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Abundance of Northwest Atlantic hooded seals (1960 – 2005)

Abondance des phoques à capuchon dans l'Atlantique Nord-Ouest (1960 – 2005)

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ABSTRACT

A population model incorporating hooded seal pup production estimates since the 1980s, reproductive rates and human induced mortality (catches, by-catch in fishing gear and struck and lost) were used to estimate total abundance for the period 1965 - 2005. Pup production and total population size are affected by the type of pup production estimates that the model is fitted to. Using only pup production estimates from the Front, pup production in 2005 was 107,900 (SE=18,800; 95% C.I.=70,600-143,300) for a total population of 535,800 (SE=93,600; 95% C.I.=350,600-711,300). Fitting to pup production estimates from all herds and making assumptions about numbers of hooded seals in the Davis Strait herd for years, when this area was not included in the survey program, results in pup production estimates of 120,100 (SE=13,800; 95% CI=94,100-147,900) and an estimated total population of 593,500 (SE=67,200; 95% C.I.=465,600-728,300). There is considerable uncertainty associated with these estimates which results from a lack of understanding of the relationship between the Davis Strait, Front and Gulf pupping areas, few surveys of all three areas, limited reproductive data and uncertain harvest statistics. Under the Objective Based Fisheries Management plan, hooded seals are considered 'Data Poor', with harvests being set using conservative methods. Recommended harvests are 27,400-32,100 animals.

RESUMÉ

On s'est servi d'un modèle de la population incorporant des estimations de la production de nouveau-nés chez le phoque à capuchon depuis les années 1980, les taux de reproduction et la mortalité causée par l'homme (prises, prises accidentelles dans des engins de pêche et individus abattus et non récupérés) pour estimer l'abondance totale de ces phoques entre 1965 et 2005. Les estimations relatives à la production de nouveau-nés chez le phoque à capuchon et à la taille totale de la population sont fonction du type d'estimations sur la production de nouveau-nés qui sont modélisées. Si on intègre uniquement les estimations sur la production de nouveau-nés dans la région du Front, on obtient une production de nouveau-nés en 2005 totalisant 107 900 individus (ET = 18 800; IC 95 % = 70 600 – 143 300) pour une population totale de 535 800 individus (ET = 93 600; IC 95 % = 356 600 – 711 300). Après avoir intégré les estimations sur la production de nouveau-nés pour tous les troupeaux et formulé des hypothèses quant aux effectifs de phoques à capuchon dans le troupeau du détroit de Davis pour les années durant lesquelles cette zone a été exclue du programme de relevé, on obtient une production estimée de 120 100 individus (ET = 13 800; IC 95 % = 94 100 – 147 900) et une population totale estimée de 593 500 individus (ET = 67 200; IC 95 % = 465 600 – 728 300). L'incertitude est considérable pour ces estimations en raison d'un manque de compréhension des rapports qui existent entre les aires de mise bas du détroit de Davis, de la région du Front et du golfe, du faible nombre de relevés effectués dans chacune des trois aires, des données limitées sur la reproduction et des statistiques incertaines concernant la récolte. On considère, dans le cadre de la gestion des pêches par objectif (GPO), que le phoque à capuchon est une espèce « peu documentée » pour laquelle les données relatives à la récolte sont calculées au moyen de méthodes prudentes. Les recommandations pour la récolte se situent entre 27 400 et 32 100 individus.

INTRODUCTION

The hooded seal is a large phocid inhabiting pelagic waters of the North Atlantic. Whelping occurs on the pack ice around Jan Mayen Island (West Ice), in Davis Strait, off the northeast coast of Newfoundland (Front) and in the Gulf of St. Lawrence (Gulf)(Sergeant 1974). After whelping, hooded seals return to the pack ice off eastern Greenland to moult during June-July, and then they may remain off the eastern Greenland coast, disperse to the Greenland Sea, or Davis Strait over the summer and fall before returning to their respective breeding areas (Sergeant 1974; Folkow et al. 1996; Hammill 1993; Stenson and Sjare 1997).

The relationships between the different breeding groups are poorly understood. Analyses of material from the Front and Jan Mayen herds using DNA fingerprinting (Sundt et al. 1994) and skull morphology (Wiig and Lie 1984), supports the hypothesis of a single population, although limited tag returns suggest that there may be some philopatry amongst adults in the Gulf (Hammill 1993).

Hooded seals are harvested commercially and for subsistence (Rasmussen 1960; Sergeant 1974). Although some regulations were in place to limit opening and closure dates, harvest levels were not regulated until the commercial hunt for hooded seals in the Gulf closed in 1972 (Hammill et al. 1992), and quotas were introduced to limit harvesting at the Front in 1974 (Bowen et al. 1987). At the time, the harvest was directed primarily towards young of the year, also known as bluebacks. This harvest continued until 1982 when the European Economic Community, the primary destination, banned the importation of whitecoats and bluebacks. In 1987, regulatory changes banned the commercial hunt for both the whitecoat and blueback harvests. The harvesting of older animals was permitted, but with the exception of one year when an illegal harvest of bluebacks occurred, harvests were on average much lower than the quota of 10,000 animals allowed (Stenson 2006).

