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THE 2011 ABUNDANCE OF HOODED SEALS (*CYSTOPHORA CRISTATA)* IN THE GREENLAND SEA

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ABSTRACT

On request by the previous WGHARP meeting the WGHARP population model has been modified to include historical reproductive data. All runs using the original model and the modified WGHARP population model indicated a substantial decrease in the Greenland Sea hooded seal population abundance from the late 1940s and up to the early 1980s. After 1980, the population size appears to be relatively stable at a low level, and model predictions indicate an increase between 5 - 46% in the abundance of 1+ animals over the coming 10 year period. The model is sensitive to the choice of reproduction rates, for which historical records are sparse. Regardless of the assumptions concerning the reproduction rate, all model runs gave very similar results with regard to present abundance. This is due to the recent pup production estimate obtained in 2007. Using a reproduction rate of $F = 0.9$, a 2011 abundance of 67 770 1+ animals and 18 040 pups are obtained. A 95% confidence interval for the 1+ population is (41 359 - 94 181). Thus, the total population of hooded seals in the Greenland Sea is 85 810 (58 407 – 113 212). Under this scenario, the PBR level of removal would be 2 178 (14% pups). If the model is run with this assumed cautious removal, the model predicts a 17% increase of the 1+ population over the coming 10 years. Sustainable catches estimated for this assumption of *F*, using the WGHARP population model, is 4 219 (64.4% pups). Sustainable catches using the original model is much lower, 823 animals (64.4% pups), and a PBR catch level of 2 260 animals (14% pups) indicate a 17% reduction of the abundance over the next 10 years.

Material and Methods

The population model

The population model used by ICES (The Joint ICES/NAFO Working Group on Harp and Hooded Seals, WGHARP) to assess the abundance for the NE Atlantic hooded seal population is an age-structured population dynamics model. It uses historical catch data and estimates of pup production in order to estimate the current total population. A similar model is used to assess the abundance of the NEA harp seal population and the Barents Sea harp seal population (ICES, 2006). It was also used for assessing the historical population of the Barents Sea harp seals (Skaug et al., 2007). The model presented in this working paper is a slightly modified version of the model used previously in (e.g., ICES, 2005, 2006, 2008, 2009). As requested by the WGHARP the model has been modified to incorporate historical reproductive rates.

The following parameters are used in the model.

- $N_{0,t}$ ~ number of pups born in year *t*.
- $N_{i,t}$ ~ number of individuals of age *i* in year *t*.
- N_{t_0} ~ population size in year t_0.
- M_0 ~ mortality rate for pups.
- M_{1+} ~ mortality rate for 1+ age group.
- $p_{i,t}$ ~ proportion of mature females at age *i* in year *t*.
- F_t ~ proportion of females giving birth in year *t*.

The ”1+” denotes all ages older than or equal to 1 year. The assumption that the mortality rate is age-independent within the 1+ is because available data do not allow for a more detailed age-dependence to be estimated.

Due to the changes in the model the proportion of mature females at age *i*, is now time-variant, and applies historical data. In time periods where no data are available, a linear smooth transition of the reproduction data is used. This is shown in Figure 1. The reproduction rate *F* is no longer a constant estimated by the model. It now assumed to be known and historical data is used.

The mortality rates M_0 and M_{1+} determine the survival probabilities $s_0 = \exp(-M_0)$ and $s_{1+}=\exp(-M_{1+})$, which are the quantities that appear in the population dynamics equations that follow.

It is assumed that the population had a stable age structure in year $t_0 = 1945$, i.e.

$$N_{i,t_0} = N_{t_0} s_{1+}^{i-1}(1-s_{1+}), \quad i = 1,\ldots,A-1, \tag{1}$$

$$N_{A,t_0} = N_{t_0} s_{1+}^{A-1}. \tag{2}$$

The maximal age group A=20 contains all individuals aged A or more. The catch records give information about the following quantities:

$C_{0,t}$ ~ Catch in number of pups born in year *t*,

$C_{1+,t}$ ~ Catch in number of 1+ age group in year *t*.

