ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS (WGHARP)

VOLUME 1 | ISSUE 72

ICES SCIENTIFIC REPORTS

RAPPORTS
SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
CIEM CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

The material in this report may be reused for non-commercial purposes using the recommended citation. ICES may only grant usage rights of information, data, images, graphs, etc. of which it has ownership. For other third-party material cited in this report, you must contact the original copyright holder for permission. For citation of datasets or use of data to be included in other databases, please refer to the latest ICES data policy on ICES website. All extracts must be acknowledged. For other reproduction requests please contact the General Secretary.

This document is the product of an expert group under the auspices of the International Council for the Exploration of the Sea and does not necessarily represent the view of the Council.

ISSN number: 2618-1371 I © 2019 International Council for the Exploration of the Sea

ICES Scientific Reports

Volume 1 | Issue 72

ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS (WGHARP)

Recommended format for purpose of citation:

ICES. 2019. ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP). ICES Scientific Reports. 1:72. 193 pp. http://doi.org/10.17895/ices.pub.5617

Editor

M.O. Hammill

Authors

M. Biuw • A.K. Frie • T. Haug • K. Murray • K.T. Nilssen • A. Rosing-Asvid • G.B. Stenson • S. Smout • V. Zabavnikov • J. Grecian • F. Wickson • S. Hansen

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Contents

i Executive summary

The main objective of the working group was to review recent surveys of Greenland Sea harp and hooded seals and examined harvest scenarios for these populations as well as harp seals in the White Sea. No new model developments were undertaken for this meeting owing to changes in personnel and illness. No new survey to estimate pup production of Barents Sea/white Sea harp seals was completed.

The 2018 aerial surveys resulted in Greenland Sea harp and hooded seal pup production estimates of 54 181 (95% CI: 36 078–72 284) and 12 977 (95% CI: 9404–16 550) animals respectively. The harp seal estimate was significantly lower than the previous survey, while no significant change in estimated pup abundance was observed for hooded seals. Models incorporating catch and reproductive rate data were fitted to the time-series of pup production estimates to obtain an estimate of total population size.

For the Greenland and White Sea harp seal populations, there is considerable variability and uncertainty associated with the time-series of pup production estimates and reproductive rate data, and there are very poor fits of the models to the underlying data. The WG recommends that some of the input data be re-examined for possible bias and that alternative model formulations be tested to improve the models. For the Greenland Sea harp seals, highly variable pup production estimates are obtained from a series of mark-recapture studies conducted in the 1990s. The WG recommends that these data be re-examined to attempt to understand why estimates are so variable. For the White Sea harp seal there appears to have been a major change in ecosystem conditions resulting in a sharp decline in pup production, in 2004, and pup production has remained low since then. The model is unable to account for this decline. Exploratory work completed during the meeting suggests that incorporating some ecosystem indices into the model might improve model fit to the data. This needs to be examined further. The WG concluded that the models did not provide reliable estimates of population trends, but that estimates of current population size were robust. Therefore, harvest scenarios for these two stocks were provided using the Potential Biological Removal approach based upon estimates of current abundance from the models.

The Greenland Sea hooded seal population has declined and remains below the Lower Reference Limit despite no hunting since 2007.

ii Expert group information

Expert group name	Report of the Joint ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP)
Expert group cycle	Annual
Year cycle started	2019
Reporting year in cycle	1/1
Chair	M. O. Hammil
Meeting venue and dates	2–6 September 2019, Tromsø, Norway

1 Recommendation from WGIBAR: Take into account the changes in the Barents Sea ecosystem and ecosystem components

Haug *et al.* (2017) presented a review of possibilities and constraints in future harvest of living resources in a changing Northeast Atlantic and adjacent Arctic Ocean. Global warming drives changes in oceanographic conditions in the Arctic Ocean and the adjacent continental slopes. This may result in favourable conditions for increased biological production in waters at the northern continental shelves. However, production in the central Arctic Ocean will continue to be limited by the amount of light and by vertical stratification reducing nutrient availability. Upwelling conditions due to topography and inflowing warm and nutrient rich, Atlantic Water may result in high production in areas along the shelf breaks. This may particularly influence distribution and abundance of marine mammals, as can be seen from analysis of historical records of hunting.

Northward shifts in the distribution of commercial species of fish and shellfish have been observed in the Barents Sea, especially during the summer period, which is related to increased inflow of Atlantic Water and reduced ice cover. This indicates a northward extension of boreal species and potential displacement of lipid-rich Arctic zooplankton, altering the distribution of organisms that depend on such prey. However, euphausiid stocks expanding northward into the Arctic Ocean may be a valuable food resource as they may benefit from increases in Arctic phytoplankton production and rising water temperatures.

Although no scenario modelling or other prediction analyses have been made, scientific ecosystem surveys in the northern areas and changes in fisheries indicate a recent northern expansion of species such as mackerel, cod, haddock, and capelin. These stocks are found as far north as the shelf break north of Svalbard. It is assumed that cod and haddock have reached their northernmost limit, whereas species such as capelin have potential to expand their distribution further into the Arctic Ocean. As boreal species migrate northwards for feeding, the question of relocating spawning grounds and egg, larval, and juvenile distribution becomes vital for predicting the future. Summer and autumn spawners are found among several species, even if the dominant spawning time is spring. This may indicate a certain probability of expanding spawning grounds to the shelf areas of Svalbard and Franz Josef Land, as the production blooms are later in these areas.

Boreal whale species, such as blue, fin, humpback, and minke whales, are regular seasonal migrants to the Northeast Atlantic side of the Arctic Ocean where they take advantage of the summer peak in productivity as the sea ice recedes northward. Furthermore, during the spring to autumn period, most harp seals on the Northeast Atlantic side of the Arctic are found in the central and northern parts of the Barents Sea where the sea ice edge is a platform from which they make foraging trips into open waters. Both migrant cetaceans and harp seals are likely to follow any further receding of the sea ice edge, if sufficient food resources become available. Such northward expansions of more boreal marine mammal species are likely to cause competitive pressure on some endemic Arctic species (bowhead whales, white whales, narwhals), as well as putting them at risk of predation and diseases.

Barents Sea harp seal body condition exhibited a significant decrease in the early 2000s, apparently with associated declines in pup production (Øigård *et al.*, 2013). A time-series of minke whale blubber measurements in the period 1992–2013, shows a significant negative trend over the entire period for this species as well (Solvang *et al.*, 2017), and it has been suggested that the two mammal stocks may have been outcompeted by the now record-large cod stock in the area (Bogstad *et al*., 2015). For harp seals, also longer migration routes with increased energy expenditure between the breeding/moulting areas and feeding areas along the ice edge may have contributed to the recent reduced body condition. Furthermore, poor ice conditions are known to increase pup mortality (Stenson and Hammill, 2014). Harp seals are long lived, so the loss of one or two cohorts will not have a major impact on the population, but if severe negative ice conditions increase in frequency, then the impact on future population trends may become significant (Hammill *et al.,* 2015). Stenson *et al*. (2016) have also observed that climate changes may affect indirectly through changes in prey and subsequent decrease in reproduction rates.

The assessment model currently in use by WGHARP to determine stock status and provide harvest scenarios for harp and hooded seals in the Northeast Atlantic is not currently able to capture the observed dynamics in pup production and total population size, especially rapid changes in abundance occur-ring in some stocks. The WG discussed various ways in which ecological indicators could be incorporated into the seal assessment models. One approach has been used in the NWA harp seal model and this may provide some indication of a way forward. Exploratory model runs were carried out during the WGHARP 2019 meeting, which included some candidate environmental drivers (historical capelin biomass estimates as a prey resource index and historical cod biomass estimates as a potential competition index) and this is discussed further in Section 1.2 Barents Sea/ White Sea population. Initial results look promising when applied to the Barents Sea/White Sea harp seal stock, suggesting further integration of data on specific ecosystem components into marine mammal population and assessment models should be explored. Such efforts should naturally involve further interactions between WGHARP and WGIBAR, as well as other communities working on ecosystem modelling and multispecies assessment. Some members of the WG are participating in various ecosystem modelling projects focusing on the Barents Sea, as well as other ecosystems. These, and future collaborations, should also contribute to future developments in WGHARP.

2 Address ToR A the special request from Norway on the management of harp and hooded seal stocks in the Northeast Atlantic.

ToR A. Address the special request from Norway on the management of harp and hooded seal stocks in the Northeast Atlantic by assessing the status and harvest potential of the harp seal stocks in the Greenland Sea and the Barents Sea/White Sea, and of the hooded seal stock in the Greenland Sea.

i. current harvest levels;
ii. sustainable catches (defined as the fixed annual catches that stabilizes the future 1+ population);
iii. catches that would reduce the population over a 15-year period in such a manner that it would remain above a level of 70% of the maximum population size, determined from population modelling, with 80% probability.

2.1 Harp Seals

Stock Identity
No new information.

2.1.2 The Greenland Sea Population

2.1.2.1 Information on recent catches and regulatory measures

Based on advice from ICES (ICES 2016a) the 2017–2019 Total Allowable Catch (TAC) for harp seals in the Greenland Sea was set at 26 000 1+ animals (where 2 pups were considered equal to one 1+ animal) (Haug *et al.*, SEA 249). This was the estimated removal level that would reduce the population to N70 over the next 10 year period (see ICES 2016, Annex 8, Table 1). The total removals of Greenland Sea harp seals in 1946–2019 are shown in Annex 7, Table 1. No Russian vessels have hunted in this area since 1994. Total catches (performed by one vessel in 2017 and 2018, and two vessels in 2019) of harp seals were 2000 (including 1934 pups) in 2017, 2703 (including 1218 pups) in 2018 and 5813 (including 2168 pups) in 2019 (Annex 7, Table 1).

Catches in the Greenland Sea are taken on the ice. Therefore, struck and loss is considered to be minimal (Sjare and Stenson, 2002) and is not included in the catch. There are no significant gillnet fisheries in the areas frequented by Greenland Sea harp seals and therefore, bycatch is considered to be minimal. In any case, this source of mortality is incorporated into the model estimate of mortality.

The WG was informed that up to the 2014 season, Norwegian seal hunts were subsidized by the Norwegian government. For the 2015 season, these subsidies were completely removed. They were reinstated in 2016, although on a considerably lower scale than in previous years. This level of support was also maintained in 2017–2019. It should be noted that the observed reductions in catch rates over time are a result of changes in harvest effort, and do not indicate changes in stock abundance or availability.[**]

[**] Last sentence added based on reviewers' comments (Annex 8)

2.1.2.2 Current research

Estimates of pup production of harp and hooded seals are based primarily on photographic surveys, which are time-consuming to analyse manually. Software-based detection methodology using artificial intelligence (deep learning) is being developed through a collaboration between the Norwegian Computing Centre and Institute of Marine Research, Norway and Fisheries and Oceans, Canada. Deep learning has revolutionized image analysis in recent years in terms of its ability to extract content and information from images. An initial test on the West Ice 2018 survey data using the Faster R-CNN object detection architecture shows the potential of automatic detection of seal pups. The detector was trained on data from the surveys in Canada 2008 and 2012, and the Greenland Sea in 2007 and 2012. The results show that the detector misses only a few of the harps, and only output a limited number of false positives when tested on images from the 2018 West Ice survey. However, when tested on data from the 2017 Northwest Atlantic harp seal survey, it identified an unacceptably large number of false positives. The reason for this difference is unknown but several avenues are being pursued to identify the issue. The development of a semi-automatic approach where the reader validates the automatic detections appears to be feasible. The results for hooded seals are not as good as several hooded seals are misclassified as harp seals. The reason for this is the heavy imbalance between harp and hooded seals in the training dataset; additional training data may be needed to compensate for this effect.

Researchers at the Sea Mammal Research Unit (SMRU), at the University of St Andrews (UK) are working to understand the response of harp seals to changes in the Arctic ecosystem as part of the ARISE project funded by the UK Natural Environmental Research Council. For this project, researchers from SMRU have collated telemetry data deployed on harp seals from all three populations by members of WGHARP and others over the last 25 years. This represents the movements of approximately 80 individually tracked seals. To address differences in tag manufacturer, technological development and gaps in animal tracks likely due to harp seals swimming upside down, the locations have been filtered using a new continuous-time random walk algorithm. The distribution of harp seals has then been estimated from these inferred locations using a Bayesian spatio-temporal model [††]. This Bayesian model accurately captures the migratory behaviour of the three breeding populations. Arctic sea ice conditions have changed dramatically over the last 25 years and the model is currently being used to estimate the link between harp seal migratory behaviour and seasonal patterns in sea ice concentration, using data from the National Sea Ice Data Centre. The model will then be used to forecast changes in harp seal migratory behaviour under a range of climate change scenarios using data from Phase 5 of the IPCC Coupled Modelling Intercomparison Project.

2.1.2.3 Biological parameters

Pup production

In the period 18–31 March 2018 aerial surveys were performed in the Greenland Sea pack-ice (the West Ice), to assess the pup production of the Greenland Sea populations of harp and hooded seals (Biuw et al., SEA 247). One fixed-wing aircraft, stationed in Akureyri (Iceland), was used for reconnaissance flights and photographic surveys along-transects over the whelping areas. A helicopter, operated from the expedition vessel (K/V Svalbard) also flew reconnaissance flights, and was subsequently used for monitoring the distribution of seal patches and age-staging of the pups.

[††] Model description updated based on reviewers' comments (Annex 8)

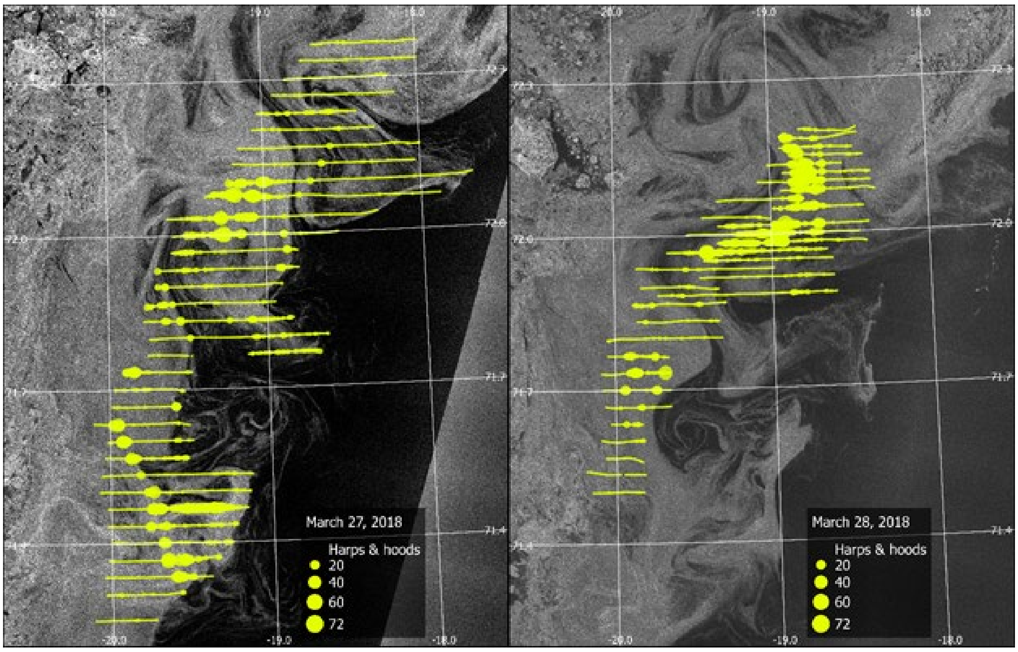

Figure 2.1. Photo surveys in the West Ice on March 27 and 28 in 2018 overlaid on ice images. Each survey photograph is represented by a yellow filled circle with the radius proportional to the total number of harp and hooded seals counted on each photograph.

The reconnaissance surveys were flown by the helicopter (18–22 March) and the fixed-wing aircraft (18-31 March) in an area along the eastern ice edge between 68°40′and 74°47′N. The ice cover was narrow and the edge closer to the Greenland coast in 2018 compared to previous survey years. The reconnaissance surveys were adapted to the actual ice configuration, usually flown at altitudes ranging from 160–300 m, depending on weather conditions. Repeated systematic east-west transects with a 10 nm spacing (sometimes 5 nm) were flown from the eastern ice edge and usually 20–30 nautical miles (sometimes longer) over the drift ice to the west.

On 27 March, two photographic surveys were flown to cover the entire whelping patch area which was a little more than 60 nm in south-north direction. Due to fog in the northwest areas, these areas had to be revisited with new transect surveys the following day (28 March). To define the transect lines for this second survey day, data from the ice-deployed GPS beacons were used to account for the ice drift between the two days. In total, 5104 photos were taken during the surveys (3016 photos on 27 March; 2088 photos on 28 March).

Estimates of pup production must be adjusted for the proportion of pups that are missed by the photo readers and also for the proportion of births that occur after the surveys are flown. The counts of one reader were increased by 1.8% to account for missed pups. Only one survey was completed to determine the proportion of pups in the different developmental stages. This proportion was compared to that observed during the 2012 aerial survey and the estimates were adjusted assuming that the shapes of the curves were similar between the two surveys. Overall, the adjustment was small, with the estimated proportion of pups on the ice during the 2018 survey of 0.98 (SD = 0.0025).

Combining data from the two survey days gave an estimated pup production of harp seals of 54 181 (95% CI = 38 884–75 494), which is significantly lower than estimates obtained in similar surveys in 2002, 2007, and 2012.

There has been a decline in extent and concentration of drift ice, particularly within the region north of Jan Mayen island where the drifting ice traditionally formed an ice-peninsula (Wilkinson and Wadhams, 2005; Divine and Dick, 2006) which used to be the main harp seal breeding location (Sergeant, 1991). Observed ice reductions have obviously changed the harp seal breeding habitat in the Greenland Sea.

Population estimate

The current abundance of harp seals in the Greenland Sea was estimated using a population dynamics model that incorporates historical catch records, historical fecundity rates, and age specific proportions of mature females. The model is fitted to independent estimates of pup production (Biuw *et al.*, SEA 250). It is a deterministic age-structured population dynamics model with three unknown parameters (pup mortality, mortality of 1-year and older seals, initial population size). This model is the same as used previously by the WG to provide harvest scenarios and determine stock status for this stock (ICES 2016).

Two types of reproductive data are used: information on the proportion of females that are mature at a given age (i.e. maturity curve) and the proportion of mature females that are pregnant at a given year (i.e. fecundity rate) (Tables 2.1 and 2.2). The historical data of the maturity curve is sparse, consisting of only three curves (Figure 2.2 and Table 2.1). One curve is from the period 1959–1990, one is from 2009 and the last one is from 2014. For the periods with missing data (1990–2009 and 2009–2014), a linear transition between the available maturity curves is assumed.

Table 2.1. Estimates of proportions of mature females ($p_{i,t}$). The P_1 estimates are from the period 1950–1990 (ICES, 2009), the P_2 estimates are from 2009 (ICES, 2011) and the P_3 estimates are from 2014 (ICES 2016b).

Age	1	2	3	4	5	6	7	8	9	10	11	12	13
P1	0	0	0.06	0.29	0.55	0.74	0.86	0.93	0.96	0.98	0.99	1.00	1.00
P2	0	0	0	0	0.06	0.28	0.55	0.76	0.88	0.95	0.98	0.99	1.00
P3	0	0	0	0	0.33	0.71	0.89	0.96	0.99	0.99	1.00	1.00	1.00

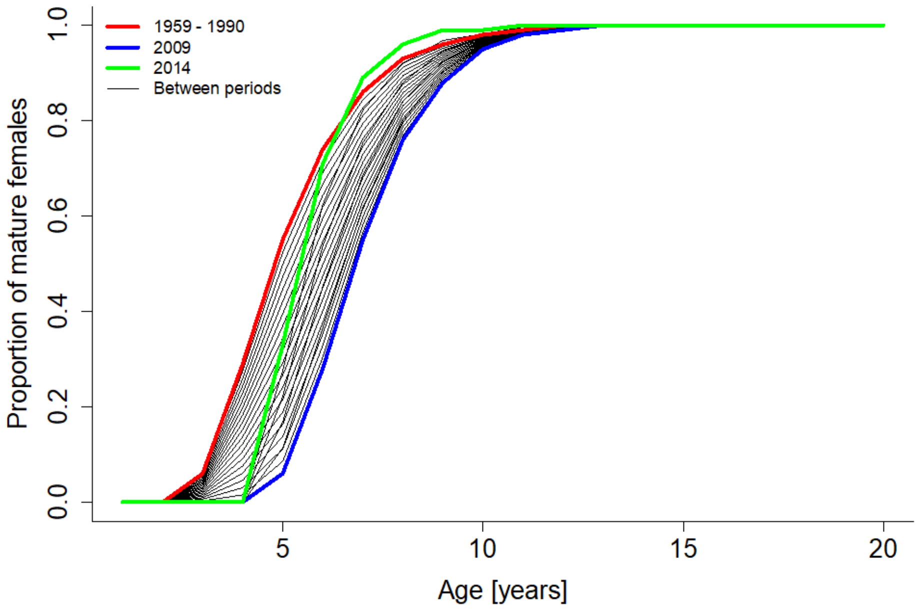

Figure 2.2. Proportion of mature females and the interpolated values for years without data among Greenland Sea harp seals in three periods. Values are taken from Table 2.1.

Table 2.2. Estimates of proportion of parous Greenland Sea harp seal females giving birth. Data from ICES (2016b).

Year	Fecundity rate	Standard Deviation
1964	0.92	0.04
1978	0.88	0.03
1987	0.78	0.03
1990	0.86	0.04
1991	0.83	0.05
2008	0.80	0.06
2009	0.81	0.03
2014	0.91	0.03

Pup production estimates are available from mark-recapture estimates (1983–1991) and aerial surveys conducted (2002–2018) (Table 2.3). Catch levels for the period 1946–2019 are listed in Annex 7, Table 1.

Table 2.3. Estimates of Greenland Sea harp seal pup production (ICES 2016b; Biuw *et al.,* SEA 247). The data from 1983–1991 are mark–recapture estimates; those from 2002, 2007, 2012, and 2018 are from aerial surveys.

Year	Estimated Number of Pups	Coefficient of Variation.
1983	58 539	0.104
1984	103 250	0.147
1985	111 084	0.199
1987	49 970	0.076
1988	58 697	0.184
1989	110 614	0.077
1990	55 625	0.077
1991	67 271	0.082
2002	98 500	0.179
2007	110 530	0.250
2012	89 590	0.137
2018	54 181	0.170

Population model

For initiation of the population model (Biuw *et al.,* SEA 250) it is assumed that the population had a stable age structure in year y_0 = 1945, i.e.

$$N_{i,y_0} = N_{y_0} s_{1+}^{i-1}(1-s_{1+}), \quad i = 1,\ldots, A-1, \tag{1}$$

$$N_{A,y_0} = N_{y_0} s_{1+}^{A-1}. \tag{2}$$

Here A is the maximum age group containing seals aged A and higher, set to 20 years (ICES, 2013), and N_{y_0} is the estimated initial population size in the first year (y_0). The model is parameterized by the natural mortalities M_0 and M_{1+} for the pups and seals 1 year and older , respectively. These mortalities determine the survival probabilities $s_0 = \exp(-M_0)$ and $s_{1+} = \exp(-M_{1+})$.

The model has the following set of recursion equations:

$$\begin{aligned} N_{1,y} &= (N_{0,y-1} - C_{0,y-1})s_0, \\ N_{a,y} &= (N_{a-1,y-1} - C_{a-1,y-1})s_{1+}, \quad a = 2,\ldots, A-1, \\ N_{A,y} &= \left[(N_{A-1,y-1} - C_{A-1,y-1}) + (N_{A,y-1} - C_{A,y-1})\right]s_{1+}. \end{aligned} \tag{3}$$

Data are not available to estimate age-specific mortality rates. Therefore it is assumed that the mortality rates are constant across ages within the 1+ group. The $C_{a,y}$ are the age-specific catch numbers, but catch records are available only as the number of pups and number of 1+ seals caught. To obtain $C_{a,y}$ in (3) we assume that the age-distribution in the catch follows the estimated age distribution of the population (Skaug *et al.*, 2007):

$$C_{a,y} = C_{1+,y}\frac{N_{a,y}}{N_{1+,y}}, \quad a = 1,\ldots,A, \tag{4}$$

where $N_{1+,y} = \sum_{y=1}^{A} N_{a,y}$, with $N_{a,y}$ being the number of individuals at age a in year y.

The modelled pup abundance is given by

$$N_{0,y} = F_y \sum_{a=1}^{A} p_{a,y}\frac{N_{a,y}}{2} \tag{5}$$

where $N_{0,y}$ is number of pups born in year y ;

F_y is fecundity in year y ;

$p_{a,y}$ is the proportion mature females at age a in year y (from the corresponding curve) ;

$N_{a,y}$ is the total number of adults (including males) of age a in year y.

Assuming normality for the pup production counts, their contribution to the log-likelihood function is

$$\sum_t -\log(cv_{0,y}) - \frac{1}{2}\frac{(N_{0,y} - n_{0,y})^2}{cv_{0,y}n_{0,y}}, \tag{6}$$

where $n_{0,y}$ and $cv_{0,y}$ denotes the survey pup production count and corresponding coefficient of variation (CV) for year y, respectively (Table 3).

The model calculates a coefficient D_{1+}, which describes the increase or decrease in the 1+ population trajectory over a 15-year period,

$$D_{1+} = \frac{N_{1+,2032}}{N_{1+,2017}}. \tag{7}$$

The coefficient is used for finding the equilibrium catch levels. The equilibrium catch level is defined as the constant catch level that results in the population size in 2032 being the same as in 2017, i.e. the catch level that gives $D_{1+} = 1$.

The population dynamics model is a Bayesian type model as priors are imposed on the parameters. A vague normal prior is assumed for the initial population size N_{y_0} and a truncated normal prior for both the pup mortality M_0 and the mortality for the 1+ group M_{1+}.

The combined likelihood-contributions for these priors are

$$-\frac{1}{2}(\mathbf{b}-\mathbf{m})^{\mathrm{T}}\Sigma^{-1}(\mathbf{b}-\mathbf{m}) - \frac{1}{2}\ln|\Sigma| - \frac{3}{2}\ln(2\pi), \tag{8}$$

where $\mathbf{b} = (N_{0,y}, M_0, M_1)^{\mathrm{T}}$ is a vector containing the parameters estimated by the model, T denotes the vector transpose, **m** is a vector containing the respective mean values of the normal priors for the parameters in **b**, and Σ is a diagonal matrix with the variance of the respective prior distributions on the diagonal. The mean of the prior for M_0 was set at three times the mean of M_{1+}.

All data processing and analyses were done using R (R Core Team, 2018). Model fitting was done using the R package TMB (Kristensen *et al.*, 2016).

The estimated population sizes and parameters used in the model are presented in Table 2.7. The model trajectory indicates a substantial increase in the population abundance from the 1970s to the present (Figure 2.3).

The model estimates a 2019 1+ abundance of 360 400 (95% CI : 258 245–462 556) and 66 407 (95% CI : 51 605–81 209)(rounded to nearest 100) pups. The total estimate is 426 808 (95% CI : 313 005–540 612) seals.

Table 2.7. Estimated and derived mean values and standard deviations of the parameters used in the model for Greenland Sea harp seals. N70 is 70% of N_{max}, Nlim is 30% of N_{max}.

Parameter	Mean	SD
N_{1946}	369 522	29 505
M_0	0.24	1.09
M_{1+}	0.14	0.16
$N_{0,2019}$	66 407	7552
$N_{1+,2019}$	360 400	52 120
$N_{Total,2019}$	426 808	58 063
N70	370 266	105 665
Nlim	142 189	-

The 2018 pup production estimate is significantly lower than the previous survey estimate of 89 590 (95% CI = 68 578–117 040). This is inconsistent with the model, which predicts an increasing pup population. As in previous assessment, the model was not able to reliably fit to the pup production estimates from the mark-recapture studies and aerial surveys. There is considerable variability between the different mark-recapture (MR)-based pup production estimates obtained in the 1990s. Øien and Øritsland (1995) suggested that the dramatic interannual fluctuations in these MR pup production estimates may be caused by social associations affecting the distribution of marked pups in the breeding patches, and that these recapture data may violate the assumptions underlying the MR methodology. They also speculated that a mechanism of temporary emigration resulted in a bias in the estimates. In addition to these MR-based pup production estimates, there is one aerial survey estimate from 1991 (55 270, 95% CI = 40 104–70 436; Øritsland and Øien, 1995), that has not previously been included in the model runs. Given the uncertainty in the MR-based estimates, the WG suggested that the impact of using only the aerial survey estimates including the survey from 1991 should be explored and recommended that the M-R estimates be re-examined to determine which ones are considered reliable for use in future assessments.

The WG also raised concerns regarding the reliability of some of the reproductive parameters that have been measured at sparse intervals throughout the period from 1946 to the present. To explore the impact of using different reproductive data, the group suggested that the model be run with fecundity fixed at the long-term mean from all sampling, (F = 0.84), and with maturity curves being combined to a single curve representing the mean maturity curve throughout the period. The final set of models considered was therefore:

1) All pup production estimates included (except aerial survey estimate from 1991). This is similar to past assessments;
2) Pup production estimates from aerial surveys only (including 1991);
3) Same as scenario 2), with constant F=0.84 and a single maturity curve;

The three runs resulted in some differences in estimated population trajectories (Figure 2.3), but the estimates of the 2019 population size were relatively consistent between runs.

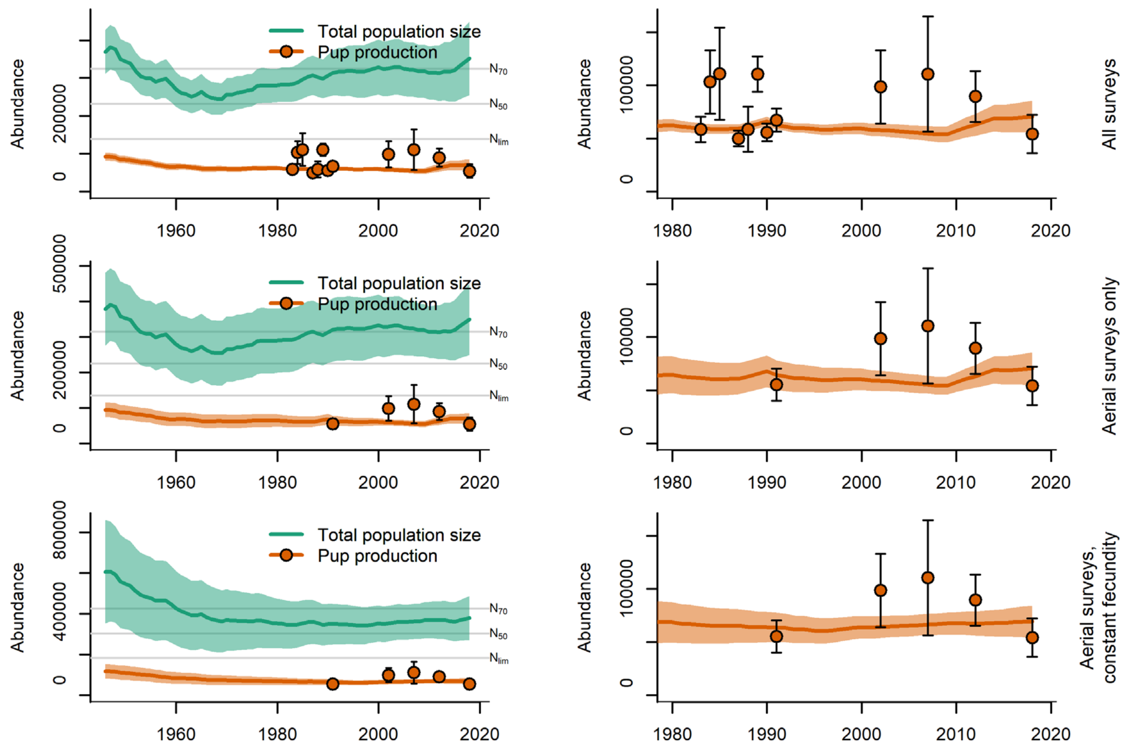

Figure 2.3. Model trends for the Greenland Sea harp seal population, with models fitted to different combinations of historical pup production estimates and fecundity values. Total population and pup abundance estimates on the left; Pup abundance estimates on the right; Top row A: all surveys were included; middle row B: only aerial survey data were fitted ; bottom row C: only aerial survey data were fitted, fecundity rates were set at a single constant value, and a single maturity curve was used throughout the period of the study.

2.1.2.4 Catch scenarios

Given the apparent significant drop in pup production between the 2012 and 2018 surveys, the unexplained variability of the M-R estimates, the poor fit of the model to all historical pup production estimates and the subsequent uncertainty regarding model-based trajectories and projections, the consensus in the WG was that management recommendations for this population should not be based on model projections at this stage.

However, despite the different model trajectories, the model estimates of current population size were very similar and appeared to be robust to the assumptions of the various runs. Therefore, the WG agreed that catch options should be based on the estimate of current pup and adult population sizes through the Potential Biological Removal (PBR) framework.

PBR was developed by the United States for the management of marine mammals and has been used to set harvest scenarios by WGHARP, particularly in situations where the population is considered to be data poor (ICES 2003, 2005). The strength of the PBR approach is that it only requires a single abundance estimate to calculate a PA compliant harvest level. The PBR is estimated as:

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

where: N_{min} is the minimum estimated population size (usually calculated as the 20-percentile of the lognormal distribution around the estimate of N); R_{max} is the maximum rate of population increase with a default value for pinnipeds of 0.12; F_R is a recovery factor (between 0.1 and 1), (Wade, 1998). The F_R is considered as an additional safety factor to account for additional uncertainties associated with our understanding of the stock (Wade, 1998). Some guidelines have been developed for setting F_R, but to date these remain very jurisdiction specific and qualitative (Wade, 1998; NMFS, 2016; Hammill *et al.*, 2017).

Given the very small difference in estimated current population size irrespective of model run, and similarity between PBR estimates based on these population estimates, we suggest that the PBR based on the averaged population estimates (and associated averaged CVs), be used when providing catch scenarios (Table 2.4).

Table 2.4. Potential Biological Removal (PBR) given various pup production data subsets, and fecundity inputs, "All" = aerial surveys and mark-recapture; "Aerial only" = aerial survey data only (includes additional aerial survey data from 1991); "constant F" = all fecundities set to their historical mean (0.84), and one combined maturity curve used throughout time-series; All PBR estimates were calculated using F_R = 0.5.

Scenario	Population estimate	N_{min}	CV	PBR
All	426 808	379 624	0.140	11 389
Aerial only	422 688	374 224	0.145	11 227
Aerial only, constant F	452 117	400 999	0.143	12 030
Average scenarios	433 871	384 948	0.143	11 548

2.1.3 The Barents Sea/White Sea Population

2.1.3.1 Information on recent catches and regulatory measures

Due to a sharp decline in pup production observed after 2003, ICES (2016a) recommended that removals be restricted to the estimated sustainable equilibrium level which was 10 090 1+ animals (where two pups balanced one 1+ animal) in 2017–2019 (Haug *et al.*, SEA 249). The Joint Norwegian-Russian Fisheries Commission has followed this request and allocated 7000 seals of this TAC to Norway and 3090 to Russia. A ban implemented on all pup catches prevented Russian hunt in the White Sea during the period 2009–2013. This ban was removed before the 2014 season. However, the availability of ice was too restricted to permit sealing, resulting in no commercial Russian harp seal catches in the White Sea in 2014–2019. Total reported catches of Barents Sea/White Sea harp seals in 1946–2019 are shown in Annex 7, Table 2. No Norwegian vessels operated in the southeastern Barents Sea (the East Ice) in 2017, while one Norwegian vessel hunted in the area in both 2018 and 2019. In September 2017, 1 harp seal (1+ animal) was taken for scientific purposes north of Svalbard – presumably from the Barents Sea/White Sea population. Total catches of harp seals were 1 in 2017, 2241 (including 21 pups) in 2018, and 602 (including 34 pups) in 2019. Annex 7, Table 3 lists reported bycatch along the Norwegian coast. These are assumed to come from the Barents Sea/White Sea population and have been incorporated into the estimated total removals.

2.1.3.2 Current research

Ice conditions and possible influence on harp seal pupping

Harp seal pup production in the White Sea and adjacent areas of the Barents Sea will be influenced by the ice conditions in the area and therefore monitoring of conditions during the whelping period is important. Russian scientists are now monitoring ice conditions in the region each year, spanning the period from December (when ice cover starts to form) until the end of March (when whelping is typically finished).

The monitoring of ice conditions that took place from December 2018-March 2019 was done using both current and forecasted ice conditions, as well as the current and forecasted synoptic situation from sources that were free and available on the Internet. Other available information (in text or photo form) from vessels, aircraft, inhabitants, was also used.

This monitoring showed that stable ice cover began to appear at the end of December 2018, initially in the bays, inlets and gulfs, as a result of an extensive period of freezing temperatures and northerly winds , which formed stable and close young ice in the White Sea and adjacent waters of the Barents Sea. Hydrometeorological conditions favorable for ice formation continued into the middle of March.

As a result, ice conditions were favorable for the Barents/White Sea harp seal population during the beginning of whelping in 2019. Most of the whelping occurred in areas that have traditionally been used. However, from the middle to the end of March (i.e. when whelping is ending), ice conditions began to deteriorate. This was due to warmer (>0°C) temperatures and southerly winds. A variety of sources (vessels and onshore meteorological stations) reported that harp seal patches were widely distributed across the White Sea. It is unknown if these conditions resulted in increased pup mortality during 2019.

