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How many walrus are there in the Hudson Bay-Davis Strait stock?

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

A Bayesian surplus production model was fitted to aerial survey estimates of abundance (n = 10) and reported harvests of walruses from the Hudson Bay-Davis Strait (HBDS) stock from 1954–2017. Model fit was poor, owing to the high abundance estimate resulting from the most recent survey conducted in 2017. Modelling exercises to explore possible reasons for the high estimate in 2017 included higher than assumed proportion of animals hauled out during the survey, as well as an influx of animals moving into Hudson Bay and Hudson Strait from neighbouring regions. Model fit improved when the possibility of mixing of animals between the HBDS and Foxe Basin management stocks was considered, and when the assumed proportion of animals hauled out was increased from 0.3 to 0.8. The survey abundance estimate from 2017 likely reflected one or a combination of these factors. The model-derived abundance estimate for the northern Hudson Bay-Strait component of the stock was 8,200 (95% CI = 5,800–19,700). Adding this to the survey-estimated abundance for walruses along the east coast of Baffin Island (3,900; 95% CI = 2,200–7,200), for which a sufficient time series of abundance estimates for population modelling was unavailable, provided a total HBDS stock abundance estimate of 12,200 (95% CI = 7,000–20,800) in 2017. The estimated potential biological removal (PBR) using this estimate and a recovery factor of 1 was 360 animals. The total annual removal through hunting, after adjusting reported catches for struck-and-loss and non-reporting, is estimated at 137 animals for the HBDS stock.

Key words: walrus, *Odobenus rosmarus*, abundance, Nunavik, Nunavut, harvest.

INTRODUCTION

Two genetically distinct populations of Atlantic walrus (*Odobenus rosmarus rosmarus*) occur in the Canadian Arctic (Shafer et al. 2014). The central Arctic population, whose range encompasses Hudson Bay, Hudson Strait, Foxe Basin and Davis Strait, comprises four largely discrete management stocks based on genetics, distribution, growth patterns, and stable lead isotope ratios: Hudson Bay-Davis Strait (HBDS), South and East Hudson Bay, North Foxe Basin, and Central Foxe Basin, with the latter two managed as one unit (Figure 1; Stewart 2008). Walrus are hunted by Inuit for food and other products throughout their range in Canada, and animals from both populations are also hunted in West Greenland (Born et al. 1995).

The range of the HBDS walrus stock spans 1500 km from northwestern Hudson Bay through Hudson Strait, and extends north along the eastern coast of Baffin Island up to 180 km northwest of Clyde River (Stewart 2008). An unknown portion of this stock moves along the southeastern Baffin Island coast during summer, and overwinters along the coast of Central West Greenland (Dietz et al. 2014). In 2014, an aerial survey covered the northern Hudson Bay-Hudson Strait component of the HBDS stock and resulted in an abundance estimate of 7,147 (SE = 4,122). A more recent survey was flown in 2017, resulting in an abundance estimate of 38,514 (SE = 22,084) for the same area covered by the 2014 survey (Mosnier et al*.* 2023).

The management of marine mammals in Canada is governed by the Fisheries Act, Oceans Act and Species at Risk Act. None of these pieces of legislation specify management objectives. Consequently, marine mammal harvesting in Canada is managed using a patchwork of approaches such as sustainable yield (Nunavik beluga; Hammill et al. 2017), a Precautionary Approach framework with precautionary and reference limit levels (Atlantic seal management, e.g., Hammill and Stenson 2007) and with harvests set using the Potential Biological Removal (PBR) formula (e.g., narwhal, bowhead and walrus; DFO 2015, 2016, Richard 2008). Guidelines have been developed to evaluate whether the stock lends itself to a Data Rich or a Data Poor framework within the context of applying the Precautionary Approach (DFO 2018).

Several surveys of walrus have been completed over the last 61 years in the Hudson Bay-Strait area, and over the last 32 years in Foxe Basin. These surveys have differed in their methods and area covered, and are characterized by large uncertainty associated with estimates. Previously, we have applied a Bayesian population model to provide harvest advice for two stocks of Atlantic walrus in Canada (Hammill et al. 2016). Here, we fitted the same model to the time series of aerial survey estimates, taking into account annual removals via hunting. The most recent abundance estimate from the 2017 survey was much greater than that from 2014, possibly reflecting changes in the proportion of animals hauled out, or immigration of animals from the Foxe Basin management stock. These possibilities were explored assuming:

1. 80% of the population was hauled out during the 2017 survey instead of the assumed 30% that has been used previously (Hammill et al. 2016);
2. mixing occurred between walrus from the Hudson Bay-Davis Strait and Foxe Basin stocks; or
3. a combined scenario where there was movement between the two stocks and 60% of the animals present in the study area were hauled out during the survey.

MATERIALS AND METHODS

A population model was fitted to the aerial survey estimates of abundance for the northern Hudson Bay-Strait component of the HBDS stock, the Foxe Basin stock, and both stocks combined, and incorporated information on harvests from each area (tables 1 and A1; Hammill et al. 2016, Matthews et al. 2018, Mosnier et al. 2023, Stewart et al. 2014). For years with unreported harvest data for a community, we used a 5-year average harvest for that community to interpolate for the missing values (Figure 2).

POPULATION MODEL

A stochastic stock-production model, assuming density dependence acting on the population growth rate, was fitted by Bayesian methods to the aerial survey data (Hammill et al. 2016):

$$N_t = N_{t-1} + N_{t-1}(\lambda_{max} - 1) \cdot \left(1 - (N_{t-1}/K)^{\theta}\right) \cdot \varepsilon_p - R_t$$

where *N* is number of animals at time *t*, λ_{max} is the maximum growth rate, *K* is environmental carrying capacity and *theta* (θ) defines the shape of the density-dependent function. ε_p is a stochastic term for the process error and R_t is the total removals for that year.

Removals were calculated as reported catches, C_t, corrected for the proportion of animals that were struck and lost (*SL*), which includes non-reporting as well:

$$R_t = C_t \cdot (1 + SL)$$

The observation process describes the relationship between true population size and observed data. In our model, survey estimates (S_t) are linked to population size (N_t) by a multiplicative error term ε_{S_t}:

$$\ln(S_t) = \ln(N_t) + \varepsilon_{S_t}$$

Existing information, traditional knowledge and expert opinions were used to formulate prior distributions for the random variables included in the model (Table 2) following Hammill *et al.* (2016). The starting population is not known; the model was provided with a wide range that encompassed the adjusted estimate of walrus from surveys flown in 1954 (Hammill et al. 2016). The maximum rate of increase (λ_{max}) of walrus lies between 7 and 8% (Witting and Born 2005); in the most recent assessments of Pacific walrus in the United States, the default was 8% (U.S. Fish and Wildlife Service 2013). *Theta* was set to 2.39, resulting in maximum productivity at 60% of *K*, which lies within the range identified by Taylor and DeMaster (1993). Reported harvests underestimate the number of walrus killed because of animals wounded or killed but not recovered, as well as an absence of reporting. Taking into account both factors, we set a moderately informative prior with a median value of 0.42 (Table 2).