In absence of information about age-specific catch numbers, we employ *pro rata* rules in the model (see Skaug et al., 2007):

$$C_{i,t} = C_{1+,t}\frac{N_{i,t}}{N_{1+,t}}, \quad i = 1,\ldots,A, \tag{3}$$

where $N_{1+,t} = \sum_{i=1}^{A} N_{i,t}$. The model has the following set of recursion equations:

$$\begin{aligned}
N_{1,t} &= (N_{0,t-1} - C_{0,t})s_0, \\
N_{i,t} &= (N_{i-1,t-1} - C_{i-1,t-1})s_{1+}, \quad i = 2,\ldots,A-1, \\
N_{A,t} &= ((N_{A-1,t-1} - C_{A-1,t-1}) + (N_{A,t-1} - C_{A,t-1}))s_{1+}.
\end{aligned} \tag{4}$$

The pup production is given as

$$N_{0,t} = \frac{F_t}{2}\sum_{i=1}^{A} p_{i,t} N_{i,t}, \tag{5}$$

where $N_{i,t}/2$ is the number of females at age *i*.

The model also calculates the depletion coefficient D_{1+}, which describes the degree of increase or decrease in the population trajectory on the most recent 10-year scale,

$$D_{1+} = \frac{N_{1+,2021}}{N_{1+,2011}}. \quad (6)$$

The estimated parameters are the initial population, N_{t_0} along with the biological parameters M_0 and M_{1+}. These are found by minimizing an objective function consisting of the sum of squares of the differences between the model value and the survey estimates of pup production. To minimize the total objective function the statistical software AD Model Builder (ADMB Project 2009) is used. AD Model Builder calculates standard deviations for the model parameter, as well as the derived parameters such as present population size and D_{1+}. AD Model Builder uses a quasi-Newton optimization algorithm with bounds on the parameters, and calculates estimates of standard deviations of model parameter using the ”delta-method” (Skaug et al., 2007). The catch data enter the model through Eq. (4), but do not otherwise contribute to the objective function. As the model involves prior distributions on some parameters, the analysis has a Bayesian flavour.

Reproductive rates

Maturity curves were constructed based on female reproductive material collected over the period 1990-94 and 2008-10 (Table 1). Data for the first period was collected by Russian scientists and data for the latter period was collected by Norwegian scientists. All data were collected in the period May-July. Further details on estimation of maturity curves are given in Frie (2011, this meeting).

Survey pup production estimates and catch history

Pup production estimates are available from aerial surveys conducted in 1997, 2005 and 2007 (Table 2). Catch level for the period 1946 – 2011 are shown in Figure 2.

Results

Population estimates

The estimated population, along with the parameters for the normal priors used are presented in Table 3. The mean of the prior for M_0 was taken to be three times that of the mean of M_{1+}. In previous WGHARP meetings the model has been run for various choices of the prior distributions of M_{1+}, with mean in the range of 0.09 – 0.13, standard deviation 0.05, and in the range of 0.10 – 0.11 with standard deviation 0.01 (ICES 2006, 2008). The model has been sensitive to choices of M_{1+}, which is poorly estimated due to lack of data. In the previous WGHARP meetings a non-informative prior with mean 0.11 with standard deviation 0.05 was selected. In this working paper we selected to use the same prior for M_{1+}.

The previous version of the model did utilize a prior for the reproduction rate F and estimated F. In according to requests by the Working Group on Harp and Hooded Seals in 2009 the model has been changed to use historical values of F. Thus, the reproduction rate is no longer estimated, and hence, considered as a known quantity. However, the historical record of the reproduction rate is sparse, consisting of only one estimate from the 1990s (ICES 2006). A normal prior with mean 0.88 has been used previously (ICES 2008). The model was run for four scenarios; the original model with constant reproduction rates and three choices of the reproduction rate F, i.e., $F = 0.5$, $F = 0.7$, and $F = 0.9$.

The fitted models for various choices of F are shown in Figure 3. Model estimates using the three reproductive rates were not statistically significantly different from each other on a 5% level. The model estimates around late 1940s differ most, but the model 95% confidence interval around those years are very large.

All model runs seem to indicate a substantial decrease in the population abundance from the late 1940s and up to the early 1980s. In the most recent two decades, the population size appears to have stabilized at a low level. All model predictions indicate a recent increase in the abundance of 1+ animals on a 10 year scale, ranging from an increase of 5% - 46%, depending on the choice of reproduction rate.

Using a reproduction rate of $F = 0.9$, a 2011 abundance of 67 770 1+ animals and 18 040 pups are obtained. A 95% confidence interval for the 1+ population is (41 359 - 94 181). The total 2011 population of hooded seals in the Greenland Sea therefore count 85 810 (58 407 – 113 212) seals of all ages.