Hooded seals are important predators in the Northwest Atlantic waters around Newfoundland (Hammill and Stenson 2000). However, compared to harp seals, there has been much less effort expended in monitoring changes in hooded seal abundance in the Northwest Atlantic. Prior to 1984, estimates of pup production were obtained using various methods including survival indices, sequential population analyses and catch curves (Stenson et al. 1997). Aerial surveys were flown at the Front and in Davis Strait in 1984, at the Front only in 1985, at the Front and in the Gulf in 1990, and in the Gulf during March1994, and 1996 (Bowen et al. 1987; Hammill et al. 1992; Stenson et al 1997). As a result of this sporadic monitoring, there is considerable uncertainty surrounding hooded seal abundance. The most recent estimates date from 1990, when Hammill and Stenson (2000) suggested that the population may have numbered around 469,900 animals in the Gulf and at the Front, but this estimate is very sensitive to the underlying assumptions and it was strongly recommended by the Eminent Panel to complete a new survey (McLaren et al. 2001). In order to do so, new estimates of pup production were required. These were completed in 2004 and 2005 (Stenson et al. 2006)

Here, we estimate total Northwest Atlantic hooded seal population size, using a general population model structure, that has been modified from the model used in the harp seal assessment (Hammill and Stenson 2005). We provide recommendations for harvest levels that Fisheries and Aquaculture Management (FAM) would like explored, and indicate the impact of these removals with respect to the biological reference points identified under OBFM (Hammill and Stenson 2003).

MATERIAL AND METHODS

The current model is fitted to survey estimates of pup production by adjusting the initial population size and adult mortality rates to minimize the mean sum of square differences between pup production estimated by the model, and estimates obtained from survey data. Pup mortality is fixed at three times adult mortality. The model is described in Hammill and Stenson (2005) and is briefly reviewed here.

Model structure

The basic model has the form : $n_{a,t} = ((n_{a-1,t-1*} w_t) - c_{a-1,t-1})\, e^{-(\gamma)m}$ (1)

for a =1

$$n_{a,t} = (n_{a-1,t-1}e^{-m/2} - c_{a-1,t-1})e^{-m/2} \quad (2)$$

for 1 < a < A,

$$n_{A,t} = (n_{A-1,t-1}e^{-m/2} - c_{A-1,t-1})e^{-m/2} \quad (3)$$

for a = A, where A-1 is taken as ages A-1 and greater, and for a = 0;

$$n_{0,t} = \sum_{a=1}^{A} n_{a,t} P_{a,t} \quad (4)$$

where
- $n_{a,1}$ = population numbers-at-age a in year t,
- $c_{a,t}$ = the numbers caught at age a in year t,
- $P_{a,t}$ = per capita pregnancy rate of age a parents in year t, assuming a 1:1 sex ratio. P is expressed as a Normally distributed variable, with mean and standard error taken from the reproductive data
- m = the instantaneous rate of natural mortality.
- γ = a multiplier to allow for higher mortality of first year seals. Assumed to equal 3, for consistency with previous studies.
- W = is the proportion of pups surviving an unusual mortality event arising from poor ice conditions or weather prior to the start of harvesting.
- A = the 'plus' age class (i.e. older ages are lumped into this age class and accounted for separately, taken as age 25 in this analysis).

The model was adapted to function within an EXCEL spreadsheet and incorporated uncertainty in the parameters using an EXCEL add in called @Risk (@Risk , Palisade Corporation 2000). @Risk allows statistical distributions (e.g. Normal, Negative binomial, Triangle, Uniform) to be associated with parameters within the spreadsheet. The parameters can then be resampled repeatedly (Monte Carlo resampling) from within the distributions to estimate the impact of variability in input parameters.

A second feature called RiskOptimizer uses genetic algorithms to search for optimal answers to simulation models (Palisade Corporation 2000). For some model inputs (e.g. reproductive rates) information is available to describe sample variability in our estimates (mean and standard error). To capture some of the variability in these parameters, single parameter values were replaced by statistical distribution functions with mean and standard error estimated from the available data. In the current fitting of the model, the uncertainty in the population trajectory was estimated using the following re-sampling scheme. The set of pup production estimates were re-sampled (N=1000) assuming that the survey estimates of pup production, $\tilde{n}_{0,t}$, are normally distributed as:

$$\tilde{n}_{0,t} \sim N(n_{0,t}, \tilde{\sigma}^2_t),$$

where $n_{0,t}$ is the true pup production for year t, and $\tilde{\sigma}^2_t$ is the estimated variance of $\tilde{n}_{0,t}$.

where $N_{0,t\ j}$ is the j-th re-sampled estimate of $n_{0,t}$. Samples were drawn from the reproductive rates, and pup survey estimates. For each set of pup production estimates the model was refitted by calculating new estimates of initial population size and adult mortality rates, which in turn were used to generate population trajectories.

Data Input

The model was fitted to the independent estimates of pup production obtained from the aerial surveys between 1984 and 2005 (Tables 1 and 2).

Removals from the population were incorporated into the model using catch at age data (Tables 3 and 4; Stenson 2006). Reported catches were obtained from Anon (2006) and the DFO Statistics Branch. Prior to the end of the large vessel hunt (1982) it was assumed that 99% of the Canadian harvest was recovered. From 1983 onward, it was assumed that 95% of the pups killed in the Canadian hunt and that 50% of animals aged 1+ years and 50% of all animals killed in the Greenland and Canadian Arctic harvests were recovered (Stenson 2006).

The age structure of the harvest was incorporated from Stenson (2006). Two different harvest age structures were examined. Stenson (2006) noted a change in the harvest age structure after 1984. Therefore, we fitted the model to the pup production estimates using an age structure that was split, using one age structure based on samples collected prior to 1985, and a second age structure for the model period from 1985 onwards (Table 3).