Testing of Unmanned Automated Vehicle (UAV) in White Sea

The potential for the use of Unmanned Aerial Vehicles (UAV) as a platform for surveying harp seal pups and adults in the Barents Sea/ White Sea during the whelping season was examined during a study carried out by Russian scientists in 2018. Traditionally, aerial surveys in this region are conducted by manned aircraft equipped with optical systems and infrared (IR) scanners. UAVs offer a potentially less expensive means to survey the harp seal population compared to manned aircraft. Three Orlan-10 UAVs (rented from VNIRO and Giprorygflot), equipped with photo- and video cameras, IR scanner were used in the experiment. All flights were made from Varzuga, Russia (on the Kola Peninsula southern coast) on 21, 23, and 24 March, spanning an area from the coast to latitude 65°N and between 37°00E and 39°00E. Total survey flight duration was 36 h 49 min during the 3-day study: 21 March – 8 h 10 min; 23 March – 19 h 58 min (two UAVs participated); 24 March – 8 h 41 min. Compared to the UAV flights, the 2013 aerial survey covered an area five times larger than that covered by the UAV with fewer flying hours. The quality of photos, videos and IR images from the drones was poorer than those obtained from the manned aircraft aerial surveys. For example, fewer than 50% of the images obtained from the UAVs could be used for analysis, likely as a result of instability of the drone due to winds. Preliminary results suggest that the Orlan-10 platform may be useful for some localized surveys under appropriate weather conditions, but it should not be used as a substitute for traditional manned aircraft intended to survey entire whelping areas. Researchers will continue to evaluate the data from these experimental flights.

2.1.3.3 Biological parameters

There is no new survey information regarding pup production. The WG underlined the need for a new survey for March 2020.

The mean age of maturity (MAM) for Barents Sea/White Sea harp seals was estimated at 6.9±0.9 years for 168 females collected during the 2018 moulting period in the southern Barents Sea (Frie, SEA 252). This estimate is not significantly different from the previous estimate from 2006, but about a year lower than the values observed in the early 1990s. Compared with typical values for the Greenland Sea and Northwest Atlantic (5–6 years), the present level of MAM for Barents/White Sea harp seals is still high. A general near absence of first-time ovulators in samples from the Barents Sea raises a concern that values of MAM for the Barents Sea/White Sea harp seal stock may be affected by temporal and/or spatial sampling bias. GAM analyses showed a significant effect of day of the year on the age specific proportions of mature females in both the Barents Sea/White Sea and Greenland Sea harp seal samples, but the direction of this effect varied significantly among years, which may indicate spatial clustering of reproductive classes. This supports the idea that some of the variability of the estimated maturity curves may be due to sampling problems. Proportions of post parturient females among parous females, and the mean age of post parturient females, did not vary significantly with day of year in any of the Northeast Atlantic datasets. Therefore, estimates of pregnancy rates do not appear to be affected by temporal or spatial sampling problems. The estimated pregnancy rate for the 2018 Barents Sea/White Sea sample was 0.91±0.06. This is the highest pregnancy rate among the available estimates for this population, but it is only significantly different ($P<0.001$) from the minimum value of 0.68 from 2006. Estimates of pregnancy rates for Northeast Atlantic harp seals are based on the presence/absence of a regressing corpus luteum in ovaries examined during the moulting period and may be overestimates as they may not take potential late term abortions into account.

2.1.3.4 Population assessment

The population model used to assess the abundance of the Barents Sea/White Sea harp seal population (Biuw *et al.*, SEA251) is identical with the one used for the Greenland Sea harp and hooded seal populations (Skaug *et al.*, 2007; ICES, 2016b). An analysis of abundance of Barents Sea/White Sea harp seals was completed in a working paper (Korzhev and Zabavnikov, SEA 253), but this analysis was not presented, nor discussed. The WG noted that the WP used estimates of pup production based on adult counts, which have not been used in previous assessments.

Reproductive data

Two types of reproductive data are used in the model: information on the proportion of females that are mature at a given age (i.e. maturity curve) and the proportion of mature females that are pregnant in a given year (i.e. fecundity rate)(Tables 2.5 and 2.6). Estimates of age specific proportions of mature females are available for five historical periods; 1962–1972, 1976–1985, 1988–1993, 2006 and 2018 (Table 2.5; Frie, SEA252; ICES, 2016b). For years with no data, a linear interpolation of the age specific proportions of mature females between two periods is assumed (Figure 2.4; ICES, 2016b).

Table 2.5.‡ Estimates of proportions of mature females (pi,t).The P1 estimates are from the period 1962–1972 , P2 estimates are from 1976-1985, P3 estimates are from 1988–1993, while the P4 and P5 estimates are from 2014 and 2018 respectively (ICES 2016b; Frie, SEA 252).

Age	2y	3y	4y	5y	6y	7y	8y	9y	10y	11y	12y	13y	14y	15y
p_1	0.00	0.01	0.17	0.64	0.90	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
p_2	0.00	0.00	0.00	0.24	0.62	0.81	0.91	0.95	0.98	0.99	0.99	1.00	1.00	1.00
p_3	0.00	0.00	0.02	0.08	0.21	0.40	0.59	0.75	0.85	0.91	0.95	0.97	0.98	0.99
p_4	0.01	0.02	0.05	0.11	0.25	0.55	0.90	0.99	1.00	1.00	1.00	1.00	1.00	1.00
p_5	0.00	0.00	0.00	0.00	0.52	0.77	0.89	0.95	0.97	0.99	0.99	0.99	1.00	1.00

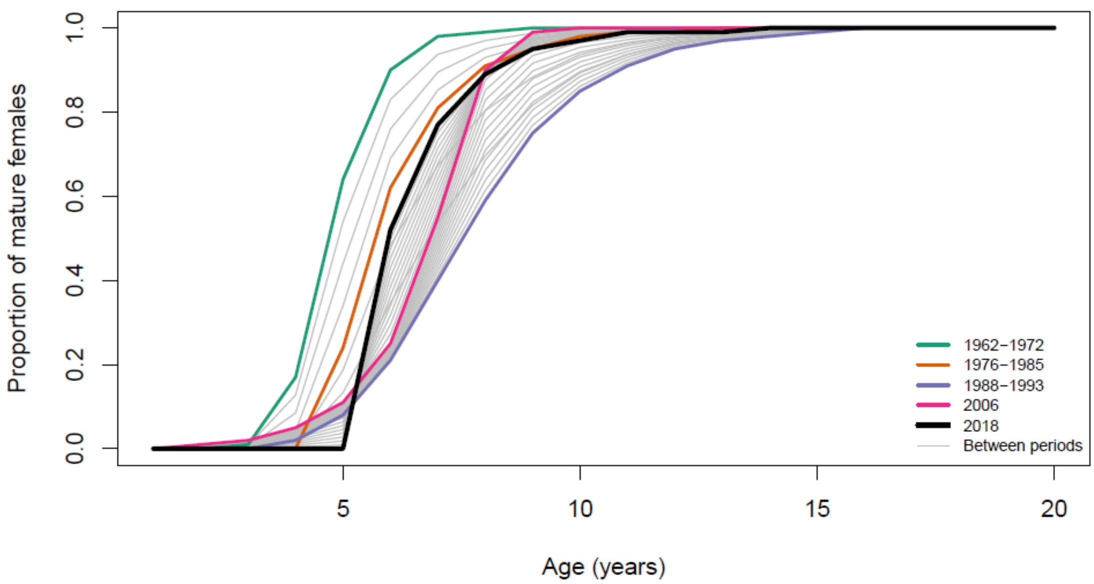

Figure 2.4.‡ Proportion of mature females and the interpolated values for years without data among Barents Sea / White Sea harp seals.

The population dynamics model assumes the observed fecundity is a known quantity as opposed to being part of the data to which the model is fit. For periods with missing pregnancy rates, a linear transition was assumed, i.e. a linear transition from 0.84 in 1990 to 0.68 in 2006, from 0.68 in 2006 to 0.84 in 2011, and from 0.84 in 2011 to 0.86 in 2018. In the periods before 1990, the pregnancy rate was assumed constant at 0.84.

‡ Table 2.5 and Figure 2.4. updated following reviewers' comments (Annex 8)

Table 2.6. Estimates of proportion of Barents Sea/White Sea harp seal females giving birth. Data from (ICES, 2016b) and (Frie, SEA 252).

Year	Fecundity	SD
1990	0.84	0.06
1991	0.84	0.06
1992	0.84	0.06
1993	0.84	0.06
2006	0.68	0.06
2011	0.84	0.06
2018	0.91	0.03

Pup production and Catch data

Pup production estimates are available from surveys conducted at 1 to 3-year intervals between 1998 and 2013 (Table 2.7).

Table 2.7. Estimates of Barents Sea/White Sea harp seal pup production. Numbers and CVs are drawn from ICES (2016b).

Year	Estimated number of pups	CV
1998	286 260	0.150
2000[a]	322 474	0.098
2000[b]	339 710	0.105
2002	330 000	0.103
2003	328 000	0.181
2004	231 811	0.190
2004	234 000	0.205
2005	122 658	0.162
2008	123 104	0.199
2009	157 000	0.108
2010	163 032	0.198
2013	128 786	0.237

a Photographic survey. Represented the sum of 291 745 pups (SE = 28 708) counted plus a catch 30 729 prior to the survey for a total pup production of 322 474.

b Visual survey. Represents the sum of 298 000 pups (SE = 53 000) counted, plus a catch of 35 000 prior to the survey for a total pup production of 328 000.

Catch data come from commercial hunts and distinguish between the number of pups (0-group) and the numbers of 1-year and older animals (1+) caught per year, but contain no additional information about the age composition of the catches. Catch data prior to 1946 are unreliable and they make no distinction between pups and older seals. Because of this the model began in 1946. Catch levels for the period 1946–2019 are presented in ICES (2016b) and Haug. *et al.* (SEA 249).

The estimated population sizes are presented in Table 2.8, and Figure 2.5 shows the model fit to the observed pup production estimates along with the modelled total population trajectory. The model only has three parameters that are allowed to vary and because of this, it is very stiff. As pointed out in the previous assessment (ICES, 2016b) the model fit to the pup production estimates is poor, and not able to capture the dynamics of the survey pup production estimates. In particular, the model does not capture the apparent drop in pup production that occurred from 2003 to 2005. The modelled total populations indicate that harp seal abundance in the Barents Sea/White Sea has been decreasing from 1946 to the early 1960s, and increasing from the early 1960s to early 1980s. After that, the model indicates a decreasing population until around 2007. From 2007 to the present the model indicates an increase in population size but this is inconsistent with the dramatic reduction in observed pup production. Despite this inconsistency, the estimate of current abundance appears to be relatively realistic, given the reasonably good fit between estimated pup production during the most recent survey. The model estimates a 2019 abundance of 1 276 900 (1 100 264–1 453 500) 1+ animals and 220 291 (191 193–249 389) pups, yielding a total estimate of 1 497 190 (1 292 939–1 701 440) seals.

Table 2.8. Estimated and derived mean values and standard deviations of the parameters used in the model for Barents Sea/White Sea harp seals. N_{max} is the historically largest total population, N_{70} is 70% of N_{max}, and N_{lim} is 30% of N_{max}.

Parameter	Mean	SD
N_{1946}	1 728 344	141 686
M_0	0.27	0.25
M_{1+}	0.13	0.05
$N_{0,2019}$	220 291	14 845
$N_{1+,2019}$	1 276 900	90 119
$N_{Total,2019}$	1 497 189	104 209
N_{70}	1 422 716	
N_{lim}	639 109	
N_{max}	2 130 362	-

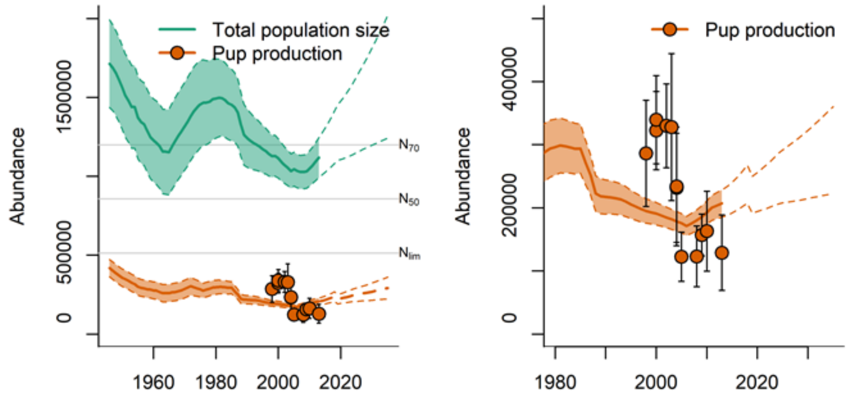

Figure 2.5. Modelled population trajectories for Barents Sea/White Sea harp seal pups and adults (full lines), 95% confidence intervals (shaded areas) and future projections (dashed lines). N_{70}, N_{50}, and N_{lim} denote the 70%, 50%, and 30% of the historical maximum population size, respectively. Observed pup production estimates are indicated by filled circles.

As discussed in previous reports, the model estimates are stable for various choices of precision of the prior of M_{1+} and for various choices of initial values. Since the population dynamics model assumes the observed fecundity is known as opposed to being part of the data to which the model is fit, the uncertainties in the observed fecundity rates are not accounted for.

The inability of the population model to account for the rapid decline in pup production in the mid-2000s is not surprising, given the deterministic nature of the current model, and the fact that only three parameters are estimated (initial population size, N_{1946}, and mortality of pups, M_0, and adults, M_{1+}). In 2011, the WG explored various scenarios assuming changes in fecundity, mortality and/or cohort failure in this population (ICES 2011). For instance, the impact of additional mortality and expected cohort failures associated with the years of capelin collapse, and a concomitant invasion of harp seals along the Norwegian coast, on the population trend were examined. While some of the inputs into these scenario simulations (e.g. expected cohort failures) are based on assumed effects, others are actual observations. In particular, the WG was pointed out that data on additional mortalities during the seal invasions in the 1980s and 1990s should be included in the catch data in future modelling and assessments of this stock. This was done here during the final model runs.

During the meeting, the inclusion of potential ecosystem drivers into the model was investigated to assess if this could allow the model to better fit with the rapid decline in pup production in the mid-2000s. Estimates of historical capelin and cod biomass in the Barents Sea (based on recent ICES stock assessments) were used as indices of prey resource and competition respectively. These were combined into a standardized 'suitability index', which was entered into the model as a 'fecundity index', assuming that fecundity in year t is a function of both capelin and cod abundance in year t-1. The model using this index was able to predict the rapid decline in pup production, but did not reflect the most recent estimate of fecundity. However, the ability to capture the rapid change in pup production suggests that the inclusion of such data should be considered. The WG felt that although the work done on this within the meeting was too preliminary to be reported in detail, the approach was a useful way to incorporate ecosystem indicators more directly into the assessment.

Catch Scenarios

The WG noted that no new pup production estimates are available for this stock since 2013. New reproductive estimates obtained in 2018 indicate a substantial increase in fecundity, which leads to a substantial increase in the estimate of current population size, compared to the 2017 estimate from the previous assessment, and the subsequent estimate of a catch level that would result in a stable population. It was also recognized that the current model does not fit well to the pup production estimates and cannot accommodate the rapid decline in pup production that occur after 2003.

Given the lack of updated pup production estimates (>5 years since last survey), and the poor fit of the current model, the WG suggests that a precautionary approach should be taken when recommending catch options. While the equilibrium catch was considered the most conservative approach during the previous assessment, inclusion of the new fecundity data changes this perception. Currently, the use of PBR is considered the most conservative. As the time since the last pup survey is greater than five years, it is also in keeping with the approach to determine catch scenarios used by the WG.

Two PBR scenarios are presented (Table 2.9, Biuw *et al.*, SEA 251), using recovery factors of 0.5 and 0.25. Under PBR, the age structure of the catch is assumed to be proportional to the age structure of the population. Therefore, PBR represents a total allowable catch irrespective of age.

Given the uncertainty regarding the status of this population, the WG suggests using the most conservative estimate (i.e. using a recovery factor of 0.25) when setting future catch options.

Table 2.9. Abundance, N_{min}, recovery factor and PBR estimates for Barents/White Sea harp seals. N_{min} is the lower 20th percentile of the lognormal distribution around the abundance estimate.

2019 Abundance	Nmin	Fr	PBR
1 497 190	1 411 469	0.5	42 344
1 497 190	1 411 469	0.25	21 172

2.1.4 The Northwest Atlantic Stock

2.1.4.1 Information on recent catches and regulatory measures

Canada

Catches

After 2005, TACs were set annually to ensure that the population did not decline below the precautionary reference level (i.e. N_{70} or 70% of the maximum population size) within a 15 year period (e.g. Hammill and Stenson 2007, 15 000 in 2011 (Stenson and Upward, SEA 254; Annex 8, Table 3). Since then, the quota remained the same. However, hunting of harp and hooded seals in Canadian waters has been very limited in recent years and there has been very little interest in reviewing the catch limits. Since 2017, the TAC has not actually been announced.

After more than a decade of high catches, harp seal catches in Canada have remained below 100 000 since 2009, averaging ~63 000 animals (Stenson and Upward, SEA 254; Annex 7, Table 4). Catches declined to 35 382 (8% of the TAC) in 2015 after which they increased to 68 380 (17% TAC) in 2016 and 81 360 (20.5% TAC) in 2017. Catches declined again in the most recent years with 61 022 (15.25% TAC) seal reported taken in 2018 and a preliminary estimate of 32 038 (8% TAC) in 2019. Since the late 1990s, over 97% of the catch have been young of the year (YOY) which in some years accounted for 100% of the harvest. Since 2016, however, the proportion of

1+ animals in the catch has increased with the proportion of YOY in the catch averaging 90%. An additional 1000 seals are assumed to be taken in the Canadian Arctic.

Bycatch

Sjare *et al.* (2005) provided estimates of harp seal bycatch in the Newfoundland lumpfish fisheries from 1970–2003. These estimates were based upon reported landings of lumpfish roe and estimates of seal bycatch rates obtained from a bycatch logbook monitoring program that was carried out by DFO, Marine Mammal Section from 1989 to 2003. Harp seal bycatch per tonne of lumpfish roe were calculated based on the logbook data on the weight of lumpfish roe landed and the number of seals caught per trip. These estimates were used to hind-cast from 1988 to 1970 based on lumpfish roe landings over that period and the average number of seals taken per tonne of roe from 1989 to 1991.

However, since 2003 there have been significant changes in the lumpfish fishery. Therefore, it was necessary to revisit the previous estimates. In the absence of new logbook data on catch rates, the bycatch rates estimated by Sjare *et al*. (2005) were used along with updated lumpfish roe landings to estimate harp seal bycatch in the Newfoundland lumpfish fishery from 1970 through 2018 (Stenson and Upward, SEA 254). As in Sjare *et al.* (2005) the average of the bycatch rates from 1989 to 1991 was used to hind-cast the 1970–1988 period. The average rates from 1999 to 2003 (i.e. the last five years) were then used for the subsequent years. The proportion of YOY seals caught from 1989 to 2000 were estimated using age-class records provided by fishers over that period (Sjare *et al.*, 2005). The average age classes from 1989 to 1991 were applied to the 1970–1988 period while averages for 1996 to 2000 were applied to 2000 onward.

Bycatch was low until the early 1990s due to limited effort in the fishery. In the mid-1990s, however, effort increased dramatically and bycatch rose to over 45 000 seals per year. By the late 1990s, bycatch dropped dramatically although it rose again briefly before dropping again in the early 2000s. Another peak (~35 000) in bycatch occurred in the mid-2000s before declining. Since 2010, bycatch has remained low. In 2018, it was estimated to be 555 seals.

In addition to estimated bycatch in the Newfoundland lumpfish fishery, estimates of bycatch in the northeast US fisheries (Hayes *et al.,* 2019) were also examined. Only small numbers of harp seals are caught in the US fisheries. The combined estimates from the Canadian and the US fisheries are shown in Annex 7, Table 8 . The Canadian statistics also identify a correction for Struck and Lost (Hammill *et al.*, 2015).

Greenland

Greenland catches of harp seals have been reported up to 2017. Catches over the past decade have varied from 90 909 in 2010 to 48 593 in 2017 with an average catch on 67 492 (Annex 7 Tables 4, 6). The reported catch for 2016 and 2017 was 56 730 and 48 593, respectively. Along the west coast where the majority of seals were caught, the percentage of adults reported varied between ¼ and ⅓ of the catch.

The most recent catch reports differ slightly from previous reports. The reason for these changes has been the discovery of a minor error in the technical setup of the database.

Total reported catches for Canada and Greenland are summarized in Annex 7, Table 4. In Annex 7, Table 8 presents estimated total removals including bycatch in Canadian and US fisheries, and estimates of struck and lost. It also assumes that Canadian catches in 2016 were all young of the year.

2.1.4.2 Current research

2.1.4.3 Biological Parameters

Since the 1950s, pregnancy rates of Northwest Atlantic harp seals have declined while interannual variability has increased. Stenson *et al.* (2016) found that pregnancy rates were influenced by both density- dependent and independent factors. While the general decline in pregnancy rates was a reflection of density-dependent processes associated with increased population size, including late term abortion rates captured much of the large interannual variability observed at high population levels. Changes in the abortion rate were best described by a model that incorporates ice cover in late January and capelin biomass obtained from the previous fall. A previous study (Buren *et al.*, 2014) showed that capelin abundance is correlated with ice conditions suggesting that late January ice conditions should be considered a proxy for environmental conditions that may influence a number of prey species.

Stenson *et al*. (2016) hypothesized that the impact of changing prey availability influences reproductive rates through changes in body condition and growth. To test this hypothesis, Canadian scientists have recently examined growth rates and body condition of harp seals collected off the coast of Newfoundland Canada over the past four decades. Comparing lengths and weights of seals among decades indicated that growth-rates and asymptotic weights of harp seals have decline significantly since the 1980s. The average body condition of females prior to pupping varied greatly among years, although the condition of pregnant females did not change among years. Annual pregnancy rates were positively correlated with improved condition while abortion rates declined rapidly with only slight improvements in condition. As with abortion rates, condition was related to capelin biomass and midwinter ice cover. These data indicate that changes in abundance and environment influence reproductive rates in harp seals through changes in body condition and suggest that females must maintain a certain level of body condition if they are to complete their pregnancy successfully.

Pup Production

Photographic and visual aerial surveys were conducted off Newfoundland (i.e. Front) and in the Gulf of St. Lawrence to determine pup production of Northwest Atlantic harp seals in 2017. Surveys were carried out in the southern Gulf (6–7 March), northern Gulf (17 March) and off northeast Newfoundland (14, 18, 19, 22 March). Approximately 35 000 photos were obtained which took over three person-years to analyse. Ice conditions in the southern Gulf were very poor and pup production estimates in this area was extremely low (≤25 000). There was some indication that some Gulf seals may have moved to the Front and pupped there. The number of pups born in the northern Gulf was also lower than in recent surveys. The majority of pups born at the Front were found in a large whelping patch, which was located on 6 March. However, a number of small, scattered, groups formed up after this although pupping appeared to be finished by mid-March. Final estimates have not been completed, but preliminary estimates indicate that pup production may have been about 700 000. This is lower than the previous (2012) survey estimate of 790 000 (SE = 69 700, CV = 8.8%)

2.1.4.4 Population Assessment

No new information on current abundance was presented.

2.2 Hooded seals

2.2.1 The Greenland Sea Stock

2.2.1.1 Information on recent catches and regulatory measures

Concerns over low pup production estimates resulted in a recommendation from ICES that no harvest of Greenland Sea hooded seals should be permitted, with the exception of catches for scientific purposes (ICES, 2016) (Annex 8, Table 1). This advice was immediately implemented (Annex 8, Table 1). The total removals of Greenland Sea hooded seals in 1946–2016 are shown in Annex 6, Table 1. Total catches for scientific purposes (all taken by Norway, Russian sealers did not operate in the Greenland Sea) were 17 (including 14 pups) in 2017, 17 (including nine pups) in 2018 and 23 (including 14 pups) in 2019 (Haug *et al.*, SEA 249).

2.2.1.2 New Research

Pup Production

Pup production of Greenland Sea Hooded seals was estimated from images obtained during the harp seal survey (Biuw *et al.*, SEA 247). A total of 1315 hooded seal pups were counted in the 5093 photos from the 70 transects, without correcting for reading errors. Of these, 645 hoods were counted in the 3005 photos from 35 transects flown on 27 March, while 670 hoods were counted in 2088 photos from 35 transects flown on 28 March.

Estimates of pup production must be adjusted for the proportion of pups that are missed by the photo readers and also for the proportion of births that occur after the surveys are flown. The counts of one reader were increased by 3.5% to account for missed pups. No stage determination survey for hooded seals was flown. Instead, observers noted the stages on the aerial survey imagery and adjusted the expected proportion of pups born assuming that the distribution of births was similar to that observed in 2012. This resulted in an estimated proportion of births of 0.83 (SD = 0.019) occurring prior to the survey flights.

Taking into account the reader error and adjustment for the proportion of births prior to the survey, the estimated hooded seal pup production was 12 977 (95% CI = 9867–17 067) which is lower than estimates obtained from comparable surveys in 2005 and 2007 but comparable with the estimate from the most recent survey in 2012.

Table 2.10. Estimates of Greenland Sea hooded seal pup production, based on data from ICES (2016), and Biuw et al. (SEA 247).

Year	Estimated number of pups	CV
1997	23 762	0.192
2005	15 250	0.228
2007	16 140	0.133
2012	13 655	0.138
2018	12 977	0.140

2.2.1.3 Biological parameters

Maturity curves were constructed based on female reproductive material collected over the period 1990–1994 and 2008–2010 (ICES, 2011). The record of historical fecundity rate is sparse, but previous analyses have indicated that fecundity rates remained constant around F = 0.7 during the period 1958–1999 (ICES, 2013). This is lower than the estimate of F = 0.9 used by the WG in 2011 (ICES, 2011). WGHARP (ICES, 2016) ran the population model for a range of fecundity rates, and found that while they resulted in relatively large variations in historical population sizes, the effects were non-significant in terms of estimated population sizes in recent decades. While we present estimates for all fecundity rates evaluated by ICES (2016), we propose the model that was run using F = 0.7 be considered when assessing the stock. This is within the range of expected fecundities and in accordance with the most recent assessments (ICES, 2016).

Table 2.11. Estimates of proportions of mature females. The P_1 estimates are from ICES (2008) and the P_2 estimates are from ICES (2011). Mature females had at least one Corpus Luteum or Corpus Albicans in the ovaries.

Age	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y	11y
p_1	0.00	0.05	0.27	0.54	0.75	0.87	0.93	0.97	0.98	0.99	1.00
p_2	0.00	0.00	0.06	0.60	0.89	0.97	0.99	1.00	1.00	1.00	1.00

2.2.1.4 Population Assessment

The population model used to assess the abundance for the Greenland Sea hooded seal population is a deterministic age-structured population dynamics model. It uses historical catch records, fecundity rates, age specific proportions of mature females, and estimates of pup production to estimate the population trajectory. The model is the same as described for Greenland Sea harp seals (above) (ICES, 2016; Biuw et al. SEA 250, 251).

The estimated population, along with the parameters for the normal priors used are presented in Table 2.12. The population size and pup production trajectories are shown in Figure 2.6. All model runs indicate a substantial decrease in the population abundance from the late 1940s until the early 1980s. In the two most recent decades, the population size appears to have been stable at a low level, or decreased slowly. Using a fecundity rate of F = 0.7, the total estimated population was 76 623 (95%CI: 58 299–94 947) seals. For comparison, the total population size of hooded seals in the Greenland Sea was estimated to be 85 790 seals in 2011 (ICES, 2011), 82 830 seals in 2013 (ICES, 2013), and 80 460 in 2017 (ICES, 2016).

Table 2.12. Estimated mean values and standard deviations of the parameters used in the current management model for Greenland Sea hooded seals. Estimates are provided for a range of choices of the fecundity rate, F. Priors used were the same as those used in ICES (2016).

	F=0.5		F=0.7		F=0.9	
Parameter	Mean	SD	Mean	SD	Mean	SD
N_{1946}	1 304 560	356 883	1 136 055	300 842	1 013 514	256 437
M_0	0.33	0.22	0.34	0.22	0.34	0.22
M_{1+}	0.14	0.1	0.17	0.09	0.19	0.09
$N_{0,2019}$						
$N_{1+,2019}$						

$N_{Total,2019}$	91 123	10 952	76 623	9348	68 551	8347

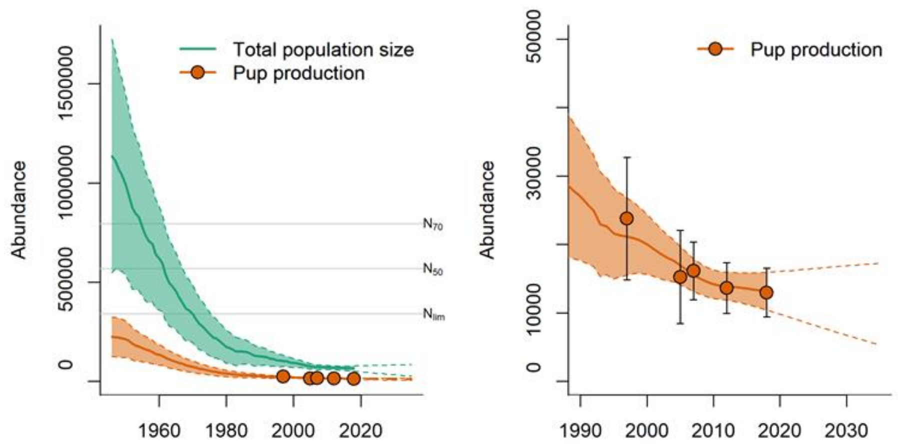

Figure 2.6. Modelled population trajectories for Greenland Sea hooded seal pups and adults (full lines), 95% confidence intervals (shaded areas) and future projections (dashed lines). N70, N50, and Nlim denote the 70%, 50%, and 30% of the historical maximum population size, respectively (obtained from the scenario of a mean fecundity rate of F = 0.7). Observed pup production estimates are indicated by filled circles.

Catch scenarios

All model runs indicate a population currently well below N_{lim} (30% of largest observed population size). Following the precautionary approach framework developed by WGHARP (ICES 2003, 2005), no commercial catches should be taken from this population.

2.2.2 The Northwest Atlantic Stock

2.2.2.1 Information on recent catches and regulatory measures

Atlantic hooded seals are considered to be data poor. Under this approach, TAC are set by considering a PBR approach. Prior to 2007, the TAC for hooded seals was set at 10 000 (Annex 8, Table 4). Because of new data on the status of the population (Hammill and Stenson, 2006) the quota was reduced to 8200 in 2007. Hooded seals have not been assessed since 2006 and as a result, no changes have occurred in the TAC. The TAC has not actually been formally announced since 2016.

Although the number of hooded seals taken in Canada has increased in recent years, the numbers are still very low. One 1 hooded seal was reported taken in each of 2015 and 2016 (Stenson and Upward SEA 254; Annex 6, Table 2). Catches increased to 12 in 2017 and 79 in 2018. The preliminary estimate of hooded seal catches in 2019 is 30 seals. These are all 1+ individuals as the hunting of bluebacks is illegal in Canada.

2.2.2.2 Biological parameters:

There are no new data on biological parameters.

2.2.2.3 Current Research

The WG noted that the collection of small numbers of hooded seals has continued in Canada. When analysed, these samples may provide some new data on diets, condition and reproductive rates. However, numbers are small.

2.2.2.4 Population Assessments

No new information.

Annex 1: List of participants

Name	Address	Email
Mike Hammill (chair)	Fisheries and Oceans Canada Institut Maurice-Lamontagne Canada	mike.hammill@dfo-mpo.gc.ca
Sophie Smout	Sea Mammal Research Unit ,Scottish Oceans Institute, University of St Andrews, UK	scs10@st-and.ac.uk
Anne Kirstine Frie	Institute of Marine Research Norway	anne.kirstine@hi.no
Tore Haug	Institute of Marine Research Norway	tore.haug@hi.no
Martin Biuw	Institute of Marine Research Norway	martin.biuw@hi.no
Kjell T. Nilssen	Institute of Marine Research Norway	kjell.tormod.nilssen@hi.no
Aqqalu Rosing-Asvid	Greenland Institute of Natural Resources, Greenland	aqqalu@natur.gl
Garry Stenson	Fisheries and Oceans Canada, Northwest Atlantic Fisheries Canada	Garry.Stenson@dfo-mpo.gc.ca
Vladimir Zabavnikov	Polar Branch of Federal State Budget Scientific Institution Russia	ltei@pinro.ru
Fern Wickson	NAMMCO	fern@nammco.no
Kimberly Murray	Northeast Fisheries Science Center USA	kimberly.murray@noaa.gov
James Grecian	Sea Mammal Research Unit ,Scottish Oceans Institute, University of St Andrews, UK	wjg5@st-andrews.ac.uk
Sabine Hansen	NAMMCO	intern@nammco.no
Genevieve Desportes	NAMMCO	genevieve@nammco.no
Ruth Fernandez	ICES Secretariat	Ruth.Fernandez@ices.dk

Annex 2: Agenda

Meeting of WGHARP, 2-6 September 2019
IMR, Fram Centre, Tromsø, Norway

Monday 2 September 2019

9:00am to noon

- Introductory Comments
- Discussion of Terms of References
- ICES-new report format
- Code of conduct
- Varia
- Request from WGIBAR (Take into account the changes in the Barents Sea ecosystem and ecosystem components)

Noon to 1:30 pm lunch

1:30pm to 5:00pm – Harp Seals: Greenland Sea Stock

- Biological parameters
- Population model new developments
- Current harvests
- Catch options

5:00pm Break for Day

Tuesday 3 September 2019

9:00 am to noon – Harp Seals: Greenland Sea Stock

- • Continue Monday discussions on population model

Noon to 1:00pm – Lunch

1:00pm to 5:00pm - White Sea and Barents Sea Stock

- Biological parameters
- New estimates
- Population assessment ()

5:00pm Break for Day

Wednesday 4 September 2019

9:00am to noon -- Harp Seals: Northwest Atlantic Stock

- Biological parameters
- Population assessment
- Population Model development
- Population modelling development and simulation scenarios
- Impacts on Greenland harvest

Noon to 1:00pm – lunch

1:00pm to 3:00pm -- Recent research

Harp seal telemetry

3:30pm to 4:30pm –Hooded seals NE Atlantic

- Biology,
- Catches
- New research

4:30pm Break for Day

Thursday 5 September 2019

9:00am to 10:00am-Hooded seals NW Atlantic

- Biology
- Catches
- New research

10:00 to noon

- Write report

Noon to 1:00pm – Lunch

1:00pm to 3:00pm –

- Write report

3:30pm – 4:30

- Review report

4:30 Break for Day

Friday 6 September 2019

9:00 am to noon

- Review/complete report
- Next meeting
- Other business

12:00 end meeting

Annex 3: Draft Resolution for next meeting

The **ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP)** chaired by Sophie Smout*, UK, and Martin Biuw*, Norway, will meet at St John's NL, Canada, on XX September 2021 to:

a) Evaluate new model developments and comparisons with the old assessment mod-els;
b) Review results of new abundance surveys for harp seals in the White Sea and southeast-ern portion of Barents Sea, if available;
c) Review results from the biological samples obtained.
d) Address potential special requests on the management of harp and hooded seal stocks by assessing their status and harvest potential;
e) Re-evaluate and review the mark-recapture abundance estimates from the Greenland Sea harp seal stock.

WGHARP will report by 1 October 2021 for the attention of ACOM.

Annex 4: Recommendations

Recommendation	Recipient
New pup aerial survey of harp seals in the White and Barents Seas (Action by 2020)	ACOM (Russia, Denmark, Iceland, Norway), ACOM, SCICOM
New pup aerial survey of harp and hooded seals in the Greenland Sea (Action by 2022)	ACOM (Norway, Iceland, Denmark), ACOM, SCICOM,
The WG recommends that the population model(s) used to describe the dynamics of North Atlantic harp and hooded seals, in particular the Greenland Sea, Barents /White Sea be developed to include uncertainty in fecundity and to examine including environmental variables into the model structure (Action by 2021)	ACOM (Norway, Russia, Canada)
The WG recommends that ICES and/or NAMMCO convene a workshop on population assessment models for seals in the North Atlantic to advance model development in the ways identified as required, before the next WGHARP	WGMME
The WG recommends increased communication and collaboration with the regional integrated assessment and ecosystem modelling communities (Action by 2025)	ACOM (Norway, Russia, Canada), WGIBAR
The WG recommends that efforts continue to obtain reproductive samples, particularly in years when an aerial survey is completed. These are required for use in the population model. (Continuing Action)	ACOM (Canada, Norway, Russia)
The WG recommends that during all aerial surveys, staging surveys also be conducted to determine the correction for pups not available to be photographed when the aerial survey is flown. This should be done for all populations of harp and hooded seals. (Continuing Action)	ACOM (Canada, Norway, Russia, Greenland)
The WG recommends that satellite telemetry tagging studies be undertaken of the White Sea\Barents Sea harp seal population (Action by 2020)	ACOM (Norway, Russia)

Annex 5: References

Working Papers

Number	Author	Title
SEA 247	Biuw, M., T.A. Øigård, K.T. Nilssen, G. Stenson, L. Lindblom, M. Poltermann, M. Kristianssen, and T. Haug	Estimation of pup production of harp and hooded seals in the Greenland Sea in 2018.
SEA248	Biuw M., T. Haug and T.A Øigård	The 2019 abundance of hooded seals (*Cystophora cristata*) in the Greenland Sea
SEA249	Haug T., M. Biuw and V. Zabavnikov	Norwegian and Russian catches of harp and hooded seals in the Northeast Atlantic in 2017-2019
SEA250	Biuw M., T.A, Øigård and T. Haug	The 2019 abundance of harp seals (*Pagophilus groenlandicus*) in the Greenland Sea
SEA251	Biuw M., A.K., Frie, M. Kristiansen, M Poltermann, T.A, Øigård and T. Haug	The 2019 abundance of harp seals (*Pagophilus groenlandicus*) in the Barents Sea / White Sea
SEA252	Frie, A.K.	A 2018 update and reassessment of reproductive parameters of Northeast Atlantic harp seals (*Pagophilus groenlandicus*)
SEA253	Korzhev,V. and V. Zabavnikov	Analysis of the White Sea/Barents Sea harp seal population(*Phoca groenlandica*) calculated quantity estimation by cohort models in present stage when hunting is absented
SEA254	Stenson, G. and P. Upward	Updated Estimates of Harp Seal Bycatch and Total Removals of NW Atlantic Harp and Hooded Seals in Canadian waters

References

Biuw, M., T.A. Øigård, K.T. Nilssen, G. Stenson, L. Lindblom, M. Poltermann, M. Kristianssen, and T. Haug . Estimation of pup production of harp and hooded seals in the Greenland Sea in 2018. WP SEA 247

Biuw, M, T. A. Øigård, and T. Haug. The 2019 abundance of harp seals (Pagophilus groenlandicus) in the Greenland Sea. WP SEA 250.

