural survival rate (stratified by age and sex as supported by the data), age of first reproduction, age-specific litter production rates for females available to have cubs (i.e., females with no cubs and females with 2-year-olds), litter size, the sex ratio of cubs, initial population size, and demographic distribution of the harvest.

The standing age distribution was female-biased due to long-term overharvest of males (Table 1). Because we wished to err on the side of caution, for all simulations we used the stable age distribution expected to be achieved by the population for a given harvest rate as the initial age/sex distribution (i.e., initializing the population at the stable age distribution produced more conservative outcomes compared to that of the existing standing age distribution). The harvest selectivity and vulnerability array was identified by comparing the standing age distribution of the historical harvest to the total mortality, stable

age distribution. Harvest was stratified by sex, age (cubs and yearlings, age 2–5, age 6–19, and age >20) and family status (alone, or with cubs and yearlings, or with 2-year-olds). We ran harvest simulations using natural survival rates, upon which incrementally increasing rates of harvest (i.e., human-caused mortality from all sources) were added (0–100 bears/year). We present our harvest risk analysis as the estimated probability of decline (any decline and >20%) from initial population size after 15 years vs. annual kill of bears. Simulations were time referenced to the last year of study (2000). The starting population size was the average of the 1998–2000 population estimates obtained from mark-recapture analysis. The RISKMAN manual and online help file (Taylor *et al.*, 2001b) provides a comprehensive description of the model structure and approach to variance estimation.

Results

CAPTURES, RECAPTURES, AND RECOVERIES

We captured 630 individual polar bears in the study area from 1976–2000 (Table I). Recapture rates were approximately equal between the sexes; however, as expected males were more likely to be recovered (i.e., harvested) than females (Table I).

SURVIVAL AND ABUNDANCE

Our best-fitting model specified temporal variation in survival probability for cubs, subadults, and adults, temporal variation in recovery probabilities for cubs and non-cubs

(pooled subadults and adults), and modelled recapture probability as a constant (Table II). There was only slight support for a sex effect in survival/recovery probabilities (Table II), which precluded inclusion of sex effects when estimating final parameters. One additional model was sufficiently close to the best-fitting model to be included in a model average (Table II): a model identical to the best-fitting model but with only cub and non-cub specifications for survival rates. Model averaged, annual mean total survival rates (S) were 0.817 ± 0.201 (SE) for cubs, 0.875 ± 0.085 for subadults, and 0.935 ± 0.040 for adults. Model averaged, annual mean natural survival rates (S_N) were 0.817 ± 0.201 for cubs, 0.907 ± 0.084 for subadults, and 0.959 ± 0.039 for adults. Recovery probabilities were 0.162 ± 0.263 for subadults and 0.385 ± 0.214 for adults. Recapture probability for all marked bears was 0.113 ± 0.019 .

Annual estimates of total abundance ranged from 1393 ± 261 (SE) in 1998 to 1648 ± 305 in 2000 with a mean of 1528 bears ± 285 , of which 835 ± 165 were female and 693 ± 141 were male.

REPRODUCTION

Summary reproductive parameters for the Gulf of Boothia population based on analysis of the standing age distribution for captures from 1994–2000 included means for litter size of cubs (1.648 ± 0.098 [SE]), female litter production rates for ages 4 (0.00 ± 0.00), 5 (0.19 ± 0.18), 6 (0.47 ± 0.17), and 7+ (0.965 ± 0.30), and the proportion of newborn males in litters (0.46 ± 0.09).

POPULATION GROWTH RATE

We calculated the stable-age, zero-harvest population growth rate, δ_N , as 1.064 ± 0.020 . The harvest between 1974 and 2000 was selective for male bears (Table I) and averaged 38.4 bears/year (SE = 4.2) for the previous 5 years leading up to the end of the period of study. The harvested population growth rate, δ_H , was 1.046 ± 0.020 .

HARVEST RISK ANALYSIS

Our results suggest the past harvest of Gulf of Boothia polar bears has been sustainable and that current proposed increases in the harvest quota (74 bears/year) will likely be sustainable. For the harvest period 2000–2015, assuming all sources of removals in the population sum to 74 bears/year, the population can be expected to persist at a stable population size ($\lambda = 1.018 \pm 0.027$ [SE]). It is only at higher rates of harvest (e.g., 80–100 bears/year) that likelihoods of unacceptable outcomes increases to levels that may be cause for concern (Figure 2).