Reproductive data were taken from Duffet (2005) based upon samples collected between 1979 and 2003, primarily from females on the whelping patch, with some animals collected from other times during the year. Since it is difficult to obtain post-implantation and late-term females in Canadian waters, the presence of a corpus albicans was used to indicate pregnancy in the year prior to collection (Øritsland 1971,1975). Corpus albicans were used to indicate pregnancy only in the previous year. Further back-calculatons were not carried out because of corpus albicans resorption and the potential for increasing error (Boyd 1984). Pregnancy rates were incorporated into the model as a binomial distribution (Table 4).

In the development of the model for harp seals, variable environmental conditions were considered to have had an impact on mortality rates among years. Specifically, poor ice conditions and extensive storm activity has probably resulted in higher than normal mortality rates for pups (Hammill and Stenson 2005). In many years, the effects of increased mortality are seen in increased numbers of young of the year that are washed up on beaches or are seen floating in the water. For harp seals, this mortality was applied before animals are harvested. The impact of changes in environmental conditions on the survival of hooded seal pups is not as clear. The development of hooded seal pups is much different from that of harp seals (Bowen et al. 1985; Kovacs and Lavigne 1992; Lydersen and Kovacs 1996; Lydersen et al. 1997). In spite of these differences, access to a stable platform to haul out and rest may still be important until the animals develop their foraging skills. Furthermore, unlike harp seals, the female-pup bond is virtually non-existent. Therefore, any separation from the female prior to weaning due to ice breakup would likely lead to mortality for a very young pup. Higher mortality was included in the model, as w_t (equation 1). It was set as 0.25 in 1981 and 2005.

The effects of four different scenarios on estimates of total abundance were examined and presented at the meeting. Two scenarios were retained. The first scenario fitted the model to estimates of pup production at the Front (Table 1) since this is the largest concentration, and there are four aerial survey estimates from this area. A second scenario attempted to fit to estimates of pup production in all areas (Table 2). No aerial survey estimates are available for the Gulf for 1984 and 1985. However, it was considered at the meeting that Gulf hooded seal abundance was probably on the order of 500-800 animals (Hammill et al. 1992). In 1984, hooded seal pup production in Davis Strait was in the order of 19,000 animals. However, surveys in 2005 provided an estimate of 3,300 animals in this area (Table 1). Since we do not know if this change results from movement between colonies, a decline in abundance due to overharvesting in Greenland or an under-estimate because only a single brief survey was completed in Davis Strait in 2005, we set the Davis Strait estimate as an input with uniform distribution, lying between 1,000 and 23,000 animals. This was applied to the data from 1985, 1990 and 2004, years where Davis Strait was not covered by our aerial surveys.

For harp seals, an additional source of uncertainty relates to reported harvest rates in Greenland. Hooded seal harvests are also not regulated. However, catch levels appear to be constant at around 6,000 animals per year.

Under the Objective Based Fisheries Management approach developed for Atlantic seals, hooded seals are considered ‘Data Poor’. This means harvest levels should be calculated using the Potential Biological Removal approach, defined by:

$$PBR= PBR=0.5 \cdot RMax \cdot F \cdot NMin,$$

where RMax is the maximum rate of increase for the population , F is a recovery factor with values between 0.1 and 1 and NMin is the estimated population size using 20th percentile of the log-normal distribution (Wade 1998). RMax is set at a default of 0.12 for pinnipeds unless there is evidence for other more appropriate rates. The recovery factor (F) is set at 0.1 in the case of endangered species, 0.5 for depleted or threatened species and 1 for populations at OSP. The default value for RMax was used while the recovery factor was set at 1.

RESULTS

The population model fits to the pup production data by adjusting the initial population size and adult mortality. Fitting only to the pup estimates from the Front, resulted in an initial population size of 372,300 (SE=44,800, 95% C.I.=289,500-464,600) in 1965 and an instantaneous adult mortality rate of 0.120 (SE=0.006)(Tables 1,2). However, these two parameters are highly correlated and change in a way that is best described by a second degree polynomial relationship (Fig. 1). A linear model provides an adequate fit to the data with a correlation coefficient of r=1 and this was incorporated into the model structure.

Fitting the model to the pup production data, incorporating uncertainties outlined above, resulted in estimates of pup production of 73,400 (SE=9,200, 95% C.I.=56,400-92,400) in 1965 increasing to 107,900 (SE=18,800, 95% C.I.=70,600-143,300) in 2005 (Fig. 2). The total population was estimated to have increased to 535,800 (SE=93,600, 95% CI= 350,600-711,300) in 2005 (Fig 2).

In a second projection, the model was fitted to the pup estimates from all areas (Table 1,2). The initial population and adult mortality parameters were highly correlated and set to 1 (Fig. 1). Adult mortality was 0.130 (SE=0.004). The initial pup production in 1965 was 94,800 (SE=8,700; 78,600-112,600). Pup production increased to about 120,100 (SE=13,800; 95% C.I. 94,100-147,900). Total population size was 478,000 (SE=41,800; 95% C.I.=400,500-564,300) in 1965, increasing to 593,500 (SE=67,200, 95% CI=465,600-728,300) by 2005 (Fig. 3).

Estimates of PBR range from 27,400 using only aerial survey estimates for the Front, to 32,100 if surveys from the Gulf, and Davis Strait are also included (Table 4).