Posterior estimates of all the parameters were obtained using a Gibbs sampler algorithm implemented in JAGS. Results including mixing of chains and convergence were examined as outlined in Hammill *et al.* (2016).

POTENTIAL BIOLOGICAL REMOVAL

The Potential Biological Removal (PBR) was calculated as:

$$PBR = 0.5 \cdot R_{max} \cdot f \cdot N_{min}$$

where R_{max} is the maximum rate of population increase (set to the default of 8%; see above), *f* is a recovery factor (set to 1; DFO 2018) and N_{min} is the estimated population size using the

20-percentile of the log-normal distribution of the most recent population estimate (Wade 1998). The PBR was applied to the population model estimate of abundance for the northern Hudson Bay-Hudson Strait component of the stock following guidelines established in DFO (2018). For the east Baffin Island component of the stock, there are not enough abundance estimates to fit a population model. The PBR was therefore determined from the aerial survey estimate (Mosnier et al. 2023), as per DFO (2018).

RESULTS

POPULATION MODEL

The 2017 model estimate for the HBDS stock was 8,227 (95% CI = 5,790–19,706) walrus (Table 3). Overall model fit was very poor, with some overlap between the survey confidence intervals and the model credibility intervals, but the median estimate lay outside the model 95% credibility intervals (Figure 3). There was significant updating of the priors for *K* and the starting population, but little updating of the priors for lambda and struck and loss. The posterior for lambda had a median value of 0.077 (95% CI = 0.055–0.106) and a struck and loss of 0.436 (95% CI = 0.117–0.777; Table 3, Figure 3).

The 2017 aerial survey estimate was much higher than one would expect from the dynamics of a walrus population (Mosnier et al. 2023). We examined the possibility that the proportion of the population hauled out in 2017 was much higher than the mean value of 0.3, which is normally applied (Doniol-Valcroze et al. 2016, Hammill et al. 2016) and was used to adjust raw counts of the 2017 survey (Mosnier et al. 2023). Assuming that the proportion of the population hauled out during the 2017 survey was 0.8 instead of 0.3 reduced the survey point estimate from 38,514 (SE = 19,514; Table 1), to 14,443 (SE = 7,318). Compared to the previous run (Table 3; Figure 3), this new scenario resulted in considerable improvement in model fit to the data (Table 4; Figure 4), but little change in abundance, with the modelled 2017 estimate declining from 8,200 to 7,100 (rounded to the nearest 100). There was significant updating of the priors for initial population size and K, with some updating of the priors for lambda and struck and loss (Table 4; Figure 3).

An alternative hypothesis to the higher haulout proportion in 2017 was the possibility that animals from Foxe Basin had moved into the area normally occupied by the HBDS stock. This was modelled as if the northern Hudson Bay-Hudson Strait component of the HBDS stock and the Foxe Basin components formed a single stock. This scenario took into account harvests from the two areas but resulted in a reduction in the number of survey points to which the model could be fitted (Table 1), but there was an improvement in model fit, as the 95% credibility limits from the model showed greater overlap with the 95% confidence intervals from the survey and came close to encompassing the aerial survey estimate for the combined regions of 43,334 walrus (Table 5; Figure 5). There was almost no updating of the priors for lambda and struck and loss (Figure 5).

In the final scenario, it was assumed that there was mixing between the HBDS and Foxe Basin management units and that the proportion of the population hauled out in 2017 was 0.6 (and 0.3 for all other years). This run provided a better fit to the aerial survey data, with the 95% CI encompassing the updated estimate of 21,667 walrus and a more regular pattern to the posteriors for initial population size and *K* (Table 6; Figure 6). There was little updating of the priors for lambda and struck and loss (Table 6; Figure 6).

PBR

The PBR based on the modelled 2017 abundance estimate for the northern Hudson Bay-Strait portion of the HBDS walrus stock (assuming a F_R of 1) was 239. Combined with the PBR estimate for the east Baffin Island component of the HBDS stock (PBR = 121), results in an overal PBR for the HBDS stock of 360 walrus (Table 7).

Reported harvest levels by Canadian communities harvesting from the northern Hudson Bay-Strait component of the HBDS stock have declined from a high of 463 in 1954, to an average of 76 animals over the last five years. Including the east Baffin component, the reported harvest from the HBDS stock has declined from a high of 604 in 1954 to an annual estimated average of 95 animals over the last five years. Assuming a combined struck and loss and non-reporting rate of 44% derived from the population model results in an estimated total annual removal of 109 animals for the northern Hudson Bay-Hudson Strait component, or an overall removal of 137 animals, which is less than half of the PBR estimate for the entire stock (i.e., northern Hudson Bay-Hudson Strait component + East Baffin Island component of HBDS).

DISCUSSION

The 2017 aerial survey estimate was much higher than the 2014 estimate, when comparing similar areas (Hammill et al. 2017, Mosnier et al. 2023). The difference cannot be due to population growth, as the implied finite annual rate of increase of 1.75 is inconsistent with the estimated maximum rate of increase of 1.07 to 1.08 for this species. Possible reasons for the larger survey estimate in 2017 were examined by altering our assumptions about the proportion of the population that was hauled out during the 2017 aerial survey and by assuming movement of animals from Foxe Basin into the HBDS stock area. From a modeling perspective, both scenarios seemed plausible. Genetics data (Shafer et al. 2014) and personal communications with hunters in the Foxe Basin community of Hall Beach (see Mosnier et al. 2023) suggest some exchange between the HBDS and Foxe Basin walrus stocks. However, there was no empirical evidence of movements of large numbers of walrus out of the Foxe Basin area in 2017. Movements of walrus from other neighbouring regions such as southeastern or western Hudson Bay are also plausible, although numbers in those areas (e.g. Hammill et al. 2016) are far too low (low hundreds of animals) to support the influx needed to account for the relatively high 2017 estimate. Similarly, movement of a large number of walrus from eastern Baffin Island into Hudson Strait and northern Hudson Bay is not a likely explanation, as counts along the eastern coast of Baffin Island in 2017 (Mosnier et al. 2023) were similar to, if not greater than, previous counts in that area (Stewart et al. 2014).

The modeling exercise also indicated that a higher proportion of hauled out walruses than assumed in adjustments of raw counts could account for the relatively high 2017 estimate (0.3; Mosnier et al. 2023). It is unlikely that the proportion of animals hauled out remained unusually high throughout the entire survey of the HBDS area, which was completed over several days. However, by the same rationale, because haulout numbers can change dramatically from one day to the next, any change at a major haulout site could have an important impact on our adjusted estimates (e.g., see Doniol-Valcroze et al. 2016). For example, Walrus Island, located near Coral Harbour in northern Hudson Bay, is a major haulout area for the HBDS stock, and accounted for 55% of the observations in the 2014 survey (Hammill et al. 2017). On 11 September 2014, 248 walrus were hauled out at this location, but this number was 10-fold higher on 16 September 2014, when 2,579 animals were counted on the island. In 2017, a total of 7,294 animals were photographed on Walrus Island, accounting for 63% of the overall observations made during the survey. Unfortunately, only a single count was available from this site, but if the proportion of animals hauled out was much higher than the assumed 0.3, then this would have had a major impact on the adjusted abundance estimate. If the proportion of 0.3 is used, then the adjusted abundance estimate for Walrus Island would be 24,313 animals. However, if the proportion of animals hauled out was 0.8, then the adjusted abundance estimate would only be 9,118 animals. We stress that more information is needed to understand factors affecting both walrus movements and haulout behavior (Doniol-Valcroze et al. 2016).

