



# Southern and Northern Beaufort Sea Polar Bear Subpopulation Estimates under a Proposed Boundary Shift

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This work was completed in 2009 to inform management decisions and has not been updated to reflect additional information.

The contents of this paper are the sole responsibility of the authors.



## ABSTRACT

This report presents the results of an analysis, completed in 2009, to evaluate potential effects of moving the management boundary between the Southern Beaufort Sea (SB) and Northern Beaufort Sea (NB) polar bear sub-populations. We focus on estimated relative population sizes under the proposed boundary. The analysis was motivated by radiotelemetry data suggesting that the current boundary may not reflect the spatial use patterns of polar bears in the Eastern SB. In light of this data, the Inuvialuit of Canada requested information on the potential effects of shifting the population boundary. The potential benefits of a shift include allocating polar bears harvested for subsistence purposes to biologically meaningful subpopulations, based on the best available scientific information. We found that moving the boundary from its current location of approximately 125°W longitude, to the proposed location of approximately 133°W longitude, would decrease the estimated size of the SB population by approximately 311 polar bears, and increase the estimated size of the NB population by a similar amount. This finding was based on taking population models from previously published analyses and applying them to repartitioned versions of capture-recapture datasets used in those analyses. These analyses consider data through 2006, the final year in which capture-recapture sampling was systematically distributed throughout American and Canadian sectors of the SB sub-population. We believe this study provides a reasonable approximation of the proportional changes in subpopulation sizes that would occur under the proposed boundary shift – i.e., a shift of approximately 20% of the SB to the NB subpopulation. If the boundary shift is adopted by polar bear managers, it is reasonable to make short-term use of the estimated proportional changes in sub-population size for the purpose of evaluating sustainable harvest levels. However, because this work does not reflect more recently available data, we recommend that long-term management decisions, be based on comprehensive assessments that include new population viability models fitted to up to date capture-recapture data. This work was completed in 2009 to inform management decisions and has not been updated to reflect additional information.

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## INTRODUCTION

The current boundary between the Southern Beaufort Sea (SB) and Northern Beaufort Sea (NB) polar bear sub-populations lies at approximately 125°W longitude (Brower et al. 2002). With this current boundary, harvests that occur at Baillie Islands (an important polar bear hunting area at ~128° longitude) are assigned to the SB population. Radiotelemetry studies, however, suggest that approximately 90% of the bears harvested near the Baillie Islands are actually NB bears (Amstrup et al. 2005a). The proportional representation of NB vs. SB bears reduces to approximately 50:50 (NB:SB), west of the Baillie Islands, at ~133°W longitude, near the community of Tuktoyaktuk. Consequently, the Inuvialuit Game Council (IGC) and the Wildlife Management Advisory Committee (NWT) are considering moving the boundary between the SB and NB populations to Tuktoyaktuk (133°W). This would allow the harvest to be more accurately allocated between the two populations. The analysis described here was intended to inform the decision whether to: (1) retain the historic boundary at approximately 125°W longitude, or (2) move the boundary to 133°W.

Due to the need to inform management decisions in a timely manner, a complete re-analysis of existing capture-recapture data was impractical. Therefore, we performed an abbreviated analysis that focused on evaluating how population size estimates might change if the SB-NB boundary were shifted from 125°W to 133°W. We accomplished this by fitting capture-recapture models that were already built for previous NB and SB analyses (Regehr et al. 2006, Regehr et al. 2010, Stirling et al. 2011) to versions of the datasets from those analyses that were repartitioned to reflect the proposed boundary. This approach avoided the necessity of compiling new datasets, collecting new capture-recapture data, or building new models from scratch.

This report contains methods, results, and a brief interpretation of the abbreviated re-analysis of SB and NB polar bear data using the shifted boundary. The number of bears and number of capture events that were moved from the SB to the NB population under the

boundary change are provided, and existing capture-recapture models are refitted to re-estimate the size of the SB and NB populations. For comparison, estimates of population size and survival are presented under both the current and proposed boundaries.

## METHODS

The SB re-analysis was based on 2001-2006 capture data that were originally analyzed in Regehr et al. (2006). For the re-analysis, these data were modified slightly to include 30 updated age values for polar bears, derived from tooth growth ring readings that were not available in 2006. These updated age data are superior to the earlier age data used in Regehr et al. (2006), although this addition was not expected to have a major effect on the analysis. The models fitted here are nearly identical to those fitted in Regehr et al. (2006), differing only to include a sex effect in recapture probabilities that was reported in Appendix C of Regehr et al. (2006). This sex effect was motivated by the hypothesis that females with dependent young may avoid habitats preferred by male polar bears (Stirling et al. 1981). If this hypothesis is true, males and females could have different recapture probabilities, and the sex effect was designed to allow those probabilities to differ in our models. This modification should improve estimates of the effect of a boundary shift on the SB population, but prevents direct comparison of the current re-analysis with the results of Regehr et al. (2006). The Regehr et al. (2006) estimates are provided here as a baseline, but the effect of the boundary shift should be based upon comparison of the revised model outcomes for the original and proposed boundaries.

The NB re-analysis was based on 1971-2006 capture data and a suite of capture-recapture models identical to those analyzed in (Stirling et al. 2011). Unlike the SB data, which included slight updates to age information and the candidate model set, the NB analysis used the same data and models as in Stirling et al. (2011).

Prior to re-analysis, the SB and NB capture data were repartitioned to reflect the shifted boundary. Specifically, polar bear captures between 133°W and 125°W that were previously included in the SB population, were included in the NB population (Figure 1). This affected captures in 2003-2006, the only years in which polar bear captures were conducted in the Canadian portion of the SB population. Repartitioning the data had one of two effects. Some bears that had captures on both sides of the 125 boundary (included in

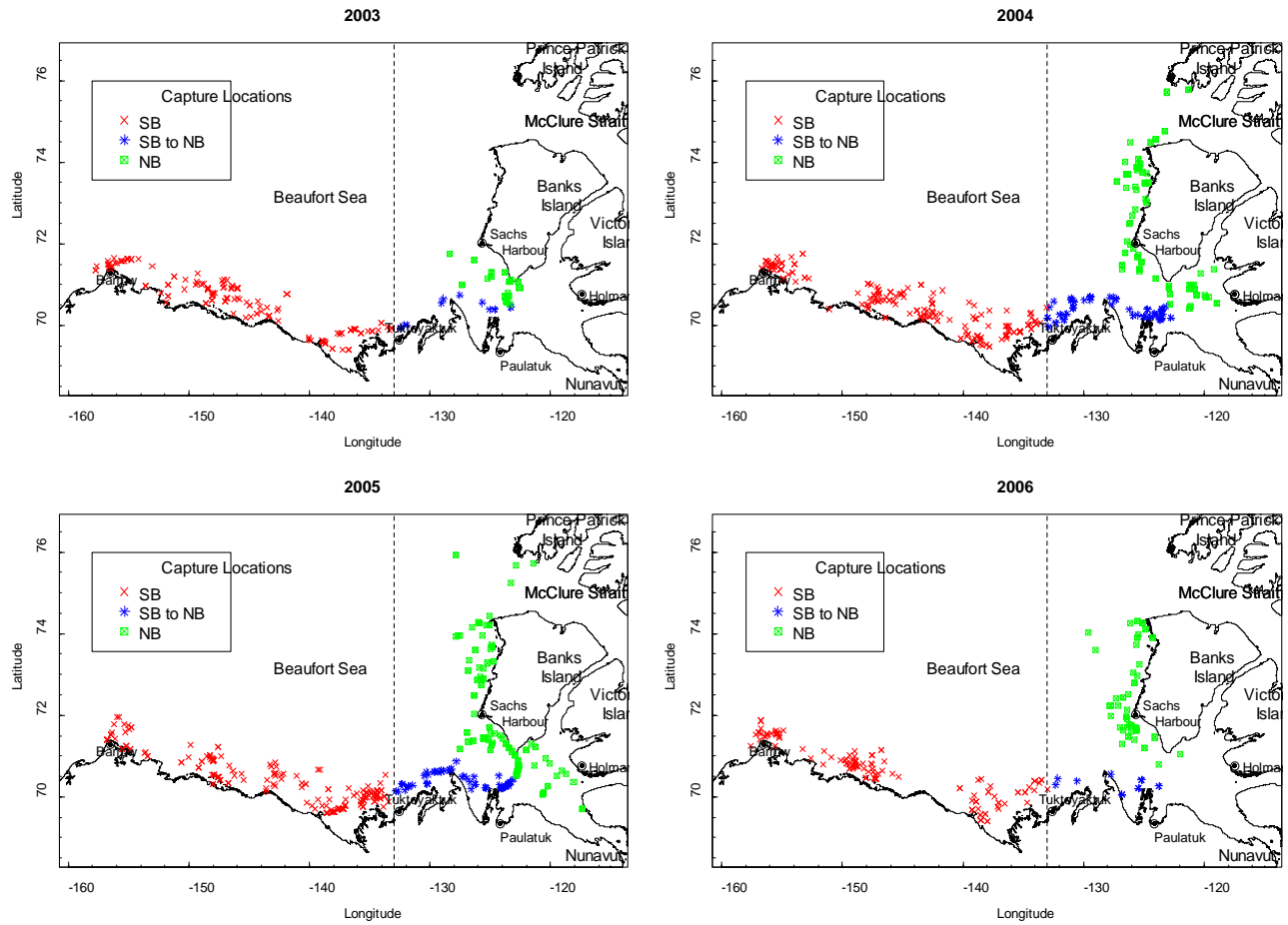


both SB and NB under the current boundary) and bears that had all captures occurring between 125 and 133 were moved to be entirely within the NB under the boundary change. Second, after partitioning bears that previously had all captures within the SB now have captures on both sides of the 133 boundary. Theoretically there could also be bears that remain in both SB and NB if they were captured west of 133 and east of 125 but these would be unaffected by the repartitioning of the data.