Bogstad, B., Gjøsæter, H., Haug, T., Lindstrøm, U., 2015. A review of the battle for food in the Barents Sea: cod vs marine mammals. Front. Ecol. Evol. 3,29. doi: 10.3389/fevo.2015.00029.

Buren, A.D., M. Koen-Alonso, P. Pepin, F. Mowbry, B. Nakashima, G. Stenson, N. Ollerhead, W.A. Montevecchi. 2014. Bottom-up regulation of capelin, a keystone forage species. PLoS One 9(2):e87589. Doi:10.1371/journal.pone.0087589.

Divine, D. V., and Dick., C. 2006. Historical variability of sea ice edge position in the Nordic Seas. J. Geophys. Res, 111.

Frie, A.K. A 2019 update and reassessment of reproductive parameters of Northeast Atlantic harp seals (Pagophilus groenlandicus). WP SEA 252.

Hammill, M. O. and G. B, Stenson. 2006. Timing of whelping among Northwest hooded seals. DFO Can. Sci. Advis. Sec Res. Doc 2006/069.

Hammill, M. O., and G.B. Stenson. 2007. Application of the Precautionary Approach and conservation reference points to the management of Atlantic seals. ICES Journal of Marine Science, 64: 702-706.

Hammill, M.O., G.B. Stenson, T. Doniol-Valcroze and A. Mosnier. 2015. Conservation of northwest Atlantic harp seals: Past success, future uncertainty? Biological Conservation 192:181-191. http://dx.doi.org/10.1016/j.biocon.2015.09.016

Hammill, M.O., Stenson, G.B., and Doniol-Valcroze, T. 2017. A management framework for Nunavik beluga. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/060. v + 34 p.

Haug, T., Bogstad, B., Chierici, M., Gjøsæter, H., Hallfredsson, E.H., Høines, Å.S., Hoel, A.H., Ingvaldsen, R.B., Jørgensen, L.L., Knutsen, T., Loeng, H., Naustvoll, L.-J., Røttingen, I. and Sunnanå, K. 2017. Future harvest of living resources in the Arctic Ocean of the Nordic and Barents Seas: A review of possibilities and con-straints. Fisheries Research 188: 38-57. Dx.doi.org/10.11016/j.fishres.2016.12.002.

Haug, T, Biuw, M., and Zabavnikov, V. Norwegian and Russian catches of harp and hooded seals in the Northeast Atlantic in 2017-2019. WP SEA 249.

ICES 2003. Report of the joint ICES/NAFO working group on harp and hooded seals. 2-6 September 2003. Arkhangelsk, Russia. 53 pp.

ICES 2005. Report of the joint ICES/NAFO working group on harp and hooded seals. 30August-3 September 2005. St John's NL Canada. 46 pp.

ICES. 2008. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 27-30 Aug. 2008, Tromsø, Norway. ICES CM 2008 / ACOM 17. 63 pp.

ICES. 2011. ICES WGHARP REPORT 2011 Report of the Working Group on Harp and Hooded Seals (WGHARP), 15-19 Aug, 2011, St Andrews, Scotland.: 15–19. St Andrews, Scotland.

ICES 2013. Report of the ICES Working Group on Harp and Hooded Seals, 26-30 August 2013, PINRO, Murmansk, Russia. ICES CM 2013/ACOM 20. 65 pp.

ICES. 2016a. Norway request to ICES on the status and harvest potential of the harp seal stocks in the Greenland Sea and the White Sea/Barents Sea, and of the hooded seal stock in the Greenland Sea. ICES Special Request Advice.

ICES. 2016b. ICES WGHARP REPORT. 2016 Report of the Working Group on Harp and Hooded Seals (WGHARP), 26-30 September 2016, ICES HQ, Copenhagen, Denmark

Kristensen, K., Nielsen, A., Berg, C. W., Skaug, H., and Bell, B. 2016. TMB: Automatic Differentiation and Laplace Approximation. J. Stat. Softw., 70. http://arxiv.org/abs/1509.00660%0Ahttp://dx.doi.org/10.18637/jss.v070.i05.

Korzhev, V. and V. Zabavnikov. Analysis of the Barents Sea / White Sea harp seal population (Phoca groenlandica) calculated quantity estimation by cohort models in present stage when hunting is absented. WP SEA 253.

National Marine Fisheries Service (NMFS). 2016. Guidelines for the preparing stock assessment reports pursuant to the 1994 amendments to the MMPA. 23p. Available at : http://www.nmfs.noaa.gov/op/pds/documents/01/101/01-101-03.pdf

Sergeant, D.E., 1991. Harp seals, man and ice. Can. Spec. Publ. Fish. Aquat. Sci. 114.

Sjare, B., Stenson, G.B., 2002. Estimating struck and loss rates for harp seals (Pagophilus groenlandicus) in the northwest Atlantic. Mar. Mamm. Sci. 18, 710–720.

Sjare, B., D. Walsh, G. B. Stenson and S. Benjamins. 2005. An update on harp seal (Pagophilus groenlandicus) by-catch estimates in the Newfoundland lumpfish fishery. Canadian Science Advisory Secretariat. Res. Doc. 2005/049.

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

Solvang, H.K., Yangihara, H., Øien, N., Haug, T., 2017. Temporal and geographical variation in body condition of common minke whales (Balaenoptera acutorostrata acutorostrata) in the Northeast Atlantic. Polar Biol. 40, 667-683. Doi 10.1007/s00300-016-1992-0.

Stenson, G.B., Buren, A.D., Koen-Alonso, M., 2016. The impact of changing climate and abundance on reproduction in ice-dependent species, the Northwest Atlantic harp seal, Pagophilus groenlandicus. ICES J. Mar. Sci. 73, 250-262. doi: 10-1093/icesjma/fsv202.

Stenson, G.B., Hammill, M.O., 2014. Can ice breeding seals adapt to habitat loss in a time of climate change? ICES J. Mar. Sci. 71, 1977-1986. Doi: 10.1093/icesjms/fsu074.

Stenson, G.B. and P. Upward. Updated estimates of harp seal bycatch and total removals of NW Atlantic harp and hooded seals in Canadian waters. WP SEA 254.

Wade, P.R. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Mar. Mamm. Sci. 14:1-37.

Wilkinson, J. P., and Wadhams., P. 2005. A method of detecting change in the ice conditions of the central Greenland Sea by the whelping locations of harp seals. J. Clim., 18: 1216–1226.

Øien, N., and Øritsland, T. 1995. Use of mark-recapture experiments to monitor seal populations subject to catching. In Whales, Seals, Fish and Man. Elsivier Science B. V., Amsterdam, pp. 35-45.

Øigård, T.A., Lindstrøm, U., Haug, T., Nilssen, K.T., Smout, S., 2013. Functional rela-tionship between harp seal body condition and available prey in the Barents Sea. Mar. Ecol. Progr. Ser. 484, 287-301.

Øritsland, T. and N. Øien. 1995. Aerial surveys of harp and hooded seal pubs in the Greenland Sea pack ice. In Whales, Seals, Fish and Man. Elsivier Science B. V., Amsterdam, pp. 77-87.

Annex 6: Catches of hooded seals including catches taken according to scientific permits

Table 1. Catches of hooded seals in the Greenland Sea ("West Ice") from 1946 through 2016. Totals include catches for scientific purposes.

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and older	Total	Pups	1 year and older	total	Pups	1 year and older	Total
1946–50	31152	10257	41409	-	-	-	31152	10257	41409
1951–55	37207	17222	54429	-	-	-b	37207	17222	54429
1956–60	26738	9601	36339	825	1063	1888b	27563	10664	38227
1961–65	27793	14074	41867	2143	2794	4937	29936	16868	46804
1966–70	21495	9769	31264	160	62	222	21655	9831	31486
1971	19572	10678	30250	-	-	-	19572	10678	30250
1972	16052	4164	20216	-	-	-	16052	4164	20216
1973	22455	3994	26449	-	-	-	22455	3994	26449
1974	16595	9800	26395	-	-	-	16595	9800	26395
1975	18273	7683	25956	632	607	1239	18905	8290	27195
1976	4632	2271	6903	199	194	393	4831	2465	7296
1977	11626	3744	15370	2572	891	3463	14198	4635	18833
1978	13899	2144	16043	2457	536	2993	16356	2680	19036
1979	16147	4115	20262	2064	1219	3283	18211	5334	23545
1980	8375	1393	9768	1066	399	1465	9441	1792	11233
1981	10569	1169	11738	167	169	336	10736	1338	12074
1982	11069	2382	13451	1524	862	2386	12593	3244	15837
1983	0	86	86	419	107	526	419	193	612
1984	99	483	582	-	-	-	99	483	582
1985	254	84	338	1632	149	1781	1886	233	2119
1986	2738	161	2899	1072	799	1871	3810	960	4770
1987	6221	1573	7794	2890	953	3843	9111	2526	11637

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and older	Total	Pups	1 year and older	total	Pups	1 year and older	Total
1988	4873	1276	6149c	2162	876	3038	7035	2152	9187
1989	34	147	181	-	-	-	34	147	181
1990	26	397	423	0	813	813	26	1210	1236
1991	0	352	352	458	1732	2190	458	2084	2542
1992	0	755	755	500	7538	8038	500	8293	8793
1993	0	384	384	-	-	-	0	384	384
1994	0	492	492	23	4229	4252	23	4721	4744
1995	368	565	933	-	-	-	368	565	933
1996	575	236	811	-	-	-	575	236	811
1997	2765	169	2934	-	-	-	2765	169	2934
1998	5597	754	6351	-	-	-	5597	754	6351
1999	3525	921	4446	-	-	-	3525	921	4446
2000	1346	590	1936	-	-	-	1346	590	1936
2001	3129	691	3820	-	-	-	3129	691	3820
2002	6456	735	7191	-	-	-	6456	735	7191
2003	5206	89	5295	-	-	-	5206	89	5295
2004	4217	664	4881	-	-	-	4217	664	4881
2005	3633	193	3826	-	-	-	3633	193	3826
2006	3079	568	3647	-	-	-	3079	568	3647
2007	27	35	62	-	-	-	27	35	62
2008	9	35	44	-	-	-	9	35	44
2009	396	17	413	-	-	-	396	17	413
2010	14	164	178	-	-	-	14	164	178
2011	15	4	19	-	-	-	15	4	19
2012	15	6	21	-	-	-	15	6	21
2013	15	7	22	-	-	-	15	7	22
2014	24	0	24	0	0	0	24	0	24
2015	5	6	11	0	0	0	5	6	11

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and older	Total	Pups	1 year and older	total	Pups	1 year and older	Total
2016	10	8	18	0	0	0	10	8	18
2017	14	3	17	0	0	0	14	3	17
2018	9	8	17	0	0	0	9	8	17
2019	14	9	23	0	0	0	14	9	23

a For the period 1946–1970 only 5-year averages are given.

b For 1955, 1956, and 1957 Soviet catches of harp and hooded seals reported at 3900, 11 600 and 12 900, respectively. These catches are not included.

c Including 1048 pups and 435 adults caught by one ship which was lost.

Table 2. Canadian catches of hooded seals off Newfoundland and in the Gulf of St Lawrence, Canada ("Gulf" and "Front"), 1946–2019. Catches from 1995 onward includes catches under personal use licences. YOY refers to Young of Year. Catches from 1990–1996 were not assigned to age classes. With the exception of 1996, all were assumed to be 1+.

	Large Vessel Catches				Landsmen Catches				Total Catches			
Year	YOY	1+	Unk	Total	YOY	1+	Unk	Total	YOY	1+	Unk	Total
1946-50	4029	2221	0	6249	429	184	0	613	4458	2405	0	6863
1951-55	3948	1373	0	5321	494	157	0	651	4442	1530	0	5972
1956-60	3641	2634	0	6275	106	70	0	176	3747	2704	0	6451
1961-65	2567	1756	0	4323	521	199	0	720	3088	1955	0	5043
1966-70	7483	5220	0	12703	613	211	24	848	8096	5431	24	13551
1971-75	6550	5247	0	11797	92	56	0	148	6642	5303	0	11945
1976	6065	5718	0	11783	475	127	0	602	6540	5845	0	12385
1977	7967	2922	0	10889	1003	201	0	1204	8970	3123	0	12093
1978	7730	2029	0	9759	236	509	0	745	7966	2538	0	10504
1979	11817	2876	0	14693	131	301	0	432	11948	3177	0	15125
1980	9712	1547	0	11259	1441	416	0	1857	11153	1963	0	13116
1981	7372	1897	0	9269	3289	1118	0	4407	10661	3015	0	13676
1982	4899	1987	0	6886	2858	649	0	3507	7757	2636	0	10393
1983	0	0	0	0	0	128	0	128	0	128	0	128
1984	206	187	0	393d	0	56	0	56	206	243	0	449
1985	215	220	0	435d	5	344	0	349	220	564	0	784
1986	0	0	0	0	21	12	0	33	21	12	0	33

	Large Vessel Catches				Landsmen Catches				Total Catches			
Year	YOY	1+	Unk	Total	YOY	1+	Unk	Total	YOY	1+	Unk	Total
1987	124	4	250	378	1197	280	0	1477	1321	284	250	1855
1988	0	0	0	0	828	80	0	908	828	80	0	908
1989	0	0	0	0	102	260	5	367	102	260	5	367
1990	41	53	0	94[d]	0	0	636[e]	636	41	53	636	730
1991	0	14	0	14[d]	0	0	6411[e]	6411	0	14	6411	6425
1992	35	60	0	95[d]	0	0	119[e]	119	35	60	119	214
1993	0	19	0	19[d]	0	0	19[e]	19	0	19	19	38
1994	19	53	0	72[d]	0	0	149[e]	149	19	53	149	221
1995	0	0	0	0	0	0	857[e]	857	0	0	857e	857
1996	0	0	0	0	0	0	25754[e]	25754	0	22847[f]	2907	25754
1997	0	0	0	0	0	7058	0	7058	0	7058	0	7058
1998	0	0	0	0	0	10148	0	10148	0	10148	0	10148
1999	0	0	0	0	0	201	0	201	0	201	0	201
2000	2	2	0	4[d]	0	10	0	10	2	12	0	14
2001	0	0	0	0	0	140	0	140	0	140	0	140
2002	0	0	0	0	0	150	0	150	0	150	0	150
2003	0	0	0	0	0	151	0	151	0	151	0	151
2004	0	0	0	0	0	389	0	389	0	389	0	389
2005	0	0	0	0	0	20	0	20	0	20	0	20
2006	0	0	0	0	0	40	0	40	0	40	0	40
2007	0	0	0	0	0	17	0	17	0	17	0	17
2008	0	0	0	0	0	5	0	5	0	5	0	5
2009	0	0	0	0	0	10	0	10	0	10	0	10
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	2	0	2	0	2	0	2
2012	0	0	0	0	0	1	0	1	0	1	0	1
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	7	0	7	0	7	0	7

	Large Vessel Catches				Landsmen Catches				Total Catches			
Year	YOY	1+	Unk	Total	YOY	1+	Unk	Total	YOY	1+	Unk	Total
2015	0	0	0	0	0	1	0	1	0	1	0	1
2016	0	0	0	0	0	1	0	1	0	1	0	1
2017	0	0	0	0	0	12	0	12	0	12	0	12
2018	0	0	0	0	0	79	0	79	0	79	0	79
2019[g]	0	0	0	0	0	30	0	30	0	30	0	30

a For the period 1946–1970 only 5-years averages are given.

b All values prior to 1990 are from NAFO except where noted; recent years are from DFO Statistics Branch.

c Landsmen values include catches by small vessels (<150 gr tonnes) and aircraft.

d Large vessel catches represent research catches in Newfoundland and may differ from NAFO values.

e Statistics not split by age; commercial catches of bluebacks are not allowed

f Number of YOY based upon seizures of illegal catches

g Preliminary data

Table 3. Catches of hooded seals in West and East Greenland 1954–2017.

Year	West Atlantic Population				NE	All Greenland
	West	KGHb	Southeast	Total		
1954	1097	-	201	1298	-	1298
1955	972	-	343	1315	1	1316
1956	593	-	261	854	3	857
1957	797	-	410	1207	2	1209
1958	846	-	361	1207	4	1211
1959	780	414	312	1506	8	1514
1960	965	-	327	1292	4	1296
1961	673	803	346	1822	2	1824
1962	545	988	324	1857	2	1859
1963	892	813	314	2019	2	2021
1964	2185	366	550	3101	2	3103
1965	1822	-	308	2130	2	2132
1966	1821	748	304	2873	-	2873
1967	1608	371	357	2336	1	2337
1968	1392	20	640	2052	1	2053
1969	1822	-	410	2232	1	2233

Year	West Atlantic Population				NE	All Greenland
	West	KGHb	Southeast	Total		
1970	1412	-	704	2116	9	2125
1971	1634	-	744	2378	-	2378
1972	2383	-	1825	4208	2	4210
1973	2654	-	673	3327	4	3331
1974	2801	-	1205	4006	13	4019
1975	3679	-	1027	4706	58a	4764
1976	4230	-	811	5041	22a	5063
1977	3751	-	2226	5977	32a	6009
1978	3635	-	2752	6387	17	6404
1979	3612	-	2289	5901	15	5916
1980	3779	-	2616	6395	21	6416
1981	3745	-	2424	6169	28a	6197
1982	4398	-	2035	6433	16a	6449
1983	4155	-	1321	5476	9a	5485
1984	3364	-	1328	4692	17	4709
1985	3188	-	3689	6877	6	6883
1986	2796a	-	3050a	5846a	-a	5846a
1987	2333a	-	2472a	4805a	3a	4808a
1988–92c						
1993	4982	-	1967	6950	32	6981
1994	5060	-	3048	8108	34	8142
1995	4429		2702	7131	48	7179
1996	6066	-	3801	9867	24	9891
1997	5250		2175	7425	67	7492
1998	5051		1270	6321	14	6335
1999	4852	-	2587	7439	16	7455
2000	3769	-	2046	5815	29	5844
2001	5010	-	1496	6506	8	6514

Year	West Atlantic Population				NE	All Greenland
	West	KGHb	Southeast	Total		
2002	3606	-	1189	4795	11	4806
2003	4351	-	1992	6343	10	6353
2004	4136	-	1690	5823	17	5843
2005	3092	-	1022	4114	14	4128
2006	4238	-	559	4744	3	4800
2007	2570	-	710	3287	7	3287
2008	2083	-	519	2604	2	2604
2009	1628	-	359	1982	1	1988
2010	1872		266	2137	7	2145
2011	1835		225	2052	9	2069
2012	1352	-	349	1665	6	1707
2013	1185	-	330	1520	0	1515
2014	1460	-	388	1845	1	1849
2015	1719	-	229	1948	0	1948
2016	1247	-	267	1514	1	1515
2017	1309	-	217	1526	0	1526

a Provisional figures: do not include estimates for non-reported catches as for the previous years.

b Royal Greenland Trade Department special vessel catch expeditions in the Denmark Strait 1959–1968.

c For 1988 to 1992 catch statistics are not available.

Table 4. Catches of moulting hooded seals in the Denmark Strait, 1945-1978.

Year	Norway sealing	Greenland sealing[a]	Norway scient. sampling
1945	3275	-	
1946	17 767	-	
1947	16 080	-	
1948	16 170	-	
1949	1494	-	
1950	17742	-	
1951	47 607	-	
1952	16 910	-	
1953	2907	-	
1954	18 291	-	
1955	10 230	-	
1956	12 840	-	
1957	21 425	-	
1958	14 950	-	
1959	6480	414	
1960	7930	0[b]	
1961	-	803	
1962	-	988	
1963	-	813	
1964	-	360	
1965	-	-	
1966	-	782	
1967	-	371	
1968	-	20	
1969	-	-	
1970	-	-	797
1971	-	-	
1972	-	-	869

Year	Norway sealing	Greenland sealing[a]	Norway scient. sampling
1973	-	-	
1974	-	-	1201
1975	-	-	
1976	-	-	323
1977	-	-	
1978	-	-	1201

[a]) Performed by KGH (Royal Greenland Trade Department) on behalf of the local inhabitants of Ammassalik, South-east Greenland.

[b]) The vessel was lost 23 June on its first trip that year; previous information on a catch of 773 seals is thus in error (probably confused with the 1961-catch.

Annex 7: Catches of harp seals including catches taken according to scientific permits

Table 1. Catches of harp seals in the Greenland Sea ("West Ice") from 1946 through 2016a. Totals include catches for scientific purposes. Catches are from Haug *et al*. (SEA249)

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and older	Total	pups	1 year and older	Total	Pups	1 year and older	Total
1946–50	26606	9464	36070	-	-	-	26606	9464	36070
1951–55	30465	9125	39590	-	-	-b	30465	9125	39590
1956–60	18887	6171	25058	1148	1217	2365b	20035	7388	27423
1961–65	15477	3143	18620	2752	1898	4650	18229	5041	23270
1966–70	16817	1641	18458	1	47	48	16818	1688	18506
1971	11149	0	11149	-	-	-	11149	0	11149
1972	15100	82	15182	-	-	-	15100	82	15182
1973	11858	0	11858	-	-	-	11858	0	11858
1974	14628	74	14702	-	-	-	14628	74	14702
1975	3742	1080	4822	239	0	239	3981	1080	5061
1976	7019	5249	12268	253	34	287	7272	5283	12555
1977	13305	1541	14846	2000	252	2252	15305	1793	17098
1978	14424	57	14481	2000	0	2000	16424	57	16481
1979	11947	889	12836	2424	0	2424	14371	889	15260
1980	2336	7647	9983	3000	539	3539	5336	8186	13522
1981	8932	2850	11782	3693	0	3693	12625	2850	15475
1982	6602	3090	9692	1961	243	2204	8563	3333	11896
1983	742	2576	3318	4263	0	4263	5005	2576	7581
1984	199	1779	1978	-	-	-	199	1779	1978
1985	532	25	557	3	6	9	535	31	566
1986	15	6	21	4490	250	4740	4505	256	4761
1987	7961	3483	11444	-	3300	3300	7961	6783	14744
1988	4493	5170	9663c	7000	500	7500	11493	5670	17163

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and older	Total	pups	1 year and older	Total	Pups	1 year and older	Total
1989	37	4392	4429	-	-	-	37	4392	4429
1990	26	5482	5508	0	784	784	26	6266	6292
1991	0	4867	4867	500	1328	1828	500	6195	6695
1992	0	7750	7750	590	1293	1883	590	9043	9633
1993	0	3520	3520	-	-	-	0	3520	3520
1994	0	8121	8121	0	72	72	0	8193	8193
1995	317	7889	8206	-	-	-	317	7889	8206
1996	5649	778	6427	-	-	-	5649	778	6427
1997	1962	199	2161	-	-	-	1962	199	2161
1998	1707	177	1884	-	-	-	1707	177	1884
1999	608	195	803	-	-	-	608	195	803
2000	6328	6015	12343	-	-	-	6328	6015	12343
2001	2267	725	2992	-	-	-	2267	725	2992
2002	1118	114	1232	-	-	-	1118	114	1232
2003	161	2116	2277				161	2116	2277
2004	8288	1607	9895				8288	1607	9895
2005	4680	2525	7205				4680	2525	7205
2006	2343	961	3304				2343	961	3304
2007	6188	1640	7828				6188	1640	7828
2008	744	519	1263				744	519	1263
2009	5177	2918	8035	-	-	-	5117	2918	8035
2010	2823	1855	4678	-	-	-	2823	1855	4678
2011	5361	4773	10134	-	-	-	5361	4773	10134
2012	3740	1853	5593	-	-	-	3740	1853	5593
2013	13911	2122	16033	-	-	-	13911	2122	16033
2014	9741	2245	11986				9741	2245	11986
2015	2144	93	2237	-	-	-	2144	93	2237
2016	426	1016	1442	-	-	-	426	1016	1442

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and older	Total	pups	1 year and older	Total	Pups	1 year and older	Total
2017	1934	66	2000	-	-	-	1934	66	2000
2018	1218	1485	2703	-	-	-	1218	1485	2703
2019	2168	3645	5813	-	-	-	2168	3645	5813

a For the period 1946–1970 only 5-year averages are given.

b For 1955, 1956, and 1957 Soviet catches of harp and hooded seals reported at 3900, 11 600 and 12 900, respectively (Sov. Rep. 1975). These catches are not included.

c Including 1431 pups and one adult caught by a ship which was lost.

Table 2. Catches of harp seals in the Barents and White Seas ("East Ice"), 1946–2019 (Haug *et al.*, SEA 249)

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and Older	Total	Pups	1 year and Older	Total	Pups	1 year and Older	Total
1946–50			25057	90031	55285	145316			170373
1951–55			19590	59190	65463	124653			144243
1956–60	2278	14093	16371	58824	34605	93429	61102	48698	109800
1961–65	2456	8311	10767	46293	22875	69168	48749	31186	79935
1966–70			12783	21186	410	21596			34379
1971	7028	1596	8624	26666	1002	27668	33694	2598	36292
1972	4229	8209	12438	30635	500	31135	34864	8709	43573
1973	5657	6661	12318	29950	813	30763	35607	7474	43081
1974	2323	5054	7377	29006	500	29506	31329	5554	36883
1975	2255	8692	10947	29000	500	29500	31255	9192	40447
1976	6742	6375	13117	29050	498	29548	35792	6873	42665
1977	3429	2783	6212c	34007	1488	35495	37436	4271	41707
1978	1693	3109	4802	30548	994	31542	32341	4103	36344
1979	1326	12205	13531	34000	1000	35000	35326	13205	48531
1980	13894	1308	15202	34500	2000	36500	48394	3308	51702
1981	2304	15161	17465d	39700	3866	43566	42004	19027	61031

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and Older	Total	Pups	1 year and Older	Total	Pups	1 year and Older	Total
1982	6090	11366	17456	48504	10000	58504	54594	21366	75960
1983	431	17658	18089	54000	10000	64000	54431	27658	82089
1984	2091	6785	8876	58153	6942	65095	60244	13727	73971
1985	348	18659	19007	52000	9043	61043	52348	27702	80050
1986	12859	6158	19017	53000	8132	61132	65859	14290	80149
1987	12	18988	19000	42400	3397	45797	42412	22385	64797
1988	18	16580	16598	51990	2501e	54401	51918	19081	70999
1989	0	9413	9413	30989	2475	33464	30989	11888	42877
1990	0	9522	9522	30500	1957	32457	30500	11479	41979
1991	0	9500	9500	30500	1980	32480	30500	11480	41980
1992	0	5571	5571	28351	2739	31090	28351	8310	36661
1993	0	8758f	8758	31000	500	31500	31000	9258	40258
1994	0	9500	9500	30500	2000	32500	30500	11500	42000
1995	260	6582	6842	29144	500	29644	29404	7082	36486
1996	2910	6611	9521	31000	528	31528	33910	7139	41049
1997	15	5004	5019	31319	61	31380	31334	5065	36399
1998	18	814	832	13350	20	13370	13368	834	14202
1999	173	977	1150	34850	0	34850	35023	977	36000
2000	2253	4104	6357	38302	111	38413	40555	4215	44770
2001	330	4870	5200	39111	5	39116	39441	4875	44316
2002	411	1937	2348	34187	0	34187	34598	1937	36535
2003	2343	2955	5298	37936	0	37936	40279	2955	43234
2004	0	33	33	0	0	0	0	33	33
2005	1162	7035	8197	14258	19	14277	15488	9405	22474
2006	147	9939	10086	7005	102	7107	7152	10041	17193
2007	242	5911	6153	5276	200	5476	5518	6111	11629
2008	0	0	0	13331	0	13331	13331	0	13331
2009	0	0	0	0	0	0	0	0	0

Year	Norwegian catches			Russian catches			Total catches		
	Pups	1 year and Older	Total	Pups	1 year and Older	Total	Pups	1 year and Older	Total
2010	0	105	105	5	5	10	5	110	115
2011	0	200	200	0	0	0	0	200	200
2012	0-	0-	0-	0	9	9	0	9	9
2013	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0
2016	0	28	28	0	0	0	0	28	28
2017	0	1	1	0	0	0	0	1	1
2018	21	2220	2241	0	0	0	21	2220	2241
2019	34	568	602	0	0	0	34	568	602

a For the period 1946–1970 only 5-year averages are given.

b Incidental catches of harp seals in fishing gear on Norwegian and Murmansk coasts are not included (see Table 6).

c Approx. 1300 harp seals (unspecified age) caught by one ship lost are not included.

d An additional 250–300 animals were shot but lost as they drifted into Soviet territorial waters.

e Russian catches of 1+ animals after 1987 selected by scientific sampling protocols.

f Included 717 seals caught to the south of Spitsbergen, east of 14o E, by one ship which mainly operated in the Greenland Sea.

Table 3. Incidental catches and death of harp seals at the Norwegian and Murman coasts[1]. There are no data since 1991.

Year	Norwegian coast	Murman coast	Total
1978	.		.
1979	2023	1114	3137
1980	3311		
1981	2013		
1982	517		
1983	855		
1984	1236		
1985	1225		
1986	4409		
1987	56 222		
1988	21 538		
1989	314		
1990	368		
1991	-		

1) Norwegian data are recorded catches, since 1981 recorded for compensation under regulations for damage to fishing gear.

Table 4. Reported catches of harp seals in the Northwest Atlantic for 1952-2019. Estimated catches are indicated by shading. The Greenland catches are made up of the Table 6 West Greenland catches and 1/2 of the SE Greenland. The other half of the SE Greenland and the NE Greenland are assigned to the West Ice population.

Year	Front and Gulf	Canadian Arctic	Greenland	NW Atlantic Total
1952	307 108	1784	16 400	325 292
1953	272 886	1784	16 400	291 070
1954	264 416	1784	19 150	285 350
1955	333 369	1784	15 534	350 687
1956	389 410	1784	10 973	402 167
1957	245 480	1784	12 884	260 148
1958	297 786	1784	16 885	316 455
1959	320 134	1784	8 928	330 846
1960	277 350	1784	16 154	295 288
1961	187 866	1784	11 996	201 646
1962	319 989	1784	8 500	330 273
1963	342 042	1784	10 111	353 937
1964	341 663	1784	9203	352 650
1965	234 253	1784	9289	245 326
1966	323 139	1784	7057	331 980
1967	334 356	1784	4242	340 382
1968	192 696	1784	7116	201 596
1969	288 812	1784	6438	297 034
1970	257 495	1784	6269	265 548
1971	230 966	1784	5572	238 322
1972	129 883	1784	5994	137 661
1973	123 832	1784	9212	134 828
1974	147 635	1784	7145	156 564
1975	174 363	1784	6752	182 899
1976	165 002	1784	11 956	178 742
1977	155 143	1784	12 866	169 793
1978	161 723	2129	16 638	180 490
1979	160 541	3620	17 545	181 706

Year	Front and Gulf	Canadian Arctic	Greenland	NW Atlantic Total
1980	169 526	6350	15 255	191 131
1981	202 169	4672	22 974	229 815
1982	166 739	4881	26 927	198 547
1983	57 889	4881	24 785	87 555
1984	31 544	4881	25 829	62 254
1985	19 035	4881	20 785	44 701
1986	25 934	4881	26 099	56 914
1987	46 796	4881	37 859	89 536
1988	94 046	4881	40 415	139 342
1989	65 304	4881	42 971	113 156
1990	60 162	4881	45 526	110 569
1991	52 588	4881	48 082	105 551
1992	68 668	4881	50 638	124 187
1993	27 003	4881	56 319	88 203
1994	61 379	4881	57 373	123 633
1995	65 767	4881	62 749	133 397
1996	242 906	4881	73 947	321 734
1997	264 210	2500[a]	68 816	335 526
1998	282 624	1000[a]	81 273	364 897
1999	244 552	500[a]	93 120	338 172
2000	92 055	400[a]	98 463	190 918
2001	226 493	600[a]	85 428	312 521
2002	312 367	1000	66 735	380 102
2003	289 512	1000	66 149	356 661
2004	365 971	1000	70 587	437 558
2005	323 826	1000	91 688	422 517
2006	354 867	1000	94 034	449 901
2007	224 745	1000	82 826	308 571
2008	217 850	1000	80 444	299 294

Year	Front and Gulf	Canadian Arctic	Greenland	NW Atlantic Total
2009	76 668	1000	71 862	149 530
2010	69 101	1000	90 909	160 006
2011	40 389	1000	73 462	114 851
2012	71 460	1000	54 660	127 120
2013	97 922	1000	65 241	164 163
2014	59 666	1000	63 028	123 694
2015	35 382	1000	61 767	98 149
2016	68 360	1000	56 730	124 880
2017	81 360 61 022	1000	48 593	130 258
2018	61 022 32 038	1000	58 614[b]	120 636
2019[c]	32 038	1000	58 614[b]	91 652

[a] Rounded

[b] Average of catches 2013–2017

[c] Preliminary data

Table 5. Reported Canadian catches of Harp seals off Newfoundland and in the Gulf of St. Lawrence, Canada ("Gulf" and "Front"), 1946–2019a,b. Catches from 1995 onward include catches under the personal use licences. YOY = Young of Year.

	Large Vessel Catch				Landsmen Catch[c]				Total Catches			
Year	YOY	1+	Unk	Total	YOY	1+	Unk	Total	YOY	1+	Unk	Total
1946-50	108256	53763	0	162019	44724	11232	0	55956	152980	64995	0	217975
1951-55	184857	87576	0	272433	43542	10697	0	54239	228399	98273	0	326672
1956-50	175351	89617	0	264968	33227	7848	0	41075	208578	97466	0	306044
1961-65	171643	52776	0	224419[d]	47450	13293	0	60743	219093	66069	0	285162
1966-70	194819	40444	0	235263	32524	11633	0	44157	227343	52077	0	279420
1971-75	106425	12778	0	119203	29813	12320	0	42133	136237	25098	0	161336
1976	93939	4576	0	98515	38146	28341	0	66487	132085	32917	0	165002
1977	92904	2048	0	94952	34078	26113	0	60191	126982	28161	0	155143
1978	63669	3523	0	67192	52521	42010	0	94531	116190	45533	0	161723
1979	96926	449	0	97375	35532	27634	0	63166	132458	28083	0	160541
1980	91577	1563	0	93140	40844	35542	0	76386	132421	37105	0	169526
1981d	89049	1211	0	90260	89345	22564	0	111909	178394	23775	0	202169
1982	100568	1655	0	102223	44706	19810	0	64516	145274	21465	0	166739
1983	9529	1021	0	10550	40529	6810	0	47339	50058	7831	0	57889

	Large Vessel Catch				Landsmen Catch[c]				Total Catches			
1984	95	549	0	644[e]	23827	7073	0	30900	23922	7622	0	31544
1985	0	1	0	1[e]	13334	5700	0	19034	13334	5701	0	19035
1986	0	0	0	0	21888	4046	0	25934	21888	4046	0	25934
1987	2671	90	0	2761	33657	10356	22	44035	36350	10446	0	46796
1988	0	0	0	0	66972	13493	13581	94046	66972	27074	0	94046
1989	1	231	0	232[e]	56345	5691	3036	65072	56346	8958	0	65304
1990	48	74	0	122[e]	34354	23725	1961	60040	34402	25760	0	60162
1991	3	20	0	23[e]	42379	5746	4440	52565	42382	10206	0	52588
1992	99	846	0	945[e]	43767	21520	2436	67723	43866	24802	0	68668
1993	8	111	0	119[e]	16393	9714	777	26884	16401	10602	0	27003
1994	43	152	0	195[e]	25180	34939	1065	61184	25223	36156	0	61379
1995	21	355	0	376[e]	33615	31306	470	65391	34106	31661	0	65767
1996	3	186	0	189[e]	184853	57864	0	242717	184856	58050	0	242906
1997	0	6	0	6[e]	220476	43728	0	264204	220476	43734	0	264210
1998	7	547	0	554[e]	0	0	282070	282070	7	547	282070	282624
1999	26	25	0	51[e]	221001	6769	16782	244552	221027	6794	16782	244603
2000	16	450	0	466[e]	85035	6567	0	91602	85485	6583	0	92068

	Large Vessel Catch				Landsmen Catch[c]				Total Catches			
2001	0	0	0	0	214754	11739	0	226493	214754	11739	0	226493
2002	0	0	0	0	297764	14603	0	312367	297764	14603	0	312367
2003	0	0	0	0	280174	9338	0	289512	280174	9338	0	289512
2004	0	0	0	0	353553	12418	0	365971	353553	12418	0	365971
2005	0	0	0	0	319127	4699	0	323826	319127	4699	0	323826
2006	0	0	0	0	346426	8441	0	354867	346426	8441	0	354867
2007	0	0	0	0	221488	3257	0	224745	221488	3257	0	224745
2008	0	0	0	0	217565	285	0	217850	217565	285	0	217850
2009	0	0	0	0	76668	0	0	76668	76668	0	0	76668
2010	0	0	0	0	68654	447	0	69101	68654	447	0	69101
2011	0	0	0	0	40371	18	0	40389	40371	18	0	40389
2012	0	0	0	0	71319	141	0	71460	71319	141	0	71460
2013	0	0	0	0	94,310	3,612	0	97,922	94,310	3,612	0	97,922
2014	0	0	0	0	59,616	50	0	59,666	59,616	50	0	59,666
2015	0	0	0	0	35,302	80	0	35,382	35,302	80	0	35,382
2016	0	0	0	0	51,854	7,087	9,419[f]	68,360	51,854	7,087	9,419	68,360
2017	0	0	0	0	58,234	10,062	13,446[f]	81,742	58,234	10,062	13,446	81,742

	Large Vessel Catch				Landsmen Catch[c]				Total Catches			
2018	0	0	0	0	53,222	4,728	3,072[f]	61,022	53,222	4,728	3,072	61,022
2019	0	0	0	0	0	0	32,038[fg]	32,038	0	0	32,038	32,038

a For the period 1946-1975 only 5-years averages are given.

b All values prior to 1990 are from NAFO except where noted, recent data from DFO Statistics Branch.

c Landsmen values include catches by small vessels (< 150 gr tonnes) and aircraft.

d NAFO values revised to include complete Quebec catch (Bowen, W.D. 1982)

e Large vessel catches represent research catches in Newfoundland and may differ from NAFO values

f Unspecified catches will be assigned to age class at a later date

g Preliminary data

Table 6. Catches of harp seals in Greenland, 1954–1987 (List-of-Game), and 1993–2017 (Piniarneq), and % adults [a] according to the hunters' reports [b].