Population models provide a means of integrating data from different sources into a single framework and readily quantifying the various types of uncertainty (DFO 2018). In this study, the model fit to the 2017 survey estimate was poor, suggesting, as discussed above, that some other factor(s) not explicitly accounted for within the model structure were affecting survey abundance estimates. In spite of these challenges, we feel that estimating PBR using the abundance and uncertainty estimates from the model, is the best approach for providing precautionary harvest advice, as outlined in DFO (2018). The total PBR estimated here for the HBDS stock (by combining the modelled abundance estimate for northern Hudson Bay-Hudson Strait and survey estimate for southeastern Baffin Island) of 360 animals is greater than current annual harvest levels that have been adjusted for struck and loss and non-reporting. These estimates do not include removals due to ship strikes and bycatch from commercial fisheries. We do not have information for these sources of mortality, but they are considered low due to low levels of commercial fishing and shipping in the study area.

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TABLES

Table 1. Adjusted abundance estimates for the northern Hudson Bay-Strait component of the HBDS and Foxe Basin walrus stocks, and for both stocks combined. Data are from Hammill et al. (2016, 2017) and Mosnier et al. (2023). Unless otherwise stated, survey counts were adjusted assuming a mean haulout proportion of 0.3. Errors were estimated using the method developed by Doniol-Valcroze et al. (2016).

Year	HBDS		Foxe		HBDS-Foxe combined	
	Estimate	SE	Estimate	SE	Estimate	SE
1954	9,667	7,531	-	-	-	-
1961	8,833	6,881	-	-	-	-
1976	2,733	2,130	-	-	-	-
1977	2,707	2,110	-	-	-	-
1983	-	-	7,357	3,182	-	-
1988	2,830	2,205	13,859	13,293	16,689	14,145
1989	4,427	3,449	14,892	7,824	19,319	8,230
1990	6,113	4,762	-	-	-	-
2012	5,254	4,093	12,900	2,900	18,154	3,308
2014	7,147	4,122	-	-	-	-
2017	38,514	19,514	-	-	43,334	19,769

Table 2. Prior distributions, parameters and hyper-parameters used in the population model.

Parameter	Notation	Prior distribution	Hyper-parameters	Parameter value	Prior median	0.025 quantile	0.975 quantile
Precision (Survey)	T_s	Gamma	α_s; β_s	2.5; 0.4	5.447	1.037	16.103
Precision (Process)	T_p	Gamma	α_p; β_p	1.5; 0.00005	23,853	2,191	93,294
Theta	θ	Fixed	-	-	2.39	-	-
Struck-and-lost	*SL*	Beta	α_{sl}; β_{sl}	3; 4	0.421	0.118	0.777
Initial population (HBDS)	Start	Uniform	Nupp; Nlow	30,000; 500	36,227	3,673	68,260
Initial population (HBDS-Foxe run)	Start	Uniform	Nupp; Nlow	60,000; 2,000	8,536	3,519	58,565
Carrying capacity (HBDS)	*K*	Uniform	Nupp; Nlow	35,000; 500	32,428	6,483	58,596
Carrying capacity (HBDS-Foxe run)	*K*	Uniform	Nupp; Nlow	60,000; 5,000	32,528	6,413	58,625
Maximum annual growth rate	λ_{max}	Beta	α_λ; β_λ	27.2; 311.1	0.08	0.054	0.11

*Table 3. Prior and posterior distributions for estimated carrying capacity (K), estimated abundance in 2017 (*N2017*), estimated maximum rate of population growth* (lambda*), the estimated starting population abundance (Startpop) and estimated struck and lost (Struck.and.lost, including non-reporting). The model was fitted to the aerial survey estimates of walrus abundance in the Hudson Strait and northern Hudson Bay, assuming a haulout proportion of 0.3.*

Parameter	Mean	SE	2.50% quantile	25% quantile	50% quantile	75% quantile	97.5% quantile
K	16,603	14,121	6,814	8,316	9,531	18,252	55,640
K.prior	32,416	15,786	6,495	18,707	32,335	46,040	58,596
N2017	9,591	3,742	5,790	7,205	8,227	10,788	19,706
Lambda	0.078	0.013	0.055	0.069	0.077	0.086	0.106
Lambda.prior	0.081	0.015	0.054	0.07	0.08	0.09	0.112
Startpop	7,998	1,585	5,204	6,827	7,986	9,041	11,174
Startpop.prior	36,075	19,627	3,678	19,063	36,090	53,138	68,333
Struck.and.lost	0.441	0.17	0.132	0.315	0.436	0.562	0.777
Struck.and.lost.prior	0.429	0.176	0.117	0.296	0.422	0.554	0.777

Table 4. Prior and posterior distributions for the model fitted to the aerial survey estimates of walrus abundance in northern Hudson Bay and Hudson Strait, assuming that the proportion of the population hauled out was 0.8 in 2017, and 0.3 for all other years. Prior and posterior distributions for estimated carrying capacity (K), estimated abundance in 2017 (N2017), estimated maximum rate of growth of the population (lambda), estimated starting population abundance (Startpop) and estimated struck and lost (Struck.and.lost, including non-reporting).

Parameter	Mean	SE	2.50% quantile	25.00% quantile	50% quantile	75% quantile	97.5% quantile
K	10,691	8,374	6,543	7,677	8,388	9,310	43,349
K.prior	32,333	15,834	6,435	18,516	32,195	45,982	58,470
N2017	7,373	1,443	5,532	6,549	7,105	7,773	11,429
Lambda	0.079	0.013	0.056	0.07	0.079	0.088	0.107
Lambda.prior	0.08	0.015	0.054	0.07	0.08	0.09	0.111
Startpop	8,055	1,099	5,926	7,323	8,032	8,756	10,320
Startpop.prior	36,022	19,722	3,653	18,876	36,013	53,207	68,344
Struck.and.lost	0.437	0.166	0.134	0.315	0.431	0.555	0.764
Struck.and.lost.prior	0.43	0.176	0.117	0.296	0.424	0.555	0.779

Table 5. Prior and posterior distributions for the model fitted to the aerial survey estimates of walrus abundance in northern Hudson Bay and Hudson Strait ,assuming mixing between the HBDS and Foxe Basin stocks, and the proportion of animals hauled out during all surveys was 0.3. Prior and posterior distributions for estimated carrying capacity (K), estimated abundance in 2017 (N2017), the estimated maximum rate of growth of the population (lambda*), the estimated starting population abundance (Startpop) and estimated struck and lost (Struck.and.lost), which includes non-reporting.*