Discussion

Our results suggest that adult male and female polar bears should be modeled with the same rate of survival. We did not expect this result, especially considering the male-bias in the harvest (Table I). Previous research on adjacent populations of polar bears (using the same or similar methods as in this study) detected sex effects in survival of adults (Taylor *et al.*, 2002, 2005, 2006). However, polar bears in the Gulf of Boothia have

not, at least during the period of study, been harvested to the same extent as adjacent populations. The population of polar bears in the Gulf of Boothia appears to have grown steadily under a harvest regimen of approximately 40 bears/year. Despite sex-bias in the harvest, the annual harvest rate (<2.5%) may have been too low to influence marked differences in overall survival rates among sexes.

Survival rates for male bears are generally lower than that observed for females, and any effect of averaging these survival rates between the sexes would likely serve to lower the mean survival rate for females. Hence, any bias in pooling male-female survival rates should be regarded as resulting in a lower mean female survival rate. Since for polygynous species like polar bears, whereby population growth rate is driven by female survival and reproduction (as long as there are enough males to mate available females; Caughley 1977), we expected that a pooled survival rate for adult females and males would result in a comparably low population growth rate, particularly when we consider unharvested (i.e., natural) rates of survival. However, our observed unharvested finite rate of increase ($\delta_N = 1.064$)—the summary parameter combining data on age- and sex-specific natural survival and reproduction—was very high compared to estimates for adjacent bear populations, and is probably close to the maximum observed for polar bears. For example, our estimate of δ_N was higher than that estimated for polar bears in Baffin Bay ($\delta_N = 1.055$; Taylor *et al.*, 2005) to the east and Kane Basin to the northeast ($\delta_N = 1.009$; M.K. Taylor, unpublished data), and Lancaster Sound ($\delta_N = 1.024$) and Norwegian Bay ($\delta_N = 1.006$) to the north (M.K. Taylor, unpublished data). The unharvested population growth rate for bears in the Gulf of Boothia was also higher than for polar bears in the Viscount-Melville Sound ($\delta_N =$

1.059; Taylor *et al.*, 2002) and M'Clintock Channel ($\delta_N = 1.031$; Taylor *et al.*, 2006), two populations thought to be reduced substantially below carrying capacity by years of overharvest. It is difficult to compare parameters presented in this study with those of additional polar bear populations because of different methods and different terminology; however, our estimates of reproductive parameters (e.g., litter size and timing of first reproduction) fall within the general range of published values (review in Taylor & Stirling, 2002).

Our results suggest that polar bears in the Gulf of Boothia, although likely reduced from historical numbers, are now growing at a rate that is below the maximum sustainable rate for the population. To this finding local Inuit hunters emphatically agree. Of particular importance, we believe the population is capable of absorbing the higher harvest of 74 bears/year (compared to the historical mean of approximately 40 bears/year) currently legislated for this population by the Government of Nunavut. Nonetheless, we must be cautious when information is uncertain, since higher harvest rates will always constitute an increased risk to the population. The harvest of 74 bears/year should (and is in fact regulated) to include all sources of human-caused mortality for the population. A harvest of 80 bears per year will likely approach the maximum sustainable for the population; hence, further population growth is certain to be reduced, if not stopped entirely.

Our risk assessment is an expression of the uncertainty in the demographic process and parameters. We suggest that our results are more realistic than a deterministic maximum sustained yield estimate that does not consider the uncertainty of the underlying information. Both managers and stakeholders must recognize that scientific information rarely provides exact and absolutely correct harvest rate or harvest quota values.

Researchers have a responsibility to quantify the uncertainty of their measurements and the uncertainty of their management recommendations. Reporting scientific results in this manner identifies where local and traditional knowledge may be used to guide final management decisions.