Year	West Greenland		South East Greenland		Northeast Greenland		All Greenland
	Catch numbers	% adults	Catch numbers	% adults	Catch numbers	% adults	Catch numbers
1954	18 912		475		32		19 419
1955	15 445		178		45		15 668
1956	10 883		180		5		11 068
1957	12 817		133		40		12 990
1958	16 705		360		30		17 095
1959	8844		168		7		9,019
1960	15 979		350		16		16 345
1961	11 886		219		13		12 118
1962	8394		211		10		8615
1963	10 003	21	215	28	20	50	10 238
1964	9140	26	125	40	7	86	9272
1965	9251	25	76	65	2	100	9329
1966	7029	29	55	55	6		7090
1967	4215	38	54	35	10		4279
1968	7026	30	180	47	4		7210
1969	6383	21	110	62	9		6502
1970	6178	26	182	70	15	100	6375
1971	5540	24	63	48	5		5608
1972	5952	16	84	48	6	100	6042
1973	9162	19	100	20	38	79	9300
1974	7073	21	144	29	27	95	7244
1975	5953	13	125	20	68	72	6146
1976	7787	12	260	48	27	55	8074
1977	9938	15	72	16	21	81	10 031
1978	10 540	16	408	14	30	36	10 978
1979	12 774	20	171	19	18	25	12 963
1980	12 270	17	308	14	45		12 623

Year	West Greenland		South East Greenland		Northeast Greenland		All Greenland
	Catch numbers	% adults	Catch numbers	% adults	Catch numbers	% adults	Catch numbers
1981	13 605	21	427	15	49		14 081
1982	17 244	16	267	20	50	60	17 561
1983	18 739	19	357	56	57	30	19 153
1984	17 667	16	525	19	61		18 253
1985	18 445	2	534	0	56	52	19 035
1986	13 932b	10	533b	18	37b	65	14 502b
1987	16 053b	21	1060b	24	15b	60	17 128b
1988-1992	For 1988 to 1992 comparable catch statistics are not available.						
1993	55 784	50	1054	30	40	93	56 878
1994	56 919	50	864	30	88	65	57 871
1995	62 296	53	906	36	61	52	63 263
1996	73 288	52	1320	35	68	60	74 676
1997	68 241	49	1149	28	201	58	69 591
1998	80 438	51	1670	30	109	73	82 217
1999	91 324	49	3592	12	101	67	95 017
2000	97 233	44	2459	15	109	79	99 801
2001	84 165	42	2525	18	73	68	86 763
2002	65 810	45	1849	19	66	86	67 725
2003	64 735	44	2828	24	44	77	67 607
2004	69 274	40	2625	27	206	28	72 105
2005	90 300	35	2775	18	38	58	93 113
2006	92 995	33	2077	17	89	78	95 161
2007	81 476	32	2699	21	85	53	84 260
2008	78 728	32	3432	11	7	29	82 167
2009	70 577	32	2569	9	260	6	73 406
2010	88 936	25	1938	12	35	34	90 909
2011	72 640	30	1644	16	74	26	74 358
2012	53 833	30	1653	12	147	90	55 633

Year	West Greenland		South East Greenland		Northeast Greenland		All Greenland
	Catch numbers	% adults	Catch numbers	% adults	Catch numbers	% adults	Catch numbers
2013	64 147	29	2188	15	186	28	66 521
2014	62 116	28	1824	13	28	32	63 968
2015	60 959	31	1616	18	57	46	62 632
2016	54 346	31	2348	14	36	36	56 730
2017	46 476	33	2079	16	38	5	48 593

a Seals exhibiting some form of a harp.

b These provisional figures do not include estimates for non-reported catches as for the previous years.

Table 8. Estimated total removals of harp seals in the Northwest Atlantic for 1952–2019

Year	Reported	Bycatch	Struck and Lost	Total
1952	325 292	0	129 230	454 522
1953	291 070	0	95 095	386 165
1954	285 350	0	112 084	397 434
1955	350 687	0	100 938	451 627
1956	402 167	0	64 218	466 383
1957	260 148	0	96 381	356 529
1958	316 455	0	176 883	493 340
1959	330 846	0	94 426	425 274
1960	295 288	0	140 697	435 983
1961	201 646	0	34 532	236 181
1962	330 273	0	125 277	455 550
1963	353 937	0	86 250	440 185
1964	352 650	0	88 959	441 607
1965	245 326	0	64 414	309 740
1966	331 980	0	83 382	415 361
1967	340 382	0	65 438	405 821
1968	201 596	0	46 718	248 315
1969	297 034	0	66 051	363 086
1970	265 548	77	50 313	315 938
1971	238 322	525	29 870	268 719
1972	137 661	623	22 031	160 315
1973	134 828	467	37 486	172 782
1974	156 564	183	42 899	199 647
1975	182 899	285	43 681	226 865
1976	178 742	1,095	47 991	227 828
1977	169 793	1,633	44 094	215 518
1978	180 490	3,376	65 474	249 342
1979	181 706	3,603	50 585	235 895

Year	Reported	Bycatch	Struck and Lost	Total
1980	191 131	2814	60 048	253 994
1981	229 815	4181	53 222	287 216
1982	198 547	3817	54 740	257 102
1983	87 555	5009	40 131	132 694
1984	62 254	4143	39 591	105 987
1985	44 701	4987	32 069	81 757
1986	56 914	6109	36 178	99 199
1987	89 536	10 910	55 099	155 547
1988	139 342	8398	75 895	223 634
1989	113 156	8643	59 775	181 574
1990	110 569	2769	77 978	191 317
1991	105 551	8703	65 400	179 654
1992	124 187	23 035	82 629	229 852
1993	88 203	26 975	72 665	187 845
1994	123 633	47 604	99 738	270 974
1995	133 397	20 593	101 086	255 075
1996	321 734	29 641	146 607	497 981
1997	335 526	19 048	126 654	481 229
1998	364 897	4 557	126 726	496 181
1999	338 172	16 167	113 036	467 376
2000	190 918	11 521	110 358	312 799
2001	312 521	20 064	109 069	441 653
2002	380 102	9543	98 009	487 655
2003	356 661	5445	91 233	453 340
2004	437 558	35 870	102 613	576 040
2005	422 517	26 378	115 759	564 652
2006	449 901	21 656	121 707	593 264
2007	308 571	9450	98 740	416 759
2008	299 294	7280	93 180	399 755

Year	Reported	Bycatch	Struck and Lost	Total
2009	149 530	2275	76 897	228 700
2010	160 006	3957	94 965	258 930
2011	114 851	2114	76 605	193 570
2012	127 120	2886	59 554	189 561
2013	164 163	177	74 817	239 157
2014	123 694	1166	67 216	192 075
2015	98 149	1039	64 705	163 895
2016	124 880	603	67 075	192 559
2017	130 258	226	63 686	194 169
2018	120 636	612	67 455	188 703
2019	91 652	711[a]	63 313	155 677

[a] **Average bycatch 2014–2018 in Canadian and US fisheries.**

Annex 8: Summary of harp and hooded sealing regulations

Table 1. Summaries of Norwegian harp and hooded sealing regulations for the Greenland Sea ("West Ice"), 1985–2016 (Haug and Zabavnikov, SEA 238)

Year	Opening Date	Closing Date	Quotas				Allocations	
			Total	Pups	Female	Male	Norway	Soviet and Russian
Hooded Seals								
1985	22 March	5 May	(20 000)[2]	(20 000)[2]	03	Unlim.	8000[4]	3300
1986	18 March	5 May	9300	9300	03	Unlim.	6000	3300
1987	18 March	5 May	20 000	20 000	03	Unlim.	16 700	3 300
1988	18 March	5 May	(20 000)[2]	(20 000)[2]	03	Unlim.	16 700	5 000
1989	18 March	5 May	30 000	0	03	Incl.	23 100	6900
1990	26 March	30 June	27 500	0	0	Incl.	19 500	8000
1991	26 March	30 June	9000	0	0	Incl.	1000	8000
1992-94	26 March	30 June	9000	0	0	Incl.	1700	7300
1995	26 March	10 July	9000	0	0	Incl.	1700[7]	7300
1996	22 March	10 July	9000[8]				1700	7300
1997	26 March	10 July	9000[9]				6200	2800[11]
1998	22 March	10 July	5000[10]				2200	2800[11]
1999-00	22 March	10 July	11 200[12]				8400	2800[11]
2001-03	22 March	10 July	10 300[12]				10 300	
2004-05	22 March	10 July	5600[12]				5600	
2006	22 March	10 July	4000				4000	
2007-2019			0	0	0	0	0	0
Harp Seals								
1985	10 April	5 May	(25 000)[2]	(25 000)[2]	0[5]	0[5]	7000	4500
1986	22 March	5 May	11 500	11 500	0[5]	0[5]	7000	4500
1987	18 March	5 May	25 000	25 000	0[5]	0[5]	20 500	4500
1988	10 April	5 May	28 000	0[5,6]	0[5,6]	0[5,6]	21 000	7000

1989	18 March	5 May	16 000	-	0[5]	05	12 000	9000
1990	10 April	20 May	7200	0	0[5]	05	5400	1800
1991	10 April	31 May	7200	0	0[5]	05	5400	1800
1992-93	10 April	31 May	10 900	0	0[5]	05	8400	2500
1994	10 April	31 May	13 100	0	0[5]	05	10 600	2500
1995	10 April	31 May	13 100	0	0[5]	05	10 600[7]	2500
1996	10 April	31 May[8]	13 100[9]				10 600	2500[11]
1997-98	10 April	31 May	13 100[10]				10 600	2500[11]
1999-00	10 April	31 May	17 500[13]				15 000	2500[11]
2001-05	10 April	31 May	15 000[13]				15 000	0
2006-07	10 April	31 May	31 200[13]				31 200	0
2008	5 April	31 May	31 200[13]				31 200	0
2009	10 April	31 May	40 000				40 000	0
2010	10 April	31 May	42 000				42 000	0
2011	10 April	31 May	42 000				42 000	0
2012-13	10 April	31 May	25 000				25 000	0
2014-16	10 April	31 May	21 270				21 270	0
2017-19	10 April	31 May	26 000				26 000	0

[1] Other regulations include: Prescriptions for date for departure Norwegian port; only one trip per season; licensing; killing methods; and inspection.

2 Basis for allocation of USSR quota.

3 Breeding females protected; two pups deducted from quota for each female taken for safety reasons.

4 Adult males only.

5 1 year+ seals protected until 9 April; pup quota may be filled by 1 year+ after 10 April.

6 Any age or sex group.

7 Included 750 weaned pups under permit for scientific purposes.

8 Pups allowed to be taken from 26 March to 5 May.

9 Half the quota could be taken as weaned pups, where two pups equalled one 1+ animal.

10 The whole quota could be taken as weaned pups, where two pups equalled one 1+ animal.

11 Russian allocation reverted to Norway.

12 Quota given in 1+ animals, parts of or the whole quota could be taken as weaned pups, where 1,5 pups equalled one 1+ animal.

13 Quota given in 1+ animals, parts of or the whole quota could be taken as weaned pups, where 2 pups equalled one 1+ animal.

14 Hooded seals protected, only small takes for scientific purposes allowed.

Table 2. Summary of sealing regulations for the White and Barents Seas ("East Ice"), 1979–2016.[1]

Year	Opening Dates		Closing Date	Quota-Allocation		
	Soviet/Rus.	Norway		Total	Soviet/Rus.	Norway
1979–80	1 March	23 March	30 April3	50 000[4]	34 000	16 000
1981	-	-	-	60 000	42 500	17 500
1982	-	-	-	75 000	57 500	17 500
1983	-	-	-	82 000	64 000	18 000
1984	-	-	-	80 000	62 000	18 000
1985-86	-	-	-	80 000	61 000	19 000
1987	-	-	20 April3	80 000	61 000	19 000
1988	-	-	-	70 000	53 400	16 600
1989–94	-	-	-	40 000	30 500	9500
1995	-	-	-	40 000	31 250	8750[5]
1996	-	-	-	40 000	30 500	9500
1997-98	-	-	-	40 000	35 000	5000
1999	-	-	-	21 400[6]	16 400	5000
2000	27 February	-	-	27 700[6]	22 700	5000
2001-02	-	-	-	53 000[6]	48 000	5000
2003	-	-	-	53 000[6]	43 000	10 000
2004-05				45 100[6]	35 100	10 000
2006	-	-	-	78 200[6]	68 200	10 000
2007	-	-	-	78 200[6]	63 200	15 000
2008	-	-	-	55 100[6]	45 100	10 000
2009	-	-	-	35 000	28 000[7]	7000
2010				7000	0	7000
2011				7000	0	7000
2012-13				7000	0	7000

Year	Opening Dates		Closing Date	Quota-Allocation		
	Soviet/Rus.	Norway		Total	Soviet/Rus.	Norway
2014				7000	0	7000
2015-16				19 200	12 200	7000
2017-19				10 090	3 090	7000

1 Quotas and other regulations prior to 1979 are reviewed by Benjaminsen (1979).

2 Hooded, bearded and ringed seals protected from catches by ships.

3 The closing date may be postponed until 10 May if necessitated by weather or ice conditions.

4 Breeding females protected (all years).

5 Included 750 weaned pups under permit for scientific purposes.

6 Quotas given in 1+ animals, parts of or the whole quota could be taken as pups, where 2,5 pups equalled one 1+ animal

7 Quota initially set at 28 000 animals, but then was reconsidered and set to 0.

Table 3. Major management measures implemented for harp seals in Canadian waters, 1961–2019.

Year	Management Measure
1961	Opening and closing dates set for the Gulf of the St. Lawrence and Front areas.
1964	First licensing of sealing vessels and aircraft. Quota of 50 000 set for southern Gulf (effective 1965).
1965	Prohibition on killing adult seals in breeding or nursery areas. Introduction of licensing of sealers. Introduction of regulations defining killing methods.
1966	Amendments to licensing. Gulf quota areas extended. Rigid definition of killing methods.
1971	TAC for large vessels set at 200 000 and an allowance of 45 000 for landsmen.
1972–1975	TAC reduced to 150 000, including 120 000 for large vessel and 30 000 (unregulated) for landsmen. Large vessel hunt in the Gulf prohibited.
1976	TAC was reduced to 127 000.
1977	TAC increased to 170 000 for Canadian waters, including an allowance of 10 000 for northern native peoples and a quota of 63 000 for landsmen (includes various suballocations throughout the Gulf of St. Lawrence and northeastern Newfoundland). Adults limited to 5% of total large vessel catch.
1978–1979	TAC held at 170 000 for Canadian waters. An additional allowance of 10 000 for the northern native peoples (mainly Greenland).
1980	TAC remained at 170 000 for Canadian waters including an allowance of 1800 for the Canadian Arctic. Greenland was allocated additional 10 000.
1981	TAC remained at 170 000 for Canadian waters including 1800 for the Canadian Arctic. An additional allowance of 13 000 for Greenland.
1982–1987	TAC increased to 186 000 for Canadian waters including increased allowance to northern native people of 11 000. Greenland catch anticipated at 13 000.
1987	Change in Seal Management Policy to prohibit the commercial hunting of whitecoats and hunting from large (>65 ft) vessels (effective 1988). Changes implemented by a condition of licence.
1992	First Seal Management Plan implemented.
1993	Seal Protection Regulations updated and incorporated in the Marine Mammal Regulations. The commercial sale of whitecoats prohibited under the Regulations. Netting of seals south of 54°N prohibited. Other changes to define killing methods, control interference with the hunt and remove old restrictions.
1995	Personal sealing licences allowed. TAC remained at 186 000 including personal catches. Quota divided among Gulf, Front and unallocated reserve.
1996	TAC increased to 250 000 including allocations of 2000 for personal use and 2000 for Canadian Arctic.
1997	TAC increased to 275 000 for Canadian waters.
2000	Taking of whitecoats prohibited by condition of license
2003	Implementation of 3 year management plan allowing a total harvest of 975 000 over 3 years with a maximum of 350 000 in any one year.
2005	TAC reduced to 319 517 in final year of 3-year management plan
2006	TAC increased to 335 000 including a 325 000 commercial quota, 6000 original initiative, and 2000 allocation each for Personal Use and Arctic catches
2007	TAC reduced to 270 000 including 263 140 for commercial, 4860 for Aboriginal, and 2000 for Personal Use catches

Year	Management Measure
2008	TAC increased to 275 000 including a 268 050 for commercial, 4950 for Aboriginal and 2000 for Personal Use catches Implementation of requirement to bleed before skinning as a condition of licence
2009	TAC increased to 280 000 based upon allocations given in 2008 plus an additional 5000 for market development Additional requirements related to humane killing methods were implemented
2010	TAC increased to 330 000.
2011	TAC increased to 400 000.
2017	TAC no longer announced. Catches monitored

Table 4. Major management measures implemented for hooded seals in Canadian waters for 1964–2019.

Year	Management Measure
1964	Hunting of hooded seals banned in the Gulf area (below 50°N), effective 1965.
1966	ICNAF assumed responsibility for management advice for Northwest Atlantic.
1968	Open season defined (12 March–15 April).
1974–1975	TAC set at 15 000 for Canadian waters. Opening and closing dates set (20 March–24 April).
1976	TAC held at 15 000 for Canadian waters. Opening delayed to 22 March. Shooting banned between 23:00 and 10:00 GMT from opening until 31 March and between 24:00 and 09:00 GMT thereafter (to limit loss of wounded animals).
1977	TAC maintained at 15 000 for Canadian waters. Shooting of animals in water prohibited (to reduce loss due to sinking). Number of adult females limited to 10% of total catch.
1978	TAC remained at 15 000 for Canadian waters. Number of adult females limited to 7.5% of total catch.
1979–1982	TAC maintained at 15 000. Catch of adult females reduced to 5% of total catch.
1983	TAC reduced to 12 000 for Canadian waters. Previous conservation measures retained.
1984–1990	TAC reduced to 2340 for Canadian waters.
1987	Change in Seal Management Policy to prohibit the commercial hunting of bluebacks and hunting from large (>65 ft) vessels (effective 1988). Changes implemented by a condition of licence.
1991–1992	TAC raised to 15 000.
1992	First Seal Management Plan implemented.
1993	TAC reduced to 8000. Seal Protection Regulations updated and incorporated in the Marine Mammal Regulations. The commercial sale of bluebacks prohibited under the Regulations.
1995	Personal sealing licences allowed (adult pelage only).
1998	TAC increased to 10 000.
2000	Taking of bluebacks prohibited by condition of license.
2007	TAC reduced to 8200 under Objective Based Fisheries Management based on 2006 assessment.
2008	Implementation of requirement to bleed before skinning as a condition of license.
2009	Additional requirements implemented to ensure humane killing methods are used.
2017	TAC no longer announced. Catches monitored.

Annex 9: Report from the Review Group for the ICES WGHARP REPORT 2019

(Norwegian request)
Participants: Sinéad Murphy (Chair), Don Bowen and Cornelia den Heyer

Review group participants worked both via correspondence and using a web conferencing platform.

14 October 2019

The Review Group considered the following stocks:

- Harp seal Greenland Sea
- Harp seal White Sea/Barents Sea
- Hooded Seal Greenland Sea

And the following special requests:

- Assess the status and harvest potential of the three stocks

Especially assess the impact of

1. current harvest levels,
2. sustainable catches (defined as the fixed annual catches that stabilizes the future 1 + population),
3. catches that would reduce the population over a 15-years period in such a manner that it would remain above a level of 70% of the maximum population size, determined from population modelling, with 80% probability.

General Comments

We commend the efforts of the Working Group in undertaking this task and producing the report. As these species are data-poor, it is no-mean-feat to work with limited data with large variances, using a model that must assume many key parameters. To enable the WG to continue in their efforts, it is highly recommended that systematic estimates of pup production counts and reproductive rates are obtained and where possible, variances/random error in those estimates improved as this led to wide 95% CIs for some datasets. Further, environmental variables should be incorporated into the operating model to account for possible variations in body conditions that may explain reproductive rates. Currently, catch data do not contain information on the age composition of the catches in the 1+ year group. Such information is required as currently it is assumed that the catches of 1+ are proportional to the 1+ age structure. As shown in Table 2 in Annex 7, the proportion of harp seal pups caught in Barents Sea / White Sea in 2018 and 2019 varied from 0.9 to 6.00%. Whereas between in 1956 and 2003 more pups than adults were caught on an annual basis (where data were available). If age cannot be determined for the 1+ individuals, information on sex and length may also be valuable.

Other unknown parameters include pup mortality rates and 1+ mortality rates, which are currently estimated by the model, though priors are assumed. We are currently in a period where the Arctic environment is changing, with years of poor sea ice disrupting breeding habitat. For example, it was noted in the WG report (page 17) that it is unknown if the poor sea ice conditions reported during the late whelping period in 2019 increased pup mortality in the Barents Sea / White Sea stock. Further, in the Greenland Sea, observed ice reductions over the last number of years has changed the harp seal breeding habitat (pages 10-11). As mortality rates are unknown, a conservative approach should be applied when interpreting model outputs, including estimations of population size.

The operating model that is currently employed is a deterministic age-structured population dynamics model with 3 unknown parameters which are assumed to be constant (pup mortality, mortality of 1 year and older seals, initial population size). Since the model is fit to the time series of pup production, the last pup survey should not be more than 5-years old for a data-rich species as outlined by WGHARP (2005). The proportion of mature females that are pregnant at a given year (as a proxy for the fecundity rate) is included in the model as a known quantity and no uncertainty. For years where no data on the pregnancy rate, a linear interpolation between two estimates is the base model. The RG recommends exploring using a long-term average for estimations of the fecundity/pregnancy rate in all cases. While this does not allow the fecundity rate to vary/fluctuate within the model, it may offset any sampling basis where spatial clustering of reproductive classes is a concern - and the relatively small fraction of the population size that is sampled for assessment of biological parameters.

Various approaches for improving the model or developing an alternative (such as a space-state model that includes fecundity as a stochastic process) have been discussed within WG. We recommend that approaches to improving the model fit be undertaken before the next WGHARP meeting and/or alternatives explored.

Developing and enhancing the operating model will only go so far, models are always limited by the available data. The WG has noted throughout the report the degree of uncertainty in various datasets and parameter estimates, and the need for reliable data, particularly on vital rates.

The PBR framework also has limitations and it is recommended that population size estimates not more than 8-years old should be used (Wade & Angliss 1997). While the PBR approach takes a degree of uncertainty of the population abundance estimate into account, by using the minimum estimated population size (usually calculated as the 20-percentile of the lognormal distribution around the estimate of N), the allowable catch is still largely dependent on the actual estimate of population size. However as detailed below, the WG identified some issues with the CV determined by the operating model for the Barents Sea / White Sea harp seal stock, which may have an impact on the PBR catch quota.

In some areas of the report, further information from the working papers should be incorporated, some of those areas have been highlighted below - the RG sought clarification from the working papers submitted to the WG. Further, a full description of the precautionary approach framework as outlined by WGHARP (2005) should be included as an annex in all future reports. As well as include information on how the operating model and the PBR Framework ensure delivery of stated aims.

For single-stock summary sheet advice:

The Barents Sea/White Sea Harp Seal Stock

1) *Assessment type:* Population status assessed by modelling

2) *Assessment:* Historical abundance, reference levels, potential for catches

3) *Forecast:* Population forecast from model

4) *Assessment model:* Bayesian model fitting to data on pup production. Reproductive data assumed known and input to model. Initial population size, pup mortality, and 1+ mortality (assumed constant) unknown and estimated by model, with priors assumed.

5) *Consistency:* Change in management approach to use the PBR method for setting TAC; updated mortalities to include seal invasions during 1980s and 1990s; no new estimate of pup production but recent reproductive data from 2018 available.

6) *Stock status:* Based on the operating population dynamics model, estimated around 1.7 M in 1940s and declined to around 1.5 M. A decline in pup production estimates has been observed since 2003, from 328,000 (CV = 0.181) pups to 128,786 (CV = 0.237) pups in 2013. Stock is data-poor; no pup production estimates available since 2013.

7) *Management Plan.:* The annual historical hunt has been, on average, 68 000 seals in the 1980s, which declined to about 38 000, on average, between 1990 and 2003. Since 2009, catches rates in the 100s with the exception of 2018, where 2 241 (mostly adults) taken. The PBR approach produced a TAC of 21 172 seals irrespective of age, based on a recovery factor of 0.25 – a lower recovery factor was used by the WG given the uncertainty of the status of the population. This is higher than the quota advised by ICES in 2016, of 10 090 1+ seals (where two pups balanced one 1+ animal) for the period 2017-19. The higher catch rate using the PBR method is driven by a high fecundity/pregnancy rate estimate of 0.91 for the year 2018, and relatively low catch levels com-pared to previous years. These data alone led to a substantial increase in the population size estimate.

Brief Summary

The operating model estimated a 2019 abundance of 1 276 900 (1 100 264–1 453 500) 1+ animals and 220 291 (191 193–249 389) pups, yielding a total estimate of 1 497 190 (1 292 939–1 701 440) harp seals in the Barents Sea / White Sea. A decline in pup production estimates has been observed since 2003, from 328,000 (CV = 0.181) pups to 128,786 (CV = 0.237) pups in 2013. The proportion of harp seal pups caught in Barents Sea /White Sea in 2018 and 2019 varied from 0.9 to 6.0%. Whereas between in 1956 and 2003 more pups than adults were caught on an annual basis where data were available (see Table 2 Annex 7).

General Comment

This stock is data poor. The last pup survey was undertaken in 2013 (> 5 years). The current model fit to the pup production estimates is poor. The current assessment model was not able to capture the dynamics of the survey pup production estimates, including the decline in pup production that occurred from 2003 to 2005. Further, the model does not appear to capture the apparent decrease in the most recent pup production estimate from 2013 – the confidence interval of the 2013 pup production estimate falls outside the confidence interval of the operating model (Figure 2.5b).

A new fecundity/pregnancy estimate obtained in 2018 indicated higher reproductive rates. Though this estimate was not able to account for any potential late-term abortions, which have been reported to occur in this species. Some issues with spatial clustering of reproductive classes was reported which may affect estimates of MAM, which requires further investigation. It is unknown what effects poor sea ice conditions during the late whelping period had on pup mortality rates in 2019.

As outlined earlier, The RG recommends exploring using a long-term average for estimations of the fecundity/pregnancy rate. The WG attempted to include environmental forcing in the model, which in principle is to be recommended. However, the lack of data on harp seal vital rates will severely hamper such efforts as it will not be possible to determine with any confidence the functional relationships between variation in say capelin abundance and the biological response of the population. Without this functional link this effort will be problematic.

The advice on catch levels used the PBR approach with a recovery factor of 0.25. The resulting PBR catch estimate using this conservative recovery factor is twice the TAC advised by ICES in 2016. The CV from the most recent abundance estimate of Barents Sea / White Sea harp seal stock was low (i.e. a high precision at 0.07). However, WP SEA 251 deemed that the 'uncertainty of the current management model is underestimated. Because of this a CV of 0.07 is likely to be too low. Increasing the CV when calculating the PBR catch level, i.e., increasing the uncertainty about the model estimate of the 2019 abundance, will lower the PBR catch quota.' It would be prudent to employ the 2:1 ratio for pup : 1+adults, to take account of the cost of the hunt to adult, and considering the lack a new pup production estimate, a decline in pup production, unknown pup mortality, changing sea ice conditions, uncertainty in the CV of the population estimate.

Technical Comments

Population assessment

Pup production and population model

As noted by the working group, this is another data-poor population. The early dynamics produced by the model must be driven by catches alone as there are no data on maturity, fecundity or pup production during this early period. The decline in pup production of about 200,00 pups in just two years in the early 2000s was presumably driven by changes in food, as noted. But given the lack of data on biological parameters there is no way to test this hypothesis.

Despite the poor fit to the data, the working group is forced to use the estimate of current population size from the poorly fitting model. The report states that "From 2007 to the present the model indicates an increase in population size, but this is inconsistent with the dramatic reduc-tion in observed pup production. Despite this inconsistency, the estimate of current abundance appears to be relatively realistic, given the reasonably good fit between estimated pup produc-tion during the most recent survey." From the data in the report, how did the working group come to this conclusion as the most recent estimates of pup production falls outside to the con-fidence intervals provided by the model. This would suggest that the model is overestimating population size.

The range of abundance estimates for harp seals in the Barents Sea / White Sea in WP SEA251 is different (1 338 284 (1 151 921 – 1 524 647) 1+ animals and 253 461 (220 347 – 286 575) pups, yielding a total estimate of 1 591 745 (1 373 695 – 1 809 794) seals) to that reported in the 2019 WGHARP report (The model estimates a 2019 abundance of 1 276 900 (1 100 264–1 453 500) 1+ animals and 220 291 (191 193–249 389) pups, yielding a total estimate of 1 497 190 (1 292 939–1

701 440) seals). What changed since the WG SEA paper was submitted? Are these differences due to incorporation of additional mortality data during the seal invasions during the 1980s and 1990s (see page 22 of WGHARP report).

Reproductive data

Due to a scarcity of historical data on fecundity rates, the model assumed that for the period before 1984, the fecundity/pregnancy rate was constant. While, the model uses the average of historical fecundity rates/pregnancy rates to predict population trends over the next 15 years. The high fecundity rate documented in 2018 (0.91) in WP SEA252 had a significant impact on the projected population trends. This increased the average estimate of historical fecundity rate from 0.76, which was reported in the 2016 WGHARP report, to 0.827 in the current report.

The fecundity rate is estimated from females that were caught within a few weeks or months of the breeding season (during the moulting season which for the 2018 data ranged from 20 April to 13 May for sampled individuals) for the presence or absence of a large partially luteinized Corpus albicans (i.e. a regressing Corpus luteum (CL)). Thus, the pregnancy rate estimate is based on whether a female recently possessed a Corpus luteum, and not on whether they were currently pregnant. Based on this methodology and as outlined by RGHARP in 2016, this may have overestimated pup production. As unsuccessful breeding females that may have just ovulated during the recent breeding season (and also possessed a recent CL), would also present with a LCA on their ovaries. Further, not all females that were sampled may have successfully carried pups to term, and the current assessment is unable to account for the possibility of late term abortions. As outlined for the North-west Atlantic harp seal, late term abortions occur in the species, which were found to be strongly correlated to body condition, i.e. females needed to maintain a certain body condition to carry the pup to term – and body condition was related to capelin biomass and midwinter ice cover (page 25 of the 2019 WGHARP report).

The Mean Age at Maturity (MAM) for Barents Sea/White Sea harp seals was estimated at 6.9±0.9 years for 168 females collected during the 2018 moulting period in the southern Barents Sea (WP SEA 252). While it was noted that this estimate was not significantly different compared to the 2006 estimate, quite large changes in reproductive parameters may have to occur between sampling periods, and large sample sizes are required, before statistically significant changes are detected in pregnancy rates (Murphy et al. 2009). Thus, changes will become biologically significant, before they can be detected statistically. It has been noted in the report that the current estimate for MAM is high compared to other geographic regions, and this may be due to the lack of first time ovulators (i.e. only had a fresh CL and no CA) - which may have increased the estimate. It was discussed this may be due to spatial clustering of reproductive classes. Although it was deemed that spatial clustering did not have an impact on pregnancy rate estimates, if there is a lack of first time ovulators, which could comprise females who do not successfully conceive or carry their foetus to term, this would have an impact on the overall pregnancy rate estimate. Does the pregnancy rate vary with age? An age-specific pregnancy table (akin to Table 2.5 but with sample sizes) should also be produced for the different time periods, so data can be assessed.

While the MAM approach determined an estimate of 6.9 years for 2018, the maturity ogive in the operating model, determining the proportion when 50% of females mature (Figure 2.4), estimated that sexual maturity in 2018 was attained at a younger age – approximately just under 5 years in age. Estimates of maturity ogives for the different time periods should be provided in a table, with their uncertainty.

The youngest mature female ranged from 3 years for the period 1976-1985 to 5 years in 2018 (Table 2.5). To better interpret these data, information on number and total sample size should be included for each cell – to assess the sampling effort for each year class across the time periods. Definitions of periods should also be included.

Table 2.6 high pregnancy rates with low variation between samples. 2006 has only low estimate. Linear interpolation method gives a lot of weight to that low estimate in 2006. Is this justified by sample size? Sample sizes should be included in table. Discussion of non-random sampling and bias useful but not clear how impacts the evaluation of the maturity schedule.

Catch Scenarios

As the working group notes, given the poor fit of the population model and the lack of current information on pup production, setting the recovery factor at 0.25 for the calculation of PBR is appropriate.

Additional comments

Page 21. Useful to add header for 'Population model' right before the estimates are reported.

For single-stock summary sheet advice:

Greenland Sea Harp Seal Stock

1) Assessment type: Population status assessed by modelling

2) Assessment: Historical abundance, reference levels, potential for catches

3) Forecast: Population forecast from model

4) Assessment model: Bayesian model fitting to data on pup production. Reproductive data assumed known and input to model. Initial population size, pup mortality, and 1+ mortality (assumed constant) unknown and estimated by model, with priors assumed.

5) Consistency: Change in management approach to use the PBR method for setting TAC.

6) Stock status: The model suggests a decline prior to the 1970s from around 400 000 – 600 000 seals (depending on the model run), constant or increasing since the 1970s, at about 400 000 seals. Data from aerial surveys suggests a decline in pup production since 2007, from 110 530 pups to 54 181 pups in 2018. The most recent pup estimate is for 2018 and reproductive rate data are available from 2014.

7) Management Plan.: The historical hunt during the 1980s was, on average, 9 200 seals, which declined to around 5 300 seals, on average, during the 1990s. Since the 2000s, annual catch rates ranged between 1 232 – 16 033 seals. In most years, more pups than adults were taken, excluding a period during the late 80s-early 90s. The PBR approach, using an average of model run scenarios, produced a TAC of 11 548 seals irrespective of age, based on a recovery factor of 0.5.

Brief Summary

The model estimated an abundance for 2019 of 360 400 (95% CI : 258 245–462 556) 1+ seals and 66 407 (95% CI : 51 605–81 209)(rounded to nearest 100) pups. The total estimate is 426 808 (95%

CI : 313 005–540 612) seals. Due to uncertainties in the reliability of some of the reproductive parameters, as well as uncertainties in earlier mark-recapture studies which led to the model not accurately fitting to the pup production estimates, a further two model scenarios were assessed. The WG proposed using the average of all three estimates, which produced an estimate of 433,871 (CV=0.143) harp seals, for assessing catch scenarios. The 2018 pup production estimate was significantly lower than the previous survey estimate from 2012 of 89 590 (95% CI = 68 578–117 040) individuals, which was inconsistent with the model, which predicted an increasing pup population.

General Comments

The model was not able to fit pup production estimates, from either the mark-recapture or the aerial surveys. The WG identified several issues with the historical mark-recapture based estimates and recommends reanalysis of these data. The WG raised concerns regarding the reliability of some of the reproductive parameters. There may be inter-annual variability in reproductive rates that is not being captured in the sparse sampling but the possibility that the decline in pup production could result from changes in survival and reduced total abundance cannot be ruled out.