In these cases, the bear was considered a member of both the SB and NB populations in the repartitioned data. Details of the effects of repartitioning the data are described in the following paragraph. Throughout this report, a capture will refer to an occasion on which an individual bear was recorded as alive in a given location (e.g. the bear was immobilized from a helicopter for research purposes), and capture history will refer to the complete record of a bear's captures during the study period.

Based on the current boundary, the SB dataset (2001-2006) contained 1,099 captures of 843 individual bears while the entire NB dataset (1971-2006) contained 1,090 captures of 958 bears. From 2003-2006, 170 captures occurred in the region of the SB to the east of 133°W (Figure 1). These 170 captured pertained to 159 individual bears (i.e., some bears were captured multiple times). Of these 159 bears, 13 bears had other captures that occurred east of 125°W so were included in both the NB and SB under the current boundary and thus were removed from the SB and remain in the NB under the boundary change. Another 134 bears were only ever captured between 133°W and 125°W. Thus, under the boundary change, these 134 bears were deleted from the SB data set and added to the NB data set. Another 12 bears had captures that occurred west of 133°W. Thus, under the boundary change, these 12 bears remained in the SB dataset (although their captures east of 133°W were deleted) and were also added to the NB dataset. In summary, after the repartitioning, the entire SB dataset (2001-2006) contains 929 captures of 696 bears while the entire NB dataset (1971-2006) contains 1,260 captures of 1,104 bears. A yearly breakdown of captures from 2003 to 2006 can be found in Appendix C Table 1. It is worth noting that there was only one female bear that had captures west of 133 and east of 125 that remain in both datasets regardless of repartitioning.

After the SB and NB data were re-partitioned using the 133°W boundary, capture-recapture models were fitted to both the original and re-partitioned data. We used Cormack-Jolly-Seber (CJS) models (Lebreton et al. 1992, Amstrup et al. 2005b) fitted to the data with R-language software (R Core Development Team 2006); including the R package *mra* (T. McDonald, <http://cran.cnr.berkeley.edu/web/packages/mra/index.html>), an S-Plus script provided by Eric Regehr (USFWS), and other R scripts provided by Trent McDonald (WEST, Inc.). This software implemented the “general regression” approach to capture-recapture (Amstrup et al. 2005b, Chapter 9). CJS models condition on initial captures and estimate both survival ( $\phi$ ) and recapture probabilities ( $p$ ) using maximum likelihood theory. Estimates of  $p$  were used to derive population size using a Horvitz-Thompson equation (McDonald and Amstrup 2001). Estimates of  $\phi_j$  represent total apparent survival, the cumulative probability of being alive and on the study area between annual sampling occasion's  $j$  and  $j+1$ . We fit models that contained covariates quantifying physical and environmental factors that potentially influenced survival and capture probabilities. Model selection was performed using QAICc (Burnham and Anderson 2002) and model-averaged estimates computed across all models. For more details regarding the CJS modeling process the reader is referred to Regehr et al. (2006) and Stirling et al. (2011). Details of the covariates and candidate models used in the current re-analysis are provided in Appendices A, B and C.



**Figure 1.** Shifted boundary line and distribution of polar bear captures showing a total of 170 captures that moved from SB to NB over the years 2003-2006.

## RESULTS

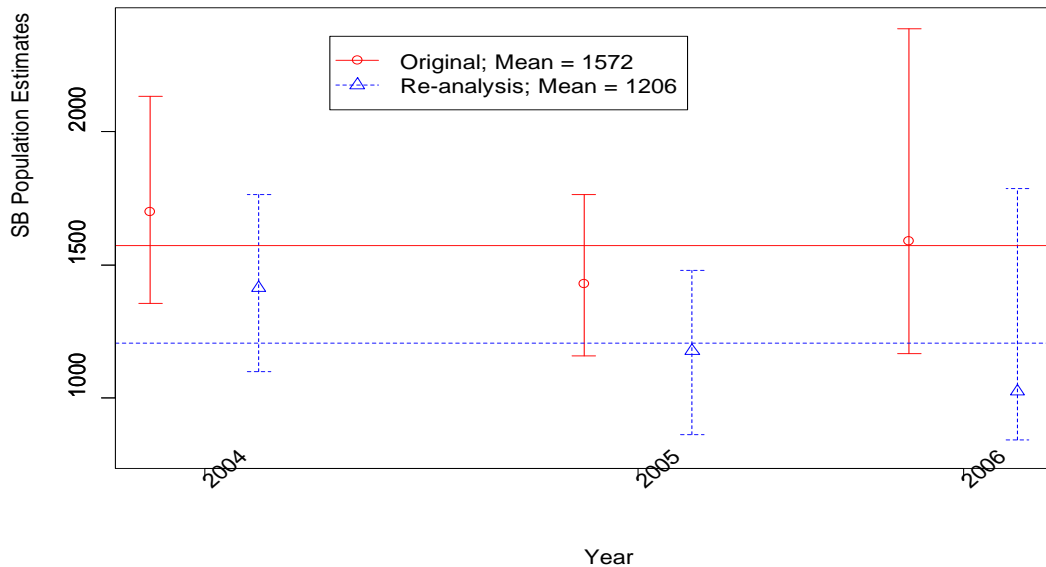
### Southern Beaufort Population Size

Abundance estimates from this re-analysis for the SB subpopulation, using the original boundary of approximately 125°W, were as follows: 1,698 (95% CI = 1,355, 2,134) for 2004; 1,429 (95% CI = 1,158, 1,763) for 2005; and 1,589 (95% CI = 1,168, 2,386) for 2006 (Table 1, Figure 2). This corresponds to a mean population size from 2004-2006 of 1,572 (95% CI = 1,289, 2,008), which is close to the previous estimate of 1,526 (95% CI = 1,211, 1,841) in Regehr et al. (2006). The slight difference in the estimates of population size between this re-analysis and Regehr et al. (2006) is due to the inclusion of updated age information and capture-recapture models with a sex effect in  $p$ . Population size estimates are provided for the years 2004-2006 only, because polar bears were not captured in the Canadian portion of the SB in early years of the study.

Abundance estimates from this re-analysis for the SB population, using the shifted boundary of 133°W, were as follows: 1,414 (95% CI = 1,098, 1,763) for 2004; 1,178 (95% CI = 863, 1,480) for 2005; 1,026 (95% CI = 844, 1,787) for 2006 (Table 1, Figure 2). This corresponds to a mean population size from 2004-2006 of 1,206 (95% CI = 964, 1,549). Mean population size estimates for the years 2004-2006 were 1,572 and 1,206 (i.e., a reduction of 366 bears) under the original and shifted boundary, respectively, equating to a proportional reduction of approximately 23% in the estimated abundance of the SB subpopulation.

**Table 1.** SB population estimates for the years 2004–2006 with 95% bootstrap confidence intervals.

Year	Original Boundary of 125W			Boundary Changed to 133W		
	$\hat{N}$	CI <sub>L</sub>	CI <sub>U</sub>	$\hat{N}$	CI <sub>L</sub>	CI <sub>U</sub>
2004	1,698	1,355	2,134	1,414	1,098	1,763
2005	1,429	1,158	1,763	1,178	863	1,480
2006	1,589	1,168	2,386	1,026	844	1,787



**Figure 2.** SB population estimates for the years 2004-2006 with 95% bootstrap confidence bands and 2004-2006 mean estimates.

### Northern Beaufort Population Size

Abundance estimates from this re-analysis for the NB population, using the original boundary of approximately 125°W, were as follows: 1,204 (95% CI = 798, 1,609) in 2004; 1,345 (95% CI = 874, 1,816) in 2005; and 767 (95% CI = 360, 1,174) in 2006 (Table 2, Figure 3). This corresponds to a mean population size from 2004-2006 of 1,105 (95% CI = 676, 1,534).

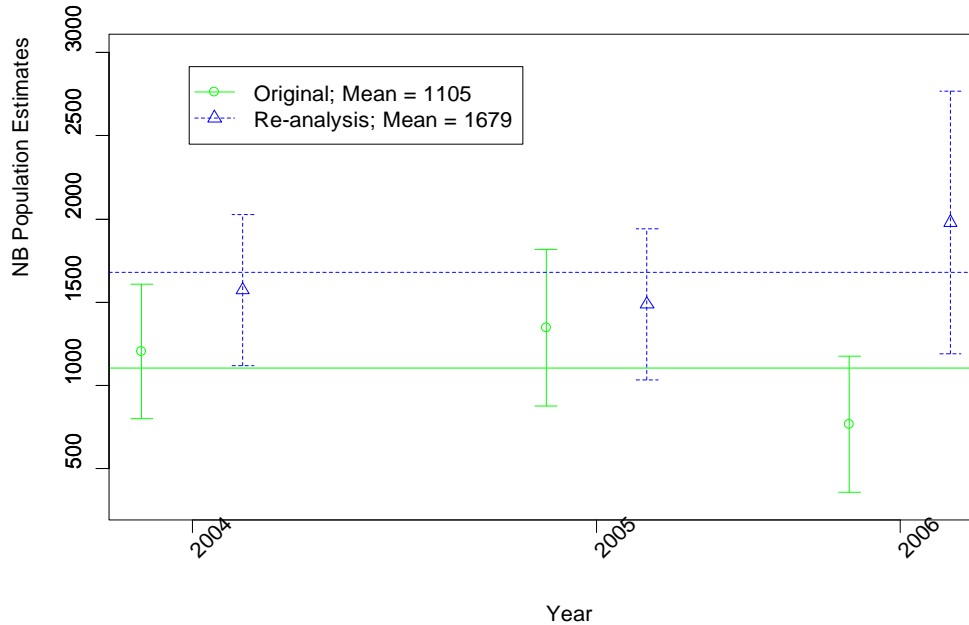
Abundance estimates from this re-analysis for the NB population, using the shifted boundary of 133°W, were as follows: 1,573 (95% CI = 1,119, 2,027) in 2004; 1,486 (95% CI = 1,033, 1,939) in 2005; 1,979 (95% CI = 1,191, 2,767) in 2006 (Table 2, Figure 3). This corresponds to a mean population size from 2004-2006 of 1,679 (95% CI = 1,093, 2,266).

