USGS
science for a changing world

Supplemental Materials for the Analysis of Capture-Recapture Data for Polar Bears in Western Hudson Bay, Canada, 1984–2004

Data Series 304

U.S. Department of the Interior
U.S. Geological Survey

Supplemental Materials for the Analysis of Capture-Recapture Data for Polar Bears in Western Hudson Bay, Canada, 1984–2004

By Eric V. Regehr, Nicholas J. Lunn, Steven C. Amstrup, and Ian Stirling

Data Series 304

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

Contents

Tables

Supplemental Materials for the Analysis of Capture-Recapture Data for Polar Bears in Western Hudson Bay, Canada, 1984–2004

By Eric V. Regehr, Nicholas J. Lunn, Steven C. Amstrup, and Ian Stirling

Abstract

Regehr and others (2007, *Survival and population size of polar bears in western Hudson Bay in relation to earlier sea ice breakup*: Journal of Wildlife Management, v. 71, no. 8, p. 2673-2683) evaluated survival in relation to climatic conditions and estimated population size for polar bears (*Ursus maritimus*) in western Hudson Bay, Canada. Here, we provide supplemental materials for the analyses in Regehr and others (2007). We demonstrate how tag-return data from harvested polar bears were used to adjust estimates of total survival for human-caused mortality. We describe the sex and age composition of the capture and harvest samples, and provide results for goodness-of-fit tests applied to capture-recapture models. We also describe the capture-recapture model selection procedure and the structure of the most supported model, which was used to estimate survival and population size.

Introduction

Longer term and more consistent demographic data are available for the Western Hudson Bay (WH) polar bear population than for any other polar bear population in the world. Recently, Regehr and others (2007) analyzed capture-recapture data for the WH population collected from 1984 to 2004 under two sampling protocols. The Canadian Wildlife Service (CWS) captured free-ranging polar bears along the western coast of Hudson Bay. The Manitoba Department of Conservation (MDOC) captured problem bears in and around the community of Churchill, Manitoba, Canada. Regehr and others (2007) used Cormack-Jolly-Seber (CJS) type models to estimate survival, investigate the relationships between survival and sea ice conditions, and estimate the size of the WH population. This report provides supplemental materials that were not included directly in Regehr and others (2007) due to space limitations in the journal.

Natural Survival

Polar bears from the WH population were harvested as part of an annual, regulated hunt by Inuit along the Nunavut coast of western Hudson Bay. We estimated natural apparent survival (φ^N) by adjusting the CJS estimates of total apparent survival (φ) using tag-return data from the harvest. For each sex and age class in the most supported CJS model for the combined CWS and MDOC data, we estimated natural apparent survival using the formula:

$$\hat{\varphi}_j^N = \hat{\varphi}_j / \left(1 - H_j / \hat{M}_j^*\right);$$

where

H_j is the number of research-marked polar bears killed in the Nunavut harvest following sampling by the CWS and MDOC in year j,

$\hat{M}_j^* = m_j / \hat{p}_j - m_j + R_j$ is the estimated number of marked polar bears in the WH population after sampling occasion j,

m_j is the number of marked polar bears captured at sampling occasion j, and

R_j is the number of marked polar bears released at sampling occasion j.

We could not estimate $\mathrm{var}\left(\hat{\varphi}^N\right)$ using the methods of Taylor and others (2002) due to the complexity of the most supported model. We approximated average φ^N by constraining the annual estimates to [0, 1] and taking the arithmetic mean. Our approach was based on the assumption of additive mortality, because evidence is lacking for compensatory mortality among polar bears (Derocher and Taylor, 1994) and because the WH population appears to be declining despite a harvest that was thought to be sustainable. If density-dependent effects were compensating for harvest mortality, our estimates of φ^N could be biased high.