Catch Options

Previously the Greenland Sea hooded seals were regarded as data poor due to old reproductive data and catch options were based on the use of the Potential Biological Removals (PBR) approach (ICES, 2006). The Potential Biological Removals has been defined as:

$$PBR = \frac{1}{2} R_{\max} \cdot F_r \cdot N_{\min} ,$$

where R_{max} is the maximum rate of increase for the population, F_r is the recovery factor with values between 0.1 and 1, and N_{min} is the estimated population size using 20th percentile of the log-normal distribution. R_{max} is set at a default of 0.12 for pinnipeds. It was regarded appropriate to set the recovery factor Fr = 0.5 given the apparent lack of the population to recover despite the low hunting pressure during the past 25 years. For comparison, model estimates of sustainable catches were also obtained. Both PBR levels of removals and estimated (using the population model) sustainable catches were found for various choices of F (Table 4).

The PBR removals were estimated to be 2 178 (14% pups) assuming a reproductive rate of $F = 0.9$. This assumes that the age structure of the removals is proportional to the age composition of the population. At this catch level the model predicts a 17% increase of the 1+ abundance in 10 years. Sustainable catches for this assumption of F would be 4 219 assuming 64.4% pups in catches. This is the average proportion of pups in catches in the years 2007 - 2011. Sustainable catches using the original model is much lower, 823 animals (64.4% pups), and a PBR catch level of 2 260 animals (14% pups) indicate a 17% reduction of the abundance over the next 10 years.

It should be noted that the 2011 population was below N_{lim} (30% of N_{max}, where the current N_{max} value is estimated at 777 900 animals). Following the Precautionary harvest strategy previously developed by WGHARP (see ICES2005, 2006), the implication of this is no current catches from the population.

References

ADMB Project. 2009 AD Model Builder: automatic differentiation model builder. Developed by David Fournier and freely available from admb-project.org.

ICES 2005. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals, 30 August – 3 September, 2005, St. John's, Newfoundland, Canada. ICES CM 2006/ACFM: 06. 48 Pp.

ICES 2006. Report of the Working Group on ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 12-16 June 2006, ICES Headquarters. ICES CM 2006/ACFM:32. 28 pp.

ICES 2008. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals, 27-30 August 2008, Tromsø, Norway. ICES CM 2008/ACOM 17. 59 pp.

ICES 2009. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals, 24-27 August 2009, ICES Headquarters. ICES CM 2009/ACOM 17. 51 pp.

Øigård, T.A., Haug, T., Nilssen, K.T. and Salberg, A.-B., 2010. Estimation of pup production of hooded and harp seals in the Greenland Sea in 2007: Reducing uncertainty using Generalized Additive Models. J. Northw. Atl. Fish. Sci. Vol. 42 pp. 103 – 123.

Salberg, A.B., T. Haug and K.T. Nilssen. 2008. Estimation of hooded seal (*Cystophora cristata*) pup production in the Greenland Sea pack ice during the 2005 whelping season. *Polar Biol.,* **31** : 867-878.

Skaug, H. J., Frimannslund, L., Øyen, N., 2007. Historical population assessment of Barents Sea harp seals (*Pagophilus groenlandicus)*. ICES Journal of Marine Science. Vol 64 pp. 1356 – 1364.

Table 1. Estimates of proportions of mature females ($p_{i,t}$). The P_1 estimates are from ICES (2008) and the P_2 estimates are from Frie (2011, this meeting). Mature females had at least one CL or CA in the ovaries.

Age	1	2	3	4	5	6	7	8	9	10	11
P_1	0	0.05	0.27	0.54	0.75	0.87	0.93	0.97	0.98	0.99	1.00
P_2	0.02	0.11	0.45	0.82	0.95	0.99	1.00	1.00	1.00	1.00	1.00

Table 2. Estimates of Greenland Sea hooded seal pup production, based on data from Salberg et al (2008) and Øigård et al. (2010).

Year	Estimated Number of Pups	Coefficient of Variation.
1997	24 000	0.280
2005	15 200	0.249
2007	16 140	0.133

Table 3: Model estimates and standard deviation of the parameters used in the model for the original model and for various choices of the reproduction rate *F*. Priors used are shown in brackets.