As stated by the WG 'Given the apparent significant drop in pup production between the 2012 and 2018 surveys, the unexplained variability of the M-R estimates, the poor fit of the model to all historical pup production estimates and the subsequent uncertainty regarding model-based trajectories and projections, the consensus in the WG was that management recommendations for this population should not be based on model projections at this stage'. An 'average' abundance estimate was determined using the operating model. The three scenarios addressed in the report understandingly provide similar population estimates, given the similar distributions of pup production estimates being fitted. Nevertheless, for completeness as forth scenario might have been considered – all pup production estimates and averaged maturities at age and fecundity.

The PBR Framework was employed to determine catch scenarios, with a default recovery factor of 0.5. This estimated a catch of 11 548 seals, irrespective of age class. The catch estimate is lower than the 2016 estimate (26 000 1+ animal) determined using the operating model. The PBR TAC is approximately 2-3 times higher than catch rates since 2015. As outlined earlier, it would be prudent to employ the 2:1 ratio for pup: adults, to take account of the cost of the hunt to adults, and considering pup production estimates suggest a relative decline since 2007, and the observed ice reductions in the region.

Technical Comments

2.1.2.1 Information on recent catches and regulatory measures

With respect to bycatch, it is stated "In any case, this source of mortality is incorporated into the model estimate of mortality." To be clear, does this mean that any minimal bycatch is accounted for in the estimate of natural mortality?

A further statement/comment would be useful with respect to interpreting reduced catch rates in recent years. To make that clear to the reader, the WG should add a statement along the lines of 'Reduced catch rates result from changes in harvest effort and do not reflect changes in stock abundance or availability.'

2.1.2.3 Current research

In the discussion of automated reading of photographs, the report would be more useful to the reader if numbers could be provided rather than qualitative statements such as "misses only a few of the harps, and only output a limited number of false positives". Similarly, "results for hooded seals are not as good as several hooded seals are misclassified as harp seals".

With respect to the research on harp seal migration, most readers will not find "a spatio-temporal log Gaussian Cox process model fitted using Inverse Nested Laplace Approximation" informative. Rather "This Bayesian model accurately captures the migratory behaviour of the three breeding populations." seems to provide the essential information. Also, with respect to this sentence, it would be more accurate to state that the model "reproduces the observed migratory behaviour of the 80 individuals modelled among the three populations."

2.1.2.4 Biological parameters

Pup production

Further details on the pup staging survey would be helpful and should be included in the report. Additional information was sought from the working papers by the RG (as follows), and similar text should also be included in the main text of the report. 'Due to weather conditions, photographic survey of the whelping areas in 2018 had to be undertaken over two days, 27th and 28th March, and datasets were combined using a number of different approaches, which includes ….. (WP SEA 247). Due to restricted ship time only one staging bout was undertaken on the 21st March, and animals were staged based on pelage colour and condition, overall appearance and muscular coordination (Biuw et al. Nr. 7-2018). During this staging bout a high proportion of thin pups were observed which suggests this date represented a relatively early stage of the pupping period (Biuw et al. Nr. 7-2018). The estimate of the number of pups on the sea ice during the photographic survey in 2018 was 0.98.

Very little information is provided with respect to the mark-recapture estimates. Given the recommendation to re-analyse these data a few words to identify the main concerns with the previous analysis would be appropriate (See page 14 for critique of the MR violation of assumption of homogeneity in recapture and possibility of temporary emigration (Oien and Oritsland 1995)). Many advances in MR methods which can address these.

Population estimate

What data exists is fraught with large interannual variation, much of which is likely measurement error as this is a difficult species to sample. Thus, the stock is data poor.

The temporal sequence of maturity ogives is difficult to interpret with respect to presumed changes in population size. There has been variation but little sign of trend in fecundity. The decision of the working group to average all the data for these two parameters seems the best option but may not lead to better understanding of the dynamics.

There is considerable discussion of the large interannual variation in pup production estimates. Although such variation is biologically possible if fecundity were to also have large variation, this does not appear to be the case here. Particular attention is given to the mark-recapture estimates which differ by a factor of two between adjacent years. This led the working group to suggest using only the aerial surveys. But these too vary by a factor of two among years, although not as dramatically. Here again, the lack of variation in fecundity would suggest this too is largely measurement error and not reflective of dynamics.

Given the poor fits of the population model, the use of PBR is a reasonable approach. The only concern is that uncertainty about the current estimate of population size is likely being underestimated as not all sources of uncertainty were included in the population model and therefore the estimate of Nlim may be overestimated. However, there is not much that can be done about this, expect to acknowledge this likelihood. To a degree, this has been done in setting the recovery factor at 0.5.

Catches are assigned to pups and 1+, for 1+ the age distribution is assumed to be proportional to population. The age distribution of the catches are strong assumption and any information to support/test would be valuable. Tables of catches in the Annexes are helpful but it is very useful to see plots of catches for both pup and 1+.

Fig. 2.3 the second column is not overly informative. The different scales on y-axis for total population size does not support argument that there is consistency in model fits but careful inspection does suggest overlap. Might be better to plot all three models on one plot of total population and another of pup production. Also, it would be useful to indicate different methods with different symbols.

Reproductive data

Actual estimates of the age at 50% maturity should be presented in the report with their uncertainty – shown graphically in Figure 2.2. While, sexual maturity was determined to be attained at an older age for the 2009 dataset, harp seals appeared to attain sexual maturity at a younger age in 2014. In general, the fecundity/ pregnancy rates were much higher than those reported in the Barents Sea / White Sea stock and ranged from 78% to 91% during 1964 to 2014, which a higher rate of 91% reported in 2014. An increase in the pregnancy rate and a decline in the age at maturity is suggestive of a density dependent compensatory response, though this is based on limited data. Biological samples were obtained in 2019, but these still have to be processed. Information on how the MAM and fecundity rate were estimated was not provided. It is assumed to be similar to Barents Sea / White Sea stock and thus comments relating to those methodologies on assessment of biological parameters are also pertinent here.

There is no information on sample sizes in Table 2.1, which makes it difficult to evaluate the importance of zeros in ages 3 and 4 in P2 (2009) and P3 (2014). It would be more intuitive to just report the time periods (1959-1990, 2009, 2014) instead of P1, P2, P3. In Table 2.2, again information on sample size and timing of sample collection are important to evaluate application.

For single-stock summary sheet advice:

The Greenland Sea Hooded Seal Stock

1) *Assessment type:* Population status assessed by modelling

2) *Assessment:* Historical abundance, reference levels, potential for catches

3) *Forecast:* Population forecast from model

4) *Assessment model:* Bayesian model fitting to data on pup production. Reproductive data assumed known and input to model. Initial population size, pup mortality, and 1+ mortality (assumed constant) unknown and estimated by model, with priors assumed.

5) *Consistency:* Model used for scientific advice

6) Stock status: Declining. Based on the model, hooded seals have undergone a dramatic decline during the last 70 years from about 1 M to less than 80 000 seals. Current estimates of pup production show a continued decline.

*7) Management Plan.: T*he historical hunt was more than 20 000 annually in early 70s and then dropped to around 180 - 8 500 annually between 1989 and up to 2006, thereafter a sharp drop in catches has occurred and in the last 9 years about 20 seals are hunted annually. The WG suggests no further hunting on this stock and the RG agree with this conclusion.

Brief Summary

The estimated total population of hooded seals in the Greenland Sea is 76 623 (95%CI: 58 299–94 947) seals. In the 1950s the population is estimated to have been around 1 M (Figure 2.6), and 'all model runs indicate a substantial decrease in the population abundance from the late 1940s until the early 1980s'. Estimated pup production was about 12 977 (CV = 0.140) in 2018 and 23 000 (CV = 0.192) in 1997.

General Comments

The operating population dynamics model did appear to fit the pup production data well. The trajectory of the model is a continued decline and the population is well below historical levels that supported high commercial catches. The WG recommended following the precautionary approach framework and that no commercial catches should be taken as all models runs indicated a population currently well below N_{lim} (30% of largest observed population size). While there is large variability in the pup production estimates, it should be highlighted that even with the low harvest levels during the last 9 years, the model is projecting a continued decline, with no indication of recovery.

Technical Comments

2.2.1.2 New Research

Pup production - In discussing the estimates of pup production since 2005, it would be more appropriate to note that, given the uncertainty about each estimate, there is no evidence of the trend over the period 2005 to 2018. The current text suggests a declining trend.

2.2.1.3 Biological parameters

Further clarification on the text/approach undertaken is required. The decision on what estimate to use for fecundity should be based on the data and not what other working group reports decided. The reader will want to know that 0.7 is supported by the available data.

Maturity ogive estimates and a corresponding figure of maturity curves were not provided for reference. It is unknown if the age at 50% maturity varied over the time period, and if a fixed estimate was used if data were poor. In Table 2.11, years sampled, and sample sizes for each age group and time period, should be included.

2.2.1.4 Population Assessment

It would be useful to note that in this case, although it is clear from Figure 2.6, the population model fits the data quite well and so the conclusion with respect to N30 is robust.

References

Biuw, M., Nilssen, K.T., Haug, T., and G. Stenson. Report from surveys to assess harp and good seal pup production in the Greenland Sea Pack-Ice in 2018. Toktrapport / Havforskningsinstituttet / ISSN 15036294/ Nr. 7–2018.

Murphy, S., Winship, A., Dabin, W., Jepson, P.D., Deaville, R., Reid, R.J., Spurrier, C., Rogan, E., López, A., González, A.F., Read, F.L., Addink, M., Silva, M., Ridoux, V., Learmonth, J.A., Pierce, G.J., and Northridge, S.P. (2009). Importance of biological parameters in assessing the status of Delphinus delphis. Marine Ecology Progress Series 388, 273-291.

Øien, N., and Øritsland, T. 1995. Use of mark-recapture experiments to monitor seal populations subject to catching. In Whales, Seals, Fish and Man. Elsivier Science B. V., Amsterdam, pp. 35-45.

Wade, P.R., and Angliss, R.P. (1997). Guidelines for assessing marine mammals stocks: Report of the GAMMS workshop. April 3 – 4, 1996. NOAA Technical Memorandum NMFS-OPR-12. 93pp.

WP SEA247 Biuw, M., T.A. Øigård, K.T. Nilssen, G. Stenson, L. Lindblom, M. Poltermann, M. Kristianssen, and T. Haug. Estimation of pup production of harp and hooded seals in the Greenland Sea in 2018.

WP SEA251 Biuw M., A.K., Frie, M. Kristiansen, M Pol-termann, T.A, Øigård and T. Haug. The 2019 abundance of harp seals (Pagophilus groenlandicus) in the Barents Sea / White Sea.

WP SEA252. Frie, A.K. A 2018 update and reassessment of reproductive parameters of Northeast Atlantic harp seals (Pagophilus groenlandicus)

Annex 10: Clarifications from experts to reviewers' comments

Page 1

"Further, environmental variables should be incorporated into the operating model to account for possible variations in body conditions that may explain reproductive rates."

This was discussed extensively during the meeting, and identified as a high priority. While work on this has now been initiated, one word of caution is warranted: While this approach is appropriate for fitting the model to historical and present data, it will be challenging to use such a model to project trends into the future, unless reliable forecasts of changes in environment/fish stocks are available. While work is underway to develop such predictions, also for ecosystem parameters, these predictions will be highly uncertain for the foreseeable future. Care will have to be exercised when assessing future population trends given different catch scenarios.

Page 2

"Such information is required as currently it is assumed that the catches of 1+ are proportional to the 1+ age structure."

Data on age-specific catches would undoubtedly be valuable, but given the fact that we will not be able to recreate historical information on age structure in the catch, it is a bit unclear how such detailed data will improve overall model performance. Nevertheless, the inclusion of such data in future sample collection will be evaluated.

"a conservative approach should be applied when interpreting model outputs, including estimations of population size."

Agreed, and this is was part of the motivation for switching to PBR, and ice conditions will also be considered in future model development using environmental data as input.

"The RG recommends exploring using a long-term average for estimations of the fecundity/pregnancy rate in all cases."

By 'in all cases' does the review committee mean for all populations? As indicated in WP SEA 248, this was done for Greenland Sea hooded seals, (consistent with practices also followed during WGHARP 2016).

Page 3

"4) Assessment model: Bayesian model fitting to data on pup production."

Strictly speaking, the model is fit by maximum likelihood, and is therefore not a fully Bayesian model. It does, however, have a 'Bayesian flavour', in that priors can be incorporated on some parameters, and the information provided by these priors are assessed by examining their contribution to the overall likelihood of the fitted model.

Page 4

"Some issues with spatial clustering of reproductive classes was reported"

We don't think this spatial clustering was actually reported, but rather it was discussed as a potential source of potential bias, such as the lack of first-time ovulators in the sample.

"It is unknown what effects poor sea ice conditions during the late whelping period had on pup mortality rates in 2019."

We agree that this is unknown. However, there are also no data on pup production in 2019, and since pup mortality is set to be constant throughout the entire time period, it is unclear what this sentence is suggesting.

"However, the lack of data on harp seal vital rates will severely hamper such efforts as it will not be possible to determine with any confidence the functional relationships between variation in say capelin abundance and the biological response of the population. Without this functional link this effort will be problematic."

We don't fully agree with this statement. While we agree that vital rates and, ideally, the causal links between early pregnancy rates > changes in condition > ultimate birth rates under different scenarios of environmental/ecosystem conditions should be examined in detail whenever possible, it is unrealistic to obtain such detailed data for a large sample of animals or at regular intervals. But I think it can be justified to rely on published information on such links (from other populations/species and from assessment of body condition from sampled animals during years of contrasting environmental conditions), to parameterise a model that can then be applied to entire datasets across years of varying data availability. Modelling this within a state-space framework, where sparse data series can be treated as latent variables with occasional data input, is probably the best we could achieve, and is worthwhile attempting.

In an effort to parameterise such models, detailed process studies should also be designed, where state-of-the-art telemetry devices, capable of continuously assessing changes in body condition in relation to spatial distribution and environmental conditions.

Page 5

"But given the lack of data on biological parameters there is no way to test this hypothesis."

It is true that we will not be able to fully test this hypothesis. But we do argue that it is possible to examine correlations between the extensive ecosystem survey data available and changes in pup production. Especially if, as stated above, detailed process studies are carried out to address the causal links on a smaller number of individuals (using intensified sampling, telemetry studies etc.).

" From the data in the report, how did the working group come to this conclusion as the most recent estimates of pup production falls outside to the confidence intervals provided by the model. This would suggest that the model is overestimating population size."

While there is a small overlap between the upper confidence interval of the most recent pup production estimate and the lower CI of the model fit, we agree that we may have misstated this. However, the recommendation given on the following page in the report nevertheless takes the poor fit, and the latest pup production estimate being old, into account. It states: 'Given the lack of updated pup production estimates (>5 years since last survey), and the poor fit of the current model, the WG suggests that a precautionary approach should be taken when recommending catch options.' It further states: 'Given the uncertainty regarding the status of this population, the WG suggests using the most conservative estimate (i.e. using a recovery factor of 0.25) when setting future catch options'. We believe that this adequately compensates for the poor fit and the potential overestimation of pup production and population size.

"What changed since the WG SEA paper was submitted? Are these differences due to incorporation of additional mortality data during the seal invasions during the 1980s and 1990s (see page 22 of WGHARP report)."

Yes, the discrepancy here is due to the inclusion of the mass mortalities associated with the seal invasion years.

"As unsuccessful breeding females that may have just ovulated during the recent breeding season (and also possessed a recent CL), would also present with a LCA on their ovaries.

Not sure, I understand this. I believe, it is generally assumed that ovulated seals retain an active CL up to the general time of implantation even if they have not been fertilized. So, CLs of the new cycle are unlikely to be regressing at the time of moulting…This means that they are unlikely to be classified as an LCA and to cause bias in the estimated postpartum pregnancy rates, as seems to be implied here…But there may certainly be a problem with late term abortions, which may very well result in an LCA.

Page 6

"The Mean Age at Maturity (MAM) for Barents Sea/White Sea harp seals was estimated at 6.9±0.9 years for 168 females collected during the 2018 moulting period in the southern Barents Sea (WP SEA 252). While it was noted that this estimate was not significantly different compared to the 2006 estimate, quite large changes in reproductive parameters may have to occur between sampling periods, and large sample sizes are required, before statistically significant changes are detected in pregnancy rates (Murphy et al. 2009). Thus, changes will become biologically significant, before they can be detected statistically."

There is an error in Table 2.5 and the figure…ogive 2018 is shifted one age class to the left… (Thought we corrected this…)…The nominal difference in MAM (not the same as age at 50% maturity) is only 0.2 years… Double check with Martin Biuw, that none of the other estimates are affected by this error.

"Although it was deemed that spatial clustering did not have an impact on pregnancy rate estimates, if there is a lack of first time ovulators, which could comprise females who do not successfully conceive or carry their foetus to term, this would have an impact on the overall pregnancy rate estimate."

A bit uncertain of what's meant here: A first-time ovulator per definition will never be included in the calculation of pregnancy rates among mature females and thus their presence or absence will not affect this estimate…but of course, through effects on the maturity ogive, there will be an impact on the total pregnancy rate…

“Does the pregnancy rate vary with age? An age-specific pregnancy table (akin to Table 2.5 but with sample sizes) should also be produced for the different time periods, so data can be assessed.”

Preliminary analyses of age effects on the pregnancy rate do not show any significant effect of age on the proportions of parous females with an LCA in the Barents Sea sample (examined with GAMs with binomial error structure). There is, however, a significant nonlinear effect of age for the Greenland Sea samples – kind of a sigmoid type increase but without a real asymptote because there is a secondary decline among older females, as might be expected. The difference in age effect between stocks could be due partly to different dynamics due to overall later recruitment in Barents Sea/White Sea females and potentially more severe age determination problems for this stock. The latter has been suggested by senior age readers, who find this stock harder to age, particularly females older than 10 years. We aim to test out aging based on stained sections of cementum for this stock. Also, it is being tested if using aspartic acid racemization ages available for parts of the data set has an impact on the estimated age effect for Barents Sea/White Sea harp seals. Based on the preliminary results for the Greenland Sea stock, age effects seem important to assess and incorporate into the model. It is being considered, if it may be more useful to simply use total age-specific proportions of females with an LCA…. This will, however, not fix the problem with absence of first-time-ovulators in the Barents Sea samples. Due to time constraints no new pregnancy rate table is constructed at this point, considering that only age-aggregated estimates are used in the present report.

The youngest mature female ranged from 3 years for the period 1976-1985 to 5 years in 2018 (Table 2.5). To better interpret these data, information on number and total sample size should be included for each cell – to assess the sampling effort for each year class across the time periods. Definitions of periods should also be included.

See tables 2.1x and Table 2.5x below.

Table 2.6 high pregnancy rates with low variation between samples. 2006 has only low estimate. Linear interpolation method gives a lot of weight to that low estimate in 2006. Is this justified by sample size? Sample sizes should be included in table. Discussion of non-random sampling and bias useful but not clear how impacts the evaluation of the maturity schedule.

See tables 2.2x and Table 2.6x below.

Have you read the working document WPSEA 252? More thoughts on the absence of first-time ovulators is presented there. Basically, it seems, that young females, that have not yet given birth, tend not to show up in the sampling areas. There are “holes” in the age distributions for the relevant age groups in all of the samples, as you can see in table 2.5x. This will tend to overestimate MAM and hence underestimate the total reproductive rate. Possibly, this effect will to some degree be balanced by a likely positive bias in the pregnancy rate of mature females (LCAs not reflecting late term abortions). But unfortunately, we don’t know the relative strengths of these two types of bias. It should, however, be noted, that the pregnancy rate estimated for the Barents Sea/White Sea stock 1990-93 is in fact based on presence/absence of fetuses in postimplantation samples. The value of 0.84 is within the typical range of the LCA-based pregnancy rates.

Requested Tables:

Table 2.5x. Estimated age specific proportions of mature females (P_{mat}) in Barents Sea/White Sea harp seals. N_{tot} designates the total number of females in each age class.

	2y	3y	4y	5y	6y	7y	8y	9y	10y	11y	12y	13y	14y	MAM (±0.95 CI)
1962-72														
P_{mat}	0.00	0.01	0.17	0.64	0.90	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	5.4±0.1 years
N_{tot}		84	84	113	121	120	83	14	9	6	-	-	-	
1976-85														
P_{mat}	0.00	0.00	0.24	0.62	0.81	0.91	0.95	0.98	0.99	1.00	1.00	1.00	1.00	6.6±0.5 years
N_{tot}	4	4	5	8	12	20	29	18	8	6	3	-	-	
1988-93														
P_{mat}	0.00	0.00	0.02	0.08	0.21	0.40	0.59	0.75	0.85	0.91	0.95	0.97	0.97	8.2±0.3 years
N_{tot}	18	16	15	39	67	64	52	30	31	21	-	-	-	
2006														
P_{mat}	0.01	0.02	0.05	0.11	0.25	0.55	0.90	0.99	1.00	1.00	1.00	1.00	1.00	7.2±0.3 years
N_{tot}	4	2	3	5	6	5	7	7	6	2	10	4	1	
2018														
P_{mat}	0.00	0.00	0.00	0.00	0.52	0.77	0.89	0.95	0.97	0.99	0.99	0.99	1.00	6.9±0.9 years
N_{tot}	2	2	-	2	7	14	9	12	16	10	10	14	10	

Table 2.6x. Proportions of parous Greenland Sea females giving birth in the previous reproductive cycle.

Year	Fecundity rate	SD	N_{parous}
1993 (1990-93)	0.84	0.06	32
2006	0.68	0.06	65
2011	0.84	0.06	46
2018	0.91	0.03	148

Table 2.1x. Estimated age specific proportions of mature females (P_{mat}) in Greenland Sea harp seals. N_{tot} designates the total number of females in each age class.

	2y	3y	4y	5y	6y	7y	8y	9y	10y	11y	12y	13y	14y	MAM (±0.95 CI)
1959-90														
P_{mat}	0.00	0.06	0.29	0.55	0.74	0.86	0.93	0.96	0.98	0.99	1.00	1.00	1.0	5.4±0.1 years
N_{tot}	11	46	47	75	77	75	65	47	47	35	27	20	13	
2009														
P_{mat}	0.00	0.00	0.00	0.06	0.28	0.55	0.76	0.88	0.95	0.98	0.99	1.00	1.00	7.6±0.5 years
N_{tot}	10	16	19	9	11	20	23	20	23	14	19	8	7	
2014														
P_{mat}	0.00	0.00	0.00	0.33	0.71	0.89	0.96	0.99	0.99	1.0	1.0	1.0	1.0	6.2±0.6 years
N_{tot}	19	20	3	6	11	16	18	6	18	8	9	4	4	

Table 2.2x Proportions of parous Greenland Sea females giving birth in the previous reproductive cycle.

Year	Fecundity rate	SD	N_{parous}
1964	0.92	0.04	39
1978	0.88	0.03	130
1987	0.78	0.03	190
1990	0.86	0.04	76
1991	0.83	0.05	70
2008	0.80	0.06	45
2009	0.81	0.03	128
2014	0.91	0.03	96

Page 7

"4) Assessment model: Bayesian model fitting to data on pup production."

See previous clarification

Page 8

"Nevertheless, for completeness as forth scenario might have been considered – all pup production estimates and averaged maturities at age and fecundity."

Agreed, this could have been done for completeness, but is unlikely to have produced substantially different estimates. We will include this in future assessment reports.

"To be clear, does this mean that any minimal bycatch is accounted for in the estimate of natural mortality?"

Since no data on bycatch-related mortality is available, any potential mortality due to bycatch is automatically allocated to natural mortality in the model, since this is the only mortality term not related to catch. While this suggests that the model would overestimate natural mortality *per se*, we believe bycatch is negligible, and so the model estimates of natural mortality are close to what natural mortality may be expected to be. However, the fact that the model only estimates two constant mortality rates (one for pups and pone for adults), is of course a limitation, but one that is shared with most other data poor populations.

"To make that clear to the reader, the WG should add a statement along the lines of 'Reduced catch rates result from changes in harvest effort and do not reflect changes in stock abundance or availability.'"

This will be included in the final version of the report.

"In the discussion of automated reading of photographs, the report would be more useful to the reader if numbers could be provided rather than qualitative statements such as "misses only a few of the harps, and only output a limited number of false positives". Similarly, "results for hooded seals are not as good as several hooded seals are misclassified as harp seals".

This will be presented in much more detail during the next WGHARP. It is still a work in progress, and only preliminary analyses had been carried out prior to WGHARP2019.

"With respect to the research on harp seal migration, most readers will not find "a spatio-temporal log Gaussian Cox process model fitted using Inverse Nested Laplace Approximation" informative. Rather "This Bayesian model accurately captures the migratory behavior of the three breeding populations." seems to provide the essential information. Also, with respect to this sentence, it would be more accurate to state that the model "reproduces the observed migratory behavior of the 80 individuals modelled among the three populations."

Agreed, this will be changed in the final version of the report.

Page 9

"Further details on the pup staging survey would be helpful and should be included in the report. Additional information was sought from the working papers by the RG (as follows), and similar text should also be included in the main text of the report. 'Due to weather conditions, photographic survey of the whelping areas in 2018 had to be undertaken over two days, 27th and 28th March, and datasets were combined using a number of different approaches, which includes ….. (WP SEA 247). Due to restricted ship time only one staging bout was undertaken on the 21st March, and animals were staged based on pelage colour and condition, overall appearance and muscular coordination (Biuw et *al.* Nr. 7-2018). During this staging bout a high proportion of thin pups were observed which suggests this date represented a relatively early stage of the pupping period (Biuw et al. Nr. 7-2018). The estimate of the number of pups on the sea ice during the photographic survey in 2018 was 0.98."

Such statements will be included in the final report. Just to clarify, the RG refers to both WP SEA 247 and Biuw et al. Nr. 7-2018. Do they mean the same working paper?

"Very little information is provided with respect to the mark-recapture estimates. Given the recommendation to re-analyse these data a few words to identify the main concerns with the previous analysis would be appropriate (See page 14 for critique of the MR violation of assumption of homogeneity in recapture and possibility of temporary emigration (Oien and Oritsland, 1995)). Many advances in MR methods which can address these."

We are happy to include some general comments about this, by referring to the original report. But any in-depth discussion is beyond the scope of the current report, as the causes of potential biases were not discussed in great detail. Future work will include the original researchers who carried out these studies, which should provide much important additional detail.

"What data exists is fraught with large interannual variation, much of which is likely measurement error as this is a difficult species to sample."

We are a bit unsure what data the RG is referring to here. As discussed above, the pup production data show large variations, probably largely due to the differences in methods (photographic surveys vs. mark-recapture). There may also be biases in reproductive data, as also discussed above. However, other data are more reliable (i.e. catch data, though not completely age-specific). It would be helpful to know exactly which data are referred to here.

"Here again, the lack of variation in fecundity would suggest this too is largely measurement error and not reflective of dynamics."

We disagree with this statement. There is the strong possibility that inter-annual variations in fecundity (as measured for this population only a short time after breeding) are smaller than actual inter-variations in birth rates, if environmental conditions in the intervening period (from May to March) exerts a strong influence on body condition and termination of pregnancy. While this has not been examined in detail, there are strong indications that this may be the case. But we believe that, suggesting that the most likely reason for the discrepancy between low variability in fecundity and large apparent variability in pup production is due to sampling variability is overly simplistic and may be misleading.

"Catches are assigned to pups and 1+, for 1+ the age distribution is assumed to be proportional to population. The age distribution of the catches are strong assumption and any information to support/test would be valuable. Tables of catches in the Annexes are helpful but it is very useful to see plots of catches for both pup and 1+."

Plots can be easily included, but to our knowledge very limited data exist to support the *pro-rata'* rule when estimating age-specific catches. The assumption is based on the reasonable assumption that sealers select targets based on availability, and that seals of all ages are equally available during the moult. To a degree, this question may be related to uncertainties about the availability of younger age groups for sampling of reproductive rates, and questions regarding the whereabouts of younger age classes. The WG recommended further studies to address these issues, and this is now incorporated into planning of future research and monitoring work.

"Fig. 2.3 the second column is not overly informative. The different scales on y-axis for total population size does not support argument that there is consistency in model fits but careful inspection does suggest overlap. Might be better to plot all three models on one plot of total population and another of pup production. Also, it would be useful to indicate different methods with different symbols."

The take-home message from the second column is that the inclusion/exclusion of different pup production data has relatively little influence on estimates of current pup production. We therefore believe that the three righthand plots are 'informative', in the sense that the lines of model fits are very similar. We will try to make plots as per the suggestions of the RG, to see if this clarifies the message. Alternatively, we will keep the range of the y-axes constant in the three lefthand plots in a final updated figure.

Annex 11: Working papers

- WP SEA 247 - Estimation of pup production of harp and hooded seals in the Greenland Sea in 2018
- WP SEA 248 - The 2019 abundance of hooded seals (*Cystophora cristata*) in the Greenland Sea
- WP SEA 249 - Norwegian and Russian catches of harp and hooded Seals in the northeast Atlantic in 2017-2019
- WP SEA 250 - The 2019 abundance of harp seals (*Pagophilus groenlandicus*) in the Greenland Sea
- WP SEA 251 - The 2019 abundance of harp seals (*Pagophilus groenlandicus*) in the Barents Sea / White Sea
- WP SEA 252 - A 2018 update and reassessment of reproductive parameters of Northeast Atlantic harp seals (*Pagophilus groenlandicus*)
- WP SEA 253 - Analysis of the White sea/Barents Sea harp seal Population (*phoca groenlandica*) calculated quantity estimation by cohort models in present stage when hunting is absented
- WP SEA 254 - Updated Estimates of Harp Seal Bycatch and Total Removals of NW Atlantic Harp and Hooded Seals in Canadian waters

WP SEA 247

ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS

IMR, TROMSØ, NORWAY, 2-6 SEPTEMBER 2019

Estimation of pup production of harp and hooded seals in the Greenland Sea in 2018

Martin Biuw[1], Tor Arne Øigård[2], Kjell Tormod Nilssen[1], Garry Stenson[3], Lotta Lindblom[1], Michael Poltermann[1], Martin Kristianssen[1] and Tore Haug[1]

[1]Institute of Marine Research, Fram Centre, PO Box 6606 Langnes, NO-9296 Tromsø, Norway

[2]Norwegian Computing Centre, PO Box 114 Blindern, NO-0314 Oslo, Norway

[3]Northwest Atlantic Fisheries Centre, Fisheries and Oceans Canada, St. John's, Newfoundland and Labrador, Canada

ABSTRACT

Pup production of the Greenland Sea populations of harp and hooded seals were estimated based upon aerial surveys in March 2018. One fixed wing aircraft was used for reconnaissance flights to identify the whelping concentrations and to carry out photographic surveys along systematic transects over the whelping areas. A helicopter, operated from the Norwegian Coastguard icebreaker *"KV Svalbard"*, flew reconnaissance flights, deployed GPS beacons within the concentrations, monitored the movements of seal patches and performed age-staging of the pups. The estimated pup production of harp seals was 54 181 (SE=9 236, CV=17%), which is significantly lower than estimates obtained in similar surveys in 2002, 2007 and 2012. Estimated hooded seal pup production was 12 977 (SE=1 823, CV=14%), which is lower than estimates obtained from comparable surveys in 2005 and 2007, but similar to estimates from the most recent survey in 2012.

INTRODUCTION

Estimating population abundance from of animals in the wild using catch-at-age data, sequential population models and mark-recapture data is associated with several underlying assumptions, each with substantial uncertainties associated with them. Independent estimates of pup production, using aerial photo or visually based strip transect methods, have been recommended and used to provide the basis for estimates of total abundance of harp (*Pagophilus groenlandicus*) and hooded (*Cystophora cristata*) seals both in the northwest Atlantic (Bowen *et al.*, 1987; Hammill *et al.*, 1992; Stenson *et al.*, 1993, 1997, 2002, 2003, 2005, 2006, 2010), in the

Greenland Sea (Øritsland and Øien., 1995; Haug *et al.*, 2006; ICES, 2006a; Salberg *et al.*, 2008; Øigård *et al.*, 2010, 2014a, 2014b) and in the White Sea (Potelov *et al.*, 2003; ICES, 2016). Total population size and status of the stocks is subsequently assessed by fitting population models, which incorporate annual reproductive rates and removals, to the independent estimates of pup production (e.g. Healey and Stenson., 2000; Hammill and Stenson., 2007; Skaug *et al.*, 2007; Øigård *et al.*, 2014a, 2014b; ICES, 2016).

Both harp and hooded seal pup production were last assessed in the Greenland Sea in 2012 (Øigård *et al.*, 2014a, 2014b). The ICES management requires that these populations are defined as "data rich" (ICES, 2006b). Data rich stocks require that a time series of at least three pup production estimates should be available spanning a period of 10-15 years with surveys separated by 2-5 years. The most recent abundance estimates should be prepared from pup production estimate surveys and supporting data on fertility (also no more than 5 years old) and catch statistics. The original plan was to conduct a new survey of the Greenland Sea harp and hooded seal stocks in 2017, to ensure these stocks met the data rich criterion. However, due to practical logistical issues this survey was postponed to 2018.

The harp seal was the prime target species for the surveys, since this population is still hunted. However, due to low hooded seal pup production numbers observed in recent decades (ICES, 2006a, 2016), this species has been protected since 2007. The last survey (in 2012), did not show any signs of recovery (ICES, 2016), a new survey after a period of ~5 years was required in order to to assess the effect of protection on the pup production due to the usually 4-5 years age at maturity observed in hooded seals (see Frie *et al.*, 2012). One secondary goal of this latest survey was therefore to obtain a new abundance estimate for hooded seals in the area. Given restricted logistical resources and the priority of harp seals, the possibility of obtaining a hooded seal pup production estimate would require that hooded seal breeding occurred within the same main areas as the harp seal breeding. During course of this survey it proved possible to obtain data of pup production for both species.

MATERIALS & METHODS

Logistics

An ice-strengthened expedition vessel was used for operations in the Greeland Sea drift ice. The ship was equipped with a helicopter platform and equipment in compliance with relevant requirements for helicopter operations.

An Ecureuil AS 350 B1 helicopter was chartered for the expedition and was used to conduct reconnaissance flights, to monitor the distribution of seal patches and to perform age-staging of the pups. A fixed-wing twin engine Twin Otter aircraft (TF-POF) was used to conduct reconnaissance and photographic surveys. The aircraft was based at Akureyri (Iceland) and at Constable Pynt airport (Nerlerit Inaat, 50 km north of Scoresbysound, East Greenland).

Reconnaissance surveys

The ice cover in 2018 was considerably reduced compared to previou surveys on 2007 (Øigård *et al.*, 2010)and 2012 (Øigård *et al.*, 2014a, 2014b), with the edge of the pack ice located closer to the East Greenland coast. In addition to revisiting all areas historically used by harp and hooded seals for breeding purposes in the Greenland Sea (see Haug *et al.*, 2006; Salberg *et al.*, 2008; Øigård *et al.*, 2010, 2014a, 2014b), reconnaissance flights also covered areas to the north and south of these historical core areas, to account for potential distributional changes over time.

Reconnaissance flights were flown at an altitude of 160-300m and transects were adapted to the actual ice-configuration during the survey period, with the ice edge generally delineating the eastern end and areas of fast ice or large ice sheets making up the western end. Due to the significant southward ice drift that occurrred in the region, and a pupping period that often spans several weeks (mid to late March, see Rasmussen, 1960; Øritsland, 1964; Øritsland and Øien., 1995; ICES, 1998; Haug *et al.*, 2006; Salberg *et al.*, 2008; Øigård *et al.*, 2010, 2014a, 2014b), most areas were surveyed repeatedly to minimize the chance of missing whelping concentrations. Color markers and 5 satellite based GPS beacons were deployed in and around the major whelping concentrations to facilitate relocation and to monitor ice drift.

The vessel encountered the ice edge at 72º30’N / 17º55’W on March 17th, and remained within the open pack ice to survey the region between 72º20’N to 73º14’N from ship and helicopter. Due to restricted time availabile for the survey, the vessel started moving southwards through a large whelping patch of both harp and hooded seals on March 23rd. At the assumed southern edge of this patch, a beacon was deployed on the ice from the vessel (position to72º19’N / 17º39’W), whereafter the vessel left the ice and returned to Norway.

Helicopter reconnaissance flights were flown from the ship between March 18th and 22nd in areas between 71º25’N and 73º40’N, as repeated systematic east-west transects between the ice edge in the east and areas of unsuitable (often fast) ice in the west. Transects were usually spaced 5 nm apart, with a length of 10-30 nm, and were modified according to the actual ice distribution during the individual survey flights.

The Twin Otter could cover much larger areas than the helicopter and was used to search for potential seal whelping areas within the drift ice outside of the historical core area, from 68°40’N/24°50’W to 74°47’N/ 13°58’W during the period 18th-30th March. These reconnaissance flights also followed east-west transects usually spaced 10 nm, although spacing was decreased to 5 nm in areas where seals were observed. In the north, reconnaissance was flown more in relation to ice distribution (also covering some areas of open water), and occasionally restricted due to fog banks covering parts of the area.

Photographic surveys

The Twin Otter was equipped with a digital camera (Phase One IXU-RS-1000 / Lens: Rodenstock 50 mm f/4.0). Images were taken at an altitude that was maintained at 1100 ft (335 m) using a radar altimeter, and at a flight speed of approximately 130 knots. The camera was operated to cover 80-90 % of the area along each transect line, with deliberate spacing between adjacent images to avoid overlap and the potential for double counting. The image footprint was 347m (cross track) x 260 m (flight direction), with a pixel ground resolution of approximately 29 mm. Transects were flown along east-west lines at a latitudinal spacing of 1-3 nm.