Estimated population size in 2006 was approximately 1.5X higher under the shifted boundary vs. the original boundary, and should be viewed with caution for two reasons. First, the estimates of survival and recapture probabilities for the final year of a study may

be partially confounded, leading to biases in one or both parameters (Amstrup et al. 2005b, Chapter 10). Recapture probabilities for the top seven AIC ranked NB shifted boundary models are given in Table C15. Second, the high population size estimate for 2006 under the shifted boundary may be an artifact associated with changes in polar bear distribution and sampling. In our re-analysis using the shifted boundary, only 14 bears were shifted from the SB to the NB population in 2006, compared to 64 and 65 bears in 2004 and 2005, respectively. It is beyond the scope of this re-analysis to determine the exact cause of the high estimate of population size in 2006 under shifted boundary. Indeed, Stirling et al. (2011) also noted potential bias in estimates of population size for 2006 due to the lower availability of polar bears for capture, and concluded that this estimate was likely unreliable. Regehr et al. (2006) noted the same issue, although it was not considered to have introduced important bias into the 2006 estimate of SB population size because the lower availability of polar bears was limited to the far eastern portion of the study area, and because Regehr et al. (2006) considered recapture models that explicitly accounted for this variation. Because of potential bias, we propose that an evaluation of the qualitative effects of moving the SB-NB population boundary to 133°W should be based on estimates of NB population size for 2004 and 2005 only. The mean 2004-2005 estimate of NB population size estimate under the original boundary was 1,275, compared to 1,530 under the shifted boundary. The resulting difference of 255 bears, equating to a proportional increase of approximately 20%, seems plausible in light of the fact that 146 new bears were added to the original NB capture history set for the years 2003-2006.

**Table 2.** NB population estimates for the years 2004–2006 with 95% confidence intervals.

Year	Original Boundary of 125W				Boundary Changed to 133W			
	$\hat{N}$	SE( $\hat{N}$ )	CI <sub>L</sub>	CI <sub>U</sub>	$\hat{N}$	SE( $\hat{N}$ )	CI <sub>L</sub>	CI <sub>U</sub>
<b>2004</b>	1,204	207	798	1,609	1,573	232	1,119	2,027
<b>2005</b>	1,345	240	874	1,816	1,486	231	1,033	1,939
<b>2006</b>	767	208	360	1,174	1,979	402	1,191	2,767



**Figure 3.** NB population estimates for the years 2004-2006 with 95% confidence bands and 2004-2006 mean estimates.

### Southern Beaufort Survival Estimates

Survival estimates (and 95% confidence intervals) for the SB under the original and shifted boundary are presented in Appendix C (Tables C6-C12). Almost all 2004-2005 estimates within years, age groups and sex were within 6% relative difference between the original analysis and the re-analysis, with the exception of cubs for which the relative difference was 12%. Estimates of apparent survival tended to be lower under the shifted boundary vs. the original boundary; this result is discussed below.

### Northern Beaufort Survival Estimates

Survival estimates (and 95% confidence intervals) for the NB under the original and shifted boundary are presented in Appendix C (Appendix C Tables C2-C5). Estimated survival for the re-analysis were close to the original survival estimates with most estimates of sub-adults (2-4) and older bears for both sexes not differing by more than 10%. The exception was for cubs-of-the-year and yearlings for which differences were as high as 46% for female yearlings and 27% for male yearlings. Cub-of-the-year 2005 survival estimates were

much higher for the re-analysis, 0.471 (0,0.945), than for the original analysis, 0.219 (0, 0.709), for 2005, though 2004 differences for cubs were moderate at less than 13%. Confidence intervals overlapped within years and sex across analysis types for all age groups for the years 2004-2005. Most survival estimates were higher for the re-analysis results for both sexes and age groups; cubs, sub-adults and adults (Tables 10-12). The number of captures moved from the SB to the NB data in 2003, 2004 and 2005 comprised 28%, 36% and 34%, respectively; of all NB captures under the proposed boundary shift, for those years (Table 1). These substantial additions may have produced the upswing in survival for the NB re-analysis model compared to the NB original boundary model survival estimates.

### **Southern Beaufort Model Selection**

The top ranked QAIC<sub>c</sub> models were the same for the original and the shifted boundary capture-recapture analysis (QAIC<sub>c</sub> weight = 0.10, 0.07, Appendix A. Tables A4 and A5). The second ranked QAIC<sub>c</sub> models were also the same for the original and the shifted boundary capture-recapture analysis (QAIC<sub>c</sub> weight = 0.06, 0.04) with the exception of one survival covariate. Covariates in the highest ranked model for survival were age1 (cubs), age234 (age 1 +), and the age234 by female interaction. Covariates in the highest ranked recapture probability models were age34 by male interaction, agency, agency.csw.2006 and radio. Covariates for the second ranked survival model for the original boundary were age1, age234, icej.phijplus1 by age1 interaction, and icej.phij by age 234 interaction while for the re-analysis the only difference was the appearance of the icej.phij by age1 interaction covariate instead of the icej.phijplus1 by age1 interaction. The second ranked recapture models did not differ and comprised the same covariates as the top ranked recapture model. The Regehr et al. (2006) model selection results are not strictly comparable as a different set of candidate models and un-revised age data were used.

### **Northern Beaufort Model Selection**

The highest AIC<sub>c</sub> ranked model in the original analysis (AIC<sub>c</sub> weight = 0.13) and shifted boundary capture-recapture re-analysis (AIC<sub>c</sub> = 0.34) differed by one covariate in both the



survival and capture model components (Appendix B. Tables B4 and B5). In the original analysis, effects included in the survival model were age0, age1, age4, age234 interaction with sex and the interaction of age0 with RSF (resource selection function values). The top ranked survival model in the re-analysis differed from the original analysis in that it contained the main effects term for RSF instead of the interaction of age0 with RSF. Both original and re-analysis top AIC<sub>c</sub> ranked recapture models consisted of radio.vhf, radio.sat and the age34 by sex interaction term. Only the effort term differed between the original and re-analysis recapture models with the original model including effort.2 while the re-analysis effort covariate was flight 1,000 km. The major difference between analysis types for models with AIC<sub>c</sub> weights greater than 0.05 was the inclusion of the PMIce ice covariate in the second and third ranked original analysis. This variable does not show up until the 6<sup>th</sup> ranked model for the re-analysis (model AIC<sub>c</sub> weight = 0.029). Over most models within seven units of the best AIC<sub>c</sub> model, age variables were similar between the original and re-analysis.

## DISCUSSION

It should be noted that other potential locations for the SB-NB boundary were discussed by the IGC, North Slope Borough (NSB) of Alaska, U.S. Fish and Wildlife Service (USFWS), Department of Environment and Natural Resources of the Government of the Northwest Territories (GNWT), and Canadian Wildlife Service (CWS). Specifically, a boundary at approximately 129°W longitude was proposed based on radiotelemetry information, relocation data for research-marked bears, and the spatial distribution of harvest records (CWS, unpublished report). This analysis does not evaluate a potential boundary of 129°W because time constraints evaluation of only one boundary option, and 133°W was the option most supported at a community level. We believe that the proposed boundary of 133°W adequately represents general space use by polar bears in the SB region, recognizing the potential for space use to change in the future due to changing sea ice conditions (Derocher et al. 2004).

### **Effects of Moving the Boundary on SB and NB Population Size**

This re-analysis indicates that moving the boundary from approximately 125°W to 133°W corresponds to a change in the mean SB 2004-2006 population size from approximately 1,572-1,206, a reduction, from the original estimate, of 366 (23%) polar bears. Similarly, the boundary shift corresponds to a change in the mean 2004-2005 size of the NB population from approximately 1,275-1,530, an increase, from the original estimate, of 255 (20%) polar bears (Table 3). The mean estimate of the number of polar bears moved from the SB to the NB is approximately 311 polar bears. This equates to a proportional shift of approximately 20% of the SB sub-population (based on the point estimate of 1,526 in Regehr et al. 2006) to the NB sub-population. We believe that this ~20% shift in numbers among the subpopulations represents a reasonable approximation of the proportional effects on population size of moving the boundary from 125°W to 133°W, conditional on the datasets and methods used in this analysis. We recommend that previously published analyses (Regehr et al. 2006, Stirling et al. 2011) represent the best available estimates of population size for the SB and NB populations, respectively, under the current boundary

and based on data available when this boundary assessment was performed in 2009. If polar bear managers adopt the proposed boundary shift, it is reasonable to use the relative change in population size of approximately 311 polar bears (~20% of SB sub-population abundance) for the purpose of making harvest management decisions in the short term, until updated analyses are available.