Parameters	**Original**		**F = 0.5**		**F = 0.7**		**F = 0.9**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N_{t_0}	751 323 (90 000)	465 170 (90 000)	1 102 995 (90000)	582 510 (90000)	828 739	498 990	620 564	379 970
M_0	0.33 (0.33)	0.05 (0.05)	0.33 (0.33)	0.05 (0.05)	0.34	0.05	0.34	0.05
M_{1+}	0.15 (0.11)	0.03 (0.05)	0.13 (0.11)	0.03 (0.05)	0.16	0.05	0.16	0.04
F	0.86 (0.88)	0.1 (0.1)	NA	NA	NA	NA	NA	NA
$N_{0,2011}$	15 340	2 967	15 690	2 563	16 710	3 120	18 040	3 723
$N_{1+,2011}$	73 340	13 963	88 860	14 280	73 440	13 336	67 770	13 476
$N_{Total,2011}$	88 680	14 275	104 550	14 500	90 150	13 695	85 810	13 981
D_{1+}	1.08	0.34	1.05	0.23	1.22	0.36	1.46	0.54

Table 4. Catch options with estimated development in relative population size (D1+) in the coming 10-years for hooded seals in the Greenland Sea. For sustainable catches average proportion of pups in catches in the period 2007 – 2011 are used.

MODEL	CATCH LEVEL	PROPORTION OF PUPS IN CATCHES	PUP CATCH	1+ CATCH	TOTAL CATCH	D_{1+}		
						Lower CI	Point	Upper CI
Original	Sustainable harvest	64.4%	530	293	823	0.55	1.00	1.47
	PBR	14.0%	318	1951	2 269	0.19	0.83	1.49
F = 0.7	Sustainable harvest	64.4%	1 578	872	2 450	0.29	1.00	1.71
	PBR	14.0%	325	1 997	2 322	0.38	0.84	1.30
F = 0.9	Sustainable harvest	64.4%	2 706	1 513	4 219	0	1.00	2.05
	PBR	14.0%	305	1 873	2 178	0.14	1.17	2.20

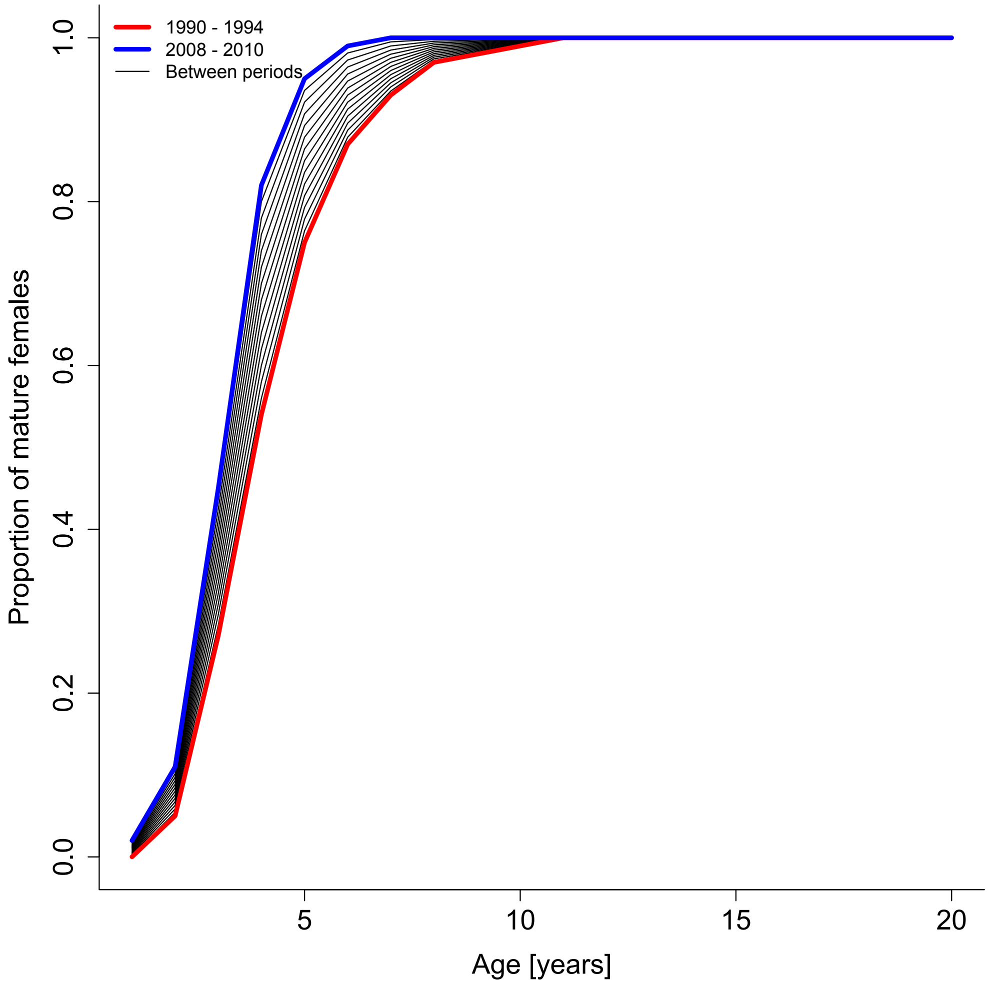

Figure 1. Proportion of mature females among Greenland Sea hooded seals in two periods. Values taken from Table 1.