Sex and Age Composition

We used standard regression techniques to describe trends in the sex and age composition of the CWS, MDOC, and Nunavut harvest samples (for example, Zar, 1996; Hosmer and Lemeshow, 2000). The proportion of females (table 1) was stable with time for the CWS capture sample (logistic regression 5-year period model versus. time-constant model; $G = 4.07$, df = 3, $P = 0.25$) and for the Nunavut harvest sample ($G = 4.72$, df = 3, $P = 0.19$). The proportion of females in the MDOC sample varied among years ($G = 14.30$, df = 3, $P < 0.001$), with a trend toward a higher proportion of females (logistic regression on the proportion of females; linear trend model versus time-constant model, $G = 9.24$, df = 1, $P = 0.002$).

Table 1.   Proportion of females among polar bears captured by the Canadian Wildlife Service (CWS) and Manitoba Department of Conservation (MDOC), and all polar bears harvested along the Nunavut coast of western Hudson Bay, 1984–2004.

Years	CWS	MDOC	Harvest
1984-1988	0.51	0.38	0.32
1989-1993	0.54	0.35	0.27
1994-1998	0.53	0.46	0.24
1999-2004[1]	0.50	0.47	0.38

[1]Harvest data available through 2003 only.

Age class composition (table 2) was relatively stable with time for the CWS capture sample (4×4 contingency table for 5-year periods; $\chi^2 = 15.17$, df = 9, $P = 0.09$). The age class composition of the MDOC sample varied among years ($\chi^2 = 25.21$, df = 9, $P = 0.003$), but there was no apparent trend. We described the age structure of the Nunavut harvest using research-marked polar bears only, because some ages were unknown for polar bears without a previous research capture. The age class composition of marked polar bears in the harvest varied among years ($\chi^2 = 25.42$, df = 9, $P = 0.003$), with a trend towards fewer subadults (logistic regression on the proportion of subadults; linear trend model versus time-constant model, $G = 7.23$, df = 1, $P = 0.007$).

Table 2.   Proportions of juveniles (0-1 years), subadults (2-4 years), prime-adults (5-19 years), and senescent-adults (≥20 years) among polar bears captured by the Canadian Wildlife Service (CWS) and Manitoba Department of Conservation (MDOC), and research-marked polar bears harvested along the Nunavut coast of western Hudson Bay, 1984–2004.

[Juv, juvenile; Subad, subadult; Prime-ad, prime-adult; Senescent-ad, senescent-adult]

	Years	Juv	Subad	Prime-ad	Senescent-ad
CWS	1984-1988	0.26	0.16	0.50	0.08
	1989-1993	0.27	0.14	0.49	0.09
	1994-1998	0.28	0.20	0.44	0.08
	1999-2004	0.27	0.15	0.49	0.09
MDOC	1984-1988	0.25	0.33	0.37	0.05
	1989-1993	0.18	0.48	0.27	0.07
	1994-1998	0.28	0.40	0.27	0.04
	1999-2004	0.29	0.36	0.29	0.06
Harvest	1984-1988	0.16	0.56	0.23	0.05
	1989-1993	0.06	0.46	0.43	0.06
	1994-1998	0.08	0.38	0.43	0.11
	1999-2003	0.13	0.38	0.34	0.15

In the CWS capture sample, the age of adult females (table 3) increased from 1984 to 1993 (linear regression; $\hat{\beta} = 0.27$, $\widehat{SE}(\hat{\beta}) = 0.09$, $P = 0.003$) and was stable from 1994 to 2004 ($\hat{\beta} = 0.06$, $\widehat{SE}(\hat{\beta}) = 0.12$, $P = 0.64$). The age of adult males varied among years, but there was not a significant linear ($\hat{\beta} = -0.03$, $\widehat{SE}(\hat{\beta}) = 0.03$, $P = 0.35$) nor quadratic ($F = 2.39$, df = 2, $P = 0.09$) trend. The age of adult females in the MDOC sample was stable from 1984 to 2004 ($\hat{\beta} = 0.05$, $\widehat{SE}(\hat{\beta}) = 0.07$, $P = 0.47$), while the age of adult males decreased ($\hat{\beta} = -0.14$, $\widehat{SE}(\hat{\beta}) = 0.05$, $P = 0.007$). The age of marked adult females in the Nunavut harvest increased from 1984 to 2003 ($\hat{\beta} = 0.54$, $\widehat{SE}(\hat{\beta}) = 0.18$, $P = 0.004$), while the age of marked adult males was stable ($\hat{\beta} = 0.13$, $\widehat{SE}(\hat{\beta}) = 0.10$, $P = 0.22$).