Acknowledgements

Support for this work was provided by the Government of Nunavut, the Government of the Northwest Territories, the Nunavut Wildlife Management Board, the Polar Continental Shelf Project, the University of Saskatchewan, and the U. S. National Marine Mammal Laboratory. We thank the hunters of Cambridge Bay, Gjoa Haven, Taloyoak, and the Kitikmeot Hunters and Trappers Association who contributed their local and traditional knowledge of polar bears, and participated in the work and harvest program. We extend a special thanks to Pat Lyall for the use of his cabin at Fort Ross. S. Atkinson, P. Krizan, and S. Polischuk assisted with field work. M. Kuc was the primary programmer for RISKMAN and contributed to the development of its algorithms.

Literature Cited

- Amstrup, S. C., I. Stirling & J. Lentfer, 1986. Size and trends of Alaskan polar bear populations. *Wildlife Society Bulletin*, 14: 251–254.
- Bernhoft, A., Ø. Wiig & J. U. Skaare, 1996. Organochlorines in polar bears (*Ursus maritimus*) in Svalbard. *Environmental Pollution*, 95: 159–175.
- Born, E. W., A. D. Renzoni & R. Dietz, 1991. Total mercury in hair of polar bears (*Ursus maritimus*) from Greenland and Svalbard. *Polar Research*, 9: 113–120.
- Burnham, K. P., & D. R. Anderson, 2002. Model selection and multimodel inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York.
- Calvert, W. & M. A. Ramsay, 1998. Evaluation of age determination of polar bears by counts of cementum growth layer groups. *Ursus*, 10: 449–453.
- Caughley, G., 1977. *Analysis of Vertebrate Populations*. John Wiley & Sons, New York, New York.
- Caughley, G. & A.R.E. Sinclair, 1994. *Wildlife Ecology and Management*. Blackwell Scientific Publications, Cambridge, Massachusetts.
- Derocher, A. E. & I. Stirling, 1995. Mark-recapture estimation of population size and survival rates for polar bears in western Hudson Bay. *Journal of Wildlife Management*, 59: 215–221.
- Derocher, A. E., N. J. Lunn & I. Stirling, 2004. Polar bears in a warming climate. *Integrative & Comparative Biology*, 44: 163–176.

Formatted: French (France)

- Durner, G.M., S.C. Amstrup & T.L. McDonald, 2001. Estimating the impacts of oil spills on polar bears. *Arctic Research of the United States*, 14: 33–37.
- Eastridge, R. & J. D. Clark, 2001. Evaluation of 2 soft-release techniques to reintroduce black bears. *Wildlife Society Bulletin*, 29: 1163–1174.
- Freeman, M. M. R. & G. Wenzel, 2006. The nature and significance of polar bear conservation hunting in the Canadian Arctic. *Arctic*, 59: 21-30.
- Furnell, D. J. & R. E. Schweinsburg, 1984. Population dynamics of central Arctic polar bears. *Journal of Wildlife Management*, 48: 722–728.
- Howe, E. J., 2002. Population viability analysis for black bear (*Ursus americanus*) on the Bruce Peninsula, Ontario, Canada. M.Sc. thesis, Trent University, Peterborough, Ontario.
- Manly, B. F. J., 1997. *Randomization, Bootstrap and Monte Carlo Methods in Biology*. Chapman & Hall, London.
- Norstrom, R. J. & D. C. G. Muir, 1994. Chlorinated hydrocarbon contaminants in arctic marine mammals. *Science of the Total Environment*, 154: 107–128.
- Paetkau, D., S. C. Amstrup, E. W. Born, W. Calvert, A. E. Derocher, G. W. Garner, F. Messier, I. Stirling, M. K. Taylor, Ø. Wiig & C. Strobeck, 1999. Genetic structure of the world's polar bear populations. *Molecular Ecology*, 8: 1571–1584.
- Schweinsburg, R. E., D. J. Furnell & S. J. Miller, 1981. Abundance, distribution, and population structure of polar bears in the lower Central Arctic Islands. *Wildlife Service Completion Report Number 2*. Government of the Northwest Territories, Yellowknife, Northwest Territories, Canada.