The ship and helicopter were used to define the geographic range of the whelping patches prior to the fixed-wing aircraft photographic survey. The GPS beacons deployed on the ice was used to guide the aircraft to the patches, since the ship and helicopter were forced to depart from the ice prior to the optimal time for the photographic surveys. Cameras were turned on when seals were observed on a transect line. Cameras were turned off when the transect line ended at the eastern ice edge, or when no seals were observed for an extended period along the line to the west.

Photographic counts

All photos were orthorectified to Universal Transverse Mercator projection (UTM, zone 32N). They were analysed by two experienced readers, using custom-made routines in the QGIS GIS package (QGIS Development Team, 2016).

After reading all photographs, the readers re-read a series of their photographs in sequence to determine if identifications had improved over the course of the readings. Photos were read until the second readings were consistently within 1% of the first. The original readings were replaced with the second readings up to this point. Additional photos were read subsequently to ensure that the first and second reading were consistent.

To correct for misidentified pups, a number of photos were selected from one reader and read by the other reader. Initial comparison of these readings revealed a relatively consistent difference between the readers, with one reader consistently overlooking seals than were identified by the other reader (and confirmed by a third independent reader). To obtain a corrected estimate for this reader, we fitted a linear model of the form:

$$n_{j,k}^{r1} = \alpha + \beta n_{j,k}^{r2} + \epsilon_{j,k}$$

where $n_{j,k}^{r1}$ is the counts by the less imprecise reader for the kth photograph in the jth transect, $n_{j,k}^{r2}$ is the counts to be corrected from the other reader, α is the estimated intercept, β is the estimated slope, and $\epsilon_{j,k}$ represents a residual error term assumed to be normally distributed with zero mean and standard deviation. Using the estimated parameters we applied a linear correction model for each of the original counts:

$$\hat{n}_{j,k}^{r2} = \alpha + \beta n_{j,k}^{r2}$$

The measurement error for each photo associated with predicting the best estimate follows naturally by:

$$\epsilon_{j,k} = \sigma^2 + var(\alpha) + 2cov(\alpha,\beta) n_{j,k}^{r2} + var(\beta)(n_{j,k}^{r2})^2$$

where $var(\alpha)$ is the variance of the intercept, $var(\beta)$ is the variance of the slope, and $cov(\alpha,\beta)$ is the covariance between the intercept and the slope.

Pup production estimation

The photographic surveys were based on a systematic sampling design with a single random start and a sampling unit of transects of variable length. The estimated number of pups on the ice at the time of survey may be written as (Salberg *et al.*, 2008; Øigård *et al.*, 2010):

$$\widehat{N} = T\sum_{j=1}^{J} W_j\, x_j$$

where $W_j = l_j/A_j$, A_j is the area covered of all photographs on transect j, l_j is the length of transect j, J is the total number of transects, and $x_j = \sum_{k=1}^{P_{ij}} \hat{n}_{j,k}$ is the sum of the corrected counts on transect j. The number of photos on the jth transect is P_j and T is the spacing between transects in the survey. This estimator takes into account changes in transect width along transects and between transects due to changes in flight altitude. The estimates of error variance V^s, based on serial differences between transects were calculated as (Salberg *et al.*, 2008):

$$V^s = \frac{TJ}{2(J-1)}\left(T - \frac{\sum_{j=1}^{J} A_j}{\sum_{j=1}^{J} l_j}\right)\sum_{j=1}^{J} l_j\,(W_j x_j - W_{j+1} x_{j+1})^2$$

This estimator assumes that the mean is constant between two neighboring transects. For the seal pup data this assumption is often not valid due to clustered data, and we will have an unwanted contribution from the difference between the transect count mean values which causes an overestimate of the variance of the pup production estimate (Cochran, 1977). However, if the seals are homogenously spread over a large area this assumption is fine.

The variance associated with mis-classification of pups, i.e., readers errors, for the whole survey is then (Salberg *et al.*, 2008):

$$V^{meas} = T^2\Big[\sum_{j=1}^{J} W_j^2\, P_j\sigma^2 + \Big(\sum_{j=1}^{J} W_j\, P_j\Big)^2 var(\alpha) + 2cov(\alpha,\beta)\Big(\sum_{j=1}^{J} W_j\, P_j\Big)\Big(\sum_{j=1}^{J} W\,j \sum_{k=1}^{P_j} n_{j,k}\Big) + var(\beta)\Big(\sum_{j=1}^{J} W\,j \sum_{k=1}^{P_j} n_{j,k}\Big)^2\Big]$$

If the intercept term is not statistically significant on a specified level it could be dropped from the linear correction model. The variance expression is then simplified to

$$V^{meas} = T^2\Big[\sum_{j=1}^{J} W_j^2\, P_j\sigma^2 + \Big(\sum_{j=1}^{J} W_j\, P_j\Big)^2\Big]$$

To obtain the total sampling variance of the survey, the variance associated with the mis-identification corrections V^{meas} was added to the sampling variance V^s, i.e.:

$$V = V^s + V^{meas}$$

Pup visibility to aerial surveys

Temporal distribution of births

To correct the estimates of abundance for seal pups that had left the ice or were not yet born at the time of the survey, it was necessary to estimate the distribution of births over the pupping season. This was done by using information on the proportion of pups in seven distinct age-dependent stages. These easily recognizable descriptive age categories were based on pelage colour and body condition, overall appearance, and muscular coordination, as described for the northwest Atlantic harp seals by (Stewart and Lavigne, 1980):

1. Newborn: Pup still wet, bright yellow colour often present. Often associated with wet placentas and blood stained snow.
2. Yellowcoat: Pup dry, yellow amniotic stain still persistent on pelt. The pup is lean and moving awkwardly.
3. Thin whitecoat: Amniotic stain faded, pup with visible neck and often conical in shape, pelage white.
4. Fat whitecoat: Visibly fatter, neck not visible, cylindrical in shape, pelage still white.
5. Greycoat: Darker juvenile pelt beginning to grow in under the white lanugo giving a grey cast to the pelt, “salt-and-pepper”-look in later stages.
6. Ragged-jackets: Lanugo shed in patches, at least a handful from torso (nose, tail and flippers do not count).
7. Beaters: Fully moulted pups (a handful of lanugo may remain).

Prior to the survey, classifications of pup stages were standardized among observers to ensure consistency. To determine the proportion of pups in each stage on a given day, random samples of pups were obtained by flying a series of transects over the patch. Pups were classified from the helicopter hovering just above the animals. The spacing between transects depended on the size of the actual patch.

A similar procedure was followed for hooded seals where information on the proportion of pups in each of five distinct age-dependent stages was used to assess the temporal distribution of births. These arbitrary, but easily recognizable age categories were based on pelage colour and body condition, overall appearance, and muscular coordination, as described for northwest Atlantic hooded seals by Bowen *et al.* (1987) and Stenson and Myers. (1988), and used in the previous surveys in the Greenland Sea (Salberg *et al.*, 2008; Øigård *et al.*, 2010):

1. Unborn: Parturient females.
2. Newborn: Skin in loose folds along flanks, fur saturated to wet, entire pelage with yellowish hue, awkward body movements. Mother present. Often associated with wet placentas and blood stained snow.
3. Thin blueback: Pup dry, ventrum white, neck well defined, trunk conical in shape. Mother present. Mainly 1-2 days old.
4. Fat blueback: Ventrum white, neck not distinguishable, trunk fusiform in shape. Mother present. Mainly 2-4 days old.
5. Solitary blueback: As in fat blueback, but mother not present. Mainly 4 days or older.

Due to a combination of the premature departure of the survey vessel from the ice, and poor weather conditions the days prior to the departure, estimates of the proportion of harp and hooded seal pups in each developmental stage were only obtained for March 21st. To partially compensate for the lack of staging data, we also attempted to stage pups in a crude way based on the aerial images obtained (see details below). To obtain an estimate of proportion of seals on ice at the time of the photographic surveys, we used the fitted curves from the 2012 survey (see details below).

Predicted proportion of pups

The temporal distribution of births for both harp and hooded seals was estimated using the method developed in Reed and Ashford (1968) and adapted for modelling the birth distribution for harp and hooded seals in Bowen *et al.* (1987), and Myers and Bowen. (1989). The life cycles of the seals were assumed to be divided into k identifiable age-dependent stages $S_1, \ldots\ldots, S_k$. Birth takes place into state S_1 and the pup then progresses in succession through states $S_1, S_2, \ldots.$ until it attains maturity when reaching state S_k. All pups reaching state S_k eventually die in that state, either from hunting or natural causes (Reed and Ashford, 1968). We assumed that for both seal populations the birth rate could be adequately described by a continuous function of time, $m_1(t)$ which denoted the temporal distribution of births. The distribution of births over time was assumed to be a normal distribution with mean value μ_1 and standard deviation σ_1.

The various development stages are denoted by the subscript j, and a pup passes from stage j to stage $j+1$. The stage durations are specified in terms of transition intensity functions $\phi_j(t)$, which is the probability that an animal passes from stage j to $j+1$ in the interval $[\tau, \tau+\Delta t]$ and has survived. Here τ is the time spent in stage j. The stage duration was assumed to be a semi-Markov process, i.e. the transition intensities depend only on the current stage and the time so far spent in that stage (Bowen *et al.*, 1987). The rate at which pups enter the stage j at time t were denoted by $m_j(t)$ and given by a recurrence relationship Myers and Bowen. (1989):

$$m_j(t) = \int_0^{\infty} m_{j-1}(t-\tau)\phi_{j-1}(\tau)d\tau \quad j = 1, .., k$$

The proportion of pups that will be observed on the ice in stage j at time t is (Bowen *et al.*, 1987; Myers and Bowen., 1989):

$$n_j(t) = \int_0^{\infty} m_{j-1}(t-\tau)(1 - \int_0^{\tau} \phi\,(s)ds)d\tau$$

This equation assumes no pup morality during these stages and that all pups on the ice are visible. In Bowen *et al.* (1987), (2007) and Myers and Bowen. (1989) the transition intensity functions $\phi_j(t)$ were assumed to follow a Gamma distribution with shape parameter κ_j and scale parameter ρ_j for stage j. The product between the shape parameter and the scale parameter, $\rho_j\kappa_j$, gives the mean duration of stage j. The numbers of individuals observed to be of stage j at time t_i were denoted S_{ij}. The S_{ij}'s were obtained by taking a random sample of the pup abundance and determining the stage of each individual. The predicted proportions of each stage present at time t_i, P_{ij}, are calculated as in Myers and Bowen. (1989), i.e. by estimating the parameters $\hat{\mu}_1$

and $\hat{\sigma}_1$ of the birth distribution. The proportion of pups on the ice at time t was estimated using (Salberg *et al.*, 2008; Øigård *et al.*, 2010):

$$Q(t) = \sum_{j=1}^{k} \eta_j (t)$$

The estimated variance of the proportion of pups on the ice at a given time was estimated by simulating from the proportion of pups in the various stages obtained from the staging by simulating from a multinomial distribution with k stages (Salberg *et al.*, 2008).

Total pup production estimate

To correct for pups still not born, and pups that had left the ice at the time of the photographic survey, the estimated numbers of pups on the ice at the time of the survey were corrected by:

$$\hat{N}^{corr} = \frac{\hat{N}}{\hat{Q}}$$

where $\hat{Q}$ is the estimated proportion of pups visible on the photographs at the time of the survey.

The estimates of N_i and Q are independent and therefore the error variance of the estimated total number of pups born in the patch $\hat{N}^{corr}$ may be obtained using the δ-method (e.g. Casella and Berger., 1990):

$$V^{corr} = (\frac{1}{Q})^2 V (\frac{N}{Q^2}) V^q$$

where V^q is the estimated variance of $\hat{Q}$.

Estimating stage progression in 2018

To make up for the lack of staging surveys in 2018, we used the predicted proportions of pups in each stage in 2012, obtained using the above modelling approach. We assumed that, while the absolute timing of the entire 2018 pupping season may be shifted relative to the 2012 survey, the relative proportions of the different stages followed the same progression over time. We estimated the stage of progression during the 2018 staging surveys on March 21st by comparing the proportions of different stages observed to the predictions from the 2012 model fits, and determining the day on which the absolute difference in proportions was at its minimum, i.e.:

$$t^{corr} = \min_t (\sum_{j=1}^{k} | \eta_j^{obs} - \eta_j^{pred}(t)|) \quad \{0 < t < \infty\}$$

where η_j^{obs} is the observed proportion in stage j on March 21st, and $\eta_j^{pred}(t)$ is the vector of predicted proportions in stage j over time. Based on the time difference between t^{corr} and the true survey date (i.e. March 21st), we could determine an optimum time correction by which to shift survey timing in 2018 (staging as well as photographic surveys) to equivalent dates, had the

2018 surveys been carried out in 2012. This allowed us to determine the best correction factor, $\hat{Q}$, for proportion of seals on ice during photo surveys.

RESULTS

Identification of whelping areas

Reconnaissance surveys were conducted by Twin Otter (March 18th-31st) and helicopter (March 18th-22nd) over the drift ice in the Greenland Sea during the harp and hooded seal pup production surveys (Fig 1). On March 18th, the Twin Otter flew reconnaissance flights along the ice edge from 73º30’N to 74º47’N on 18 March and from 70º26’N to 71º30’N on 19 March, whereas the helicopter covered the area between 71º25’N to 72º20’N on 20 March. Both harp and hooded seal whelping was observed by the fixed-wing in a patch thought to be about 300 animals in approximately 74º00’N / 13º47’W on 18 March. No harp seals were seen on the fixed-wing survey in the southern part of the area, although scattered hooded seal families (defined as adult female and pup, accompanied by adult male waiting to breed) were observed. An area with more concentrated hooded seal families was observed from the helicopter between 71º25’N and 71º33’N, and a beacon was deployed in position 71º30’N / 19º06’W at 1500 hrs Norwegian time (Fig. 2) to follow the drift of this potentially emerging patch. However no seal aggregations were found during subsequent reconnaissance flights with the fixed-wing around the southward moving position of this beacon. It is possible that poor weather conditions during the days following the deployment of this beacon may have disintegrated the ice in this region, thus also disrupting the formation of a breeding patch. It is therefore possible that some hooded seals were missed during the final aerial photo surveys, and that the estimated hooded seal pup production is slightly underestimated.

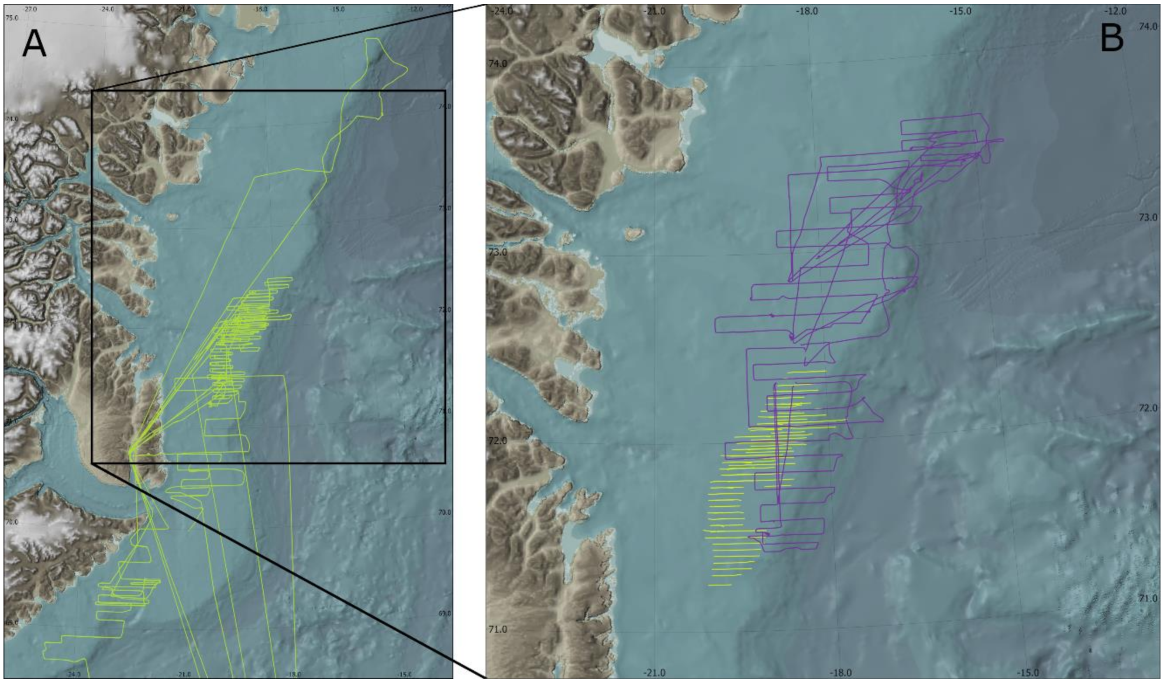

Figure 1: Reconnaissance surveys conducted by the fixed-wing aircraft (A) and helicopter (B) over the drift ice in the Greenland Sea during the period 18 - 31 March 2018. The purple track in panel B represents helicopter reconnaisance surveys, while the yellow track represents the final photo surveys conducted by the fixed-wing. These are also seen as tight transects in the middle of panel A

During helicopter reconnaissance flights on 21 March a large patch of whelping harp and hooded seals was located between 72º25'N and 72º35'N; 14º30'W and 16º00'W. There were signs suggesting that the patch extended considerably southwards from this area, but color markers and GPS beacons were deployed on ice floes at the assumed northern (73º32'N / 15º43'W) and eastern (73º27'N / 14º56'W) edges. The eastern beacon was deployed in more loose ice where breeding harp seals were observed on strips of more dense ice. Subsequent helicopter staging flights in the patch confirmed that breeding seals were distributed more toward the south than initially assumed, and another GPS beacon was deployed in position 73º13'N / 16º33'W on 22 March.

On 23 March, the weather and visibility conditions prevented helicopter operations. The vessel was therefore used to localize the north-south distribution of the patch. Apparently, the northern end was now at position 72º52'N / 16º40'W, which was close to the northernmost GPS beacon. Harp seals dominated this northern part of the patch (down to ca position 72º22'N / 17º20'W) – south of this there were mostly hooded seals. The remaining GPS beacon was deployed in the assumed southern end of the patch in position 72º19'N / 17º39'W, before the vessel left the ice to return to Norway.

The fixed-wing aircraft continued to conduct reconnaissance surveys after the vessel had left the ice. Based on observations made during these surveys, and information on localization of the identified whelping patches obtained from the ice-deployed GPS beacons, photographic surveys were conducted on 27 and 28 March. Subsequent reconnaissance surveys were conducted during

29 – 31 March to ensure that all whelping patches had been covered by the photographic surveys.

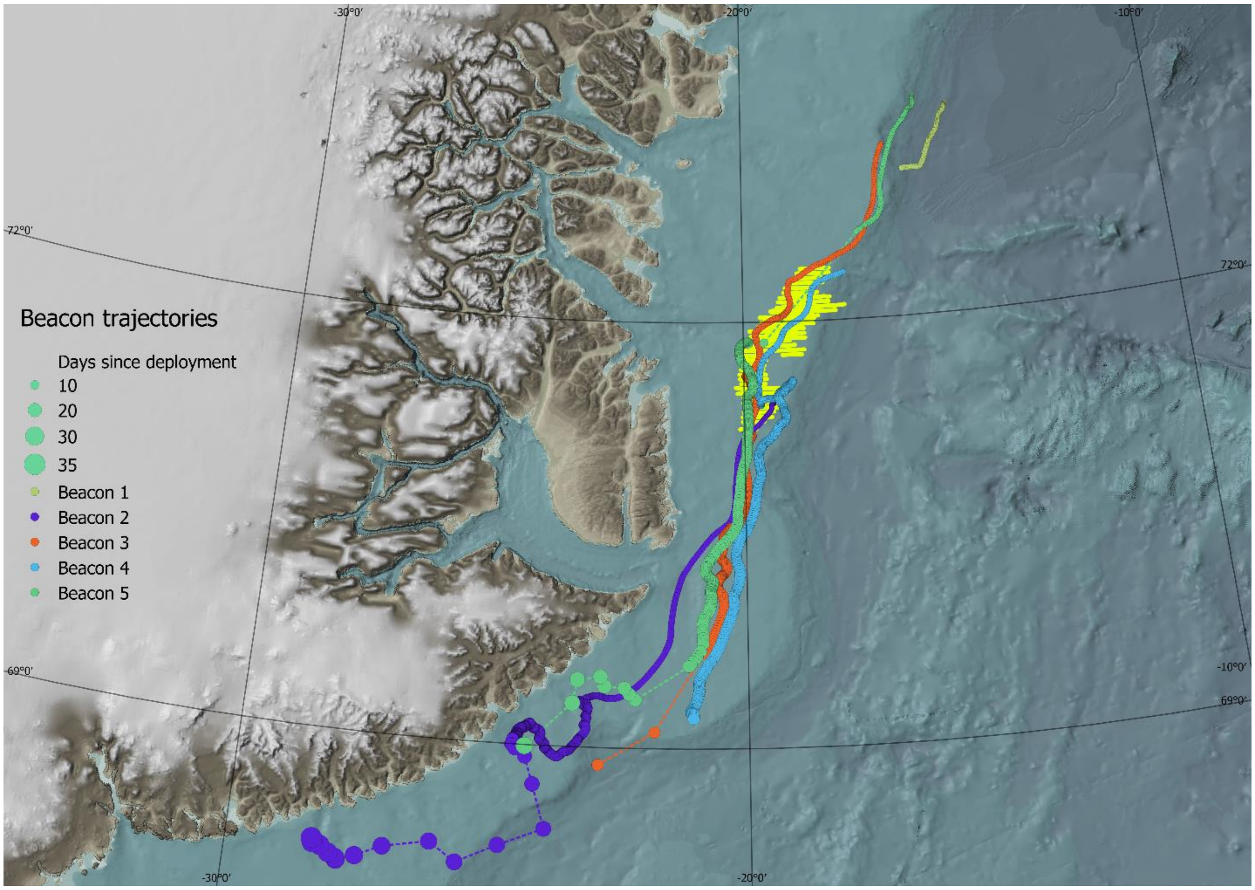

Figure 2: Trajectories of five GPS beacons deployed in the vicinity of the whelping grounds identified during helicopter and fixed wing reconnaissance surveys. Yellow lines represent transects during the aerial surveys carried out on March 27 and 28.

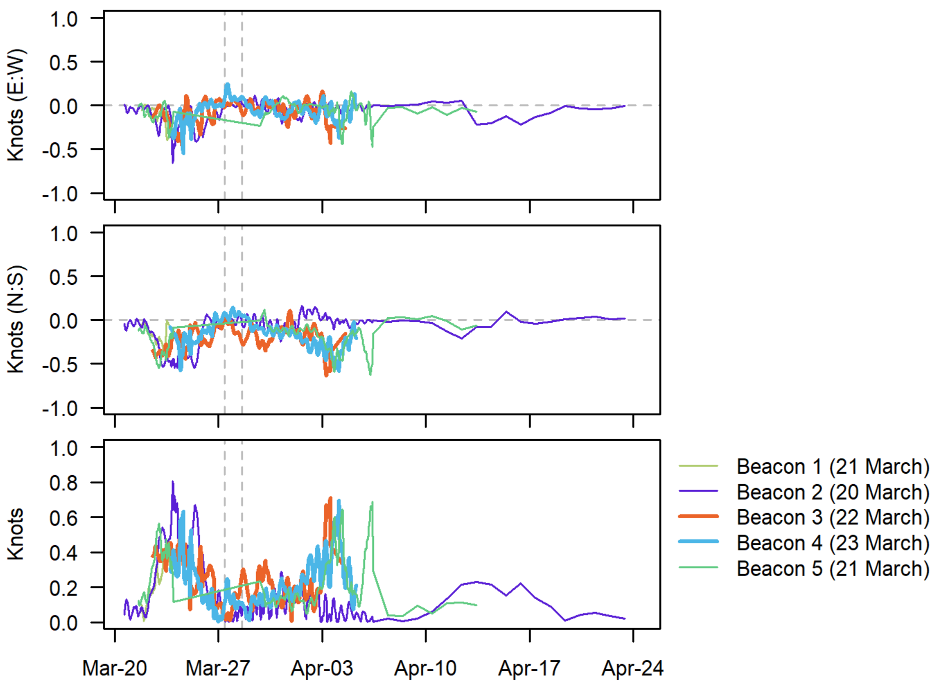

Figure 3: Drift rates of five GPS beacons deployed in the vicinity of the whelping grounds identified during helicopter and fixed wing reconnaissance surveys. The top two panels show the east/west and nort/south components of the drifts respectively, while the bottom panel shows the velocity along the drift direction. Two beacons that remained in the vicinity during the period of aerial surveys (Beacons 3 and 4) are emphasised by bold lines Vertical dashed lines represent March 27 and 28, i.e. the period when aerial photo surveys were carried out

The ice drift varied substantially throughout the survey period, as seen from the GPS beacons deployed on the ice (Fig. 2). Daily displacements of 15-20 nm were recorded (mean velocity: 0.21 kts, max velocity: 0.81 kts, Fig 3). The trajectories followed a generally south-southwesterly path. However, in the period 27-28 March, when the photo surveys were conducted, the wind shifted from predominantly northerly winds to south to southwesterly winds. This was associated with very complex ice movements within the survey region, as evidenced by dramatically different ice conditions on the two days and the entirely different trajectories of the two GPS beacons that were still in te vicinity of the whelping patch (Fig 4).

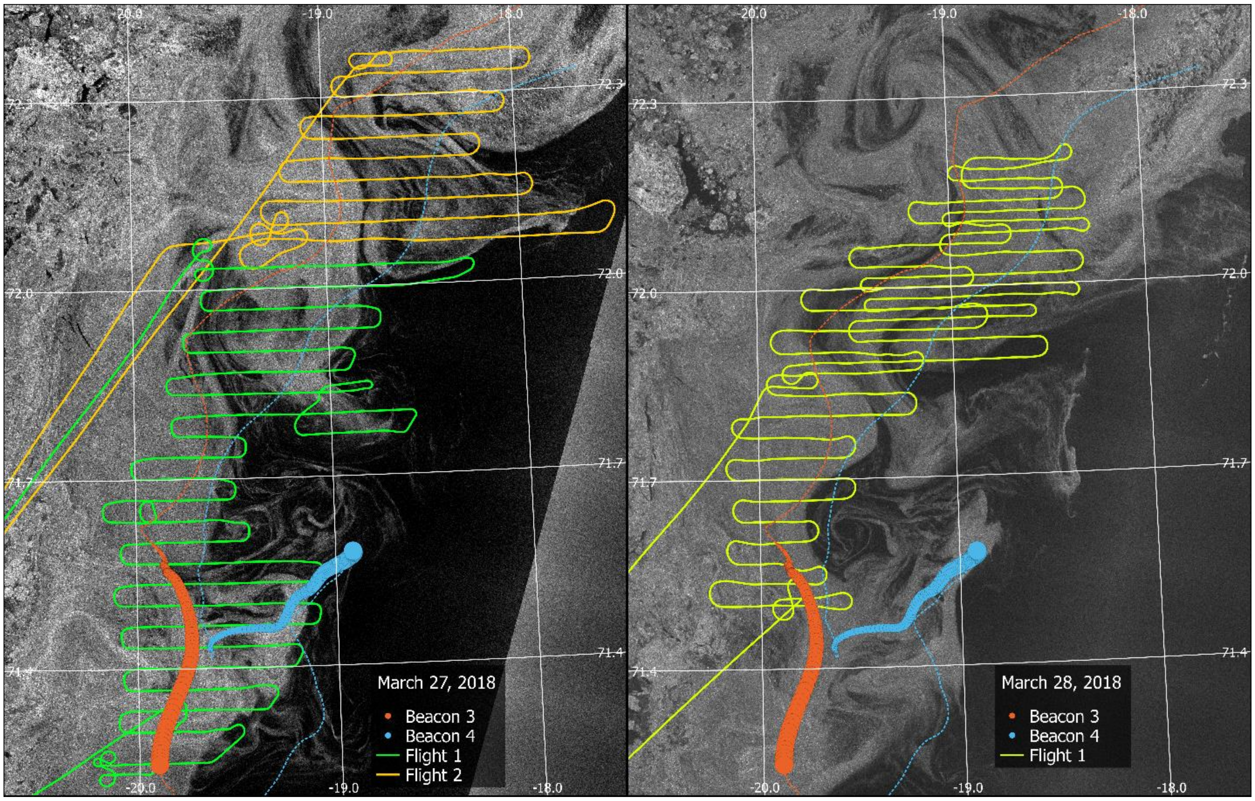

Figure 4: Aerial photo survey tracks and trajectories from two GPS beacons, overlaid on images of ice conditions on the consecutive photo survey days (March 27-28). Dashed lines represent the complete beacon trajectories, while the dots represent paths over the two survey days (dot size increases over time). Both images are from the Synthetic Aperture Radar (SAR) product, the one from March 27 was taken by the Sentinel S1A satellite at 08:11:58 UTC (March 27), and the one from March 28 by the Sentinel S1B satellite at at 13:40:39 UTC, with a ground resolution of ~40 x 120 meters (X x Y)

In general, ice drift further into the pack ice appears to have remained in a mostly southwesterly direction, while the looser pack ice appeared to be strongly affected by the SSE winds, resulting in more northeasterly drift and signs of large-scale rotational movements. This must be investigated more precisely to assess potential overlap between photo surveys on two separate days.

Temporal distribution of births

Harp seals

The number of pups in individual age-dependent stages are shown in Table 1.

Table 1. Number of harp seal pups in individual age dependent stages in the Greenland Sea. Numbers obtained during helicopter staging surveys on March 21, 2018

	Stages							
Date	Newborn	Yellow	Thin	Fat	Grey	Ragged	Beater	Total
March 21	11	49	521	3	0	0	0	584

To conform to the procedure used in 2012, we used the following binning of the various stages of the harp seal pups: stage 1 = Newborn/Yellow, stage 2 = Thin white, and stage 3 = Fat white/Greycoat.

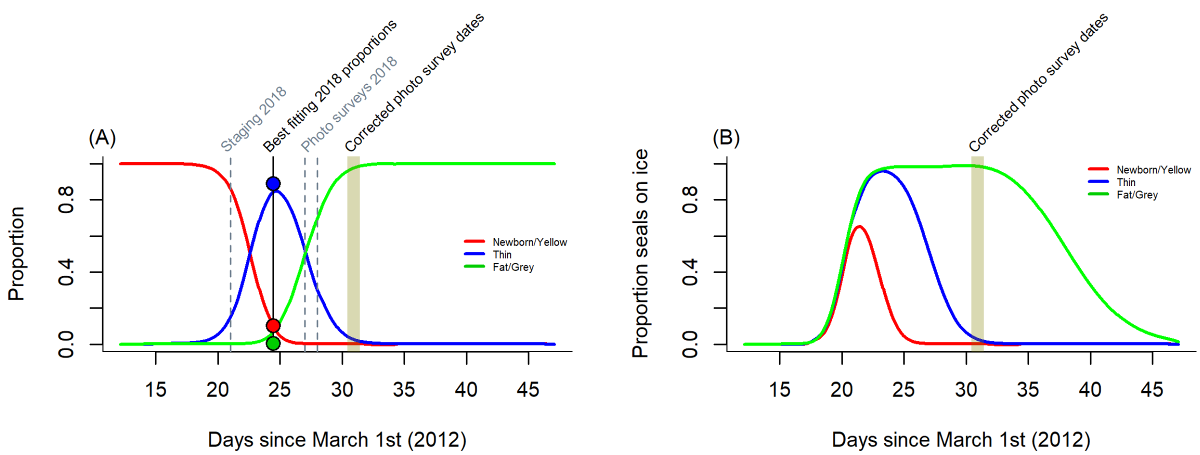

Figure 5: (A) Observed 2018 staging proportions (points) and 2012 estimates (lines) of the probability of a harp seal pup being classified as belonging to the various stages, and (B) Predicted proportion of hooded seal pups on ice as a function of time. The shaded area shows how the proportion of pups visible on ice changes during the 24 hours of 28 March when the photographic survey was carried out.

Figure 5A shows the predicted proportions in different stages based on the model fitted to the 2012 data, and reported in Øigård *et al.* (2014a), along with the observed proportions observed during the staging survey on March 21st 2018. The best fit for the observed 2018 proportions suggested that the equivalent date in 2012 would have been March 24th, providing us with a time correction of 3.4 days. Applying this correction to the dates when aerial surveys were carried out in 2018 (i.e. March 27th and 28th), suggested that the equivalent dates in 2012 would have been March 30th and 31st. Figure 5B shows the predicted proportion of harp seal pups visible on ice as a function of time, based on the model fitted to 2012 staging data (Øigård *et al.*, 2014a). The estimated proportion of pups on ice on the dates equivalent to the aerial survey dates in 2018 decreased from 0.99 around noon on March 30th to 0.98 on March 31st (mean: 0.9858, sd: 0.0025).

Hooded seals

The number of hooded seal pups in individual age dependent stages is shown in Table 2. The following binning of the various stages of the hooded seal pups was: stage 1 = Newborn and Thin, stage 2 = Fat, and stage 3 = Solitary.

Table 2. Number of hooded seal pups in individual age dependent stages in the Greenland Sea. Numbers obtained during helicopter staging surveys on March 21, 2018, or from stagings done from aerial images taken on March 27 & 28

	Stages					
Date	Parturient	Newborn	Thin	Fat	Solitary	Total
March 21	0	5	258	6	4	273
March 27-28*			231		444	675

The best fit for these observed proportions to the predicted proportions based on the 2012 survey (Øigård *et al.*, 2014b) gave an unrealistic time correction of -4.6 days, and equivalent aerial survey dates of March 16th and 17th. This would result in predicted proportions on ice during days of aerial surveys of less than 0.001. As an alternative, we used stagings from photographs obtained during the aerial survey dates. Here, it was necessary to use a different binning of stages, due to the difficulty in distinguishing between newborn, thin and fat bluebacks. The simplest approach was to merge stages 1 and 2, thereby using the following binning: stage 1 = Newborn/Thin & Fat, stage 2 = Solitary. Using a similar approach as for harp seals, the best fitting observed proportions occurred at dates equivalent to March 28, 29 (optimum time correction: 1.06 days).

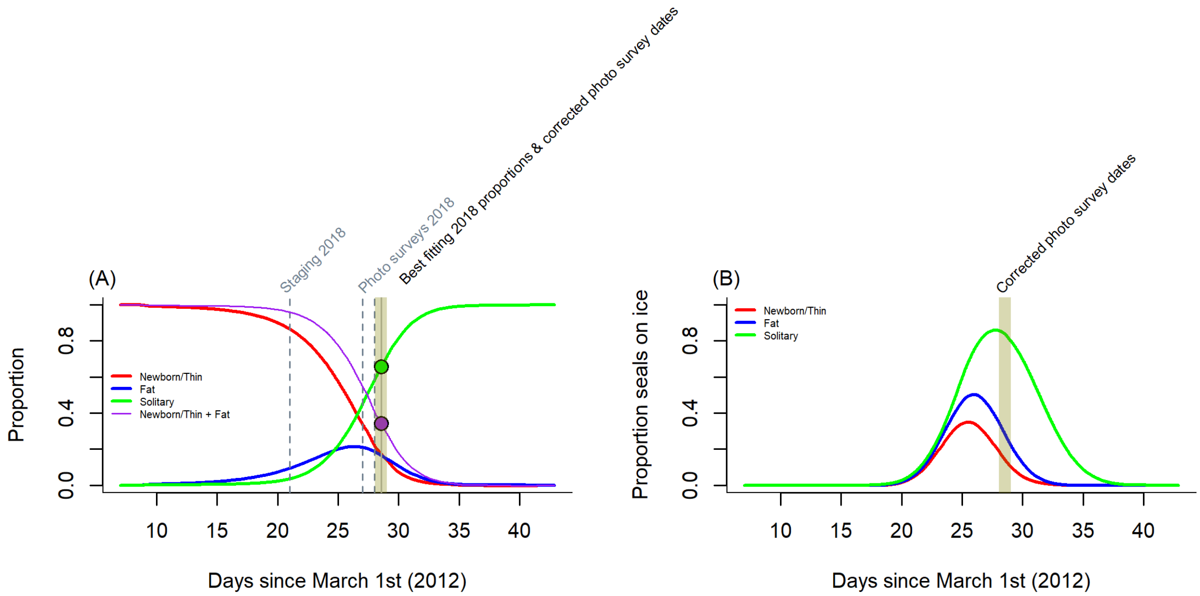

Figure 6: (A) Observed 2018 staging proportions (points) and 2012 estimates (lines) of a hooded seal pup being classified as belonging to the various stages, and (B) Predicted proportion of hooded seal pups on ice as a function of time. The shaded area shows how the proportion of pups visible on ice changes during the 24 hours of 28 March when the photographic survey was carried out.

Figure 6A shows the predicted proportions in different stages based on the model fitted to the 2012 data, and reported in Øigård *et al.* (2014b), along with the means of the proportions observed in aerial images taken on March 27th and 28th 2018. Applying the time correction to the predicted proportion of seals on ice (Fig 6B) resulted in proportions of decreasing from 0.86 on March 28 to 0.8 on March 28 (mean: 0.8335, sd: 0.0185). Since these values are similar to those used in the analyses of pup counts in 2012, we decided to follow the earlier approach and use our mean proportion as correction factor.

Photographic surveys

Two surveys with a total of 35 E/W transect lines were flown on March 27th 2018 (Fig 7; Table 3), starting at the southern end of the whelping patch at 71°15’N. The spacing between the two southernmost lines was 3.02nm, while the spacing between remaining transect lines between 71°18,0’N and 72°22’N was roughly 2 nm (mean:1.94; sd: 0.35). In total 3005 images were taken during the two surveys on this day.