Table 3.   Mean ages of adult polar bears (age ≥ 5 years) captured by the Canadian Wildlife Service (CWS) and Manitoba Department of Conservation (MDOC), and research-marked polar bears harvested along the Nunavut coast of western Hudson Bay, 1984–2004.

[F, female; M, male]

Years	CWS		MDOC		Harvest	
	F	M	F	M	F	M
1984-1988	12.4	12.4	12.5	12.0	12.8	11.6
1989-1993	13.5	12.6	14.1	11.6	12.1	11.3
1994-1998	13.7	13.1	14.5	10.0	19.0	13.0
1999-2004[1]	13.9	11.6	13.5	9.8	18.4	13.6

[1]Harvest data available through 2003 only.

Goodness of Fit

Assessment of goodness-of-fit is an important precursor to capture-recapture modeling (Cooch and White, 2005). Program RELEASE uses three contingency table components (TEST3.SR, TEST3.Sm, and TEST2.C) to compare the observed versus expected number of captures within categories that are designed to test the assumptions of the standard CJS model (Burnham and others, 1987). The standard CJS model allows survival probability (φ) and recapture probability (p) to vary independently with time and is denoted $\varphi(t)\,p(t)$. At each sampling occasion (year), we evaluated the significance and directionality of the program RELEASE components for sex- and age-based subsets of the WH capture-recapture data (Choquet and others, 2005). We also considered the interrelation of the components with regard to common assumption violations, such as temporary trap response (Pradel, 1993) and transience (that is, permanent emigration following initial capture; Pradel and others, 1997).

The CWS data for male polar bears did not fit model $\varphi(t)\,p(t)$ (overall $\chi^2_{118} = 166.08$, $P = 0.002$), due to lack of fit in TEST3.SR. The male data achieved an acceptable fit when partitioned into prime-adult versus other age classes (combined TEST3.SR $\chi^2_{38} = 37.18$, $P = 0.51$). The female data fit model $\varphi(t)\,p(t)$ marginally well (overall $\chi^2_{125} = 150.19$, $P = 0.06$). We started the CJS analysis with a model that allowed φ and p to vary with time for four independent strata: female prime-adults, male prime-adults, females of other ages, and males of other ages. This general model, denoted $\varphi^{a3}(t \times s)\,\varphi^{a124}\left\{(t + [a1, a24]) \times s\right\}\quad p(t \times [a124, a3] \times s)$, also allowed for an additive effect in φ between juveniles and an aggregate subadult and senescent-adult age class. Model notation is described in section, 'Capture-Recapture Analysis'.

The combined CWS and MDOC data for male polar bears did not fit model $\varphi(t)\,p(t)$ (overall $\chi^2_{126} = 255.13$, $P < 0.001$), due to significance in TEST3.SR and TEST2.C. The male data achieved an acceptable fit when partitioned into prime-adult vs. other age classes (combined TEST3.SR $\chi^2_{38} = 38.76$, $P = 0.44$; combined TEST2.C $\chi^2_{76} = 66.84$, $P = 0.76$). The lack of fit for males likely was due to the preponderance of young males in the harvest, as suggested by previous studies (Derocher and Stirling 1995, Lunn and others, 1997). The combined CWS and MDOC data for females fit model $\varphi(t)\,p(t)$ reasonably well (overall $\chi^2_{134} = 153.34$, overall $P = 0.12$).

Violation of the CJS assumption of independent fates should not introduce bias into parameter estimates, but may affect model selection and lead to an overstatement of estimator precision (Burnham and Anderson, 2002). To investigate whether extended maternal care in polar bears (Derocher and Stirling, 1996) resulted in a significant lack of independence, we estimated an ancillary, biological value of the variance inflation factor ($\hat{c}$) using the formula $\hat{c} = n / (n - n_c)$; where n is the total number of captures, and n_c is the number of captures of dependent cubs (Taylor and others, 2002). The biological $\hat{c}$ of 1.3 suggested that potential overdispersion due to dependent fates was minor. We used $\hat{c} = 1.0$ in our modeling, based on the program RELEASE indication of $\hat{c} < 1.0$ for both the CWS-only and combined data.