DISCUSSION

The most recent aerial surveys resulted in a pup production estimate of 107,00 (SE = 7,600) for the hooded seal pupping at the Front in 2005. An additional 6,600 (SE = 1,700) pups were estimated to have been born in the Gulf and 3,300 (SE = 2,200) in Davis Strait for a total of 116,900 (SE = 7,918) in the Northwest Atlantic (Stenson et al, 2006). Incorporating information on reproductive rates and estimates of removals from the population into a model and fitting this model to the Front survey data only, resulted in pup production estimates of 73,400 (SE=9,200, 95% C.I.=56,400-92,400) in 1965, at the start of the modeling period, increasing to 107,900 (SE=18,800, 95% CI=70,600-143,300) in 2005, depending on model assumptions. The total population at the Front has increased from 372,300 (SE=44,800, 95% C.I.=289,500-464,600) in 1965 to 535,800 (SE=93,600, 95% CI=350,600-711,300) in 2005. If survey estimates from all breeding areas are pooled, and certain assumptions are made about the abundance of hooded seals in the Gulf and in Davis Strait, during years, when these areas were not surveyed, then pup production in 1965 was 94,800 (SE=8,700; 78,600-112,600). Pup production remained relatively stable throughout the remainder of the 1960s and 1970s then began to increase again in 1985 again attaining 120,100 (SE=13,800, 95% CI=94,100-147,900) animals in 2005. The total Northwest Atlantic hood seal population size has increased from 478,000 (SE=41,800; 95% C.I.=400,500-564,300) in 1965 to 593,500 (SE=67,200, 95% CI=465,600-728,300) in 2005. Adult mortality rates varied from 0.12 to 0.13, which are much higher than adult mortality rates estimates of 0.06 for harp seals using the same modeling approach (Hammill and Stenson 2005).

The marked differences in adult mortality rates observed between harp and hooded seals might reflect real differences in life history patterns, result from uncertainties associated with the small number of reproductive tract samples, the size of the Greenland harvest, and uncertainty in the age structure of harvested animals. Harvesting patterns of this species have changed drastically over the last 45 years, in response to changes in harvesting objectives (blueback vs subsistence hunt). In trying to build the catch tables, it was necessary to search through several different sources to obtain catch data and information on the age structure of the catches. We included in the model some uncertainty associated with poor environmental conditions, but the impacts of varying ice conditions on young survival are difficult to quantify. Finally, there is considerable uncertainty associated with the catch data. Currently, the majority of harvesting now occurs in Greenland and the reporting of harvest data are often one to two years behind. There is also some uncertainty as to the how accurate the reported harvests actually are.

Two important sources of uncertainty that could have an important impact on our estimates as well as on our PBR estimates are the uncertainty associated with current stock relationships. Unlike harp seals which show some separation between the Northwest and Northeast Atlantic harp seal herds, there does not appear to be any separation among Davis Strait, Northeast and Northwest Atlantic herds of hooded seals (Coltman, Stenson and Hammill, unpublished data). One mechanism for this might be the movement of small numbers of juveniles between herds. Hooded seal juveniles are notorious for their wandering habits (Hammill 1993). This would reduce genetic differences between herds, yet still allow for philopatric behaviour among adults, as is observed in many other ice breeding phocids. Finally, we have assumed that adult male and female hooded seals have similar mortality rates. Among hooded seals there is substantial sexual dimorphism (Hammill et al. 1997; Hammill and Stenson 2000). In other pinnipeds, this is often associated with differential survival in favour of females. Unfortunately, we have no information on how adult male mortality rates might differ from females.

Estimated PBR levels range from 27,400-32,100 animals. When setting the Canadian harvest, reported removals by the Greenland hunt, as well as hunting losses and other human-induced mortality in both the Canadian and Greenland hunts must be taken into consideration.

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Table 1. Estimated pup production and standard errors of Northwest Atlantic hooded seals from aerial surveys. All estimates are rounded to the nearest hundred.

Year	Front	Gulf	Gulf [1] (corrected this study)	Davis Strait
1984	62,400 (43,700-89,400)			19,000 (14,000-23,000)
1985	61,400 (16,500-119,500)			
1990	83,100 (SE=12,700)	1,600[2] (SE=500)		
1991		2,000 (SE=190)	1,700 (SE=130)	
1994		4,000 (SE=1,000)	8,700 (SE=1,800)	
1996		4,678[2] (SE=748)		
2004	124,000 (SE=18,600)	1,400[3] (SE=300)		
2005	107,000 (SE= 7,600)	6,600 (SE=1,700)		3,300 (SE=2,200)

[1] Published estimates corrected for the temporal distribution of birth using the normal model described in this paper.
[2] Surveys were flown but insufficient stage data were collected to determine temporal distribution of births.
[3] Incomplete counts because animals were missed.

Table 2. Estimated pup production and standard errors for Northwest Atlantic hooded seals from aerial surveys in years when two or more whelping areas are surveyed. All estimates are rounded to the nearest hundred. In years for which there are no survey estimates for Davis Strait, we assumed a uniform distribution with limits of 1,000-23,000 animals.

	1984		1990		2004		2005	
	Est	SE	Est	SE	Est	SE	Est	SE
Front	62,400	11,700	83,100	12,700	124,000	18,600	107,000	7,600
Gulf			1,600	500	1,400	300	6,600	300
Davis St.	19,000	2,300					3,300	2,200
Total	81,400	11,924	84,700	12,710	125,400	18,602	116,900	7,918

Table 3. Total removals from Northwest Atlantic hooded seal population. Removals are pooled, but the age structure appeared to change after 1984, hence two age structures were incorporated into the catch table-pre-1985 and post-1984 (see Stenson 2006).