**Table 3.** Estimated changes in the mean number of bears resulting from moving the boundary. The comparison is among mean population sizes for SB and NB.

Mean	Original Boundary of 125W			Boundary Changed to 133W			Change
	$\hat{N}$	CI <sub>L</sub>	CI <sub>U</sub>	$\hat{N}$	CI <sub>L</sub>	CI <sub>U</sub>	
<b>SB 2004-2006</b>	1,572	1,289	2,008	1,206	964	1,549	-366
<b>NB 2004-2005</b>	1,275	836	1,714	1,530	1,076	1,984	255

#### Effects of Moving the Boundary on SB and NB Survival Estimates

SB survival estimates for both sexes and all age groups, with the exception of sub-adults, were slightly lower under the shifted boundary vs. the original boundary. This trend is reversed from the overall increase in NB survival estimates under the shifted boundary vs. the original boundary. The consistency among these trends, before and after the boundary shift was applied, tends to support their validity. However, given the relatively small sample sizes and large statistical uncertainty, it is not possible to derive a biological interpretation for the slight changes in survival. Rather, the changes are likely due to the fact that survival estimates from open population capture-recapture models represent total apparent survival, which is the cumulative probability of remaining alive and within the study area. In this case, the “study area” for each population changed due to the boundary shift. This was evidenced by the deletion of some capture events from the SB dataset, and their addition to the NB dataset. Because the SB and NB analyses were carried out separately, bears (or capture events) deleted from the SB dataset represented bears that were no longer within that study area (i.e., bears that emigrated, which from an analytical perspective cannot be discerned from mortality). To more clearly understand the contributions of emigration and mortality to survival estimates, it may be useful to consider a meta-analysis of SB and NB data in the future.

## CONCLUSION

Because the original analyses considered a wide range of biological and study-design effects, which were not likely to be strongly affected by the proposed boundary change, we believe that this approach is reasonable for the purpose of estimating relative changes in sub-population size based on data and published analyses available in 2009. Therefore if the boundary shift is adopted by polar bear managers, it is reasonable to make short-term use of the estimated proportional changes in sub-population size for the purpose of evaluating sustainable harvest levels. However, the abbreviated nature of this analysis also places some limitations on the interpretation of our findings. Estimates of apparent survival from capture-recapture models reflect both natural survival and the probability of being located in the sampling area and available for recapture (Lebreton et al. 1992). We expected that some polar bears that were available for recapture in the SB under the original boundary, would no longer be available for recapture under the proposed boundary shift (i.e., that some of their recaptures would be moved to within the newly expanded NB boundary). Thus, potential changes in estimates of apparent survival could reflect an unknown combination of biological and emigration effects. Furthermore, population dynamics for long-lived animals can be sensitive to small changes in survival (e.g. Eberhardt 1990). Although our abbreviated analyses included models that likely explained major patterns in apparent survival, we did not develop new statistical models that were tailored to the repartitioned datasets. Therefore, we recommend that assessments of population status that depend on accurate estimates of survival rates, should be based on comprehensive analyses that include new population models fitted to updated capture-recapture data. Until new analyses are available, management decisions should continue to reflect evidence that the SB population likely appears to be facing population declines due to sea ice loss (Hunter et al. 2010, Regehr et al. 2010, Rode et al. 2010). Management decisions also should consider that, although recent studies suggest that the NB population has been stable or increasing slowly for the past three decades, polar bears in that region may face declines in the near future if sea ice loss continues as projected (Stirling et al. 2011).

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## APPENDIX A. DESCRIPTION OF SB COVARIATES, SB MODELS AND SB MODEL SELECTION

**Table A1.** Individual and temporal covariates included in SB 2007 updated models of apparent survival ( $\varphi_{ij}$ ) and recapture probability ( $p_{ij}$ ) for original and boundary shifted analyses.

Covariate	Effects	Effects Allowed
<b>age.1</b>	$\varphi_{ij}$	coy (aged 0-1) $\neq$ older bears
<b>age.2</b>	$\varphi_{ij}$	yrlds (aged 1) $\neq$ other age classes
<b>age.3</b>	$\varphi_{ij}$	subads (aged 2-4 years) $\neq$ other age classes
<b>age.4</b>	$\varphi_{ij}$	adults (aged 5 + )
<b>age.12</b>	$\varphi_{ij}$	coy = yrlds $\neq$ other age classes
<b>age.23</b>	$\varphi_{ij}$	ages 1 – 4
<b>age.34</b>	$p_{ij}$	subads and adults (aged 2 + )
<b>age.234</b>	$\varphi_{ij}$	aged 1 +
<b>female</b>	$\varphi_{ij}$	indicator for female bears
<b>male</b>	$p_{ij}$	indicator for male bears
<b>icej.phij</b>	$\varphi_{ij}$	relates sea ice conditions in the year j to survival probabilities in year j
<b>icej.phijplus1</b>	$\varphi_{ij}$	relates sea ice conditions in the year j to survival probabilities in year j+1
<b>d.1 - d.6</b>	d.3-d.6 ( $p_{ij}$ ) d.1-d.6 ( $\varphi_{ij}$ )	year effect for years 2001 - 2006
<b>agency</b>	$p_{ij}$	indicates whether each polar bear was captured by the US
<b>agency.cws</b>	$p_{ij}$	indicates whether each polar bear was captured by the CWS
<b>agency.cws.2006</b>	$p_{ij}$	time constant p for US and Canadian bears but allows p2006 to differ for Canadian bears
<b>effort.cws</b>	$p_{ij}$	annual Canadian helicopter hours flown in capture operations
<b>effort.usgs</b>	$p_{ij}$	annual US helicopter hours flown in capture operations



**Table A2.** Parameterizations considered for SB 2007 updated models of recapture probability for both original boundary analysis and shifted boundary analysis.

<b>Model</b>	<b>Regression Equation (all structures included intercepts)</b>
<b>p1</b>	ds4.radio
<b>p2</b>	ds4.d.3 + ds4.d.4 + ds4.d.5 + ds4.d.6 + ds4.radio
<b>p3</b>	ds4.agency + ds4.radio
<b>p4</b>	ds4.d.3 + ds4.d.4 + ds4.d.5 + ds4.d.6 + ds4.agency + ds4.radio
<b>p5</b>	ds4.d.3 + ds4.d.4 + ds4.d.5 + ds4.d.6 + ds4.d.4.agency + ds4.d.5.agency + ds4.d.6.agency + ds4.radio
<b>p6</b>	ds4.agency + ds4.agency.cws.2006 + ds4.radio
<b>p7</b>	ds4.effort.usgs + ds4.effort.cws + ds4.radio
<b>p8</b>	ds4.age.34.male + ds4.radio
<b>p9</b>	ds4.age.34.male + ds4.d.3 + ds4.d.4 + ds4.d.5 + ds4.d.6 + ds4.radio
<b>p10</b>	ds4.age.34.male + ds4.agency + ds4.radio
<b>p11</b>	ds4.age.34.male + ds4.d.3 + ds4.d.4 + ds4.d.5 + ds4.d.6 + ds4.agency + ds4.radio
<b>p12</b>	ds4.age.34.male + ds4.d.3 + ds4.d.4 + ds4.d.5 + ds4.d.6 + ds4.d.4.agency + ds4.d.5.agency + ds4.d.6.agency + ds4.radio
<b>p13</b>	ds4.age.34.male + ds4.agency + ds4.agency.cws.2006 + ds4.radio
<b>p14</b>	ds4.age.34.male + ds4.effort.usgs + ds4.effort.cws + ds4.radio

**Table A3.** Parameterizations considered for SB 2007 updated models of survival probability for both original boundary analysis and shifted boundary analysis.