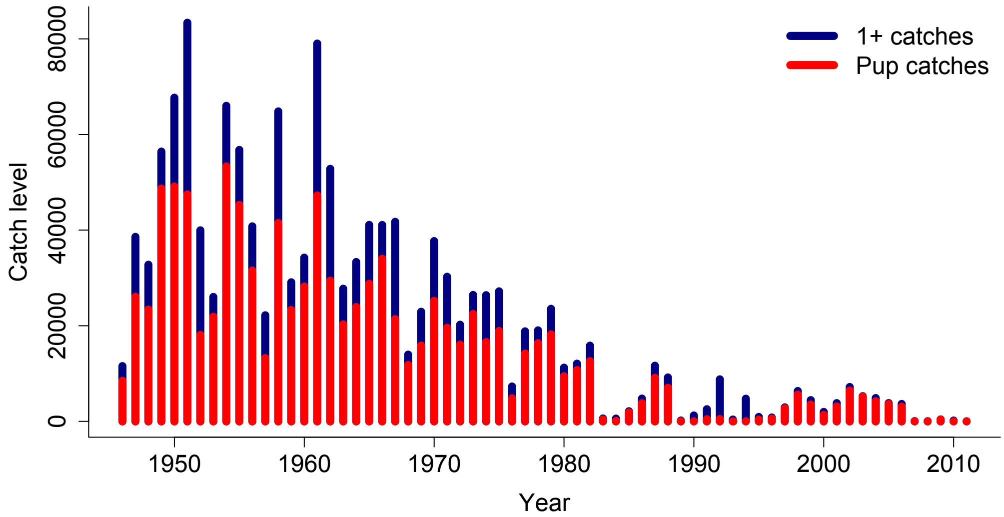

Figure 2. Catch level of hooded seals in the West Ice in the years 1946 – 2011.

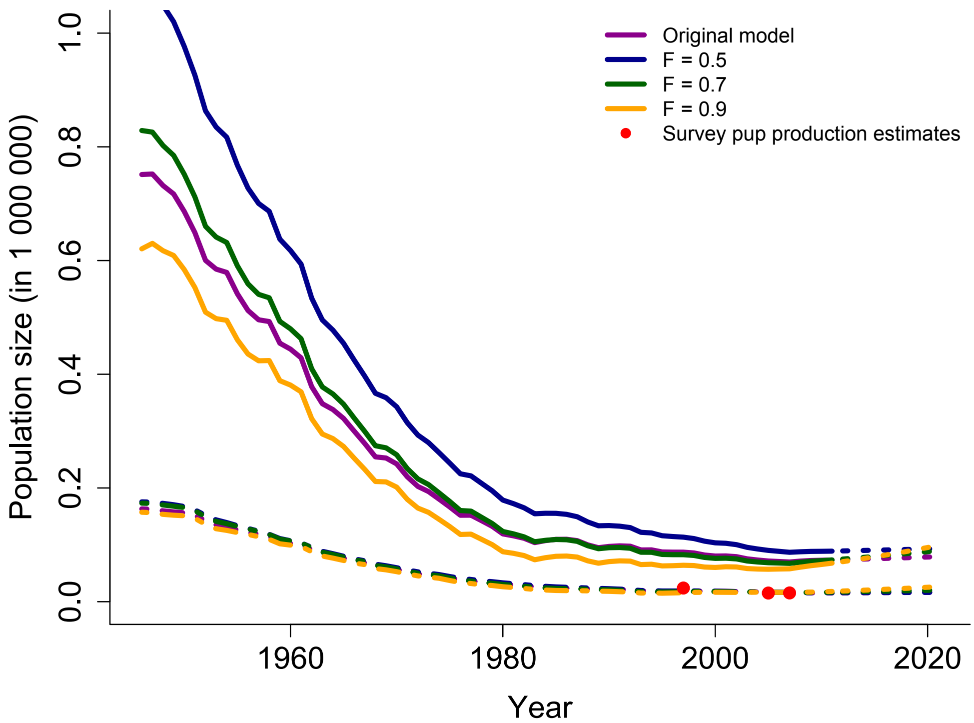

Figure 3. Estimated model trajectories for various model scenarios. Full lines show 1+ abundance, dashed-dotted lines show pup abundances, and dashed lines show model predictions.