Age	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
0	3392	2374	1158	4766	4780	2990	17045	8566	1309	9007	5469	8225	7182	4792	6225	7927
1	1870	222	226	249	390	261	368	298	250	292	431	304	764	408	806	589
2	2051	356	363	394	606	416	561	456	401	436	632	464	1018	650	1086	919
3	2528	394	402	437	671	461	622	506	444	483	650	515	1093	720	1130	1018
4	2441	457	454	601	1194	603	1320	1022	536	1221	749	1066	1601	934	1403	1697
5	2139	399	392	557	1186	550	1359	1043	475	1294	777	1093	1484	850	1352	1659
6	1725	337	322	545	1328	519	1617	1223	418	1610	704	1291	1554	796	1357	1806
7	1305	282	267	478	1210	451	1494	1126	356	1502	602	1190	1403	690	1207	1633
8	1035	233	220	402	1029	377	1276	961	295	1288	539	1016	1163	577	1019	1386
9	794	198	190	319	774	304	941	712	246	935	442	751	918	467	815	1054
10	537	160	152	272	689	256	852	642	202	857	389	679	822	392	647	930
11	561	151	141	275	732	255	922	691	194	939	343	733	817	390	669	979
12	536	112	105	195	503	182	626	471	142	633	263	498	593	279	521	676
13	409	108	105	161	366	156	432	329	131	421	217	346	449	240	397	504
14	577	110	105	178	435	170	530	401	137	527	210	423	503	261	456	592
15	246	74	72	107	236	104	275	210	89	266	134	221	285	161	257	327
16	165	72	71	101	215	100	245	188	86	233	112	197	260	154	252	300
17	166	34	32	57	142	53	175	132	42	176	67	139	161	82	163	192
18	272	38	35	73	201	67	256	192	49	263	89	203	206	102	185	267
19	139	29	28	44	101	42	120	92	35	118	53	96	121	65	101	139
20	78	30	29	43	96	42	112	86	36	108	48	90	111	65	91	133
21	47	12	12	21	53	20	66	50	15	67	27	53	56	30	69	72
22	52	17	16	27	67	26	83	62	21	82	32	66	78	40	67	92
23	31	16	15	22	46	21	53	40	19	50	25	42	53	33	61	65
24	56	8	8	14	34	13	41	31	10	41	17	33	36	20	30	46
25	119	41	40	58	128	57	148	113	49	143	66	119	150	88	147	178
Total	23270	6261	4958	10396	17213	8498	31540	19642	5988	22992	13089	19853	22881	13287	20514	25181

Table 3. continued.

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0	6824	9319	8323	12324	11542	11036	8114	237	420	4624	3943	4613	5073	4462	4551	4661
1	682	732	1059	723	780	755	786	739	711	2683	2107	2038	2297	2487	2818	6206
2	1034	1167	1636	1153	1249	1205	1257	1080	937	1343	1158	996	1247	1307	1388	1905
3	1174	1293	1689	1277	1384	1335	1392	1197	1038	869	730	649	788	834	902	1460
4	1683	1649	1991	1635	1664	1687	1722	1314	1137	886	751	660	810	854	918	1405
5	1596	1491	1739	1480	1473	1520	1540	1128	981	807	666	605	721	767	841	1496
6	1631	1376	1534	1371	1292	1393	1386	900	786	447	344	341	376	410	471	1114
7	1437	1189	1300	1185	1097	1201	1188	736	640	570	472	427	511	543	593	1026
8	1239	993	1103	990	911	1002	989	603	524	416	343	312	372	396	433	761
9	959	809	894	805	761	819	815	531	463	345	279	260	303	325	360	700
10	832	675	747	674	623	682	674	419	367	274	215	209	234	254	288	640
11	844	666	711	666	599	671	657	380	332	339	279	255	302	322	353	636
12	600	479	523	478	438	483	476	292	258	394	322	297	349	373	411	767
13	474	419	461	417	405	426	428	301	267	132	86	104	97	112	142	503
14	535	451	488	449	423	456	454	297	261	54	22	46	27	38	61	363
15	314	281	314	280	274	286	289	210	188	82	44	68	51	64	91	436
16	286	271	299	269	268	276	280	212	192	137	87	110	98	115	149	568
17	183	141	159	141	131	143	141	95	89	129	86	102	97	111	139	471
18	237	173	180	173	152	173	169	94	84	88	65	68	71	79	93	253
19	129	113	120	113	109	115	115	83	77	144	108	111	118	130	153	400
20	132	113	125	113	110	115	116	86	78	44	22	37	26	33	49	250
21	64	52	59	52	48	52	52	36	36	21	0	20	3	10	26	241
22	80	69	68	69	64	70	69	48	46	68	43	54	49	57	74	276
23	62	58	62	58	58	59	60	47	43	61	43	47	48	54	65	195
24	42	34	38	34	32	35	35	24	23	10	0	9	1	5	12	112
25	165	154	165	153	151	157	159	118	107	146	108	112	118	131	155	416
Total	23238	24169	25786	27080	26038	26152	23364	11208	10087	15114	12323	12549	14188	14273	15537	27266