Capture-Recapture Analysis

Model notation. —We extended the CJS notation of Lebreton and others (1992) to allow for the specification of more complex models. We considered four age classes: juveniles (0-1 years; denoted $a1$), subadults (2-4 years; $a2$), prime-adults (5-19 years; $a3$), and senescent-adults ($\geq$20 years; $a4$). We denoted combinations of age classes using the letter a followed by several integers. For example, an aggregate age class comprising juveniles ($a1$) and subadults ($a2$) is written $a12$. Overall age structure is written within square brackets. For example, model $\varphi\left(t \times [a12, a3, a4]\right)$ estimates values of φ_j that vary independently with time for the age classes $a12$, $a3$, and $a4$. We partitioned survival notation into prime-adult versus other age classes, which made it easier to interpret models with different types of interannual variation for the two groups. For example, in the model $\varphi^{a3}(s)\,\varphi^{a124}(t+s)$, prime-adult survival ($\varphi^{a3}$) is time constant and varies by sex; survival of other age classes (φ^{a124}) varies additively by time and sex. We denoted combinations of interactive ($\times$) and additive ($+$) effects using nested brackets. For example, model $\varphi\left\{\left(t + [a12, a3, a4]\right) \times s\right\}$ has full time $\times$ sex and age class $\times$ sex interactions, but is additive in time and age class. We denoted effects that only apply to certain age classes using the symbol •. For example, model $\varphi\left(trap' \bullet a24\right)$ includes the capture history dependence covariate *trap'* for subadults and senescent-adults ($a24$), but not for juveniles or prime-adults. Sex effects in the most supported model required special notation. In the survival parameterization, the symbol *s** denotes a common sex effect for prime-adults and other age classes. Therefore, female and male φ differ by the same constant for all polar bears, even though notation for the survival model was

otherwise partitioned by age. In the recapture parameterization, the symbol *s'* denotes an additive sex effect with two levels: female and male *p* differed by one constant from 1985 to 1995 and by another constant from 1996 to 2004.

  Model fitting.—We estimated survival and population size from the most supported model for the combined CWS and MDOC data, which contained 31 parameters and was denoted

$$\varphi^{a3}(s*)\,\varphi^{a124}\left\{ice+[a1,a2,a4]+s*+(trap\text{'}\bullet[a24])\right\}\quad p\left\{t+s\text{'}+(trap\text{'}\times[a12,a34])\right\}.$$ In this model, survival was time constant for prime-adults, and varied as a function of the date of spring sea ice breakup in the WH management area (the environmental covariate *ice*) for polar bears of other ages. Survival of juvenile, subadult, and senescent-adult polar bears differed by additive age effects. Survival of females and males differed by an additive sex effect that was common to polar bears of all ages. Following capture in Churchill, survival of subadult and senescent-adult polar bears changed by a permanent, additive effect (i.e., the time-dependent individual covariate *trap'*).

  Recapture probabilities in the most supported model were time dependent for all polar bears. Recapture probabilities of females and males differed by an additive sex effect that differed in magnitude for 1985–95 versus 1996–2004. Following capture in Churchill, recapture probabilities of all polar bears changed by a permanent, additive effect (*trap'*) that differed for juveniles and subadults versus prime-adults and senescent-adults. Although permanent capture history dependence was universally denoted as *trap'*, the values of this covariate were estimated independently within the parameterizations for *φ* and *p*.