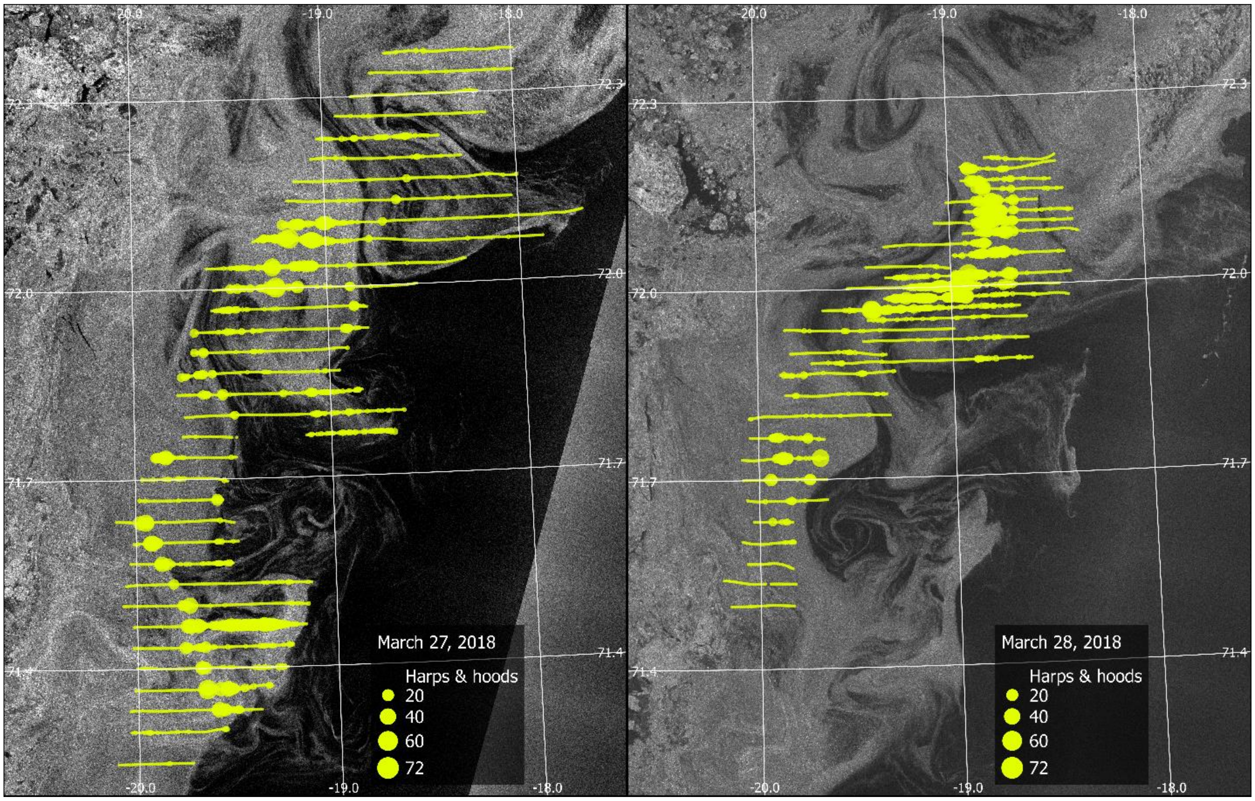

Figure 7: Photo surveys on March 27 and 28 overlaid on ice images. Each survey photograph is represented by a yellow filled circle with the radius proportional to the total number of harp and hooded seals counted on each photograph

Table 3. East-west transects (2 nm spacing) flown during fixed-wing photo surveys of harp and hooded seal whelping areas in the Greenland Sea drift ice on March 27 & 28, 2018. Positions are given in degrees & decimal minutes.

Transect	Date	Latitude	West	East	Harps	Hoods	nphotos
35002_1	March 27	71°15,0'N	20°06,0'W	19°44,0'W	1	1	42
35002_2	March 27	71°18,0'N	20°02,0'W	19°34,0'W	6	10	54
35002_3	March 27	71°20,0'N	20°02,0'W	19°23,0'W	127	33	72
35002_4	March 27	71°22,0'N	20°01,0'W	19°21,0'W	255	52	75
35002_5	March 27	71°24,0'N	20°00,0'W	19°15,0'W	88	21	83
35002_6	March 27	71°26,0'N	20°01,0'W	19°14,0'W	89	44	88
35002_7	March 27	71°28,0'N	20°01,0'W	19°09,0'W	809	105	95
35002_8	March 27	71°30,0'N	20°04,0'W	19°09,0'W	91	9	102
35002_9	March 27	71°32,0'N	20°03,0'W	19°07,0'W	14	12	102
35002_10	March 27	71°34,0'N	20°02,0'W	19°31,0'W	131	9	57
35002_11	March 27	71°36,0'N	20°01,0'W	19°29,0'W	137	9	58
35002_12	March 27	71°38,0'N	20°06,0'W	19°30,0'W	119	9	66
35002_13	March 27	71°40,0'N	19°59,0'W	19°34,0'W	32	4	46
35002_14	March 27	71°42,0'N	19°58,0'W	19°32,0'W	11	7	48
35002_15	March 27	71°44,0'N	19°54,0'W	19°29,0'W	142	14	45
35002_16	March 27	71°46,0'N	19°45,0'W	19°29,0'W	0	1	29
35002_17	March 27	71°46,0'N	19°08,0'W	18°41,0'W	22	46	49
35002_18	March 27	71°48,0'N	19°44,0'W	18°38,0'W	55	10	120
35002_19	March 27	71°50,0'N	19°47,0'W	18°50,0'W	126	17	103
35002_20	March 27	71°52,0'N	19°45,0'W	18°57,0'W	75	3	87
35002_21	March 27	71°54,0'N	19°42,0'W	18°54,0'W	38	3	87
35002_22	March 27	71°56,0'N	19°41,0'W	18°48,0'W	75	12	96
35002_23	March 27	71°58,0'N	19°36,0'W	18°48,0'W	69	15	87
35002_24	March 27	71°60,0'N	19°35,0'W	18°32,0'W	311	31	112
35002_25	March 27	72°02,0'N	19°37,0'W	18°17,0'W	310	24	146
35003_1	March 27	72°04,0'N	19°23,0'W	17°53,0'W	495	68	163
35003_2	March 27	72°06,0'N	19°13,0'W	17°40,0'W	258	39	171
35003_3	March 27	72°08,0'N	19°12,0'W	18°02,0'W	20	3	127
35003_4	March 27	72°10,0'N	19°09,0'W	18°00,0'W	9	5	127
35003_5	March 27	72°12,0'N	19°04,0'W	18°17,0'W	10	6	84
35003_6	March 27	72°14,0'N	19°02,0'W	18°24,0'W	54	12	70
35003_7	March 27	72°16,0'N	18°56,0'W	18°09,0'W	1	3	85

Table 3. East-west transects (2 nm spacing) flown during fixed-wing photo surveys of harp and hooded seal whelping areas in the Greenland Sea drift ice on March 27 & 28, 2018. Positions are given in degrees & decimal minutes.

Transect	Date	Latitude	West	East	Harps	Hoods	nphotos
35003_8	March 27	72°18,0'N	18°51,0'W	18°11,0'W	0	2	73
35003_9	March 27	72°20,0'N	18°45,0'W	17°60,0'W	0	3	81
35003_10	March 27	72°22,0'N	18°40,0'W	17°59,0'W	5	3	75
35004_1	March 28	71°30,0'N	20°09,0'W	19°50,0'W	0	0	35
35004_2	March 28	71°32,0'N	20°11,0'W	19°49,0'W	0	0	39
35004_3	March 28	71°34,0'N	20°04,0'W	19°50,0'W	0	0	26
35004_4	March 28	71°36,0'N	20°05,0'W	19°49,0'W	2	5	30
35004_5	March 28	71°38,0'N	20°02,0'W	19°50,0'W	12	8	22
35004_6	March 28	71°40,0'N	20°04,0'W	19°39,0'W	16	6	44
35004_7	March 28	71°42,0'N	20°05,0'W	19°40,0'W	78	5	46
35004_8	March 28	71°44,0'N	20°05,0'W	19°40,0'W	160	7	47
35004_9	March 28	71°46,0'N	20°03,0'W	19°40,0'W	72	17	42
35004_10	March 28	71°48,0'N	20°03,0'W	19°20,0'W	1	5	80
35004_11	March 28	71°50,0'N	19°52,0'W	19°21,0'W	6	4	56
35004_12	March 28	71°52,0'N	19°53,0'W	19°18,0'W	22	14	65
35004_13	March 28	71°54,0'N	19°50,0'W	19°21,0'W	0	11	53
35004_14	March 28	71°56,0'N	19°52,0'W	18°60,0'W	7	6	95
35004_15	March 28	71°58,0'N	19°40,0'W	19°01,0'W	188	27	72
35004_16	March 28	72°00,0'N	19°32,0'W	18°60,0'W	204	30	60
35004_17	March 28	72°02,0'N	19°26,0'W	19°00,0'W	4	0	47
35004_18	March 28	72°04,0'N	19°20,0'W	18°48,0'W	66	14	59
35004_19	March 28	72°06,0'N	19°05,0'W	18°47,0'W	69	9	32
35004_20	March 28	72°08,0'N	19°01,0'W	18°33,0'W	199	21	51
35004_21	March 28	72°10,0'N	18°56,0'W	18°28,0'W	90	22	50
35004_22	March 28	72°11,0'N	18°56,0'W	18°27,0'W	85	24	54
35004_23	March 28	72°12,0'N	18°48,0'W	18°27,0'W	0	9	41
35004_24	March 28	72°09,0'N	18°51,0'W	18°25,0'W	109	17	49
35004_25	March 28	72°07,0'N	18°55,0'W	18°22,0'W	284	20	61
35004_26	March 28	72°06,0'N	18°53,0'W	18°22,0'W	286	32	57
35004_27	March 28	72°05,0'N	18°56,0'W	18°20,0'W	191	16	65
35004_28	March 28	72°03,0'N	18°59,0'W	18°25,0'W	233	23	62
35004_29	March 28	72°01,0'N	19°20,0'W	18°23,0'W	364	43	103

Table 3. East-west transects (2 nm spacing) flown during fixed-wing photo surveys of harp and hooded seal whelping areas in the Greenland Sea drift ice on March 27 & 28, 2018. Positions are given in degrees & decimal minutes.

Transect	Date	Latitude	West	East	Harps	Hoods	nphotos
35004_30	March 28	72°00,0'N	19°01,0'W	18°27,0'W	240	43	62
35004_31	March 28	71°59,0'N	19°21,0'W	18°24,0'W	462	81	102
35004_32	March 28	71°58,0'N	19°23,0'W	18°39,0'W	128	115	80
35004_33	March 28	71°57,0'N	19°26,0'W	18°37,0'W	1	21	88
35004_34	March 28	71°55,0'N	19°27,0'W	18°37,0'W	10	4	91
35004_35	March 28	71°53,0'N	19°43,0'W	18°36,0'W	31	11	122

Due to fog in the northwestern parts of the area surveyed on March 27th, this area was re-photographed on March 28th (Fig 7; Table ??). Based on an assessment of the ice drift (10 nm southwards over 24 hours, judged by the tracks displayed by the two satellite beacons that remained in the area), this repeat survey was conducted in an area slightly offset towards the south relative to the area that was missed during the previous day (between 71°30'N and 72°12'N). Transect lines were separated by 2 nm between 71°30'N and 71°52'N. Between 71°52'N and 72°12'N, where seals were most abundant, the distance between transect lines was reduced to 1nm.

A total of 35 east-west/west-east transect lines were flown on March 28th, and 2088 images were taken.

Correcting for reader 2 bias

We estimated the parameters for the linear correction models for reader 2. The slope (β) parameters were 1.018 ($SE = 0.0032$) for harp seals and 1.035 ($SE = 0.0182$) for hooded seals (Fig. 8). For harp seals, the intercept term (α) was not statistically significant at a 95% level, and was therefore dropped. For hooded seals, the intercept term was significantly different from 0 ($\alpha = 0.055$, $SE = 0.0232$, $p = 0.02$). The counts for reader 2 were thus corrected for this bias using these fitted model parameters. Generally speaking, this suggests an underestimation by reader 2 of 1.8%, and 3.5% for harp and hooded seals respectively.

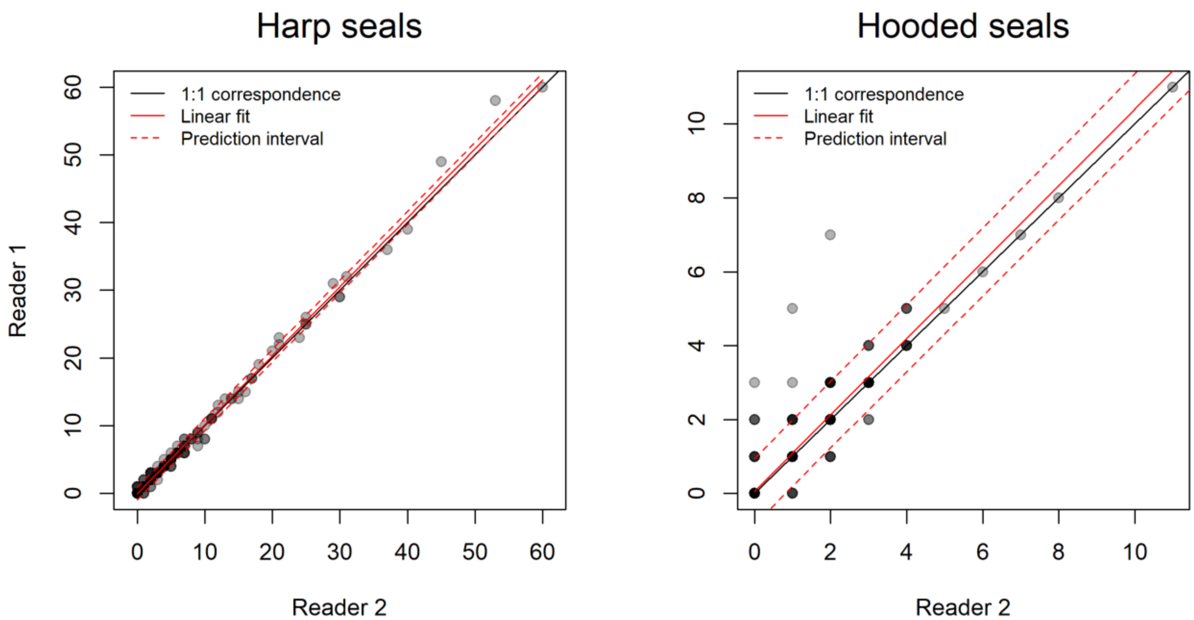

Figure 8: Inter-reader comparisons for harp and hooded seals, showing bias correction for Reader 1 using linear models with Reader 2 as explanatory variable.

Pup production estimate

A total of 7605 harp seal pups and 1315 hooded seal pups were counted in the 5093 photos from the 70 transects, without correcting for reading errors. Of these, 3985 harps and 645 hoods were counted in the 3005 photos from 35 transects flown on March 27, while 3620 harps and 670 hoods were counted in 2088 photos from 35 transects flown on March 28. The spatial distribution of the seals is found in Figure 7.

Adjusting for complex survey design

Due to the complex survey design caused by 1) flights being carried out over two consecutive days, 2) variations in transect spacing between surveys and 3) complex ice dynamics in the region during the aerial survey period (see Fig. 7), we estimated pup production using various combinations of sub-surveys.

The first approach was to split the data into three surveys:

1. All images from March 27th
2. All images from northward leg of March 28thsurvey
3. All images from southward leg of March 28thsurvey

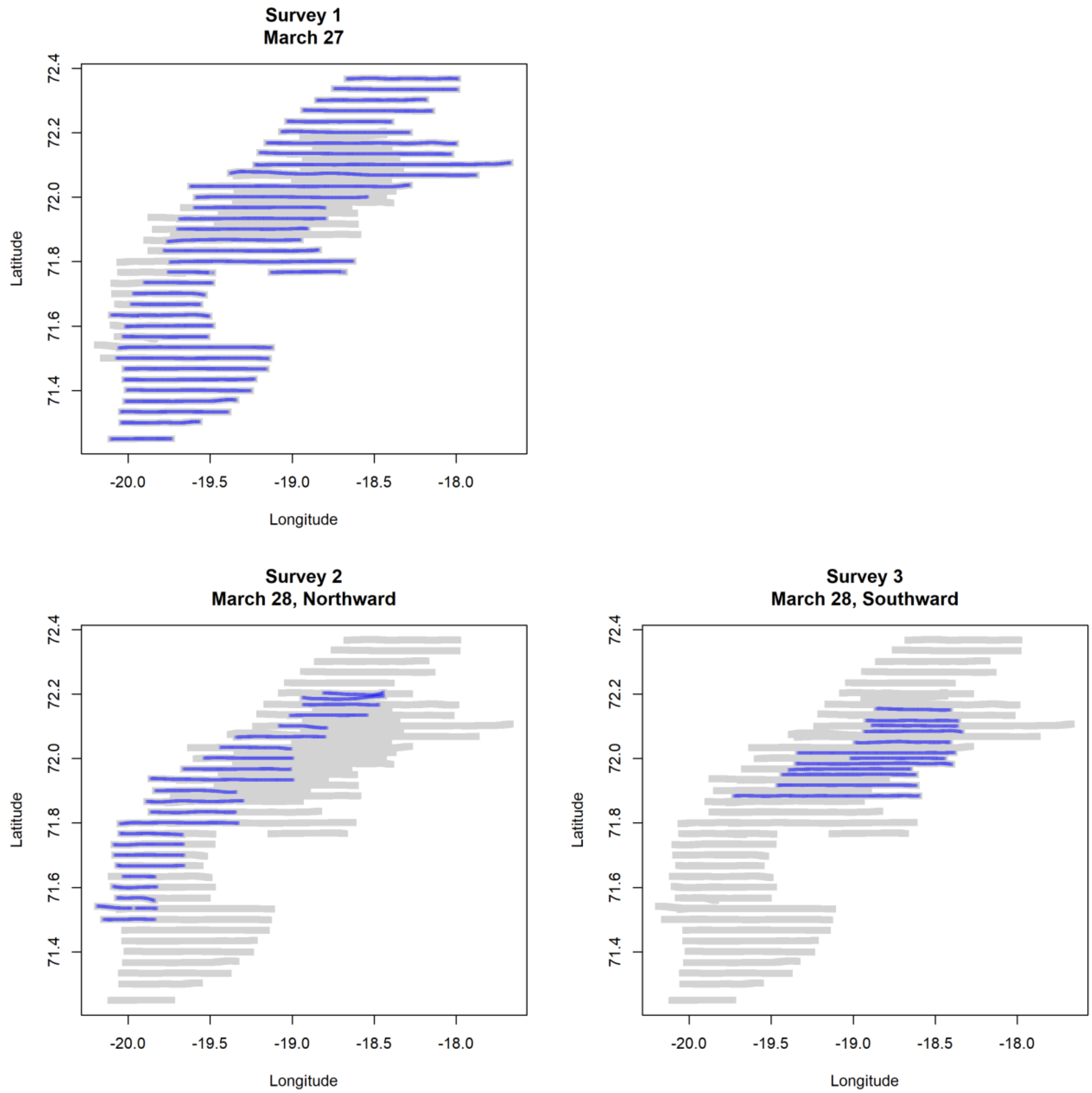

Figure 9: Maps showing the distribution of photographs designated to the three surveys (blue), overlaid on all surveys combined (grey)

These surveys are shown in Figure 9. The rationale for the split between northward and southward surveys on March 28^{t} is that the transects during the initial northward leg was spaced at roughly 2 nm, while spacing between transects during the return trip towards the south was generally around 1 nm. This initial split therefore made sense since it: a) separated the two survey days and b) allowed two estimates using different transect spacings.

Table 4. Uncorrected pup production estimates for separate surveys. Survey 1: March 27, Survey 2: March 28, northward, Survey 3: March 28 southward

Species	Survey	N	SE	lowerCI	upperCI	CV
Harp	1	51012	10448.2	40564	61460	20.5
Harp	2	17123	3303.8	13819	20427	19.3
Harp	3	22328	3353.6	18974	25682	15.0
Hood	1	8227	1364.6	6862	9592	16.6
Hood	2	3163	417.3	2746	3580	13.2
Hood	3	4089	762.0	3327	4851	18.6

Pup production estimates from these surveys for both species are presented in Table 4. For harp seals, the estimated pup production based on the survey carried out on March 27th was 51012 ($SE = 10448.2$) harp seal pups and 8227 ($SE = 1364.6$) hooded seal pups, prior to applying any corrections.

The two partially overlapping surveys carried out across a smaller latitudinal range on March 28th yielded combined mean estimates of 39451 and 7252. This lower estimate for March 28th is unsurprising, given the narrower latitudinal range covered during that day compared to March 27th. Furthermore, the two surveys on March 28th were partially, but not completely, overlapping. Direct comparison between the two is therefore not possible, and they also cannot be assumed to be completely independent.

The initial strategy to use the GPS drifters to account for ice drift between the two aerial survey dates when planning transect lines for March 28th turned out to be unsatisfactory, given the very different trajectories of the two relevant drifters (Fig 4). We therefore developed a second approach to splitting the data into three different strata:

1. Photos from March 27th in southern region (up to 71°50.2’N) at 2 nm spacing.
2. Photos from March 28th (north of 71°50.2’N and up to 72°12.3’N) at 2 nm spacing. These are based on northward leg, but extended eastwards at the same latitudes using transects ‘filled in’ during the southward leg (omitting overlapping stretches).
3. Photos from March 28th, southward transect (from 72°11.6’N to 71°53’N), omitting transects at same latitudes as used in stratum 2 in order to obtain regular spacings of roughly 2 nm. This provides an alternative estimate in a similar region.

We also created one additional fourth stratum, combined from strata 2 and 3, with 1 nm strip distance. These strata are shown in Figure 10.

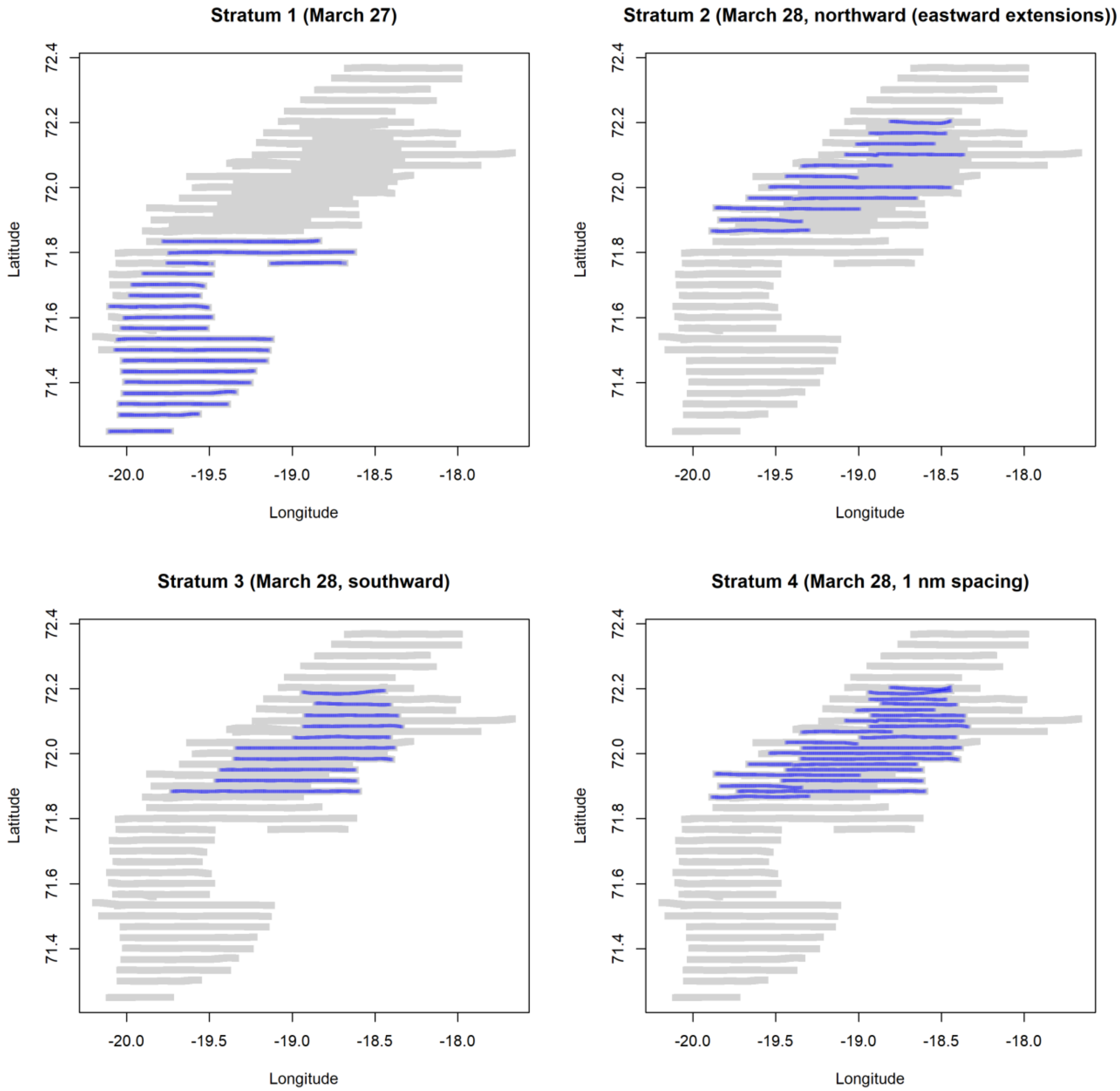

Figure 10: Maps showing the distribution of photographs designated to the four modified strata (blue), overlaid on all surveys combined (grey)

Table 5. Uncorrected pup production estimates for separate strata. Stratum 1: March 27, southern part, Stratum 2: March 28, northern part, northward, Stratum 3: March 28 southward at 2 nm spacing, Stratum 4: Strata 2 and 3 combined, 1nm spacing, Stratum 1+4: Strata 1 and 4 combined

Species	Stratum	N	SE	lowerCI	upperCI	CV
Harp	1	30393	10186.6	20206	40580	33.5
Harp	2	18217	5691.9	12525	23909	31.2
Harp	3	23322	5036.5	18285	28359	21.6
Harp	4	20629	3556.5	17073	24185	17.2
Harp	1+4	53101	9049.4	44052	62150	17.0
Hood	1	5540	1297.5	4243	6837	23.4
Hood	2	4254	1437.3	2817	5691	33.8
Hood	3	3436	732.5	2704	4168	21.3
Hood	4	3824	753.1	3071	4577	19.7
Hood	1+4	9775	1471.8	8303	11247	15.1

Pup production estimates for these modified strata are presented in Table 5. Various combined estimates for the entire surveyed area can be obtained by combining estimates for Stratum 1 (March 27th southern region) with either one of the other strata. Strata 1 and 2 combined yields mean estimates of 48610 harp seal pups and 9794 hooded seal pups; Strata 1 and 3 combined yields mean estimates of 53715 and 8976 for harp and hooded seal pups respectively.

While these mean estimates are relatively similar, the standard error of the estimate for Stratum 4 (i.e. Strata 2 & 3 combined at half transect spacing) is substantially lower. We therefore suggest that the most robust estimate for the entire region is provided by combining Strata 1 and 4, giving estimated pup productions (prior to corrections for reader bias and temporal distribution of births) of 53101 ($SE = 9049.4$) harp seal pups and 9775 ($SE = 1471.8$) hooded seal pups.

It is worth noting that this is also relatively similar to the estimated pup productions based on the March 27th flights only (51012, $SE = 10448.2$ and 8227, $SE = 1364.6$ for harp and hooded seal pups respectively, see Table ??).

Using Strata 1 and 4 combined, and after correcting for reader bias and temporal birth distribution, we obtained estimated of pup productions of 54181 ($SE = 9236$) for harp seals and 12977 ($SE = 1823$) for hooded seals.

DISCUSSION

The used survey methods are comparable with those applied in previous surveys performed for harp and hooded seal assessments in the northwest Atlantic (Bowen *et al.*, 1987; Hammill *et al.*, 1992; Stenson *et al.*, 1993, 1997, 2002, 2003, 2005, 2010; Hammill and Stenson., 2006), in the Greenland Sea (Øritsland and Øien., 1995; ICES, 1998, 1999; Haug *et al.*, 2006; Salberg *et al.*, 2008; Øigård *et al.*, 2010, 2014a, 2014b) and in the White Sea (Potelov *et al.*, 2003; ICES, 2016). In general, the survey design calls for one or more visual and/or photographic surveys of every whelping patch. Primarily due to the scattered distribution of both species during the current study, no visual surveys were attempted, and only one photographic survey was conducted.

Harp seals

Previous (1977-1991) mark-recapture experiments (Øien and Øritsland., 1995) and aerial pup production surveys performed in 1991 (Øien and Øritsland., 1995), 2002 (Haug *et al.*, 2006), and 2007 (Øigård *et al.*, 2010) suggested a prevailing increase in Greenland Sea harp seal pup production. A new estimate obtained in 2012, corrected for reader error, temporal birth distribution and overlapping photos, was 89 590 (SE = 12 310, CV = 13.7%). Although the 2012 estimate was lower than the estimates in 2002 and 2007, it was not significantly different from those estimates on a 5% level and Øigård *et al.* (2014a) therefore suggested that the pup production had not changed much over the preceding decade (Øigård *et al.*, 2014b). However, the difference in mean estimates between 2012 and the current corrected estimate of 54 181 (SE = 9 049, CV = 17.0%) is highly significant ($t = 12.723$; $df = 26$; $p < 0.0001$), indicating a reduction in pup production as also observed in the Barents Sea / White Sea population after 2003 and in the Northwest Atlantic population in 2012 (ICES, 2016).

As in previous surveys, reconnaissance surveys were conducted in the period 18-31 March 2018 of all areas historically used by harp seals in the Greenland Sea (areas between 68°40'N and 74°47'N, see Øritsland and Øien., 1995; Haug *et al.*, 2006; Øigård *et al.*, 2010, 2014a). There is good evidence to conclude that previous ice conditions in the central Greenland Sea were significantly different from those witnessed in recent decades (Divine and Dick., 2006). These differences manifest themselves as a reduction in extent and concentration of drift ice, particularly within the region around and north of the Jan Mayen island where the drifting ice traditionally formed an ice-peninsula (Wilkinson and Wadhams., 2005) which used to be the main harp seal breeding location (Sergeant, 1991). Observed ice reductions have obviously changed the harp seal breeding habitat in the Greenland Sea.

Whereas the Greenland Sea harp seal stock has been subject to commercial exploitation for centuries, the hunting pressure has been substantially reduced in the past 3-4 decades (Iversen, 1927; Nakken, 1988; Sergeant, 1991; Haug *et al.*, 2006; ICES, 2016). Based on catch per unit effort analyses and mark-recapture pup production estimates, it has been assumed that the population has increased since the early 1960s, although direct evidence has been limited (Ulltang and Øien., 1988; Øien and Øritsland., 1995). Recent model runs, performed by ICES (2016), have confirmed that the population may have increased in size since c.a. 1970, and it has been predicted that the population could continue to increase under the current harvest regime of very small annual removals. Nevertheless, the 2018 pup production estimate is significantly lower than previous estimates, which is in contrast to the assumptions of an increasing population. It is important to note that the annual fecundity rates in harp seals can be highly variable. In the Northwest Atlantic, where annual harp seal fertility estimates are available since 1954, the proportion of females that were pregnant undergoes dramatic variations, from 40% to more than 85% between years (ICES, 2011). Such changes can certainly account for rapid changes in pup production, which are therefore not necessarily an indication of a sudden population decrease or increase. Unfortunately, age at maturity and fecundity of Greenland Sea harp seal females have been examined much less regularly, and data are therefore insufficient for similar analyses to be carried out for this population.

Hooded seals

Surveys using the same methodology as in the present study were conducted to assess the hooded seal pup production in the Greenland Seas in 1997 (ICES, 1999), 2005 (Salberg *et al.*, 2008), 2007 (Øigård *et al.*, 2010) and 2012 (Øigård *et al.*, 2014b). The 1997 pup production was estimated to be 24 000 (SE = 4 600, CV = 19.0%), which was a minimum estimate as it was not corrected for the temporal distribution of births or pups born outside of the whelping patches. The 2005, 2007 and 2012 estimates, corrected both for readers error and the temporal distribution of births, were 15 250 pups (SE = 3 473, CV = 22.8%), 16 140 (SE = 2 140, CV = 13.3%) and 13 655 pups (SE = 1 888, CV = 13.8%), respectively. Also the corrected 2018 estimate (N = 12 977, SE = 1 823, CV = 15.1%) is lower than all previous estimates (but not significantly lower than the estimate in 2012: $t = 1.462$; $df = 26$; $p = 0.136$).

Hooded seals are usually found in more moderate densities than harp seals (Lavigne and Kovacs., 1988). The accuracy of estimates obtained from aerial surveys is dependent on the degree to which the possible sources of error are minimized. In assessing the relative importance of different sources of bias in estimating seal abundance from aerial surveys, Myers and Bowen. (1989) concluded that the greatest source of bias arose from missing whelping concentrations. The extensive reconnaissance surveys conducted in the period 18-31 March of all areas historically used by hooded seals in the Greenland Sea reduced the likelihood of missing major whelping concentrations in 2018, although difficult weather conditions may have left some pups unsurveyed in the very open ice fringes northeast of the area. In previous hooded seal surveys the surveyed areas have traditionally consisted of three strata types: (1) concentrations, i.e., whelping patches where both visual and photographic surveys were conducted with high-density coverage, (2) scattered pups in areas of historically high pup densities, and (3) scattered pups in areas of historically low pup densities, in cases of the two latter the methodology implied coverage with low-density photographic surveys (Bowen *et al.*, 1987; Stenson *et al.*, 1997). As both in 2005 and 2012, the pups were scattered with no major patches over a manageable area in 2018, and a high-density coverage was obtained.

Changes in the size of harvested seal populations are often attributed to hunting pressure. Although the Greenland Sea stock of hooded seals has been subject to commercial exploitation for centuries (Iversen, 1927; Sergeant, 1966; Nakken, 1988), the hunting pressure was substantially reduced in the 2-3 decades that preceded the total protection of the species in 2007 (Salberg *et al.*, 2008; ICES, 2016). However, despite reduced, from 2007 completely stop, in hunting, model runs using recent pup production estimates as input suggest that the Greenland Sea hooded seal population has decreased substantially since the 1950s and stabilized at a very low level (less than 10% of the 1946 level) since the 1970s (ICES, 2006b, 2016; Øigård *et al.*, 2014b). So far, the total protection given to the stock in 2007 seems not to have resulted in any changers in population development. In other commercially harvested seal stocks in the North Atlantic (hooded seals in the Northwest Atlantic, harp seals in both the Northwest and Northeast Atlantic), models have indicated that reduced catches were followed by population increases from the early 1970s (Hammill and Stenson., 2005, 2006, 2007, 2010; ICES, 2006a, 2006b, 2016; Skaug *et al.*, 2007). It seems unlikely that the different population development following reduced removals in Greenland Sea hooded seals could have been caused by recent hunting pressure alone. The distribution area of Greenland Sea hooded seals includes virtually all of the Nordic Seas (Greenland, Norwegian and Iceland Sea, see Folkow *et al.*, 1996) which are dynamic ecosystems influenced by a combination of factors that will have to be considered simultaneously to explain the observed population development. As for the harp seals, the observed reductions in extent and concentration of drift ice have obviously changed also the hooded seal breeding habitat in the Greenland Sea. Apparently, the reduced hooded seal abundance seems not to be accompanied by any visible reductions in female fertility (ICES, 2016). Interestingly, Northwest Atlantic hooded seal females have shown signs of reduced reproductive rates since the 1990s in spite of a modest increase in population abundance (Frie *et al.*, 2012).

ACKNOWLEDGEMENTS

We would like to thank Friðrik Adolfsson and the pilots Eggert Sæmundsson, Bjarni Helgason, Guðmundur Emilsson and Grétar Húnn Benediktsson from Norlandair, the camera operator Jaakko Koljander from Terratec, the captain and crew on KV “Svalbard” and the helicopter crew, pilot Tom Østrem and technician Karl Arvid Andersen, from Airlift AS, for invaluable assistance. We are especially grateful to M. Polterman and L. Lindblom for reading the photos.

REFERENCES

Bowen, W. D., Myers, R. A., and Hay., K. 1987. Abundance estimation of a dispersed, dynamic population: hooded seals (Cystophora cristata) in the Northwest Atlantic. Can, 44: 282–295.

Bowen, W. D., Mcmillan, J. I., and Blanchard., W. 2007. Reduced population growth of gray seals at Sable Island: Evidence from pup production and age of primiparity. Mar. Mamm. Sci, 23: 48–64.

Casella, G., and Berger., R. L. 1990. Statistical Inference. Duxbury Press, Belmont, California.

Cochran, W. G. 1977. Sampling techniques. 3rd ed. Wiley, New York.

Divine, D. V., and Dick., C. 2006. Historical variability of sea ice edge position in the Nordic Seas. J. Geophys. Res, 111.

Folkow, L. P., Mårtensson, P.-E., and Blix, A. S. 1996. Annual distribution of hooded seals (Cystophora cristata) in the Greenland and Norwegian seas. Polar Biol., 16: 179–189. http://link.springer.com/10.1007/BF02329206.