Parameter	Mean	SE	2.50% quantile	25.00% quantile	50% quantile	75% quantile	97.5% quantile
K	29,328	7,124	19,614	24,604	27,867	32,263	49,170
K.prior	32,495	15,880	6,413	18,655	32,528	46,269	58,625
N2017	26,474	6,348	17,203	22,146	25,355	29,489	42,777
Lambda	0.08	0.015	0.054	0.07	0.079	0.089	0.111
Lambda.prior	0.08	0.015	0.054	0.07	0.08	0.09	0.111
Startpop	24,105	6,549	11,740	19,868	24,353	28,179	37,347
Startpop.prior	31,103	16,700	3,519	16,614	31,222	45,524	58,565
Struck.and.lost	0.424	0.174	0.116	0.293	0.417	0.548	0.772
Struck.and.lost.prior	0.428	0.175	0.117	0.297	0.42	0.553	0.777

Table 6. Prior and posterior distributions for model fitted to the aerial survey estimates of walrus abundance assuming mixing between the northern Hudson Bay-Hudson Strait component of the HBDS stock with animals from the Foxe Basin stocks and assuming the proportion of animals hauled out during the 2017 survey was 0.6. Prior and posterior distributions for estimated carrying capacity (K), estimated abundance in 2017 (N2017), the estimated maximum rate of growth of the population (lambda), the estimated starting population abundance (Startpop) and estimated struck and lost (Struck.and.lost), which includes non-reporting.

Parameter	Mean	SE	2.50% quantile	25.00% quantile	50% quantile	75% quantile	97.5% quantile
K	24,444	4,512	17,950	21,592	23,771	26,413	35,094
K.prior	32,490	15,874	6,392	18,720	32,548	46,231	58,648
N2017	21,782	3,998	15,685	19,181	21,230	23,703	31,334
Lambda	0.082	0.015	0.055	0.071	0.081	0.091	0.113
Lambda.prior	0.08	0.015	0.054	0.07	0.08	0.09	0.112
Startpop	22,452	4,454	12,883	19,934	22,534	25,087	31,393
Startpop.prior	31,056	16,673	3,456	16,717	31,124	45,435	58,551
Struck.and.lost	0.41	0.172	0.109	0.28	0.403	0.53	0.757
Struck.and.lost.prior	0.429	0.175	0.118	0.297	0.422	0.553	0.775

Table 7. Estimated abundance from the population model and minimum population estimate (Nmin, rounded to the nearest 100), coefficient of variation (CV), and Potential Biological Removal (PBR) for the northern Hudson Bay-Hudson Strait (HBHS) and east Baffin Island components of the Hudson Bay-Davis Strait walrus stock. The PBR for the HBHS component is estimated using abundance estimates from the model fitted to the survey data assuming a haulout proportion of 0.3 and no mixing with Foxe Basin walrus (Table 3) as per the framework developed in DFO (2018). The east Baffin Island abundance estimates are from the aerial survey (Mosnier et al. 2023). PBR was calculated using a maximum rate of increase of 0.08 and a recovery factor of 1. PBR estimates from the last assessment are also presented (DFO 2016).

Area	2017				2013 PBR	2014 PBR
	Estimate	N_{min}	CV	PBR		
East Baffin Island	3,900	3,000	0.31	121	88	-
HBHS	8,200	6,000	0.39	239	-	228
Total	-	-	-	**360**	-	-

FIGURES

Figure 1. Range of Atlantic walrus stocks in the eastern Canadian Arctic. Map from Hammill et al. 2016.

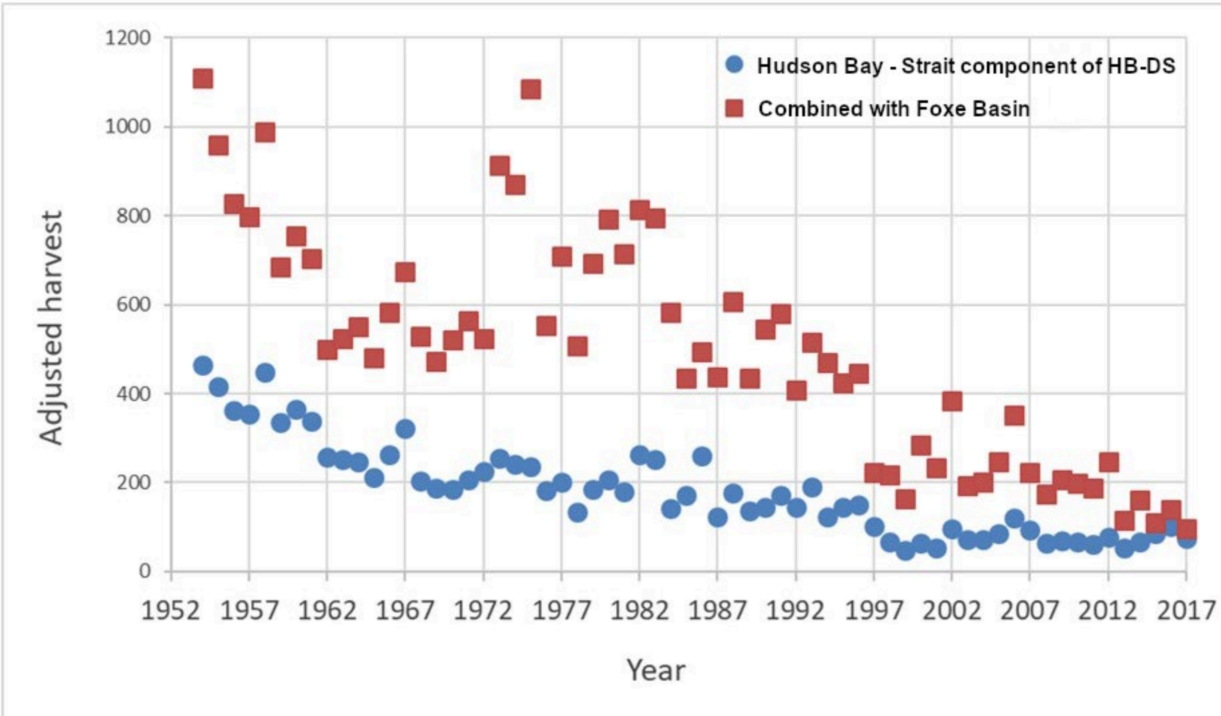

Figure 2. Adjusted harvest levels of communities harvesting walruses from the northern Hudson Bay and Hudson Strait component of the Hudson Bay Davis Strait stock (HB-DS), and combining the latter with those from Foxe Basin. Data are also presented in Table A1.