- Schweinsburg, R. E., L. J. Lee & P. B. Latour, 1982. Distribution, movement, and abundance of polar bears in Lancaster Sound, Northwest Territories. *Arctic*, 35: 159–169.
- Stirling, I., C. Spencer & D. Andriashek, 1989. Immobilization of polar bears (*Ursus maritimus*) with Telazol in the Canadian Arctic. *Journal of Wildlife Diseases*, 25: 159–168.
- Taylor, M. K. & L. J. Lee. 1995. Distribution and abundance of Canadian polar bear populations: a management perspective. *Arctic*, 48: 147–154.
- Taylor, M. K. & I. Stirling. 2002. COSEWIC assessment and update status report on the polar bear, *Ursus maritimus*, in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa, Ontario.
- Taylor, M. K., F. Bunnell, D. DeMaster, R. Schweinsburg, & J. Smith, 1987. ANURSUS: A population analysis system for polar bears (*Ursus maritimus*). *International Conference on Bear Research & Management*, 7: 117–125.
- Taylor, M. K., J. S. Carley & F. L. Bunnell. 1987. Correct and incorrect use of recruitment rates for marine mammals. *Marine Mammal Science*, 3: 171–178.
- Taylor, M. K., M. Kuc & D. Abraham, 2000. Vital Rates: Population parameter analysis program for species with three year reproductive schedules. Government of Nunavut, Iqaluit, Nunavut, Canada.
- Taylor, M. K., S. Akeagok, D. Andriashek, W. Barbour, E. W. Born, W. Calvert, S. Ferguson, J. Laake, A. Rosing-Asvid, I. Stirling & F. Messier, 2001a. Delineating Canadian and Greenland polar bear (*Ursus maritimus*) populations by cluster analysis of movements. *Canadian Journal of Zoology*, 79: 690–709.

- Taylor, M. K., M. Kuk., M. Obbard, H. D. Cluff & B. Pond, 2001*b*. RISKMAN: risk analysis for harvested populations of age structured, birth-pulse species. Software manual. Ontario Ministry of Natural Resources, Peterborough, Ontario, Canada. Also available from <http://www.nrdpfc.ca/riskman/riskman.htm>.
- Taylor, M. K., J. Laake, H. D. Cluff, M. Ramsay & F. Messier, 2002. Managing the risk from hunting for the Viscount-Melville Sound polar bear population. *Ursus*, 13: 185–202.
- Taylor, M. K., J. Laake, P. D. McLoughlin, E. W. Born, H. D. Cluff, S. H. Ferguson, A. Rosing-Asvid, R. Schweinsburg & F. Messier, 2005. Demography and viability of a hunted population of polar bears. *Arctic*, 58: 203–215.
- Taylor, M. K., J. Laake, P. D. McLoughlin, H. D. Cluff & F. Messier, 2006. Demographic parameters and harvest-explicit population viability analysis for polar bears in M'Clintock Channel, Nunavut. *Journal of Wildlife Management*, in press.
- Thompson, S. K., 1992. *Sampling*. John Wiley & Sons, New York, New York.
- White, G. C., 2000. Population viability analysis: Data requirements and essential analyses. Pages 288–331 in L. Boitani & T. K. Fullers (eds.). *Research Techniques in Animal Ecology: Controversies and Consequences*. Cambridge University Press, New York, New York.
- White, G. C. & K. P. Burnham, 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study Supplement*, 46: 120–138.
- Wilson, D. E., & D. M. Reeder (eds), 1993. *Mammal Species of the World*. Smithsonian Institution Press, Washington, D.C.

Wolkers, H., B. Van Bavel, A. E. Derocher, Ø. Wiig, K. M. Kovacs, C. Lydersen & G.

Lindström. 2004. Congener-specific accumulation and food chain transfer of polybrominated diphenyl ethers in two arctic food chains. *Environmental Science & Technology*, 38: 1667–1674.

TABLE I. Initial marks, percentage recoveries (i.e., harvested), and percentage recaptures of polar bears in the Gulf of Boothia, 1976–2000. Total percentage recaptured (at least once) and percentage recovered only use bears marked from 1976–1999 as bears marked in 2000 did not have a chance (prior to analysis) to be recaptured or recovered.