Model	Regression Equation (all structures included intercepts)
<b>phi1</b>	(null)
<b>phi2</b>	ds4.age.1
<b>phi3</b>	ds4.age.1 + ds4.age.2
<b>phi4</b>	ds4.age.1 + ds4.age.2 + ds4.age.3
<b>phi5</b>	ds4.age.1 + ds4.age.234 + ds4.age.234.female
<b>phi6</b>	ds4.age.1 + ds4.age.2 + ds4.age.3 + ds4.age.4 + ds4.age.234.female
<b>phi7</b>	ds4.age.1 + ds4.age.2 + ds4.age.2.female + ds4.age.3 + ds4.age.3.female + ds4.age.4 + ds4.age.4.female
<b>phi8</b>	ds4.d.2 + ds4.d.3 + ds4.d.4 + ds4.d.5
<b>phi9</b>	ds4.age.1 + ds4.d.2 + ds4.d.3 + ds4.d.4 + ds4.d.5
<b>phi10</b>	ds4.age.1 + ds4.age.2 + ds4.d.2 + ds4.d.3 + ds4.d.4 + ds4.d.5
<b>phi11</b>	ds4.age.1 + ds4.age.2 + ds4.age.3 + ds4.d.2 + ds4.d.3 + ds4.d.4 + ds4.d.5
<b>phi12</b>	ds4.age.1 + ds4.age.234 + ds4.age.234.female + ds4.d.1 + ds4.d.2 + ds4.d.3 + ds4.d.4 + ds4.d.5
<b>phi13</b>	ds4.age.1 + ds4.age.2 + ds4.age.3 + ds4.age.4 + ds4.age.234.female + ds4.d.1 + ds4.d.2 + ds4.d.3 + ds4.d.4 + ds4.d.5
<b>phi14</b>	ds4.age.1 + ds4.age.2 + ds4.age.2.female + ds4.age.3 + ds4.age.3.female + ds4.age.4 + ds4.age.4.female + ds4.d.1 + ds4.d.2 + ds4.d.3 + ds4.d.4 + ds4.d.5
<b>phi15</b>	ds4.age.1 + ds4.d.2.age.1 + ds4.d.3.age.1 + ds4.d.4.age.1 + ds4.d.5.age.1 + ds4.age.234 + ds4.age.234.female
<b>phi16</b>	ds4.age.1 + ds4.age.2 + ds4.age.3 + ds4.d.2.age.123 + ds4.d.3.age.123 + ds4.d.4.age.123 + ds4.d.5.age.123 + ds4.age.4 + ds4.age.4.female
<b>phi17</b>	ds4.icej.phij
<b>phi18</b>	ds4.age.1 + ds4.icej.phij
<b>phi19</b>	ds4.age.1 + ds4.age.2 + ds4.icej.phij
<b>phi20</b>	ds4.age.1 + ds4.age.2 + ds4.age.3 + ds4.icej.phij
<b>phi21</b>	ds4.age.1 + ds4.age.234 + ds4.age.234.female + ds4.icej.phij
<b>phi22</b>	ds4.age.1 + ds4.age.2 + ds4.age.3 + ds4.age.4 + ds4.age.234.female + ds4.icej.phij
<b>phi23</b>	ds4.age.1 + ds4.age.2 + ds4.age.2.female + ds4.age.3 + ds4.age.3.female + ds4.age.4 + ds4.age.4.female + ds4.icej.phij
<b>phi24</b>	ds4.age.1 + ds4.icej.phij.age.1 + ds4.age.234 + ds4.age.234.female
<b>phi25</b>	ds4.age.1 + ds4.age.2 + ds4.age.3 + ds4.icej.phij.age.123 + ds4.age.4 + ds4.age.4.female
<b>phi26</b>	ds4.age.1 + ds4.icej.phij.age.1 + ds4.age.234 + ds4.icej.phij.age.234
<b>phi27</b>	ds4.age.1 + ds4.icej.phij.age.1 + ds4.age.2 + ds4.icej.phij.age.2 + ds4.age.3 + ds4.icej.phij.age.3 + ds4.age.4 + ds4.icej.phij.age.4
<b>phi28</b>	ds4.age.1 + ds4.icej.phij.age.1 + ds4.age.234 + ds4.icej.phij.age.234 + ds4.age.234.female + ds4.icej.phij.age.234.female

Model	Regression Equation (all structures included intercepts)
<b>phi29</b>	ds4.age.1 + ds4.icej.phijplus1.age.1
<b>phi30</b>	ds4.age.1 + ds4.icej.phijplus1.age.1 + ds4.age.234 + ds4.icej.phij.age.234
<b>phi31</b>	ds4.age.1 + ds4.icej.phijplus1.age.1 + ds4.age.2 + ds4.age.3 + ds4.age.4 + ds4.icej.phij.age.234
<b>phi32</b>	ds4.age.1 + ds4.icej.phijplus1.age.1 + ds4.age.2 + ds4.icej.phij.age.2 + ds4.age.3 + ds4.icej.phij.age.3 + ds4.age.4 + ds4.icej.phij.age.4
<b>phi33</b>	ds4.age.1 + ds4.icej.phijplus1.age.1 + ds4.age.234 + ds4.age.234.female + ds4.icej.phij.age.234

**Table A4.** SB updated 2007 model selection table for CJS models for original boundary analysis (np is number of parameters).

Rank	Survival	Recapture	np	$\Delta$ QAICc	w
1	$\phi$ (age.1 + age.234 + age.234.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	8	0	0.104
2	$\phi$ (age.1 + icej.phijplus1.age.1 + age.234 + icej.phij.age.234)	agency.cws.2006 + radio)	9	0.984	0.063
3	$\phi$ (age.1 + age.2 + age.3 + icej.phij.age.123 + age.4 + age.4.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	10	0.998	0.063
4	$\phi$ (age.1 + icej.phij.age.1 + age.234 + icej.phij.age.234)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	9	1.075	0.06
5	$\phi$ (age.1 + icej.phijplus1.age.1 + age.2 + age.3 + age.4 + icej.phij.age.234)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	10	1.12	0.059
6	$\phi$ (age.1 + age.2 + age.3 + icej.phij.age.123 + age.4 + age.4.female)	$p$ (agency + agency.cws.2006 + radio)	9	1.167	0.058
7	$\phi$ (age.1 + age.234 + age.234.female)	$p$ (agency + agency.cws.2006 + radio)	7	1.533	0.048
8	$\phi$ (age.1 + age.234 + age.234.female + icej.phij)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	9	1.6	0.047
9	$\phi$ (age.1 + icej.phij.age.1 + age.234 + age.234.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	9	2.009	0.038
10	$\phi$ (age.1 + age.234 + age.234.female + icej.phij)	$p$ (agency + agency.cws.2006 + radio)	8	2.54	0.029
11	$\phi$ (age.1)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	7	2.671	0.027
12	$\phi$ (age.1 + icej.phijplus1.age.1 + age.234 + age.234.female + icej.phij.age.234)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	10	2.943	0.024
13	$\phi$ (age.1 + icej.phijplus1.age.1 + age.234 + age.234.female + icej.phij.age.234)	$p$ (agency + agency.cws.2006 + radio)	9	3.053	0.022
14	$\phi$ (age.1 + age.2 + age.3 + .age.4 + age.234.female)	$p$ (agency + agency.cws.2006 + radio)	8	3.128	0.022
15	$\phi$ (age.1 + icej.phijplus1.age.1 + age.234 + icej.phij.age.234)	$p$ (agency + agency.cws.2006 + radio)	8	3.257	0.02

Rank	Survival	Recapture	np	$\Delta$ QAICc	w
16	$\phi$ (age.1 + icej.phij.age.1 + age.234 + icej.phij.age.234)	$p$ (agency + agency.cws.2006 + radio)	8	3.398	0.019
17	$\phi$ (age.1 + age.2 + age.3 + age.4 + age.234.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	10	3.418	0.019
18	$\phi$ (age.1 + icej.phijplus1.age.1 + age.2 + age.3 + age.4 + icej.phij.age.234)	$p$ (agency + agency.cws.2006 + radio)	9	3.497	0.018
19	$\phi$ (age.1 + icej.phijplus1.age.1 + age.2 + age.3 + age.4 + icej.phij.age.234)	$p$ (agency + agency.cws.2006 + radio)	9	3.504	0.018
20	$\phi$ (age.1 + icej.phij.age.1 + age.234 + age.234.female)	$p$ (agency + agency.cws.2006 + radio)	8	3.509	0.018
21	$\phi$ (age.1 + icej.phij)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	8	3.712	0.016
22	$\phi$ (age.1 + age.2 + age.2.female + age.3 + age.3.female + age.4 + age.4.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	11	3.863	0.015

**Table A5.** SB updated 2007 model selection table for CJS models for shifted boundary re-analysis (np is number of parameters).

Rank	Survival	Recapture	np	$\Delta QAICc$	w
1	$\phi$ (age.1 + age.234 + age.234.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	8	0	0.07
2	$\phi$ (age.1 + icej.phij.age.1 + age.234 + icej.phij.age.234)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	9	1.08	0.04
3	$\phi$ dage.1 + icej.phijplus1.age.1 + age.234 + icej.phij.age.234)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	9	1.23	0.04
4	$\phi$ (age.1 + age.234 + age.234.female)	$p$ (ds4.age.34.male + ds4.radio)	6	1.39	0.04
5	$\phi$ (age.1 + age.234 + age.234.female + icej.phij)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	9	1.44	0.04
6	$\phi$ (age.1 + icej.phij.age.1 + age.234 + age.234.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	9	1.83	0.03
7	$\phi$ (age.1 + age.2 + age.3 + icej.phij.age.123 + age.4 + age.4.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	10	1.91	0.03
8	$\phi$ (age.1 + icej.phij.age.1 + age.234 + icej.phij.age.234)	$p$ (ds4.age.34.male + ds4.radio)	7	2	0.03
9	$\phi$ dage.1 + icej.phijplus1.age.1 + age.234 + icej.phij.age.234)	$p$ (ds4.age.34.male + ds4.radio)	7	2.12	0.03
10	$\phi$ (age.1 + icej.phijplus1.age.1 + age.2 + age.3 + age.4 + icej.phij.age.234)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	10	2.14	0.03
11	$\phi$ (age.1)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	7	2.3	0.02
12	$\phi$ (age.1 + age.234 + age.234.female + icej.phij)	$p$ (ds4.age.34.male + ds4.radio)	7	2.56	0.02
13	$\phi$ (age.1 + age.234 + age.234.female)	$p$ (agency + agency.cws.2006	7	2.77	0.02
14	$\phi$ (age.1 + age.2 + age.3 + icej.phij.age.123 + age.4 + age.4.female)	$p$ (ds4.age.34.male + ds4.radio)	8	2.81	0.02
15	$\phi$ (age.1 + icej.phij)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	8	2.98	0.02