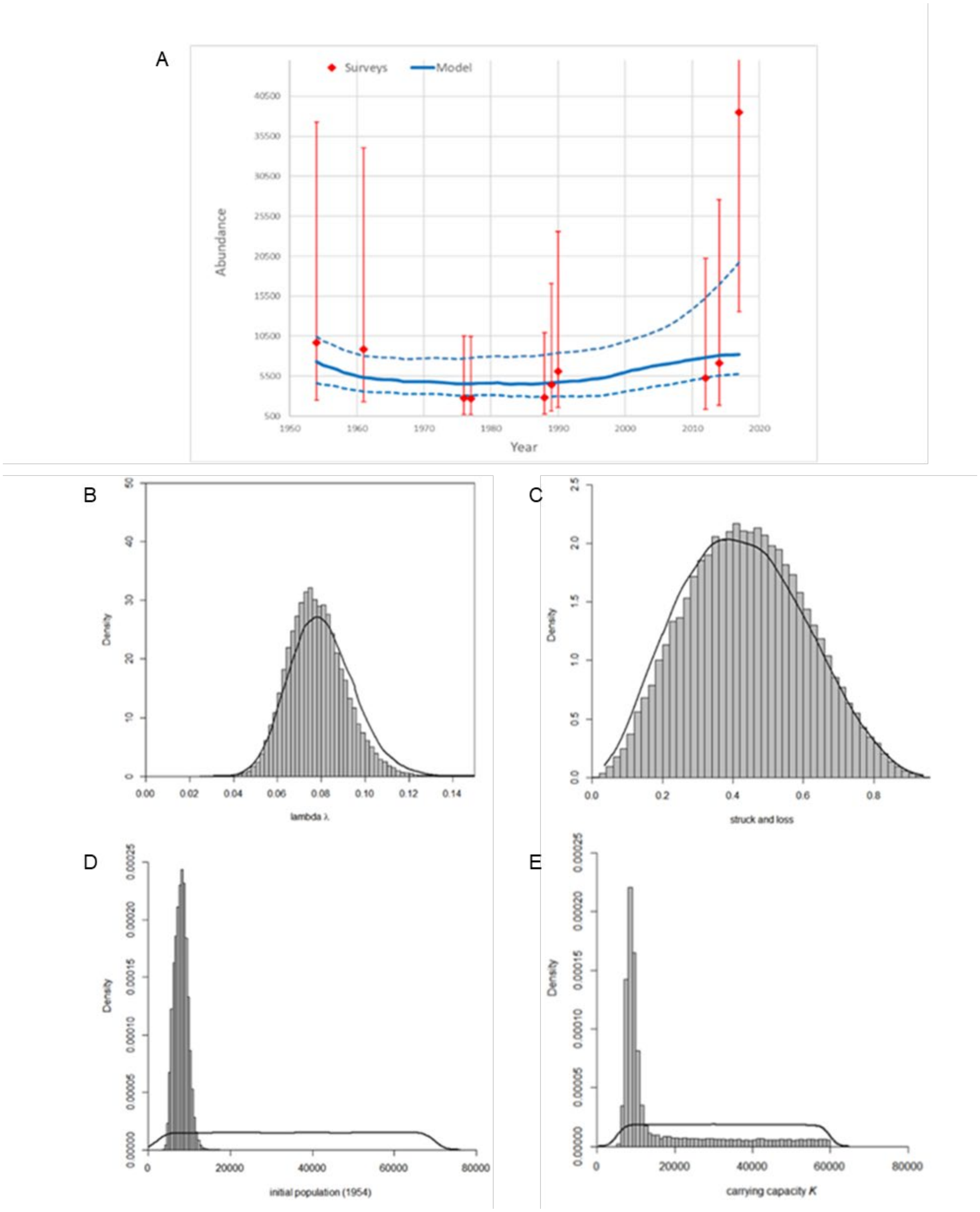

Figure 3. Estimated total abundance (median ± credibility intervals) and aerial survey estimates (± 95% CI) of abundance assuming 30% of walruses are hauled out during the surveys (A). Prior (solid line) and posterior (vertical bars) distributions for the parameters rate of increase (lambda; B), struck and loss (C), initial population (D) and carrying capacity, K (E). Model was fitted to aerial surveys in the northern Hudson Bay-Strait area only.

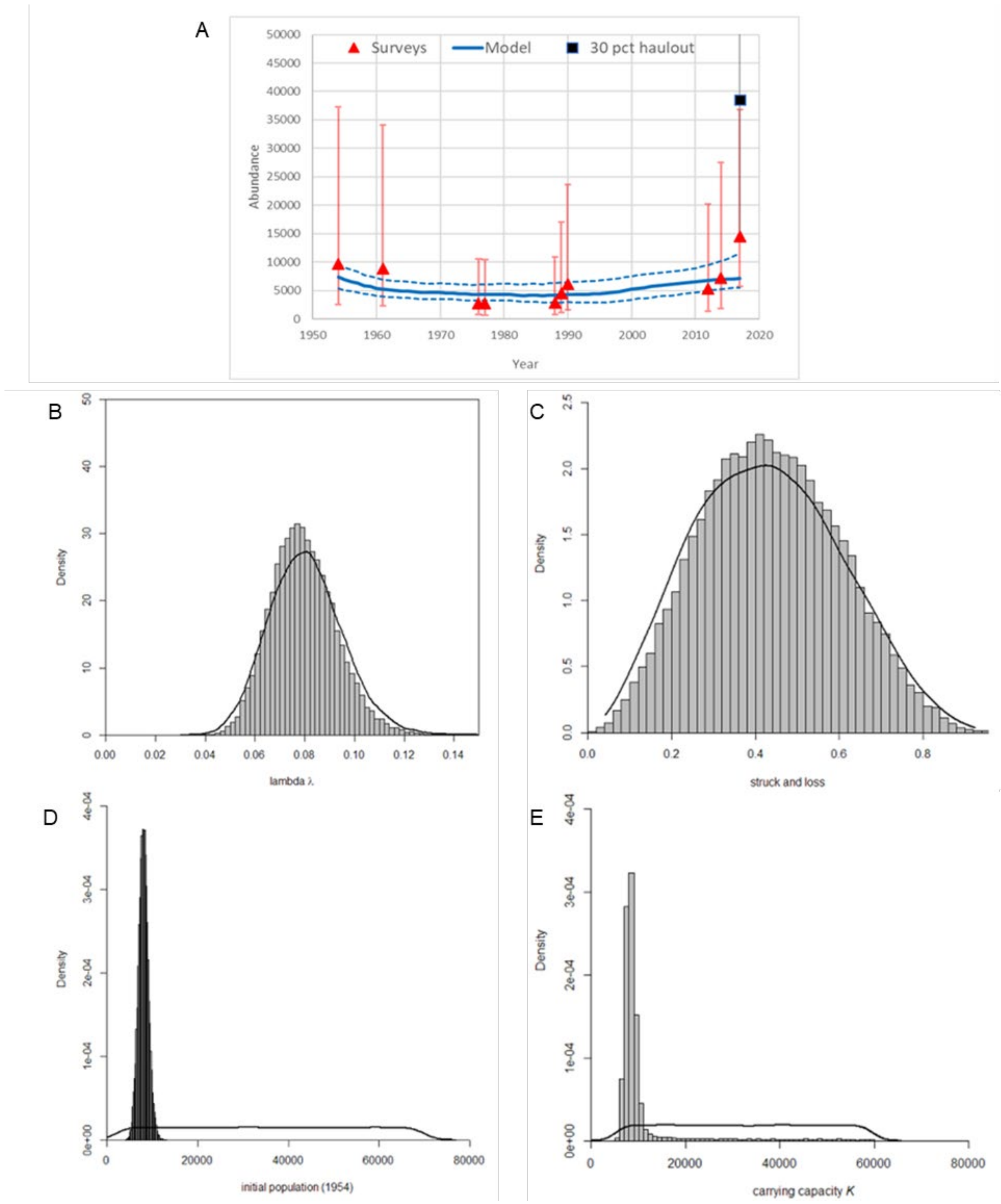

Figure 4. Model abundance estimates (median ± 95% credibility intervals) fitted to aerial surveys (± 95% CI) in the northern Hudson Bay and Hudson Strait area only (A). The scenario assumed that the proportion of the population hauled out in 2017 was 0.8, but was 0.3 for all other years (triangles). Estimated total abundance (median plus 95% CI) from model; aerial survey estimates (± 95% CI). Estimated survey abundance if 30% of population hauled out in 2017 also shown (square) for comparison. Prior (solid line) and posterior (vertical bars) distributions for the parameters rate of increase (lambda; B), struck and loss (C), initial population (D) and carrying capacity, K (E).