Sex	Year	Cub	Subadult	Adult	Total	% Recovered	% Recaptured
Females	1976	6	7	13	26	23.1%	0.0%
	1977	5	8	19	32	50.0%	0.0%
	1978	5		4	9	0.0%	0.0%
	1986	1		2	3	0.0%	0.0%
	1994		1	2	3	0.0%	33.3%
	1995	2	4	4	10	10.0%	10.0%
	1996			2	2	0.0%	0.0%
	1998	19	19	49	87	1.1%	18.4%
	1999	10	28	47	85	2.4%	9.4%
	2000	20	21	42	83		
	Total	68	88	184	340	10.1%	10.1%
Males	1976	5	7	12	24	50.0%	0.0%
	1977	3	9	21	33	18.2%	0.0%
	1978	1	2	9	12	41.7%	16.7%
	1986		1		1	0.0%	0.0%
	1987			1	1	100.0%	0.0%
	1994		1		1	0.0%	100.0%
	1995	2	1	3	6	0.0%	0.0%
	1996		1	1	2	50.0%	0.0%
	1998	15	17	36	68	8.8%	22.1%
	1999	10	28	30	68	0.0%	7.4%
	2000	18	20	36	74		
Total	54	87	149	290	14.7%	10.6%	

Table II. Models used to assess age, sex, and annual variation in survival/recovery and capture probabilities of polar bears inhabiting the Gulf of Boothia, Nunavut, 1976–2000. The best-fitting model has the lowest quasi-likelihood Akaike’s information criterion ($QAIC_c$), and all models are assessed as the difference between the candidate model to the best model (i.e., $\Delta QAIC_c$), where $\Delta QAIC_c$ of the best model is zero. Models included in a weighted-average model for final presentation of results (i.e., $\Delta QAIC_c < 2.0$) are indicated in bold. Our estimate of the overdispersion coefficient, \hat{c} , was 1.19.

Survival/recovery	Model ¹	Capture Probability			
		Constant	Year	Age	Age × sex
Constant	0	3.67	6.98	7.24	6.91
	1	4.53	8.04	7.03	6.74
	2	8.06	11.59	10.62	10.42
	3	8.14	11.67	10.66	10.43
	4	7.14	10.68	9.6	8.96
Year	0	0.66			
	1	0			
	2	3.65			
	3	3.86			
	4	3.03			
Year × Sex	0	3.59			
	1	3.13			
	2	7.2			
	3	7.26			
	4	5.14			

¹ Model coding:

Survival 0: cub, non-cub
Survival 1: cub, subadult, adult
Survival 2: cub, subadult, adult + additive sex effect for all ages
Survival 3: cub, subadult, adult + additive sex effect for non-cub
Survival 4: cub, subadult both sexes, adult males, adult females

Recovery 0: non-cub
Recovery 1: subadult, adult
Recovery 2: subadult, adult + additive sex effect
Recovery 3: same as 2
Recovery 4: subadult both sexes, adult males, adult females

Figure Legends

FIGURE 1. Location of the Gulf of Boothia (GB) polar bear population, Nunavut, 1976–2000. Boundaries are defined as in Taylor *et al.* (2001a).

FIGURE 2. Estimated probabilities of >20% decline from initial population size vs. annual kill for polar bears inhabiting the Gulf of Boothia, Nunavut, 2000–2015. The vertical dashed lined corresponds with the total removal rate currently legislated by the Government of Nunavut for this population (74 bears/year).