  We derived the most supported CJS model in several steps. Because the complexity of the analysis made it impractical to define an all-inclusive candidate model set (for example, Lebreton and others, 1992, Norman and others, 2004, Muths and others, 2006), we began by modeling the CWS-only data using a flexible approach that sequentially identified suitable parameterizations for separate parts of the model. We modeled *p* first (table 4) because we expected a simple parameterization that was primarily a function of study design and because the robust estimation of *p* is critical when estimating population size (Pollock and others, 1990). We also wanted to minimize the chance of confounding effects in *φ* and *p*. We then modeled *φ* sequentially for prime-adults, followed by other age classes (table 5). This limited the number of interactions between age, sex, and types of interannual variation, allowing us to focus on important biological hypotheses. Finally, we extended the CJS analysis to the combined CWS and MDOC data and evaluated all reasonable forms of capture history dependence associated with capture around Churchill (table 6). This approach assumed that the structure of the most

supported model for the CWS-only data was sufficiently general to represent key biological (φ) and study design (p) effects for the entire WH population, and that potential differences in φ and p associated with CWS versus MDOC sampling protocols could be modeled as additive capture history dependence. These assumptions were corroborated by the goodness-of-fit analysis, which did not identify any unmanageable heterogeneity in the combined data, and by strong support within the data for the hypothesized forms of capture history dependence. We derived final parameter estimates from a single model because model-averaging was not appropriate without an all-inclusive candidate model set, and because model selection uncertainty was low with respect to the most important effects (that is, parameter estimates were similar for models with similar support in the data [Buckland and others, 1997]).

Table 4.   Selected recapture probability (p) models fitted to capture data for polar bears collected by the Canadian Wildlife Service, 1984–2004.

[We modeled p as a function of time (t), capture effort (*effort*), sex (s), an additive sex function with different effects for 1985–95 versus 1996–2004 (s'), and the age classes $a1$ (juveniles, 0-1 years), $a2$ (subadults, 2-4 years), $a3$ (prime-adults, 5-19 years), and $a4$ (senescent-adults, $\geq$20 years). All models had the general survival parameterization $\varphi^{a3}(t \times s) \quad \varphi^{a124}\{(t+[a1,a24]) \times s\}$. AIC$_c$ = Akaike's information criterion adjusted for small sample size; ΔAIC$_c$ = difference in AIC$_c$ relative to the most supported model in table 4; w_i = normalized Akaike weight relative to models in table 4; np = number of estimated parameters]

Model	np	AIC$_c$	ΔAIC$_c$	w_i	Description
$p(t \times [a124, a3] \times s)$	137	8936.31	40.79	0.00	**General p model.** F and M p vary independently by time for two independent age classes. Age classes have different sex effects.
$p(t \times [a12, a34] \times s)$	136	8939.31	43.79	0.00	F and M p vary independently by time for two independent age classes. The age classes have different sex effects.
$p\{(t + [a12, a34]) \times s\}$	102	8909.37	13.85	0.00	F and M p vary independently by time for two additive age classes. Age classes have different sex effects.
$p(t \times s)$	100	8905.52	10.00	0.01	F and M p vary independently by time.
$p(t + s)$	87	8918.98	23.46	0.00	F and M p vary additively by time.
$p(t + s')$	85	8895.52	0	0.99	**Most supported p model.** F and M p vary additively by time, with different sex effects for 1985–95 versus 1996–2004.
$p(effort \times s)$	71	8957.97	62.45	0.00	F and M p are independent functions of *effort*.
$p(t)$	84	8937.30	41.78	0.00	p varies by time.
$p(s)$	67	8985.99	90.47	0.00	F and M p are constant by time.

Table 5.   Selected survival probability (φ) models fitted to capture data for polar bears collected by the Canadian Wildlife Service, 1984–2004.

[We modeled φ as a function of time (t), ice breakup date in the current year (ice), ice breakup date in the previous year (ice'), 3-year running mean of ice breakup date (ice''), and a linear trend ($linear$); as well as sex and age effects. All models have the most supported recapture parameterization $p(t+s')$. AICc = Akaike's information criterion adjusted for small sample size; ΔAIC_c = difference in AIC$_c$ to the most supported model in the relevant section of table 5; w_i = normalized Akaike weight relative to models in the relevant section of table 5; np = number of estimated parameters; Prime-ad, prime-adult; Senescent-ad, senescent-adult; F, female; M, male]