Table 3 continued

Age	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0	4851	4661	5458	4795	30677	4985	4235	2126	3905	4198	2364	4230	4290	4290	4290
1	2683	2518	3030	3069	5251	6802	8210	1256	2097	2330	1354	2354	2525	2309	2297
2	1436	1379	1622	1487	2199	2061	2098	644	1153	1250	710	1261	1298	1268	1266
3	911	870	1029	971	1504	1588	1739	414	726	793	453	800	834	799	797
4	935	895	1056	987	1503	1526	1633	423	747	814	464	821	852	822	821
5	836	794	944	908	1447	1632	1849	383	662	727	417	733	770	729	727
6	441	412	498	515	904	1223	1502	208	343	383	223	387	418	377	375
7	592	563	669	639	1010	1118	1255	270	470	515	295	520	544	517	516
8	431	410	487	467	742	829	936	197	342	375	215	378	397	376	375
9	352	333	398	391	640	766	892	163	278	306	177	309	327	306	305
10	274	257	309	314	539	702	849	128	214	238	138	240	258	236	234
11	351	333	396	382	611	694	790	161	278	305	175	308	323	306	305
12	406	384	458	445	720	838	964	186	321	353	203	356	375	353	352
13	117	104	132	159	329	556	736	59	86	101	61	102	118	95	94
14	36	27	40	72	191	403	563	22	22	30	21	31	44	25	23
15	64	53	72	105	249	484	664	35	43	54	35	55	71	48	47
16	118	105	134	168	359	628	839	61	86	102	63	104	122	95	94
17	116	104	131	155	314	520	684	58	86	100	60	101	116	95	94
18	84	77	95	102	190	279	352	40	64	73	43	74	81	71	70
19	139	129	157	168	306	440	553	67	107	121	71	122	134	118	117
20	33	27	37	57	139	278	383	19	22	28	18	28	37	24	23
21	7	1	8	33	111	268	386	8	0	5	6	6	15	1	0
22	59	52	67	83	176	305	406	30	43	51	31	52	61	48	47
23	57	52	64	72	139	216	278	28	43	49	29	50	56	47	47
24	3	1	4	15	52	125	180	4	0	2	3	3	7	0	0
25	140	129	158	170	314	458	579	67	107	121	71	122	135	118	117
Total	15470	14671	17451	16727	50616	29725	33555	7059	12246	13424	7703	13547	14211	13473	13433

Table 4. Age specific reproductive rates and sample size (N).

Age	Mean	N
3	0.217	60
4	0.552	87
5	0.814	118
6	0.860	93
7	0.897	78
8	0.847	59
9	0.897	68
10+	0.881	386

Table 5. Estimated total population size, source of pup production estimates and harvest age structure to develop model, N_{Min} , coefficient of variation (CV) and estimated potential biological removal (PBR) harvests for Northwest Atlantic hooded seals.

Population	Source	Harvest age structure	N_{Min}	CV	PBR
535,800	Front	Split	457,000	0.17	27,400
593,500	All	Split	535,100	0.11	32,107