Rank	Survival	Recapture	np	$\Delta$ QAICc	w
16	$\phi$ (age.1 + icej.phijplus1.age.1 + age.2 + age.3 + age.4 + icej.phij.age.234)	$p$ (ds4.age.34.male + ds4.radio)	8	2.98	0.02
17	$\phi$ (age.1 + icej.phij.age.1 + age.234 + age.234.female)	$p$ (ds4.age.34.male + ds4.radio)	7	3.18	0.02
18	$\phi$ (age.1 + icej.phijplus1.age.1 + age.234 + age.234.female + icej.phij.age.234)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	10	3.2	0.02
19	$\phi$ (age.1 + age.234 + age.234.female)	$p$ (age.34.male + agency + radio)	7	3.21	0.02
20	$\phi$ (age.1 + icej.phij.age.1 + age.234 + icej.phij.age.234)	$p$ (age.34.male + agency + radio)	8	3.4	0.01
21	$\phi$ (age.1 + age.234 + age.234.female + icej.phij)	$p$ (agency + agency.cws.2006 + radio)	8	3.46	0.01
22	$\phi$ (dage.1 + icej.phijplus1.age.1 + age.234 + icej.phij.age.234)	$p$ (age.34.male + agency + radio)	8	3.53	0.01
23	$\phi$ (ds4.age.1)	$p$ (age.34.male + radio)	5	3.61	0.01
24	$\phi$ (age.1 + age.234 + age.234.female)	$p$ (radio)	5	3.64	0.01
25	$\phi$ (age.1 + age.2 + age.3 + .age.4 + age.234.female)	$p$ (age.34.male + agency + agency.cws.2006 + radio)	10	3.71	0.01

## APPENDIX B. DESCRIPTION OF NB COVARIATES, NB MODELS AND NB MODEL SELECTION

**Table B1.** Individual and temporal covariates included in NB models of apparent survival ( $\varphi_{ij}$ ) and recapture probability ( $p_{ij}$ ). In the Effect Allowed column, M = male, F = female, coy = cub of the year, yr1g(s) = yearling(s), subad(s) = subadult(s), and ad(s) = adult(s). A ‘.’ between names implies interaction between the effects involved. Reprinted from Stirling et al. (2007).

Covariate	Effects	Effect Allowed
<b>Individual covariates</b>		
age0	$\varphi_{ij}$	coy (aged 0-1) $\neq$ older bears
age1	$\varphi_{ij}$	yr1gs (aged 1-2) $\neq$ other age classes
age2	$p_{ij}, \varphi_{ij}$	subads (aged 2-4 years) $\neq$ other age classes
age3	$\varphi_{ij}$	adults (aged 5 – 20 years) $\neq$ other age classes
age4	$\varphi_{ij}$	senescent animals (aged 21+) $\neq$ other age classes
age01	$p_{ij}, \varphi_{ij}$	coy = yr1gs $\neq$ other age classes
age23	$\varphi_{ij}$	subads = ads $\neq$ other age classes
age234	$\varphi_{ij}$	subads = ads = senescent $\neq$ other age classes
age0124		coy = yr1gs = subads = senescent $\neq$ adults
age1234	$\varphi_{ij}$	yr1gs = subads = ads = senescent $\neq$ coys
age34	$p_{ij}, \varphi_{ij}$	ads = senescent $\neq$ other age classes
age012	$\varphi_{ij}$	coy = yr1gs = subads $\neq$ other age classes
SBase	$\varphi_{ij}$	Per SB estimates, covariate values were -0.2139 for COY, 3.0234 for yearlings, 2.2210 for sub-adults, 2.6477 for adults, and 1.7774 for senescent adults.
Sex	$p_{ij}, \varphi_{ij}$	M $\neq$ F (Females used as the reference level; Females = 0, Males = 1)
age234.sex	$\varphi_{ij}$	subad M = ad M = senescent M $\neq$ subad F = ad F = senescent F
age1234.sex	$\varphi_{ij}$	yr1g M = subad M = ad M = senescent M $\neq$ yr1g F = subad F = ad F = senescent F
age34.sex	$p_{ij}$	ad M = senescent M $\neq$ ad F = senescent F
radio.vhf	$p_{ij}$	bear available for capture using radio telemetry
radio.sat	$p_{ij}$	bear available for location using a satellite radio
<b>Temporal Covariates</b>		
RSF	$\varphi_{ij}$	Resource selection function values, Durner et al. (2009). See Stirling et al. (2007)
PMIce	$\varphi_{ij}$	Extent of sea ice. See Stirling et al. (2007)
Seal	$\varphi_{ij}$	Seal productivity covariate. See Stirling et al. (2007)
yr70s, yr80s	$\varphi_{ij}$	1970s $\neq$ 1980s $\neq$ 2000s (2000s used as the reference level). Years included in the analysis were 1971-1979, 1985-1987, 1989, 2000, and 2003-2006.



Covariate	Effects	Effect Allowed
Individual covariates		
Flight km	$p_{ij}$	Number of kilometers flown searching for bears in a capture year
effort.2	$p_{ij}$	Study effort (intensive study years, high effort = 1971–1975, 1985–1989, and 2004–2006)

**Table B2:** Parameterizations considered for NB models of recapture probability. A ‘.’ between names implies interaction between the effects involved. Reprinted from Stirling et al. (2007).

Model #	Regression Equation (all structures included intercepts)
1	(null)
2	age2 + age34.sex
3	age2
4	age34.sex
5	age01 + age2 + age34.sex
6	age01 + age34.sex
7–12	radio.vhf + radio.sat + equations 1-6
13–24	effort.2 + equations 1-12
19–24	Flight km + radio.vhf + radio.sat + equations 1-12
25–36	Year + equations 1-12

**Table B3:** Parameterizations considered for NB models of apparent survival. A ‘.’ between names implies interaction between the effects involved. Reprinted from Stirling et al. (2007).

Model #	Regression Equation (all structures included intercepts)
1	(null)
2	SBage
3	age0 + age1 + age2 + age4
4	age01 + age2 + age4
5	age01 + age4
6	age01
7	age0 + age1 + age4
8	age0 + age1
9	age0 + age1 + age2
10	age01 + age2
11	age0
12–22	sex + equations 1-11
23	age0 + age1 + age2 + age4 + age1234.sex
24	age0 + age1 + age4 + age1234.sex
25	age0 + age1 + age1234.sex
26	age0 + age1 + age2 + age1234.sex

Model #	Regression Equation (all structures included intercepts)
27	age0 + age1234.sex
28	age01 + age2 + age4 + age234.sex
29	age01 + age4 + age234.sex
30	age01 + age234.sex
31	age01 + age2 + age234.sex
32-62	yr70s + yr80s + yr90s + equations 1-31
63-93	RSF + equations 1-31
94-124	PMIce + equations 1-31
125-155	Year + equations 1-31
156-186	Seals + equations 1-31

**Table B4.** NB Original boundary data model selection table for Cormack-Jolly-Seber models fitted to capture-recapture data for polar bears from 1971-2006. Rank indicates the model rank; np = the number of estimated parameters;  $\Delta AIC_c$  = difference in  $AIC_c$  value from the top model; and  $AIC_c$  weights = Akaike weights for each of the models.

Rank	Survival	Recapture	np	$\Delta AIC_c$	$AIC_c$ weight
1	$\phi$ (age0 + age1 + age4 + age234.sex + age0.rsfs)	p(radio.vhf + radio.sat + age34.sex + effort.2)	11	0.000	0.12957
2	$\phi$ (age0 + age1 + age4 + age234.sex + PMIce)	p(radio.vhf + radio.sat + age34.sex + effort.2)	11	0.591	0.09643
3	$\phi$ (age0 + age1 + age4 + age234.sex + age0.PMIce)	p(radio.vhf + radio.sat + age34.sex + effort.2)	11	1.408	0.06410
4	$\phi$ (age0 + age1 + age4 + age234.sex + age0.rsfs + age1.rsfs)	p(radio.vhf + radio.sat + age34.sex + effort.2)	12	1.563	0.05931
5	$\phi$ (age0 + age1 + age4 + age234.sex + rsf + age0.rsfs)	p(radio.vhf + radio.sat + age34.sex + effort.2)	12	1.636	0.05717
6	$\phi$ (age0 + age1 + age4 + age234.sex + PMIce + age0.PMIce)	p(radio.vhf + radio.sat + age34.sex + effort.2)	12	1.686	0.05578
7	$\phi$ (age0 + age1 + age4 + age234.sex)	p(radio.vhf + radio.sat + age34.sex + effort.2)	10	2.105	0.04523
8	$\phi$ (age0 + age1 + age4 + age234.sex)	p(radio.vhf + radio.sat + effort.2)	9	2.281	0.04142
9	$\phi$ (age0 + age1 + age4 + age234.sex)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	10	2.357	0.03988
10	$\phi$ (age0 + age1 + age4 + age234.sex)	p(radio.vhf + radio.sat + flight.1000km)	9	2.495	0.03722
11	$\phi$ (age0 + age1 + age4 + age234.sex + rsfs)	p(radio.vhf + radio.sat + age34.sex + effort.2)	11	2.704	0.03353
12	$\phi$ (age0 + age1 + age4 + age234.sex + age0.PMIce + age1.PMIce)	p(radio.vhf + radio.sat + age34.sex + effort.2)	12	3.006	0.02883
13	$\phi$ (age0 + age1 + age4 + age234.sex + rsfs + age0.rsfs + age1.rsfs)	p(radio.vhf + radio.sat + age34.sex + effort.2)	13	3.450	0.02309
14	$\phi$ (age0 + age1 + age4 + age234.sex + age0.rsfs + age1.rsfs + age4.rsfs)	p(radio.vhf + radio.sat + age34.sex + effort.2)	13	3.542	0.02205

Rank	Survival	Recapture	np	$\Delta AIC_c$	$AIC_c$ weight
15	$\phi$ (age0 + age1 + age4 + age234.sex + PMIce + age0.PMIce + age1.PMIce)	p(radio.vhf + radio.sat + age34.sex + effort.2)	13	3.741	0.01996
16	$\phi$ (age0 + age1 + age4 + age234.sex)	p(radio.vhf + radio.sat + effort.2 + age2 + age34.sex)	11	4.011	0.01744
17	$\phi$ (age0 + age1 + age4 + age234.sex + age0.seal)	p(radio.vhf + radio.sat + age34.sex + effort.2)	11	4.125	0.01647
18	$\phi$ (age0 + age1 + age4 + age234.sex + seal)	p(radio.vhf + radio.sat + age34.sex + effort.2)	11	4.149	0.01628
19	$\phi$ (age0 + age1 + age4 + age234.sex + age0.PMIce + age1.PMIce + age4.PMIce)	p(radio.vhf + radio.sat + age34.sex + effort.2)	13	4.336	0.01482
20	$\phi$ (sex + age0 + age1 + age4)	p(radio.vhf + radio.sat + effort.2 + age2 + age34.sex)	11	4.495	0.01369

**Table B5.** NB Shifted boundary data re-analysis model selection table for Cormack-Jolly-Seber models fitted to capture-recapture data for polar bears from 1971-2006. Rank indicates the model rank; np = the number of estimated parameters;  $\Delta AIC_c$  = difference in  $AIC_c$  value from the top model; and  $AIC_c$  weights = Akaike weights for each of the models.