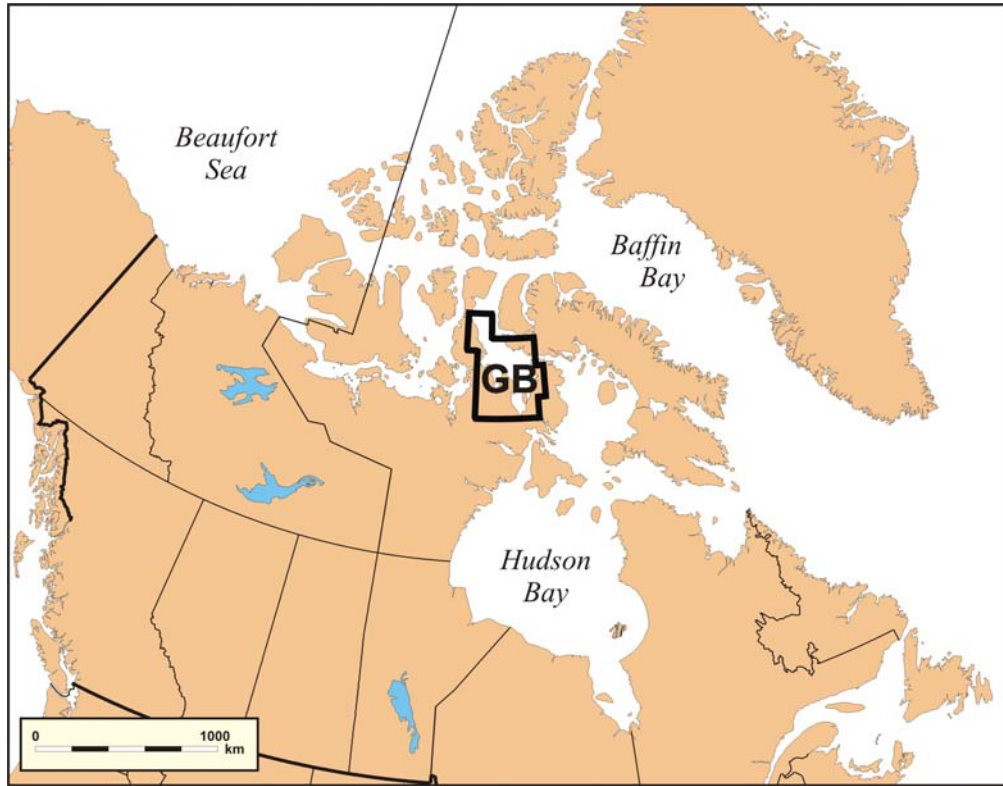


FIGURE 1

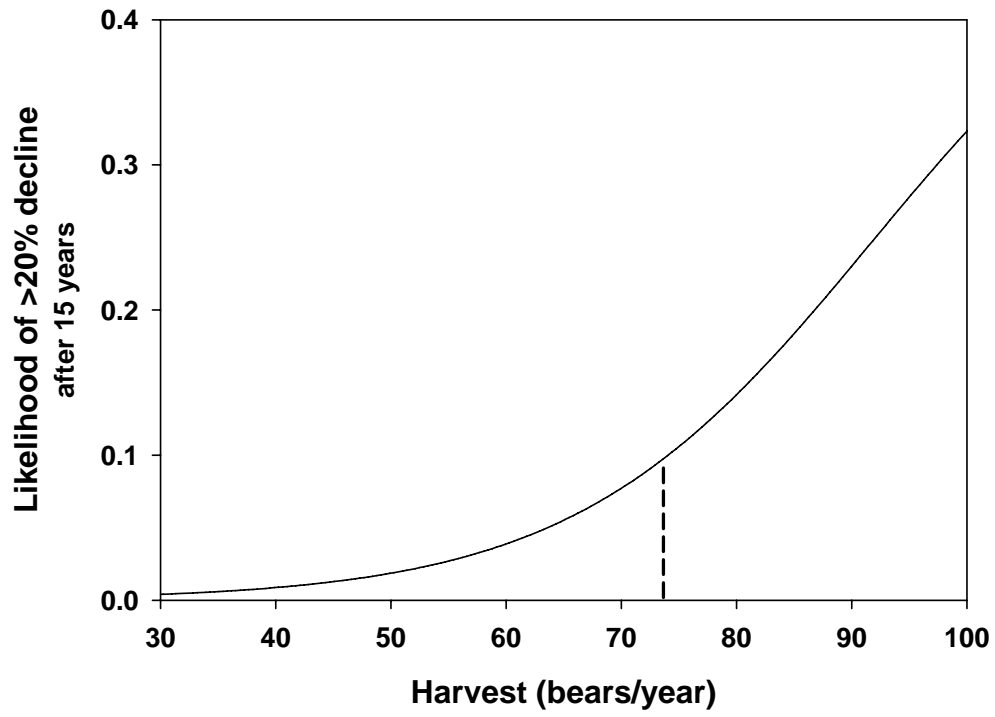


FIGURE 2