Model	np	AIC$_c$	ΔAIC_c	w_i	Description
Model φ for prime-ad (descriptions apply to prime-ad only); retain the general φ parameterization for juv, subad, and senescent-ad.					
$\varphi^{a3}(t \times s)$ $\varphi^{a124}\{(t+[a1,a24]) \times s\}$	85	8895.52	11.15	0.00	**General φ model.** For prime-ad, F and M φ vary independently by time. For other ages, F and M φ vary independently by time for two additive age classes. Age classes have different sex effects.
$\varphi^{a3}(t+s)$ $\varphi^{a124}\{(t+[a1,a24]) \times s\}$	78	8904.55	20.18	0.00	F and M φ vary additively by time.
$\varphi^{a3}(s)$ $\varphi^{a124}\{(t+[a1,a24]) \times s\}$	62	8884.37	0.00	0.78	F and M φ are constant by time.
$\varphi^{a3}(ice \times s)$ $\varphi^{a124}\{(t+[a1,a24]) \times s\}$	64	8887.01	2.64	0.21	F and M φ are independent functions of ice.
$\varphi^{a3}(.)$ $\varphi^{a124}\{(t+[a1,a24]) \times s\}$	60	8892.46	8.09	0.01	φ is constant by time.
Model φ for juv, subad, and senescent-ad (descriptions apply to these ages only); retain the most supported φ parameterization for prime-ad.					
$\varphi^{a3}(s)$ $\varphi^{a124}\{(t+[a1,a2,a4]) \times s\}$	64	8878.04	11.48	0.00	F and M φ vary independently by time for three additive age classes. Age classes have different sex effects.
$\varphi^{a3}(s)$ $\varphi^{a124}(t+[a1,a2,a4]+s)$	47	8879.23	12.67	0.00	F and M φ vary additively by time for three additive age classes. Age classes have the same sex effect.
$\varphi^{a3}(s)$ $\varphi^{a124}([a1,a2,a4]+s)$	28	8877.47	10.91	0.00	F and M φ are constant by time for three age classes. Age classes have the same sex effect.
$\varphi^{a3}(s)$ $\varphi^{a124}(ice \times [a1,a2,a4] \times s)$	36	8873.28	6.72	0.02	F and M φ are independent functions of ice for three independent age classes. Age classes have different sex effects.
$\varphi^{a3}(s)$ $\varphi^{a124}(ice+[a1,a2,a4]+s)$	29	8868.17	1.61	0.30	F and M φ are additive functions of ice for three additive age classes. Age classes have the same sex effect.
$\varphi^{a3}(s)$ $\varphi^{a124}(ice'+[a1,a2,a4]+s)$	29	8877.12	10.56	0.00	F and M φ are additive functions of ice' for three additive age classes. Age classes have the same sex effect.
$\varphi^{a3}(s)$ $\varphi^{a124}(ice''+[a1,a2,a4]+s)$	29	8875.06	8.50	0.01	F and M φ are additive functions of ice'' for three additive age classes. Age classes have the same sex effect.
$\varphi^{a3}(s)$ $\varphi^{a124}(linear+[a1,a2,a4]+s)$	29	8879.74	13.18	0.00	F and M φ are additive functions of $linear$ for three additive age classes. Age classes have the same sex effects.
$\varphi^{a3}(s)$ $\varphi^{a124}(ice+[a1,a2,a4])$	28	8877.10	10.54	0.00	φ is a function of ice for three additive age classes.
$\varphi^{a3}(s*)$ $\varphi^{a124}(ice+[a1,a2,a4]+s*)$	28	8866.56	0	0.66	**Most supported φ model.** For prime-ad, F and M φ are constant by time. For other ages, F and M φ are additive functions of ice for three additive age classes. All age classes have the same sex effect.
$\varphi^{a34}(s*)$ $\varphi^{a12}(ice+[a1,a2]+s*)$	27	8945.77	79.21	0.00	For prime-ad and senescent-ad combined, F and M φ are constant by time. For other ages, F and M φ are additive functions of ice for two additive age classes. All age classes have the same sex effect.

Table 6. Selected models including capture history dependence (CHD), fitted to capture data for polar bears collected by the Canadian Wildlife Service and the Manitoba Department of Conservation (MDOC), 1984–2004.