Rank	Survival	Recapture	np	$\Delta AIC_c$	$AIC_c$ weight
1	$\phi$ (age0 + age1 + age4 + age234.sex + rsf)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	11	0	0.341776
2	$\phi$ (age0 + age1 + age4 + age234.sex + rsf + age0.rsfs)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	12	1.3791	0.171501
3	$\phi$ (age0 + age1 + age4 + age234.sex + rsf + age0.rsfs + age1.rsfs)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	13	3.0338	0.074982
4	$\phi$ (age01 + age2 + age4 + age234.sex)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	10	3.9017	0.048584
5	$\phi$ (yr70s + yr80s + age01 + age2 + age4 + age234.sex)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	12	4.2139	0.041562
6	$\phi$ (age0 + age1 + age4 + age234.sex + PMIce + age0.PMIce)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	11	4.8753	0.029859
7	$\phi$ (age01 + age2 + age4 + age234.sex)	p(radio.vhf + radio.sat + age01 + age34.sex + flight.1000km)	11	5.0143	0.027855
8	$\phi$ (age0 + age1 + age4 + age234.sex + seal + age0.seal + age1.seal + age4.seal)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	14	5.4434	0.022476
9	$\phi$ (yr70s + yr80s + age01 + age2 + age4 + age234.sex)	p(radio.vhf + radio.sat + age01 + age34.sex + flight.1000km)	13	5.4603	0.022287
10	$\phi$ (age0 + age1 + age4 + age234.sex + age0.rsfs)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	11	5.6585	0.020184
11	$\phi$ (age0 + age1 + age4 + age234.sex + age0.yr70s + age0.yr80s)	p(radio.vhf + radio.sat + age34.sex + flight.1000km)	12	5.7188	0.019585

Rank	Survival	Recapture	np	$\Delta AIC_c$	$AIC_c$ weight
12	$\phi$ (age0 + age1 + age4 + age234.sex + age0.PMIce + age1.PMIce)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	12	5.7222	0.019551
13	$\phi$ (age0 + age1 + age4 + age234.sex + PMIce)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	11	5.7916	0.018884
14	$\phi$ (age0 + age1 + age4 + age234.sex + seal)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	11	5.8638	0.018216
15	$\phi$ (age0 + age1 + age4 + age234.sex + age0.seal)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	11	5.9446	0.017494
16	$\phi$ (age0 + age1 + age4 + age234.sex + yr70s + yr80s + age0.yr70s)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	13	6.2029	0.015374
17	$\phi$ (age0 + age1 + age4 + age234.sex + PMIce + age0.PMIce)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	12	6.8889	0.01091

**APPENDIX C. REAPPORTIONMENT OF CAPTURES, SB AND NB SURVIVAL ESTIMATES, MODEL SELECTION FOR REGHER 2006 AND SB AND NB PARAMETER ESTIMATES FOR TOP RANKED MODELS AND PROBABILITY OF CAPTURE FOR 2006 NB SHIFTED-BOUNDARY MODELS**

(SubPop – Subpopulation; SB – Southern Beaufort; NB – Northern Beaufort)

**Table C1.** Re-apportionment of SB and NB captures for the years 2003-2006.

	2003		2004		2005		2006		Total	
SubPop	Original	Shift	Original	Shift	Original	Shift	Original	Shift	Original	Shift
SB	170	154	285	212	250	184	145	130	850	680
NB	37	53	113	186	125	191	62	77	337	507

**Table C2.** NB annual apparent survival of male cub-of-the-year, yearling, subadult, adult, and senescent adult polar bears from 2003-2005 using original boundary line data (Stirling et al. 2007).

Year	Cubs-of-the-year			Yearlings			Sub-adults			Adults			Senescent Adults		
	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>
2003	0.495	0.107	0.884	0.295	0.041	0.550	0.823	0.738	0.908	0.825	0.745	0.905	0.384	0.102	0.665
2004	0.651	0.168	1.000	0.349	0.007	0.691	0.844	0.738	0.951	0.846	0.745	0.948	0.442	0.115	0.769
2005	0.219	0.000	0.709	0.348	0.000	0.838	0.769	0.500	1.000	0.771	0.505	1.000	0.368	0.000	0.784

**Table C3.** NB annual apparent survival of male cub-of-the-year, yearling, subadult, adult, and senescent adult polar bears from 2003-2005 re-analysis using shifted boundary line data.

Year	Cubs-of-the-year			Yearlings			Sub-adults			Adults			Senescent Adults		
	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>
2003	0.557	0.127	0.987	0.336	0.078	0.595	0.873	0.762	0.984	0.829	0.760	0.898	0.379	0.097	0.661
2004	0.587	0.176	0.998	0.442	0.111	0.772	0.861	0.752	0.970	0.848	0.751	0.946	0.398	0.100	0.695
2005	0.471	0.000	0.945	0.442	0.085	0.800	0.854	0.740	0.967	0.851	0.740	0.961	0.388	0.083	0.694

**Table C4.** NB annual apparent survival of female cub-of-the-year, yearling, subadult, adult, and senescent adult polar bears from 2003-2005 analysis using original data (Stirling et al. 2007).

Year	Cubs-of-the-year			Yearlings			Sub-adults			Adults			Senescent Adults		
	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>
2003	NA	NA	NA	0.300	0.042	0.559	0.906	0.854	0.958	0.907	0.858	0.955	0.561	0.319	0.802
2004	0.657	0.181	1.000	0.354	0.011	0.697	0.917	0.853	0.982	0.918	0.857	0.979	0.616	0.348	0.884
2005	0.224	0.000	0.727	0.353	0.000	0.847	0.867	0.678	1.000	0.868	0.682	1.000	0.525	0.118	0.932

**Table C5.** NB annual apparent survival of female cub-of-the-year, yearling, subadult, adult, and senescent adult polar bears from 2003-2005 re-analysis using shifted boundary line data.

Year	Cubs-of-the-year			Yearlings			Sub-adults			Adults			Senescent adults		
	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>
2003	0.661	0.000	1.000	0.336	0.078	0.595	0.929	0.879	0.979	0.919	0.877	0.961	0.591	0.354	0.828
2004	0.587	0.176	0.998	0.512	0.142	0.881	0.933	0.873	0.992	0.926	0.872	0.980	0.609	0.367	0.850
2005	0.471	0.000	0.945	0.515	0.104	0.926	0.928	0.866	0.990	0.929	0.866	0.992	0.599	0.340	0.858

**Table C6.** SB model averaged annual apparent survival of cub-of-the-year (both sexes), male yearling, subadult, and adult polar bears from 2003-2005 using updated 2007 data for original boundary line analysis with 95% bootstrap percentile confidence intervals.

Year	Cubs-of-the-year (both sexes)			Yearlings			Sub-adults			Adults		
	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>
<b>2003</b>	0.437	0.228	0.715	0.942	0.858	0.999	0.931	0.826	0.999	0.924	0.849	0.998
<b>2004</b>	0.403	0.115	0.638	0.923	0.786	0.998	0.850	0.457	0.984	0.894	0.753	0.993
<b>2005</b>	0.395	0.086	0.657	0.924	0.802	0.998	0.858	0.542	0.994	0.896	0.782	0.994

**Table C7.** SB model averaged annual apparent survival of cub-of-the-year (both sexes), male yearling, subadult, and adult polar bears from 2003-2005 using updated 2007 data for proposed shifted boundary line analysis with 95% bootstrap percentile confidence intervals.

Year	Cubs-of-the-year (both sexes)			Yearlings			Sub-adults			Adults		
	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>
<b>2003</b>	0.388	0.200	0.622	0.924	0.732	0.999	0.913	0.801	0.998	0.920	0.851	0.999
<b>2004</b>	0.353	0.112	0.629	0.900	0.663	0.998	0.856	0.464	0.992	0.889	0.757	0.997
<b>2005</b>	0.347	0.094	0.652	0.900	0.674	0.998	0.859	0.544	0.994	0.892	0.768	0.997

**Table C8.** SB model averaged annual apparent survival of cub-of-the-year (both sexes), female yearling, subadult, and adult polar bears from 2003-2005 using updated 2007 data for original boundary line analysis with 95% bootstrap percentile confidence intervals.