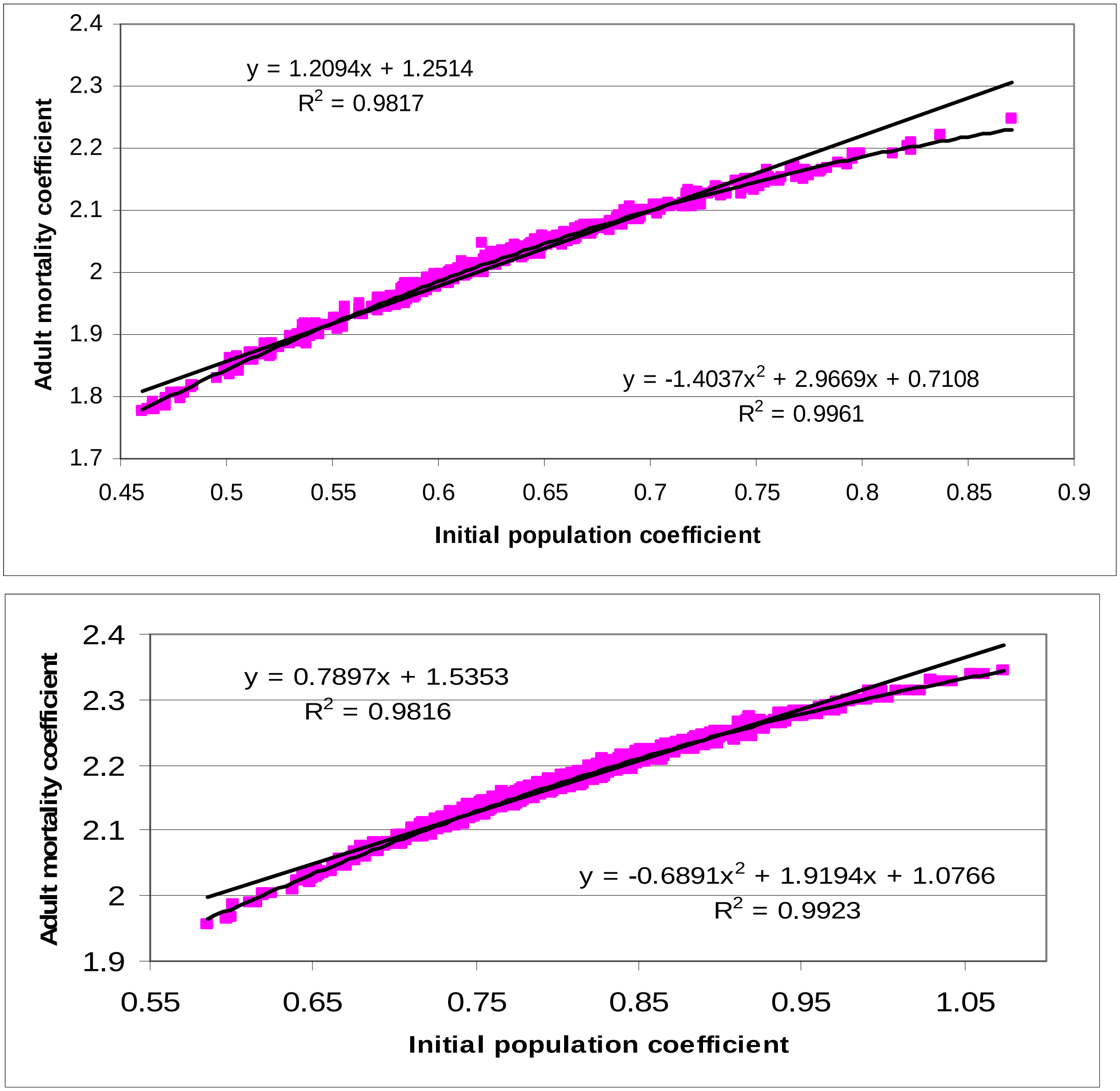
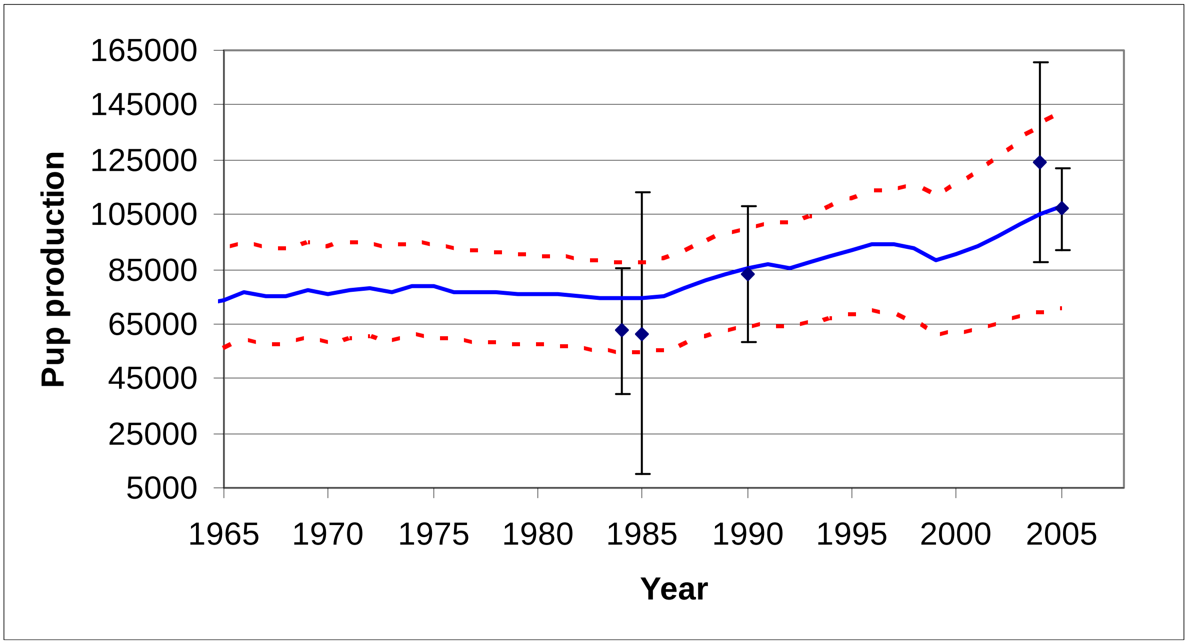


Figure 1. Relationship between adjustable parameters (Initial population size and Adult mortality) used to fit the population model to the pup survey data. The top panel shows the relationship using only the Front pup production estimates. The bottom figure shows the relationship using pup production estimates from all areas.