[We modeled temporary (*trap*) and permanent (*trap'*) CHD following capture around Churchill by the MDOC, and all reasonable sex and age interactions. Parameterizations for CHD in recapture probabilities were evaluated retaining the general CHD survival parameterization $\varphi^{a3}\left(s*+trap'\right)\varphi^{a124}\left\{ice+\left[a1,a2,a4\right]+s*+\left(trap'\times\left[a1,a2,a4\right]\right)\right\}$. AIC_c = Akaike's information criterion adjusted for small sample size; ΔAIC_c = difference in AIC_c to the most supported model in the relevant section of table 6; w_i = normalized Akaike weight relative to models in the relevant section of table 6; np = number of estimated parameters.

Model	np	AIC_c	ΔAIC_c	w_i	Description
Model CHD in *p*; retain the general CHD *φ* parameterization.					
$p\left\{t+s'+\left(trap'\times\left[a1,a2,a3,a4\right]\times s\right)\right\}$	40	11954.06	9.57	0.01	**General model for CHD in *p*.** Permanent CHD independent for F and M for four independent age classes.
$p\left\{t+s'+\left(trap'\times\left[a1,a2,a3,a4\right]\right)\right\}$	36	11947.27	2.78	0.17	Permanent CHD for four independent age classes.
$p\left\{t+s'+\left(trap\times\left[a1,a2,a3,a4\right]\right)\right\}$	36	11984.68	40.19	0.00	Temporary CHD for four independent age classes.
$p\left\{t+s'+\left(trap'\times\left[a12,a34\right]\right)\right\}$	34	11944.49	0.00	0.68	**Most supported model for CHD in *p*.** Permanent CHD for two independent age classes.
$p\left\{t+s'+\left(trap'\times\left[a1234\right]\right)\right\}$	33	11948.80	4.31	0.08	Permanent CHD for one inclusive age class.
$p\left\{t+s'+\left(trap'\bullet\left[a12\right]\right)\right\}$	33	12022.28	77.79	0.00	Permanent CHD for one non-inclusive age class.
$p\left\{t+s'+\left(trap\bullet\left[a12\right]\ \&\ trap'\bullet\left[a34\right]\right)\right\}$	34	11949.21	4.72	0.00	Temporary CHD for one non-inclusive age class; permanent CHD for one non-inclusive age class.
$p\left(t+s'\right)$	32	12071.46	126.97	0.00	No CHD in *p*.
Model CHD in *φ*; retain the most supported CHD *p* parameterization.					
$\varphi^{a3}\left(s*+trap'\right)\varphi^{a124}\left\{ice+\left[a1,a2,a4\right]+s*+\left(trap'\times\left[a1,a2,a4\right]\right)\right\}$	34	11944.49	4.64	0.05	Permanent CHD for four independent age classes.
$\varphi^{a3}\left(s*\right)\varphi^{a124}\left\{ice+\left[a1,a2,a4\right]+s*+\left(trap'\times\left[a1,a2,a4\right]\right)\right\}$	33	11942.62	2.77	0.14	Permanent CHD for three independent, non-inclusive age classes.
$\varphi^{a3}\left(s*\right)\varphi^{a124}\left\{ice+\left[a1,a2,a4\right]+s*+\left(trap'\bullet\left[a2,a4\right]\right)\right\}$	32	11941.40	1.55	0.25	Permanent CHD for two independent, non-inclusive age classes.
$\varphi^{a3}\left(s*\right)\varphi^{a124}\left\{ice+\left[a1,a2,a4\right]+s*+\left(trap'\bullet\left[a24\right]\right)\right\}$	31	11939.85	0.00	0.55	**Most supported model for CHD in *φ*.** Permanent CHD for one non-inclusive age class.
$\varphi^{a3}\left(s*\right)\quad\varphi^{a124}\left(ice+\left[a1,a2,a4\right]+s*\right)$	30	11951.13	11.28	0.00	No CHD in *φ*.

Summary

This report provides supplementary materials for an analysis of capture-recapture data for polar bears in western Hudson Bay. We presented methods of estimating natural survival. We described the capture samples and provided results for goodness-of-fit tests. We also described the model selection procedure and the structure of the final model that was used for inference.