Year	Cubs-of-the-year (both sexes)			Yearlings			Sub-adults			Adults		
	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>
<b>2003</b>	0.437	0.228	0.715	0.942	0.802	0.999	0.914	0.793	0.999	0.928	0.801	0.998
<b>2004</b>	0.403	0.115	0.638	0.927	0.779	0.999	0.837	0.455	0.979	0.902	0.746	0.993
<b>2005</b>	0.395	0.086	0.657	0.928	0.781	0.999	0.844	0.539	0.990	0.904	0.769	0.996

**Table C9.** SB model averaged annual apparent survival of cub-of-the-year (both sexes), female yearling, subadult, and adult polar bears from 2003-2005 using updated 2007 data for proposed shifted boundary line analysis with 95% bootstrap percentile confidence intervals .

Year	Cubs-of-the-year (both sexes)			Yearlings			Sub-adults			Adults		
	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>	Survival	95% CI <sub>L</sub>	95% CI <sub>U</sub>
<b>2003</b>	0.388	0.200	0.622	0.915	0.714	0.997	0.899	0.777	0.995	0.909	0.789	0.995
<b>2004</b>	0.353	0.112	0.629	0.897	0.643	0.996	0.847	0.461	0.968	0.884	0.745	0.991
<b>2005</b>	0.347	0.094	0.652	0.896	0.649	0.996	0.850	0.541	0.969	0.886	0.755	0.991



**Table C10.** SB model averaged estimates of total apparent survival using 2007 updated models for original boundary line analysis.

Year	COYs of Both Sexes		Females Older than COYs		Males Older than COYs	
	Survival	SE(Survival)	Survival	SE(Survival)	Survival	SE(Survival)
2001	0.47	0.15	0.95	0.05	0.95	0.07
2002	0.46	0.14	0.95	0.05	0.95	0.07
2003	0.44	0.13	0.93	0.06	0.93	0.08
2004	0.40	0.15	0.88	0.09	0.89	0.10
2005	0.40	0.17	0.89	0.08	0.89	0.09

**Table C11.** SB model averaged estimates of total apparent survival using 2007 updated models for proposed shifted boundary line re-analysis.

Year	COYs of Both Sexes		Females Older than COYs		Males Older than COYs	
	Survival	SE(Survival)	Survival	SE(Survival)	Survival	SE(Survival)
2001	0.43	0.14	0.95	0.05	0.93	0.07
2002	0.42	0.14	0.95	0.05	0.93	0.07
2003	0.39	0.12	0.92	0.06	0.91	0.07
2004	0.35	0.15	0.88	0.09	0.87	0.09
2005	0.35	0.16	0.88	0.08	0.88	0.09

**Table C12.** SB model averaged estimates of total apparent survival taken from Regehr 2006 which uses the original boundary capture histories and a slightly different set of models.

Year	COYs of Both Sexes		Females Older than COYs		Males Older than COYs	
	Survival	SE(Survival)	Survival	SE(Survival)	Survival	SE(Survival)
2001	0.47	0.14	0.92	0.05	0.94	0.05
2002	0.45	0.13	0.92	0.05	0.94	0.05
2003	0.43	0.12	0.92	0.05	0.93	0.05
2004	0.39	0.14	0.9	0.05	0.92	0.06
2005	0.37	0.16	0.9	0.07	0.91	0.07

**Table C13.** SB model selection table for Regehr 2006.

Rank	Survival	Recapture	np	QAIC	$w_i$
1	$\varphi([a1,a234])$	$p(\text{agency}^*+\text{radio})$	6	1,076.73	0.18
2	$\varphi([a1+\{[a234]\times\text{sex}\}])$	$p(\text{agency}^*+\text{radio})$	7	1,077.20	0.14
3	$\varphi([a1,a234]+ice^{j, \varphi^{j+1}})$	$p(\text{agency}^*+\text{radio})$	7	1,077.54	0.12
4	$\varphi([a1,a234]+\text{linear})$	$p(\text{agency}^*+\text{radio})$	7	1,077.73	0.11
5	$\varphi([a1,a234]+ice^{j, \varphi_j})$	$p(\text{agency}^*+\text{radio})$	7	1,077.86	0.10
6	$\varphi(\{a1 \times ice^{j, \varphi^{j+1}}\}+[a234])$	$p(\text{agency}^*+\text{radio})$	7	1,078.53	0.08
7	$\varphi(\{a1 \times \text{linear}\}+[a234])$	$p(\text{agency}^*+\text{radio})$	7	1,078.64	0.07
8	$\varphi(\{a1 \times ice^{j, \varphi_j}\}+[a234])$	$p(\text{agency}^*+\text{radio})$	7	1,078.65	0.07
9	$\varphi([a1, a2, a34])$	$p(\text{agency}^*+\text{radio})$	7	1,078.68	0.07
10	$\varphi([a1+\{[a2a3a4]\times\text{sex}\}])$	$p(\text{agency}^*+\text{radio})$	9	1,080.56	0.03
11	$\varphi[a1a2a3a4]$	$p(\text{agency}^*+\text{radio})$	8	1,080.65	0.03
12	$\varphi([a12,a34])$	$p(\text{agency}^*+\text{radio})$	6	1,082.15	0.01
13	$\varphi([a1,a2,a34]+\text{trans})$	$p(\text{agency}^*+\text{radio})$	8	1,080.68	NA <sup>a</sup>
14	$\varphi([a1,a2,a3,a4]+t)$	$p(\text{agency}^*+\text{radio})$	10	1,082.74	NA <sup>a</sup>
15	$\varphi([a1,a234]+ice^{j, \varphi^{j+1}})$	$p(\text{radio})$	5	1,083.68	0.01

<sup>a</sup>Models No. 13 and 14 were excluded from model averaging due to estimability problems.

**Table C14.** Parameter estimates of QAIC<sub>c</sub> top ranked NB and SB models.

Parameter	NB Original		NB Shifted	
Survival	Estimate	SE	Estimate	SE
<b>(Intercept)</b>	2.330	0.252	2.360	0.241
<b>age0</b>	-2.330	0.734	-2.320	0.684
<b>age1</b>	-3.080	0.595	-2.740	0.587
<b>age4</b>	-2.020	0.544	-2.010	0.558
<b>age234.sex</b>	-0.740	0.323	-0.740	0.300
<b>age0.rsf.centered</b>	2.690	2.324	-	-
<b>rsf.centered</b>	-	-	0.000285	NA
<b>Recapture</b>				
<b>(Intercept)</b>	-2.370	0.169	-3.320	0.177
<b>radio.vhf</b>	1.180	0.611	1.170	0.616
<b>radio.sat</b>	2.540	0.755	2.550	0.670
<b>age34.sex</b>	0.360	0.258	0.490	0.230
<b>effort.2</b>	-1.160	0.234	-	-
<b>flight.1000km</b>	-	-	0.110	0.018
<b>Population Estimate</b>				
<b>2004</b>	1223	196.5	1621	228.2
<b>2005</b>	1377	220.5	1533	227.5
<b>2006</b>	693	127.8	2059	401.4
<b>Mean</b>	1098		1738	
Survival	SB Original		SB Shifted	
<b>ds4.age.1</b>	-0.190	0.489	-0.390	0.483
<b>ds4.age.234</b>	2.000	0.674	1.940	0.636
<b>ds4.age.234.female</b>	0.930	1.210	0.940	1.175
<b>Recapture</b>				
<b>(Intercept)</b>	-2.050	0.196	-2.130	0.206
<b>ds4.age.34.male</b>	0.540	0.284	0.660	0.305
<b>ds4.agency</b>	0.410	0.240	0.560	0.305
<b>ds4.agency.cws.2006</b>	-1.320	0.372	-1.010	0.457
<b>ds4.radio</b>	1.900	0.258	2.000	0.266
<b>Population Estimate</b>				
<b>2004</b>	1776	246.8	1411	217.6
<b>2005</b>	1496	215.0	1134	178.4
<b>2006</b>	1755	415.6	1241	272.7
<b>Mean</b>	1676		1262	

**Table C15.** NB boundary shift models with 2006 probability of capture ( $\hat{p}$ ) for the seven top ranked AIC models (within five units of minimum AIC).

Rank	Survival	Recapture	$\hat{p}$	$s\hat{e}(\hat{p})$	$\hat{p}$	$s\hat{e}(\hat{p})$	$\hat{p}$	$s\hat{e}(\hat{p})$	$\hat{N}$	$s\hat{e}(\hat{N})$
			Females	Male	Age01					
1	$\varphi$ (age0 + age1 + age4 + age234.sex + rsf)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	0.0349	0.006	0.056	0.011	-	-	2,059	401
2	$\varphi$ (age0 + age1 + age4 + age234.sex + rsf + age0.rsfs)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	0.0355	0.006	0.055	0.011	-	-	2,029	394
3	$\varphi$ (age0 + age1 + age4 + age234.sex + rsf + age0.rsfs + age1.rsfs)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	0.0356	0.0059	0.056	0.011	-	-	2,019	387
4	$\varphi$ (age01 + age2 + age4 + age234.sex )	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	0.0363	0.0064	0.058	0.012	-	-	1,977	393
5	$\varphi$ (yr70s + yr80s + age01 + age2 + age4 + age234.sex)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	0.0366	0.0064	0.056	0.011	-	-	1,972	390
6	$\varphi$ (age0 + age1 + age4 + age234.sex + PMIce + age0.PMIce)	p(radio.vhf + radio.sat + age34.sex + flight.1000km )	0.0370	0.0067	0.059	0.012	-	-	1,942	391
7	$\varphi$ (age01 + age2 + age4 + age234.sex)	p(radio.vhf + radio.sat + age01 + age34.sex + flight.1000km)	0.0357	0.0065	0.058	0.012	0.061	0.033	1,738	382
<b>Mean</b>			0.0359		0.0568		0.0610		1,962	