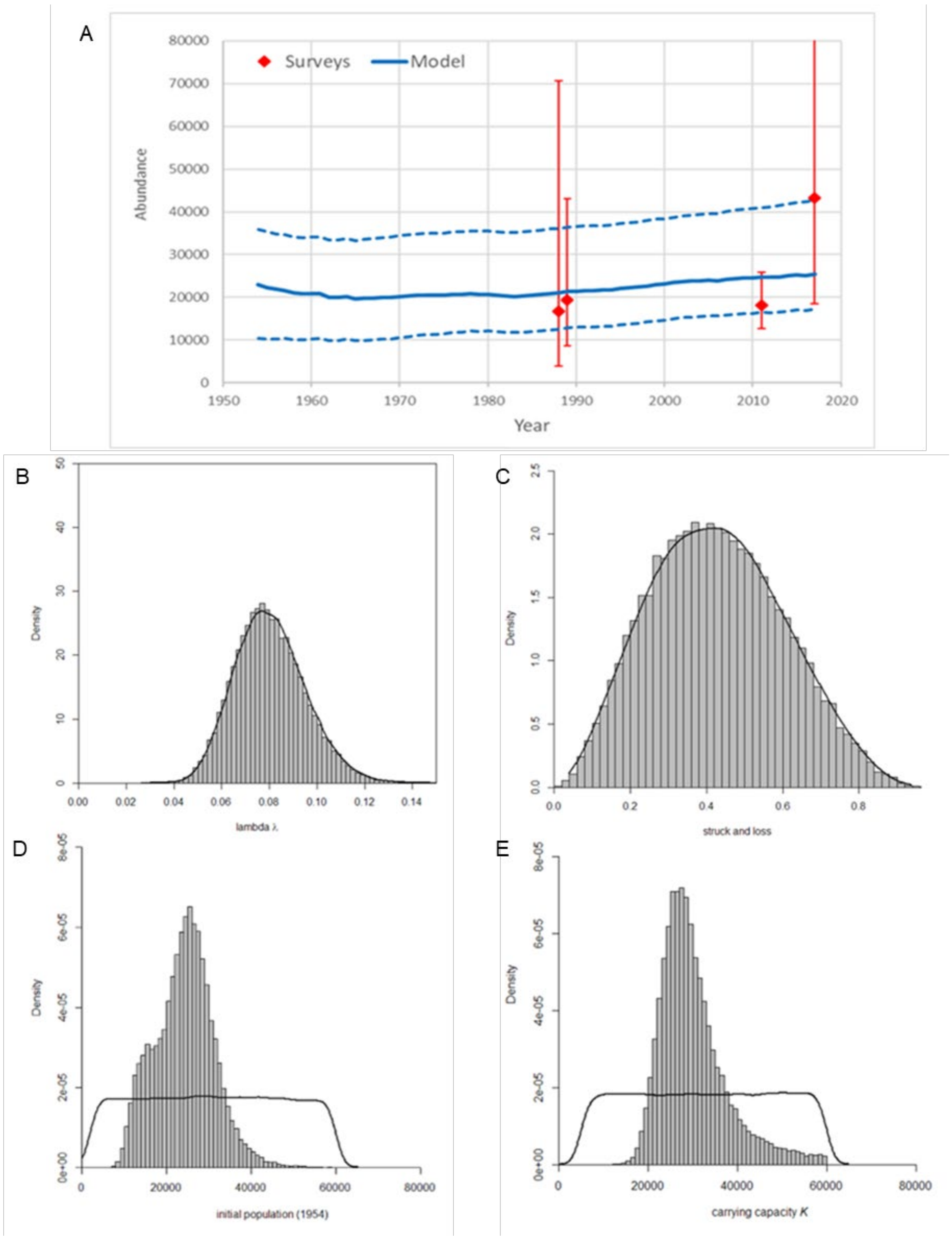

Figure 5. Model abundance estimates (median ± 95% credibility intervals) fitted to aerial surveys (± 95% CI) assuming mixing between the northern Hudson Bay-Hudson Strait component of the HBDS stock with animals from the Foxe Basin walrus stock, and that the proportion of the population hauled out during the surveys was 0.3 (A) and prior (solid line) and posterior (vertical bars) distributions for the parameters rate of increase (lambda; B), struck and loss (C), initial population (D) and carrying capacity, K (E).