References Cited

Buckland, S.T., Burnham, K.P., and Augustin, N.H., 1997, Model selection: an integral art of inference: Biometrics, v. 53, p. 603-618.

Burnham, K.P., and Anderson, D.R., 2002, Model selection and multimodel inference: 2nd edition, Springer-Verlag, New York, New York, USA.

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C., and Pollock, K.H., 1987, Design and analysis methods for fish survival experiments based on release–recapture: American Fisheries Society Monograph 5, Bethesda, Maryland, USA.

Choquet, R., Reboulet, A.M., Lebreton, J.D., Gimenez, O., and Pradel, R., 2005, U-CARE 2.2 User's Manual: CEFE, Montpellier, France. Available from ftp://ftp.cefe.cnrs-mop.fr/biom/Soft-CR/.

Cooch, E., and White, G.C., 2005, Program MARK: a gentle introduction: 5th edition. http://www.phidot.org/software/mark/docs/book/. Accessed August 22, 2006.

Derocher, A.E., and Stirling, I., 1995, Estimation of polar bear population size and survival in Western Hudson Bay: Journal of Wildlife Management, v. 59, no. 2, p. 215-221.

Derocher, A.E., and Stirling, I., 1996, Aspects of survival in juvenile polar bears: Canadian Journal of Zoology, no. 74, p. 1246–1252.

Derocher, A.E., and Taylor, M., 1994, Density-dependent population regulation of polar bears *in* Taylor, M. (ed.), Density-Dependent Population Regulation of Black, Brown, and Polar Bear: 9th International Conference on Bear Research and Management, Monograph 3, p. 25-37.

Hosmer, D.W., and Lemeshow S., 2000, Applied logistic regression. John Wiley and Sons, New York, New York, USA.

Lebreton, J.-D., Burnham, K.P. , Clobert, J., and Anderson, D.R., 1992, Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies: Ecological Monographs, v. 62, p. 67–118.

Lunn, N.J., Stirling, I., Andriashek, D., and Kolenosky, G.B., 1997, Reestimating the size of the polar bear population in Western Hudson Bay: Arctic, v. 50, p. 234–240.

Muths, E., Scherer, R.D., Corn, P.S., and Lambert, B.A., 2006, Estimation of temporary emigration in male toads: Ecology, v. 87, no. 4, p. 1048-1056.

Norman, G.C., Conner, M.M., Pack, J.C., and White, G.C., 2004, Effects of fall hunting on survival of male wild turkeys in Virginia and West Virginia: Journal of Wildlife Management, v. 68, no. 2, p. 393-404.

Pollock, K.H., Nichols, J.D., Hines, J.E., and Brownie C., 1990, Statistical inference for capture–recapture experiments: Wildlife Monographs 107.

Pradel, R., 1993, Flexibility in survival analysis from recapture data: handling trap-dependence *in* Lebreton, J.-D., and Nichols, J.D. (eds.), Marked individuals in the study of bird populations: Birkhauser Verlag, Basel, Switzerland, p. 29-37.

Pradel, R., Hines, J.E., Lebreton, J.-D., and Nichols, J.D., 1997, Capture-recapture survival models taking account of transients: Biometrics, v. 53, p. 60-72.

Regehr, E.V., Lunn, N.J., Amstrup, S.C., and Stirling, I., 2007, Survival and population size of polar bears in western Hudson Bay in relation to earlier sea ice breakup: Journal of Wildlife Management, v. 71, no. 8, p. 2673-2683.

Taylor, M.K., Laake, J., Cluff, H.D., Ramsay, M., and Messier, F., 2002, Managing the risk from hunting for the Viscount Melville Sound polar bear population: Ursus, v. 13, p. 185–202.

Zar, J.H., 1996, Biostatistical analysis: 3rd edition, Prentice Hall, Upper Saddle River, New Jersey, USA.

For more information concerning the research in this report, contact
Director, Alaska Science Center
U.S. Geological Survey
1011 East Tudor Road
Anchorage, Alaska 99503
http://alaska.usgs.gov/