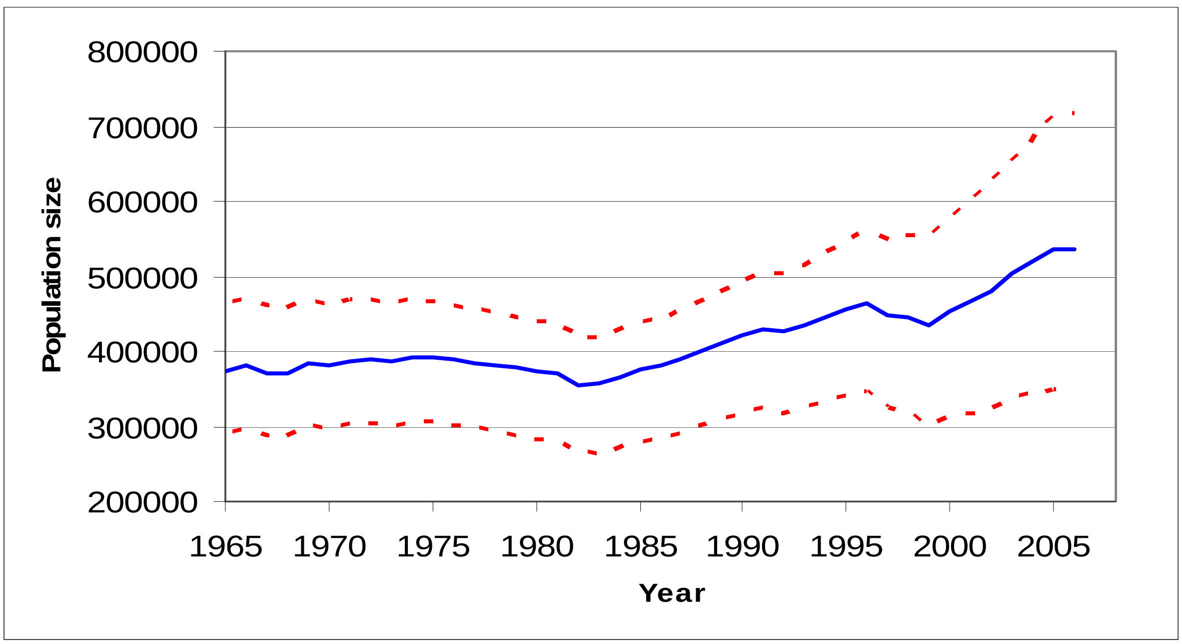


Figure 2. Changes in pup production (± 95% C.I.) and survey estimates (± 95% C.I.) (top) of Northwest Atlantic hooded seals between 1965 and 2005, fitting the model to the Front pup production data only. Total estimated population size and 95% C.I. are shown in the bottom panel.

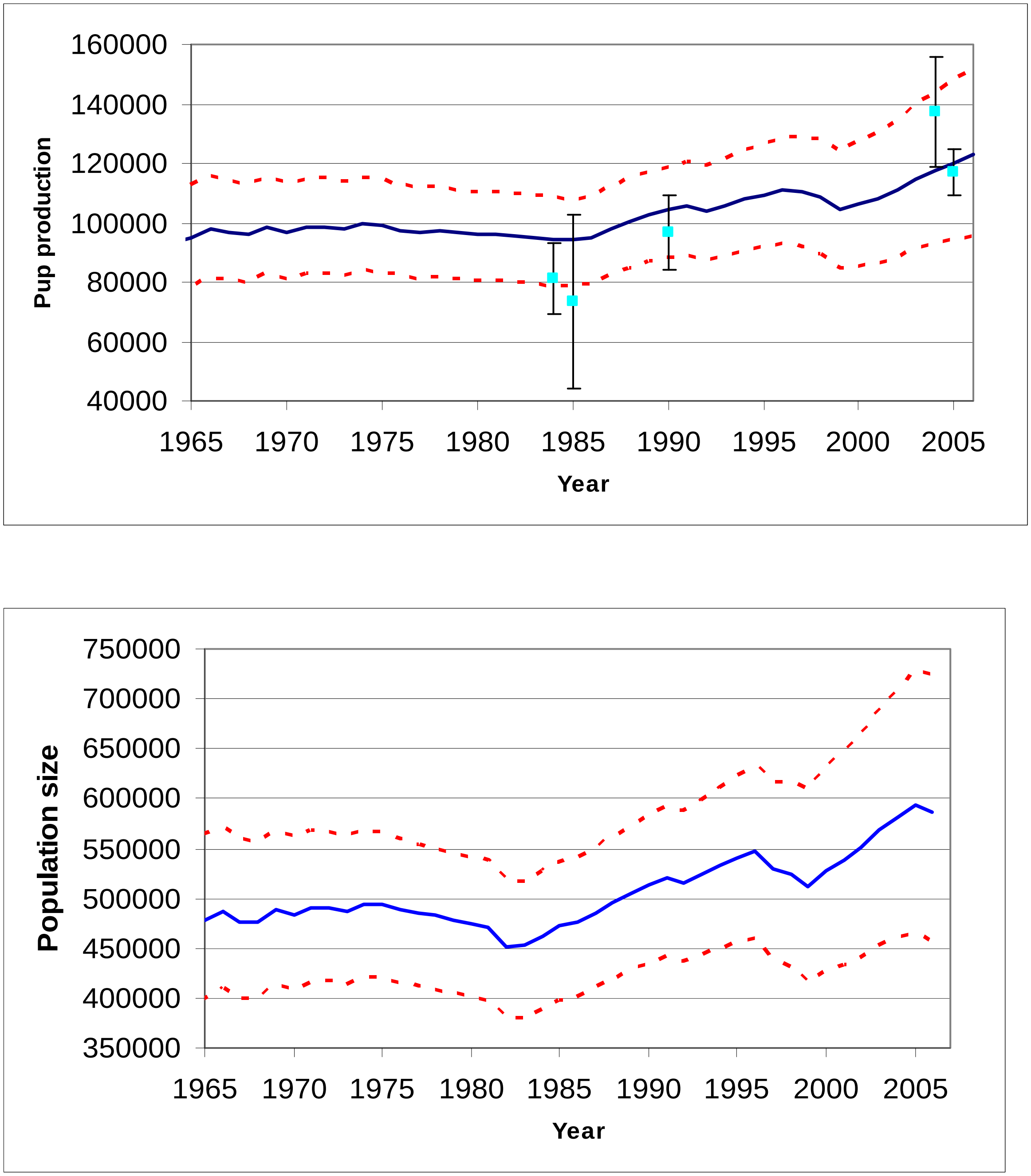


Figure 3. Changes in pup production (± 95% C.I.) and survey estimates (± 95% C.I.) (top) of Northwest Atlantic hooded seals between 1960 and 2007, fitting the model to all pup production data only. Total estimated population size and 95% C.I. are shown in the bottom panel.