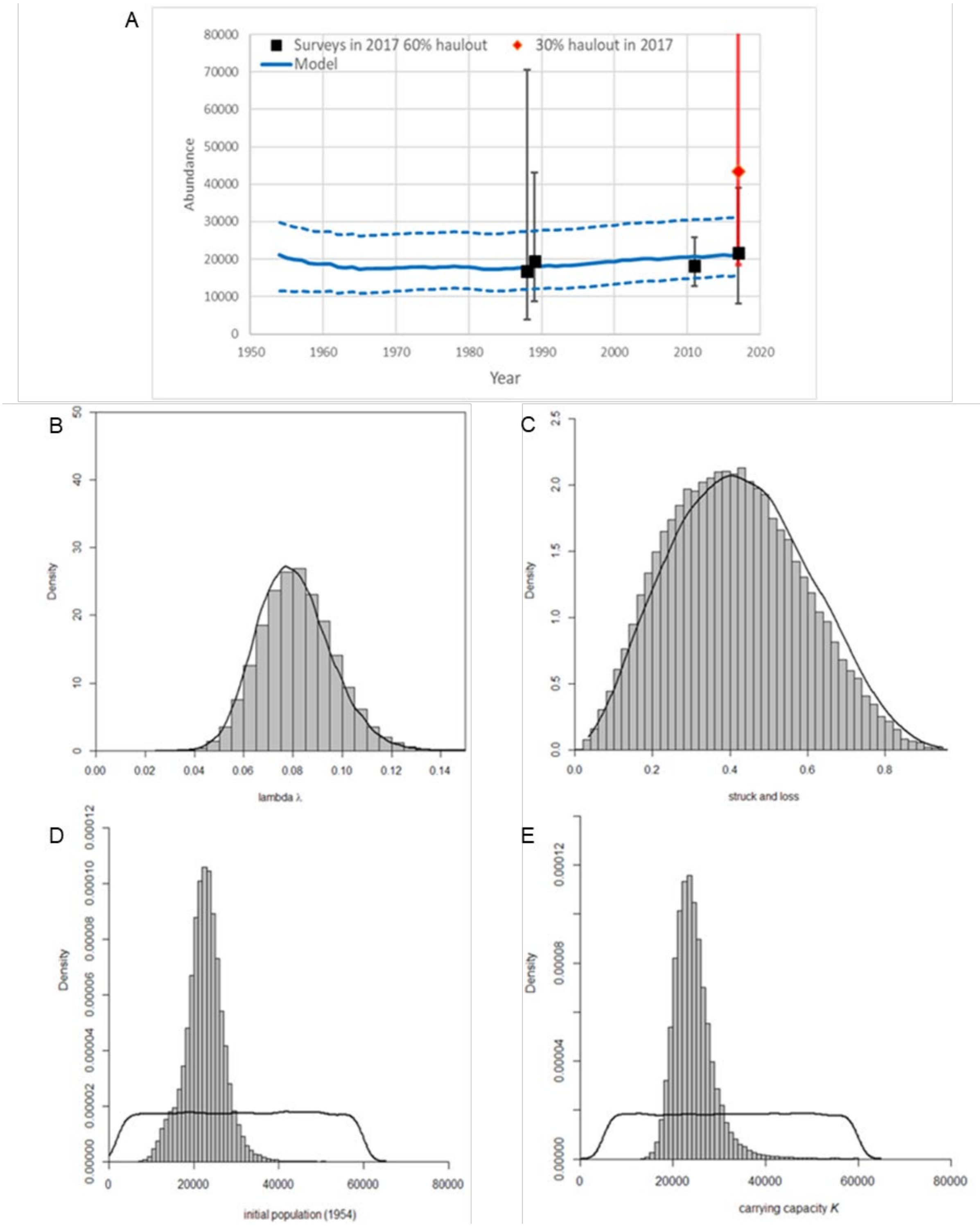

Figure 6. Model fitted assuming mixing of the Hudson Strait-northern Hudson Bay component of the HBDS stock with animals from the Foxe Basin stocks, and that the proportion of animals hauled out in 2017 was 0.6. Estimated total abundance (median ±95% CI). Aerial survey estimates (black squares ± 95% CI) assuming that the proportion of the population hauled out was 0.6 in 2017. Included for reference is the 2017 aerial survey estimate assuming the proportion of the population hauled out during the 2017 survey was 0.3. Prior (solid line) and posterior (vertical bars) distributions for the parameters rate of increase (lambda; B), struck and loss (C), initial population (D) and carrying capacity, K (E).

APPENDIX A

Table A1. Walrus catches in Nunavut and Nunavik communities (1954–2017). Numbers in bold italics are estimates using a 5-year average from the most recent years with reported catches.

Nunavut

Year	Cape Dorset	Clyde River	Iqaluit	Kimmirut	Pangnirtung	Qikiqtarjuaq	Arviat	Chesterfield Inlet	Coral Harbour	Rankin Inlet	Repulse Bay	Whale Cove	Hall Beach/Igloolik
1954	48	***15***	50	55	47	***28***	10	20	204	***12***	***14***	***3***	506
1955	50	19	***17***	55	47	***28***	10	20	155	***12***	***15***	***3***	431
1956	99	***10***	***15***	46	45	***28***	***1***	***11***	77	***11***	***16***	***3***	365
1957	30	40	25	48	0	***28***	***1***	2	146	***11***	***16***	***3***	350
1958	87	1	30	14	35	***28***	1	0	229	***10***	7	***3***	445
1959	60	3	4	8	21	***28***	***1***	***19***	113	***14***	***18***	***3***	293
1960	***22***	5	***12***	***3***	15	***29***	***1***	18	194	***12***	***16***	***2***	329
1961	1	3	***6***	4	23	***28***	***1***	***18***	180	***9***	25	4	303
1962	30	6	6	4	1	***28***	***1***	18	***83***	***9***	***11***	***2***	201
1963	40	8	7	3	***15***	***28***	***1***	***9***	***81***	***8***	***10***	***2***	213
1964	20	10	26	1	12	***29***	***1***	34	30	31	30	2	226
1965	***17***	***9***	16	1	22	***29***	2	***3***	***85***	***2***	***5***	***2***	193
1966	34	9	26	100	12	***28***	1	***3***	20	***2***	***6***	***2***	244
1967	7	***9***	16	***5***	9	***28***	1	***3***	200	***2***	***6***	***2***	289
1968	***23***	***14***	***48***	***6***	***18***	***28***	***1***	***3***	***72***	***3***	1	1	217
1969	6	***12***	***48***	1	4	***31***	***1***	***3***	***71***	***3***	***7***	***3***	189
1970	14	***0***	51	0	41	***29***	1	3	63	***0***	***7***	***3***	213
1971	21	11	***51***	10	35	***26***	4	3	60	***3***	***7***	***3***	234
1972	38	***10***	***48***	9	4	***23***	***0***	***3***	64	***4***	***10***	***3***	215
1973	35	37	42	8	4	***29***	***0***	3	103	***3***	***6***	***3***	823
1974	14	3	46	17	38	***49***	0	2	65	***3***	5	***3***	743
1975	49	3	70	6	125	***20***	***0***	***5***	24	***5***	***5***	***3***	950
1976	***20***	3	***50***	***10***	3	***7***	***0***	3	43	***3***	***10***	***2***	466
1977	72	2	***32***	3	31	***12***	***0***	***3***	42	***5***	10	3	648
1978	66	7	12	4	33	***12***	***0***	0	***16***	***0***	***0***	***3***	465
1979	67	0	65	0	***0***	***26***	***0***	***1***	***41***	***0***	***0***	***6***	629
1980	20	2	65	1	20	***46***	***0***	5	54	8	6	0	681
1981	***10***	***3***	58	5	62	***4***	0	***4***	***11***	***13***	***33***	***1***	614
1982	35	2	40	10	12	***35***	0	***3***	39	***15***	***35***	***3***	693
1983	59	***6***	25	***6***	33	***6***	0	***5***	67	***15***	***10***	***3***	711
1984	***4***	***1***	***39***	***0***	***13***	***37***	***0***	***14***	***60***	***2***	5	0	525

Year	Cape Dorset	Clyde River	Iqaluit	Kimmirut	Pangnirtung	Qikiqtarjuaq	Arviat	Chesterfield Inlet	Coral Harbour	Rankin Inlet	Repulse Bay	Whale Cove	Hall Beach/Igloolik
1985	15	***0***	***27***	7	6	***5***	***1***	***10***	***24***	***4***	***14***	***0***	338
1986	***19***	0	4	4	0	9	0	20	43	2	9	0	330
1987	5	3	29	8	12	9	0	***9***	31	4	18	0	383
1988	35	1	10	4	44	12	3	11	41	5	13	2	547
1989	24	0	8	9	8	15	0	9	45	5	11	0	402
1990	24	1	16	8	40	10	0	9	45	3	11	0	501
1991	7	7	16	22	21	13	0	9	60	2	18	0	525
1992	11	2	16	7	3	21	***0***	***5***	***34***	3	***8***	***0***	332
1993	23	0	29	***2***	0	0	0	6	55	4	25	2	443
1994	24	0	26	2	40	5	0	0	31	2	8	0	414
1995	10	0	25	0	8	16	0	3	48	6	0	0	348
1996	30	1	9	5	15	13	0	12	26	12	7	0	390
1997	8	0	0	***2***	16	3	***2***	***2***	10	***8***	0	***0***	154
1998	4	1	27	***3***	4	0	0	0	9	12	0	0	179
1999	10	0	15	***3***	3	0	2	3	8	3	2	0	147
2000	46	0	19	0	15	0	1	4	1	7	1	0	282
2001	11	1	7	0	19	1	***2***	***2***	***17***	***6***	***8***	***0***	227
2002	5	0	1	4	9	33	3	***2***	30	12	20	1	363
2003	1	0	1	7	15	1	5	4	10	2	***6***	***0***	155
2004	***7***	2	***11***	4	***9***	0	***0***	3	***12***	2	3	***0***	160
2005	6	***0***	10	6	***9***	***6***	1	3	17	3	6	***0***	201
2006	25	1	9	2	15	9	0	0	18	13	6	0	294
2007	***1***	0	11	***2***	***7***	6	0	2	4	6	12	0	155
2008	***1***	***0***	***13***	***2***	10	***5***	***0***	0	4	3	***2***	***0***	121
2009	***1***	***0***	14	***2***	***5***	***4***	***0***	***6***	15	6	4	***0***	171
2010	1	***0***	14	7	7	6	0	5	8	2	1	0	157
2011	2	0	14	0	7	5	0	7	11	4	0	0	151
2012	0	0	19	1	7	10	0	4	15	6	5	0	201
2013	0	0	6	0	0	0	0	0	22	0	0	0	84
2014	0	0	1	2	4	0	0	15	22	0	0	0	132
2015	0	3	11	2	***5***	7	0	9	27	15	12	0	47
2016	2	0	10	3	25	4	1	5	51	2	12	0	245
2017	4	***1***	***9***	2	***8***	***4***	3	***7***	31	2	16	2	4

Nunavik

Year	Killiniq	Kangiksualujjuaq	Kuujjuaq	Tasiujaq	Kangirsuk	Aupaluk	Quaqtaq	Kangiksujuaq	Salluit	Ivujivik	Akulivik	Puvirnituq
1954	1	0	0	0	6	0	7	4	***29***	33	9	7
1955	1	0	0	0	6	0	7	4	***29***	33	9	7
1956	1	0	0	0	6	0	7	4	***29***	33	9	7
1957	1	0	0	0	6	0	7	4	***29***	33	9	7
1958	1	0	0	0	6	0	7	4	***29***	33	9	7
1959	1	0	0	0	6	0	7	4	***29***	33	9	7
1960	1	0	0	0	6	0	7	4	***29***	33	9	7
1961	1	0	0	0	6	0	7	4	***28***	33	9	7
1962	1	0	0	0	6	0	7	4	30	33	9	7
1963	1	0	0	0	6	0	7	4	30	33	9	7
1964	1	0	0	0	6	0	7	4	30	33	9	7
1965	1	0	0	0	6	0	7	4	26	33	9	7
1966	1	0	0	0	6	0	7	4	26	33	9	7
1967	1	0	0	0	6	0	7	4	26	33	9	7
1968	1	0	0	0	6	0	7	4	26	33	9	7
1969	1	0	0	0	6	0	7	4	26	33	9	7
1970	1	0	0	0	6	0	7	4	26	33	9	7
1971	1	0	0	0	6	0	7	4	26	33	9	7
1972	1	0	0	0	6	0	7	4	26	33	9	7
1973	***1***	***0***	***0***	***0***	***6***	***0***	***7***	***4***	***26***	***33***	***9***	***7***
1974	1	0	0	0	7	***0***	13	2	57	***33***	12	***7***
1975	4	1	0	0	7	***0***	9	5	59	***32***	15	***7***
1976	0	1	0	2	7	1	5	4	13	***32***	18	***7***
1977	2	0	0	0	9	0	7	7	1	***32***	0	***7***
1978	***0***	0	0	0	2	0	0	0	0	***36***	0	***7***
1979	***0***	1	15	0	1	0	7	0	5	***32***	3	***7***
1980	***0***	1	7	0	8	0	10	9	36	***29***	5	***7***
1981	***0***	0	0	0	4	0	3	0	30	33	24	***8***
1982	***0***	0	0	0	5	0	2	0	73	29	8	***6***
1983	***0***	0	0	0	12	1	6	1	2	57	1	***8***
1984	***0***	0	0	0	3	1	9	0	27	***11***	0	***7***
1985	1	0	0	0	15	3	8	17	16	16	16	***6***
1986	0	0	0	9	3	0	7	41	91	0	1	11
1987	0	3	0	7	0	0	6	2	1	19	18	0
1988	0	0	0	3	7	0	10	0	8	8	10	16
1989	0	5	3	5	5	0	4	0	0	11	1	0

Year	Killiniq	Kangiksualujjuaq	Kuujjuaq	Tasiujaq	Kangirsuk	Aupaluk	Quaqtaq	Kangiksujuaq	Salluit	Ivujivik	Akulivik	Puvirnituq
1990	0	0	0	3	***6***	3	12	0	10	3	4	3
1991	0	0	0	2	6	2	10	3	3	13	9	6
1992	0	0	4	0	7	5	9	6	15	7	12	12
1993	0	1	0	2	2	3	7	2	11	33	1	12
1994	0	1	0	5	5	5	6	3	19	0	9	3
1995	0	1	0	3	10	2	20	2	19	20	0	0
1996	0	1	4	9	9	2	3	4	18	0	3	4
1997	0	3	0	0	0	0	8	0	20	23	9	6
1998	0	0	0	0	4	0	11	5	7	1	10	0
1999	0	0	6	0	0	0	2	1	0	7	1	0
2000	0	0	0	0	3	0	0	0	0	0	0	0
2001	0	0	0	0	0	1	0	4	1	0	0	0
2002	0	0	0	0	7	0	0	0	0	0	14	0
2003	0	0	0	0	0	0	6	1	2	9	11	9
2004	0	0	0	0	0	0	11	9	10	0	12	0
2005	0	0	0	2	0	0	5	0	17	8	4	8
2006	0	0	5	3	0	0	2	4	14	11	9	9
2007	0	0	0	0	1	0	3	0	24	13	5	21
2008	0	0	0	0	0	0	6	0	17	8	9	13
2009	0	0	0	0	0	0	7	2	7	0	3	17
2010	0	0	1	1	0	0	6	1	14	5	5	9
2011	0	1	0	0	0	0	2	2	11	5	5	12
2012	0	0	0	0	0	0	5	5	12	0	8	17
2013	0	0	0	0	7	0	10	2	0	0	9	3
2014	0	0	0	0	0	0	4	0	14	0	10	0
2015	0	0	0	0	0	0	0	0	10	0	10	0
2016	0	0	0	0	3	1	0	5	0	8	8	0
2017	0	2	0	0	4	0	2	0	0	0	0	0