Frie, A. K., Stenson, G. B., and Haug., T. 2012. Long term trends in reproductive and demographic parameteres of female Northwest Atlantic hooded seals (Cystophora cristata Erxleben 1777): Population responses to ecosystem change? Can, 90: 376–392.

Hammill, M. O., Stenson, G. B., and Myers., R. A. 1992. Hooded seal pup production in the Gulf of St. Lawrence. Can, 49: 2546–2550.

Hammill, M. O., and Stenson., G. B. 2005. Abundance of Northwest Atlantic harp seals (1960-2005). DFO CSAS Res, 90: 38. http://www.meds-sdmm.dfo-mpo.gc.ca/csas/applications/publications).

Hammill, M. O., and Stenson., G. B. 2006. Abundance of Northwest Atlantic hooded seals (1960-2005). DFO CSAS Res, 68: 23. http://www.meds-sdmm.dfo-mpo.gc.ca/csas/applications/publications.

Hammill, M. O., and Stenson., G. B. 2007. Application of the precautionary approach and conservation reference points to the management of Atlantic seals. ICES J. Mar, 64: 701–706.

Hammill, M. O., and Stenson., G. B. 2010. Abundance of Northwest Atlantic harp seals (1952-2010). DFO CSAS Res, 114: 12.

Haug, T., Stenson, G. B., Corkeron, P. J., and Nilssen., K. T. 2006. Estimation of harp seal (Pagophilus groenlandicus) pub production in the North Atlantic completed: Results from surveyws in the Greenland sea in 2002. ICES J. Mar, 63: 95–104.

Healey, B. P., and Stenson., G. B. 2000. Estimating pup production and population size of the Northwest Atlantic harp seal (Phoca groenlandica). DFO CSAS Sec, 81: 28.

ICES. 1998. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals, 28 Aug- 3.Sept 1997, ICES Headquarters, Copenhagen.: 35 pp.

ICES. 1999. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals, 29 Sept. - 2. Oct. 1998, Tromsø, Norway.: 35 pp.

ICES. 2006a. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 30 Aug-3 Sept. 2005, St.Johns, Newfoundland, Canada.: 48 pp.

ICES. 2006b. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 12-16 June. 2006, ICES Headquarters, Copenhagen, Denmark.: 28 pp.

ICES. 2011. ICES WGHARP REPORT 2011 Report of the Working Group on Harp and Hooded Seals (WGHARP), 15-19 Aug, 2011, St Andrews, Scotland.: 15–19. St Andrews, Scotland. http://www.ices.dk/sites/pub/Publication Reports/Expert Group Report/acom/2011/WGHARP/WGHARP 2011.pdf.

ICES. 2016. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 26-30 Sept. 2016, ICES Headquarters, Copenhagen, Denmark.: 85 pp.

Iversen, T. 1927. Drivis og selfangst. Årsber. Vedk. Norges Fisk., 1927: 1–84.

Lavigne, D. M., and Kovacs., K. M. 1988. Harps and hoods: Ice-breeding seals of the northwest Atlantic. Univ. Waterloo Press. Waterloo, 174.

Myers, R. A., and Bowen., W. D. 1989. Estimating bias in Aerial surveys of harp seal pup production. J. Wildl. Manag., 53: 361–372.

Nakken, O. 1988. Fangsthistorikk. Fisk. Gang, 74: 14–15.

Potelov, V. A., Golikov, A. P., and Bondarev., V. A. 2003. Estimated pup production of harp seals Pagophilus groenlandicus in the White Sea, Russia. in, 2000: 1012–1017.

QGIS Development Team. 2016. QGIS Geographic Information System, Version 2.18.16. Open Source Geospatial Foundation Project. http://qgis.osgeo.org.

Rasmussen, B. 1960. Om klappmyssbestanden i det nordlige Atlanterhav. Fisk. Hav., 1960: 1–23.

Reed, K. L. Q., and Ashford, J. R. 1968. A system of models for the life cycle of a biological organism. Biometrika, 55: 211–221.

Salberg, A. B., Haug, T., and Nilssen, K. T. 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.

Sergeant, D. E. 1966. Exploitation and conservation of harp and hooded seals. Polar Rec. (Gr. Brit)., 12: 541–551.

Sergeant, D. E. 1991. Harp seals, man and ice. Can. Spec. Publ. Fish, 114: 1–153.

Skaug, H. J., Frimannslund, L., and Øien., N. I. 2007. Historical population assessment of Barents Sea harp seals (Pagophilus groenlandicus). ICES J. Mar, 64: 1356–1365.

Stenson, G. B., and Myers., R. A. 1988. Accuracy of pup classifications and its effect on population estimates in the hooded seals (Cystophora cristata). Can, 45: 715–719.

Stenson, G. B., Myers, R. A., Hammill, M. O., I.-h., N., Warren, W. G., and Kingsley., M. C. S. 1993. Pup production of harp seals, Phoca groenlandica. Northwest Atl., 50: 2429–2439.

Stenson, G. B., Myers, R. A., I.-h., N., and Warren., W. G. 1997. Pup production and population growth of hooded seals (Cystophora cristata) near Newfoundland, Canada. Can. J. Fish. Aquat. Sci, 54: 209–216.

Stenson, G. B., Hammill, M. O., Kingsley, M. C. S., Sjare, B., Warren, W. G., and Myers., R. A. 2002. Is there evidence of increased pup production in northwest Atlantic harp seals, Pagophilus groenlandicus? ICES J. Mar, 59: 81–92.

Stenson, G. B., Rivest, L.-p., Hammill, M. O., Gosselin, J. F., and Sjare., B. 2003. Estimating pup production of harp seals, Pagophilus groenlandicus. Norhtwest Atl., 19: 141–160.

Stenson, G. B., Hammill, M. O., Lawson, J., Gosselin, J. F., and Haug., T. 2005. 2004 Pup production of harp seals, Pagophilus groenlandicus. in the Northwest Atlantic. DFO CSAS, Res. Doc. 2005/037. 47 pp.

Stenson, G. B., Hammill, M. O., Lawson, J., and Gosselin., J. F. 2006. 2005 Pup production of hooded seals, Cystophora cristata. in the Northwest Atlantic. DFO CSAS, Res. Doc. 2006/067. 40 pp.

Stenson, G. B., Hammill, M. O., and Lawson., J. 2010. Estimating pup production of Northwest Atlantic harp seals, Pagophilus groenlandicus: resulta of the 2008 surveys. DFO CSAS, Res, 2009.

Stewart, R. E. A., and Lavigne., D. M. 1980. Neonatal growth of northwest Atlantic harp seals (Pagophilus groenlandicus). J. Mammol., 61: 670–680.

Ulltang, Ø., and Øien., N. 1988. Bestandsutvikling og status for grønlandssel og klappmyss. Fisk. Gang, 74: 8–10.

Wilkinson, J. P., and Wadhams., P. 2005. A method of detecting change in the ice conditions of the central Greenland Sea by the whelping locations of harp seals. J. Clim., 18: 1216–1226.

Øien, N., and Øritsland., T. 1995. Use of mark-recapture experiments to monitor seal populations subject to catching. Whales, Seals, Fish Man: 35–45.

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. Northwest Atl. Fish. Sci., 42: 103–123.

Øigård, T. A., Haug, T., and Nilssen, K. T. 2014a. From pup production to quotas: Current status of harp seals in the Greenland Sea. ICES J. Mar, 71: 537–545.

Øigård, T. A., Haug, T., and Nilssen, K. T. 2014b. Current status of hooded seals in the Greenland Sea. Victims of climate change and predation? Biol. Cons., 172: 29–36.

Øritsland, T. 1964. Klappmysshunnens forplantningsbiologi. Fisk. Hav., 1964: 1–15.

Øritsland, T., and Øien., N. 1995. Aerial surveys of harp and hooded seal pubs in the Greenland Sea pack ice. Whales, Seals, Fish Man: 77–87.

WP SEA 248

ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS

IMR, TROMSØ, NORWAY, 2-6 SEPTEMBER 2019

The 2019 abundance of hooded seals (*Cystophora cristata*) in the Greenland Sea

Martin Biuw[1], Tore Haug[1], Tor Arne Øigård[2]

[1]Norwegian Computing Centre, P.O. Box 114 Blindern, NO-0314 Oslo, Norway

[2]Institute of Marine Research, Fram Centre, P.O. Box 6606 Langnes, NO-9296 Tromsø, Norway

ABSTRACT

Historical records of fecundity rates on mature female hooded seals in the Greenland Sea are very sparse. In previous work (Øigård and Haug, 2016a) the population dynamics model was therefore run for a range of fecundity rates. It was determined that a fecundity rate of 0.7 was realistic for this population. While we present estimates for the same range of fecunduty as in Øigård and Haug (2016a), we consider the model with a fecundity rate of 0.7 to be the most robust ad realistic. In agreement with previous model runs, our results 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. Including the new estimate of pup production obtained in 2018, a 2019 abundance of 64 267.28 1+ animals (49 935 – 78 600) and 12 944 (9 821 – 16 068) pups were estimated. The total 2019 population of hooded seals in the Greenland Sea therefore was estimated to 76 623 (58 299 – 94 947) seals of all ages. Even when assuming no catch, the model predictions indicated a decrease in the 1+ population of about 13% (SD:14%) over the next 15 years. The 2019 population of hooded seals in the Greenland Sea was about 6.7% of N_{max}, which is well below N_{lim} (30% of N_{max}). Following the Precautionary harvest strategy previously developed by WGHARP (see ICES, 2006a, 2006b), the implication of the population being below N_{lim} is that no catch from the population is advised.

INTRODUCTION

The total population size of hooded seals in the Greenland Sea is estimated using a deterministic age-structured population dynamics model which makes use of historical catch records, fecundity rates, age specific proportions of mature females, and estimates of pup production to estimate the population size trajectory (ICES, 2011). Prior to 2011, the model that was used to assess the Northeast Atlantic hooded seal population assumed a constant maturity ogive and pregnancy rate over the entire time period over which the model was run. At the 2011 meeting of WGHARP, the traditional model was modified to allow for non-constant maturity ogives and pregnancy rates in order to utilize all historical data available (ICES, 2011). The model also allowed the estimates obtained to be projected into a future population size for which statistical uncertainty is provided for several relevant harvest options. While the historical data on fecundity rates available for the Greenland Sea hooded seal population is very sparse, all observed rates are around 0.7 (ICES, 2016). Because of this, the most recent model run (ICES, 2016) used a fixed fecundity rate of F = 0.7 for all years.

MATERIALS & METHODS

Reproductive rates

Maturity curves were constructed based on female reproductive material collected over the period 1990-94 and 2008-10 (ICES, 2011). The record of historical fecundity rate is sparse, but previous analyses have indicated that fecundity rates remained constant around F = 0.7 during the period 1958 – 1999 (ICES, 2013). This is lower than the estimate of F = 0.9 used by the WG in 2011 (ICES, 2011). Øigård and Haug (2016a) ran the population model for a range of fecundity rates, and found that while they resulted in relatively large variations in historical population sizes, the effects were non-significant in terms of estimated population sizes in recent decades. While we present estimates for all fecundity rates evaluated by Øigård and Haug (2016a), we propose the model that was run using F = 0.7 to be considered when providing assessment and advice. This is in accordance with what was done for the most recent assessments (ICES, 2016).

Survey pup production estimates and catch history

Pup production estimates are available from aerial surveys conducted in 1997, 2005, 2007, 2012 2018 (Table 2, ICES, 1998, 2011; Salberg *et al.*, 2008; Øigård *et al.*, 2014; Biuw *et al.*, 2019). Catch levels for the period 1946 – 2019 are presented in ICES (2016) and Haug. *et al.* (2019).

The population model

The population model used to assess the abundance for the Greenland Sea hooded seal population is a deterministic age-structured population dynamics model. It uses historical catch records, fecundity rates, age specific proportions of mature females, and estimates of pup production to estimate the population trajectory. The model is similar to the models used to assess the abundance of the Greenland Sea harp seal population and the Barents Sea / White Sea harp seal population (ICES, 2013; Øigård and Haug, 2016b).

RESULTS & DISCUSSION

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+}. The population size and pup production trajectories are shown in Figure 1. All model runs indicates a substantial decrease in the population abundance from the late 1940s until the early 1980s. In the two most recent decades, the population size appears to have been stable at a low level, or decreased slowly. Using a fecundity rate of F = 0.7, we estimated a 2019 abundance of 64 267.28 1+ animals (49 935 – 78 600) and 12 944 (9 821 – 16 068) pups. The total 2019 population of hooded seals in the Greenland Sea therefore is estimated to 76 623 (58 299 – 94 947) seals of all ages. For comparison, the total population size of hooded seals in the Greenland Sea was estimated to 85 790 seals in 2011 (ICES, 2011), 82 830 seals in 2013 (ICES, 2013), and 80 460 in 2017 (ICES, 2016).

Catch options

Since the only available fecundity rates are based on data from the 1990s, the Greenland Sea hooded seals should be regarded as data poor. The impacts of the catch scenarios are explored over a 15 years period. Summary of requested options for various catch scenarios of hooded seals in the Greenland Sea are:

1. Current catch level (average of the catches in the period 2015 – 2019).
2. Equilibrium catches.
3. Catches that would reduce the population to N70 with probability 0.8 over a 15-years period.

Current catch level is defined as the average catch level of the last 5 years, i.e., the average catch level of the period 2015 – 2019. Due to the low pup production numbers the Greenland Sea hooded seal population has been protected since 2007 (ICES, 2006b, 2013, 2016). While there is no commercial hunt on hooded seals in the Greenland Sea, there is a small scientific hunt. The equilibrium catch level is defined as the (fixed) annual catch level that stabilizes the future 1+ population under the estimated model. As the model predicts a decline of the population size even for no catch, and that the total abundance is way below N_{lim}, the catch options for equilibrium catch level, and the catch level that would reduce the population to N_{70} with probability 0.8 over a 15 year period is not applicable.

At current catch levels, and using a fecundity rate F = 0.7, the model indicates a 13% (SD:14%) decrease of the 1+ population over the next 15 years. Note however, that the confidence intervals for the depletion coefficient are quite wide.

The 2019 population of hooded seals in the Greenland Sea remains way below N_{lim} (30% of N_{max}). Following the Precautionary harvest strategy previously developed by WGHARP (see ICES, 2006a, 2006b), the implication of the population being below N_{lim} is that no catch from the population is advised.

REFERENCES

Biuw, M., Øigård, T. A., Nilssen, K. T., Stenson, G., and Haug, T. 2019. Estimation of pup production of harp and hooded seals in the Greenland Sea in 2018.

Haug., T., Biuw, M., and Zabavnikov, V. 2019. Norwegian and Russian catches of harp and hooded seals in the Northeast Atlantic in 2017-19.

ICES. 1998. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals, 28 Aug- 3.Sept 1997, ICES Headquarters, Copenhagen.: 35 pp.

ICES. 2006a. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 30 Aug-3 Sept. 2005, St.Johns, Newfoundland, Canada.: 48 pp.

ICES. 2006b. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 12-16 June. 2006, ICES Headquarters, Copenhagen, Denmark.: 28 pp.

ICES. 2011. ICES WGHARP REPORT 2011 Report of the Working Group on Harp and Hooded Seals (WGHARP), 15-19 Aug, 2011, St Andrews, Scotland.: 15–19. St Andrews, Scotland. http://www.ices.dk/sites/pub/Publication Reports/Expert Group Report/acom/2011/WGHARP/WGHARP 2011.pdf.

ICES. 2013. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 30 Aug-3 Sept. 2005, St.Johns, Newfoundland, Canada.: 48 pp.

ICES. 2016. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 26-30 Sept. 2016, ICES Headquarters, Copenhagen, Denmark.: 85 pp.

Salberg, A. B., Haug, T., and Nilssen, K. T. 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.

Øigård, T. A., Haug, T., and Nilssen, K. T. 2014. Current status of hooded seals in the Greenland Sea. Victims of climate change and predation? Biol. Cons., 172: 29–36.

Øigård, T. A., and Haug, T. 2016a. The 2017 abundance of Hooded Seals (Cystophora cristata) in the Greenland Sea.

Øigård, T. A., and Haug, T. 2016b. The 2017 abundance of harp seals (Pagophilus groenlandicus) in the Barents Sea / White Sea.

Table 1. Estimates of proportions of mature females (pi,t). The P_1 estimates are from ICES (2008) and the P_2 estimates are from ICES (2011). Mature females had at least one Corpus Luteum or Corpus Albicans in the ovaries.

Age	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y	11y
p_1	0.00	0.05	0.27	0.54	0.75	0.87	0.93	0.97	0.98	0.99	1.00
p_2	0.00	0.00	0.06	0.60	0.89	0.97	0.99	1.00	1.00	1.00	1.00

Table 2. Estimates of Greenland Sea hooded seal pup production, based on data from ICES (1998), ICES (2011), Salberg et al., 2008, Øigård et al., 2014 and Biuw et al. (2019).

Year	Estimated number of pups	CV
1997	23 762	0.192
2005	15 250	0.228
2007	16 140	0.133
2012	13 655	0.138
2018	12 977	0.140

Table 3. Estimated mean values and standard deviations of the parameters used in the current management model for Greenland Sea hooded seals. Estimates are provided for a range of choices of the fecundity rate, F. Priors used were the same as those used in Øigård & Haug (2016b). See text for parameter definitions.

	F=0.5		F=0.7		F=0.9	
Parameter	Mean	SD	Mean	SD	Mean	SD
N_{1946}	1 304 560	356 883	1 136 055	300 842	1 013 514	256 437
M_0	0.33	0.22	0.34	0.22	0.34	0.22
M_{1+}	0.14	0.1	0.17	0.09	0.19	0.09
$N_{0,2019}$	12 732	1 542	12 944	1 593	13 164	1 616
$N_{1+,2019}$	79 314	8 907	64 267	7 312	55 765	6 331
$N_{Total,2019}$	91 123	10 952	76 623	9 348	68 551	8 347
D_{1+}	0.84	0.13	0.87	0.14	0.91	0.15
$N_{Total,2035}$	76 670	19 873	66 978	17 950	62 137	16 791

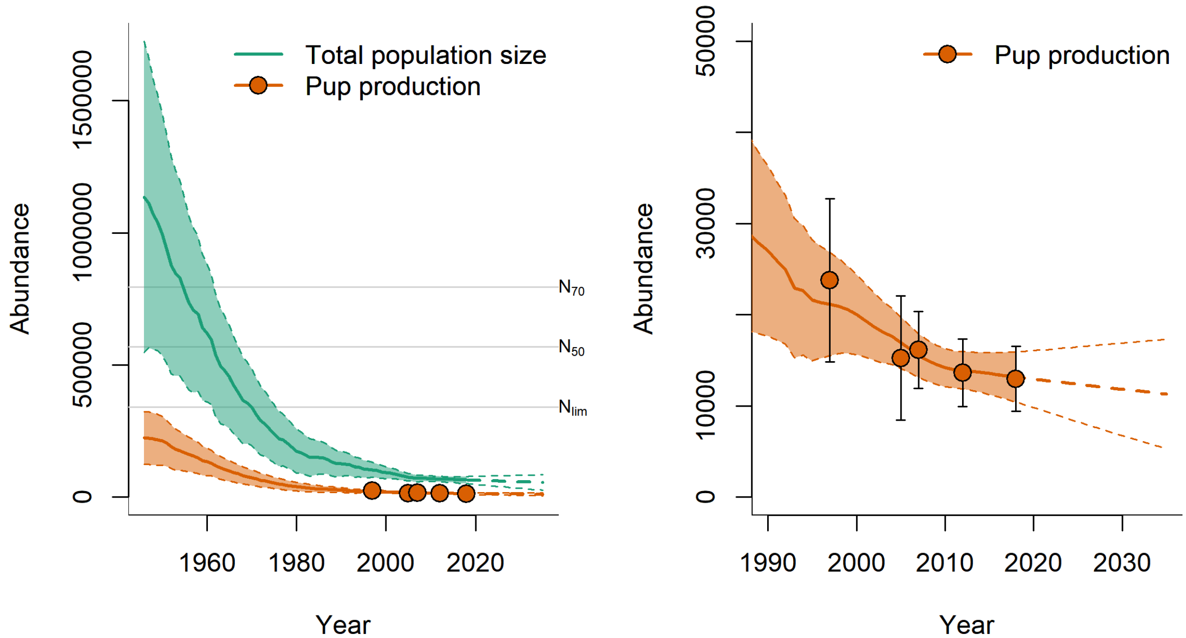

Figure 1: Modelled population trajectories for Greenland Sea hooded seal pups and adults (full lines), 95% confidence intervals (shaded areas) and future projections (dashed lines) for various choices of fecundity rates (F). N70, N50, and Nlim denote the 70%, 50%, and 30% of the historical maximum population size, respectively (obtained from the scenario of a mean fecundity rate of F = 0.7). Observed pup production estimates are indicated by filled circles.

WP SEA 249

ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS

IMR, TROMSØ, NORWAY, 2-6 SEPTEMBER 2019

NORWEGIAN AND RUSSIAN CATCHES OF HARP AND HOODED SEALS IN THE NORTHEAST ATLANTIC IN 2017-2019

Tore Haug[1], Martin Biuw[1] and Vladimir Zabavnikov[2]
[1]Institute of Marine Research, Fram Centre, PO Box 6606 Langnes, N-9296 Tromsø, Norway
[2]PINRO, Knipovich st. 6, 183763 Murmansk, Russia

The 2017-2019 TAC for harp seals in the Greenland Sea was set at 26 000 1+ animals (where 2 pups balanced one 1+ animal), i.e. the removal level that would reduce the population with 30% over the next 15 year period (see ICES 2016). The total removals of Greenland Sea harp seals in 2017-2019 are listed in Table 1. No Russian vessels have targeted this area since 1994. Total catches of harp seals (performed by one vessel in 2017 and 2018, and two vessels in 2019) were 2,000 (including 1,934 pups) in 2017, 2,703 (including 1,218 pups) in 2018, and 4,599 (including 2,168 pups) in 2019.

Concerns over low pup production estimates in 2007 resulted in a recommendation from ICES that no harvest of Greenland Sea hooded seals should be permitted, with the exception of catches for scientific purposes, from 2007 (see ICES 2006). This advice was immediately implemented, and has been maintained due to subsequent low pup production estimates in 2012 (ICES 2016). Three pups (2018) and one adult (2019) were taken by mistake by the commercial sealers. Total catches (Table 2) were 17 (whereof 14 pups) in 2017, 17 (whereof 9 pups) in 2018, and 23 (whereof 14 pups) in 2019.

Following the potential dramatic decline in White Sea harp seal pup production observed in 2003, pup production appears to have stabilized at this low level, and still persists. Due to concern over this, ICES (2016) recommended that removals be restricted to the estimated sustainable equilibrium level which was 10,090 1+ animals (where 2 pups balanced one 1+ animal) in 2017-2019. The Joint Norwegian-Russian Fisheries Commission has followed this request and allocated 7,000 seals of this TAC to Norway in all years. A ban implemented on all pup catches prevented a Russian hunt in the White Sea during the period 2009-2013. This ban was removed before the 2014 season. However, the availability of ice has been too restricted to permit sealing, resulting in no commercial Russian harp seal catches in the White Sea after 2014 and including the period 2017-2019 (Table 3). While no Norwegian vessels targeted for the hunting area in the southeastern Barents Sea (the East Ice) in 2017, one Norwegian vessel hunted in the area in both 2018 and 2019. In September 2017, 1 harp seal (1+ animal) was taken for scientific purposes north of Svalbard – presumably from the White Sea / Barents Sea population. Total catches of harp seals were 1 in 2017, 2,241 (including 21 pups) in 2018, and 602 (including 34 pups) in 2019.

Up to and including the 2014 season, Norwegian seal hunts were subsidized by the Norwegian government. For the 2015 season these subsidies were removed entirely, only to be reinstalled at a considerably lower level in 2016.

References

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

ICES 2016. Report of the ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals (WGHARP), ICES HQ, Copenhagen, Denmark, 26-30 September 2016. ICES CM 2016 / ACOM:21: 81 pp.

Table 1. Catches of **harp seals** in the Greenland Sea ("West Ice"), 2017-2019.

	Norwegian catches			Russian catches			Total catches		
Year	Pups	1yr+	total	Pups	1yr+	total	Pups	1yr+	Total
2017	1934	66	2000	0	0	0	1934	66	2000
2018	1218	1485	2703	0	0	0	1218	1485	2703
2019	2168	3636	5804	0	0	0	2168	3636	5804

Table 2. Catches of **hooded seals** in the Greenland Sea ("West Ice"), 2017-2019 for scientific purposes.

	Norwegian catches			Russian catches			Total catches		
Year	Pups	1yr+	total	Pups	1yr+	total	Pups	1yr+	Total
2017	14	3	17	0	0	0	14	3	17
2018	9	8	17	0	0	0	9	8	17
2019	14	9	23	0	0	0	14	9	23

Table 3. Catches of **harp seals** in the Barents Sea / White Sea ("East Ice"), 2017-2019.

	Norwegian catches			Russian catches			Total catches		
Year	Pups	1yr+	total	Pups	1yr+	total	Pups	1yr+	Total
2017	0	1	1	0	0	0	0	1	1
2018	21	2220	2241	0	0	0	21	2220	2241
2019	34	568	602	0	0	0	34	568	602

WP SEA 250

ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS

IMR, TROMSØ, NORWAY, 2-6 SEPTEMBER 2019

The 2019 abundance of harp seals (*Pagophilus groenlandicus*) in the Greenland Sea

Martin Biuw[1], Tor Arne Øigård[2], and Tore Haug[1]

[1]Institute of Marine Research, Fram Centre, PO Box 6606 Langnes, NO-9296 Tromsø, Norway

[2]Norwegian Computing Centre, PO Box 114 Blindern, NO-0314 Oslo, Norway

ABSTRACT

Here we present an updated population assessment of the Greenland Sea harp seal pupulation, based on a new pup production estimate from 2018, and catch data up to and including the 2019 season. In agreement with previously published assessments, our model runs indicated an increase in abundance of the Greenland Sea harp seal population from around 1970s. However, the rate of increase is considerably lower than previous estimates, with estimated abundances being stable or slighly decreasing since the early 2000's. We obtained an estimated 2019 abundance of 360 401 (258 245 – 462 556) 1+ animals and 66 407 (51 604 – 81 211) pups, yielding a total estimate of 426 808 (313 004 – 540 613) seals. Current catch levels indicated an increase in the 1+ population of 28% over the next 15 years. The equilibrium catch level was found to be 8 422 (100% 1+ animals). If pups are hunted two pups balance one 1+ animal. A catch level of 11 505 animals (100% 1+) will bring the population size down to N70 with probability 0.8 within the next 15 years. These values are all considerably lower than previous estimates. The reason for these differences compared to previous assessments is most likely the relatively low pup production estimate obtained in 2018 (54 181, CV=0.17), highlighting the sensitivity of the model to sparse observational data.

INTRODUCTION

Total abundance of harp seals in the Greenland Sea is estimated using a model which incorporates data on age specific reproductive rates and removals with independent, periodic estimates of pup production (see Skaug *et al.*, 2007; Hammill and Stenson., 2010; ICES, 2011). Previous to 2011, the model used to assess the Greenland Sea harp seal population only made use of a constant maturity ogive and pregnancy rate over the entire time period the model was run. In the 2011 meeting of WGHARP, however, the traditional model was modified to allow for non-constant maturity ogives and pregnancy rates in order to utilize all historical data available (ICES, 2011). The model also allowed the estimates obtained to be projected into a future population size for which statistical uncertainty was provided for several relevant harvest options. By incorporating the full range of reproductive data available, both the abundance estimate and the estimated harvest options provided by the model were lower, but presumably more realistic, than those provided by the original model (ICES, 2011). The model was used for management of the Greenland Sea harp seal population in 2013 (ICES, 2013) and 2016 (ICES, 2016). We have continued to use this model for providing advice for setting catch quotas for the Greenland Sea harp seal population for 2020 and subsequent years.

MATERIALS & METHODS

Reproductive data

The population dynamics model use historical catch records, fecundity rates, age specific proportions of mature females, and estimates of pup production to estimate the population trajectory.

Two types of reproductive data are used: information on the proportion of females that are mature at a given age (i.e., maturity ogive) and the proportion of mature females that are pregnant at a given year (i.e. fecundity rate). The historical data of the maturity curve is sparse, consisting of only three curves (Table 1). One curve is from the period 1959 – 1990, one is from 2009 and the last one is from 2014. For the periods with missing data (1990 – 2009 and 2009 – 2014), a linear transition between the available maturity curves is assumed. Figure 1 show the maturity curves in Table 1, along with the linear transition between the curves in years with missing data.

The model also makes use of historical values of the fecundity rates F rates that are obtained through sampling during commercial hunt (Table 2). Data are available from a Russian long term data set (1959 - 1991, see Frie *et al.*, 2003) and later updated with new Norwegian data for 2008 and 2009 (ICES, 2011), and for 2014 (ICES, 2016). The most recent values are now 5 years old, which secures data-rich status for the stock. To maintain this status, samples were collected during the hunting season in 2019, but these materials have not yet been analysed and are thus not available for this meeting. The long term data set on pregnancy rates relies on the assumption that pregnancy in the previous cycle can be estimated based on the presence/absence of a large luteinised Corpus albicans (LCA) in the ovaries of females sampled in April-June (ICES, 2009). A similar approach has previously been used for estimation of pregnancy rates of ringed seals (Stirling, 2005). For periods where data are missing, a linear transition between estimates is assumed. Figure 2 shows the available historical pregnancy rates and the linear transition in periods with missing data. As opposed to being part of the data to which the model is fit by maximum likelihood, these rates are treated as known quantities by the population dynamics model.

Survey pup production estimates and catch history

Pup production estimates are available from mark-recapture estimates (1983-1991, see Øien and Øritsland., 1995) and aerial surveys conducted in 2002 (Haug *et al.*, 2006), in 2007 (Øigård *et al.*, 2010), in 2012 (Øigård *et al.*, 2014), and in 2018 (Biuw *et al.*, 2019). Catch levels for the period 1946 – 2019 are presented in ICES (2014) and Haug. *et al.* (2019).

The population model

The population model used to assess the abundance for the NW Atlantic harp seal population is a deterministic age-structured population dynamics model. A similar model is used to assess the abundance of the Greenland Sea hooded seal population and the Barents Sea / White Sea harp seal population (ICES, 2013). It was also used for assessing the historical population of the Barents Sea harp seals (Skaug *et al.*, 2007). For initiation of the model it is assumed that the population had a stable age structure in year $y_0 = 1945$, i.e.,

$$N_{i,y_0} = N_{y_0} s_{1+}^{i-1}(1 - s_{1+}) \quad j = 1, .., A - 1 \quad (1)$$

$$N_{A,y_0} = N_{y_0} s_{1+}^{A-1} \quad (2)$$

Here, A is the maximum age group containing seals aged A and higher, and set to 20 years (ICES, 2013), and N_{y_0} is the estimated initial population size in year y_0. The model is parameterized by the natural mortalities M_0 and M_{1+} for the pups and seals 1 year and older seals, respectively. These mortalities determine the survival probabilities $s_0 = exp(-M_0)$ and $s_{1+} = exp(-M_{1+})$.

The model has the following set of recursion equations:

$$N_{1,y} = (N_{0,y-1} - C0, y - 1)s_0$$

$$Na, y = (N_{a-1,y-1} - C_{a-1,y-1})s_{1+} \quad a = 2, .., A - 1 \quad (3)$$

$$N_{A,y} = [(N_{A-1,y-1} - C_{A-1,y-1}) + (N_{A-1,y-1} - C_{A,y-1})]s_{1+}$$

Since available data do not allow for more detailed age-dependence in survival to be estimated it is assumed that the mortality rates are age-independent within the 1+ group. The $C_{a,y}$ are the age-specific catch numbers. Catch records are aggregated over age, and only provide information about the annual number of pups and number of 1+ seals caught. To obtain $C_{a,y}$ in the last of the reqursive equations, we assume that the age-distribution in the catch follows the modelled age distribution and employ pro rata rules in the model (Skaug *et al.*, 2007):

$$C_{a,y} = C_{1+,y} \frac{N_{a,y}}{N_{1+,y}} \quad a = 1, \ldots, A \quad (4)$$

where $N_{1+,y} = \sum_{y=1}^{A} N_{a,y}$, with $N_{a,y}$ being the number of individuals at age a in year y.

The modelled pup abundance is given by:

$$N_{0,y} = \frac{F_y}{2}\sum_{a=1}^{A} p_{a,y}\,N_{a,y} \quad (5)$$

where $N_{a,y}$ is the number of females at age a in year y, F_y is the time-varying fecundity rates and $p_{a,y}$ are the time-varying age specific proportions of mature females.

The model calculates a depletion coefficient D_{1+}, which describes the degree of increase or decrease in the 1+ population trajectory on a 15-year scale:

$$D_{1+} = \frac{N_{1+,y+15}}{N_{1+,y}} \quad (6)$$

where y is the year of last available data on catch and/or pup production (i.e in this case 2019). The depletion coefficient is used for finding the equilibrium catch levels. The equilibrium catch level is defined as the catch level that maintains the population size at the current level, i.e. the catch level that gives $D_{1+} = 1$.

Parameter estimation

Assuming normality for the pup production counts, their contribution to the log-likelihood function is:

$$\sum_{y=y_{E_1}}^{y=y_{E_Y}} - log(cv_{0,y}) - \frac{1}{2}\frac{(N_{0,y} - n_{0,y})}{(cv_{0,y}n_{0,y})} \quad (7)$$

where $y_{E_1}...y_{E_Y}$ are the Y years with available pup production estimates, $n_{0,y}$ and $cv_{0,y}$ denotes the survey pup production count and corresponding coefficient of variation (CV) for year y, respectively (Table 3).

The population dynamics model is a Bayesian type model as priors are imposed on the parameters. A vague normal prior is assumed for the initial population size N_{y_0} and a truncated normal prior for both the pup mortality M_0 and the mortality for the 1+ group M_{1+}. The priors used are found in Table 4. The combined likelihood-contributions for these priors are:

$$-\frac{1}{2}(\mathbf{b} - \mathbf{m})^T \Sigma^{-}1(\mathbf{b} - \mathbf{m}) - \frac{1}{2}ln|\Sigma| - \frac{3}{2}ln(2\pi) \quad (8)$$

where $\mathbf{b} = (N_{y_0}, M_0, M_{1+})^T$ is a vector containing the parameters estimated by the model, T denotes the vector transpose, **m** is a vector containing the respective mean values of the normal priors for the parameters in **b**, and Σ is a diagonal matrix with the variance of the respective prior distributions on the diagonal. The mean of the prior for M_0 was taken to be three times that of the mean of M_{1+}.

All parameter estimates are found by minimizing the likelihood function using the statistical software Template Model Builder (Kristensen *et al.*, 2016). Template Model Builder (TMB) calculates standard errors (SE) for the model parameters, as well as the derived parameters such as present population size and D_{1+}. Template Model Builder uses a quasi-Newton optimization algorithm with bounds on the parameters, and calculates estimates of standard errors of model parameters 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. All data processing and analyses were done using R (R Core Team, 2018). Model fitting was done using the R package TMB (Kristensen *et al.*, 2016).

RESULTS

Population estimates

The estimated population sizes and parameters used in the model are presented in Table 4. The modelled population trajectory is shown in Figure 3. Similar to previous assessments, the estimated population trajectory indicates an increase from the 1970s up until about 2004, after which the population appears to have stabilized (with some fluctuations) around about 1+ 325 000 animals. This represents roughly 70% of the estimated maximum historical population size estimated using the updated estimates. Assuming annual catches at levels representing the mean catches over the last five years, the model indicates an increase in total abundance of 28% over the next 15 years. However, the confidence intervals are very wide and indicate that the 15 year projections could range from below N70 (around 342 000) to around 765 000 seals. In addition to the wide confidence intervals, these projections are substantially lower than projections obtained from model runs presented in ICES (2016). and any future projections should therefore be interpreted with care.

The model estimates a 2019 abundance of 360 401 (258 245 – 462 556) 1+ animals and 66 407 (51 604 – 81 211) pups, yielding a total estimate of 426 808 (313 004 – 540 613) seals. Again, these estimates are considerably lower than those predicted for 2017 (543 800 (366 500 – 719 400) 1+ animals and 106 500 (76 500 – 136 400) pups, yielding a total estimate of 650 300 (471 200 – 829 300) seals).

In light of the relatively sparse fecundity estimates available for this population, we also ran the same basic model, except that fecundity was kept at its average value (F=0.849) throughout the entire time series. This had very modest effects on the population trajectories and parameter estimates (see Fig 2). The most obvious differences were:

1. Slightly higher mean estimate of maximum historical population size (516 774 vs. 473 963),
2. Slightly lower estimate of minimum historical population size (303 918 vs. 305 107),
3. Slightly smoother overall population trajectories
4. No sudden decrease in pup production estimate immediately after last estimate, and
5. Slightly higher estimate of average projected total population size (592 076 vs. 553 515).

However, none of these differences are sufficiently large to fundamentally change the conclusions or our assessment of the population status for Greenland Sea harp seals.

Catch Options

The impact of different catch scenarios are explored over a 15 year period. Options considered were: 1. Current catch level (average of the catches in the period 2015 – 2019). 2. Equilibrium catches. 3. Catches that would reduce the population to N70 with probability 0.8 over a 15-years period.

Current catch level is defined as the average catch level of the last 5 years (i.e. 2015-2019). The equilibrium catch level is defined as the (fixed) annual catch level that stabilizes the future 1+ population under the estimated model. We ran two sets of models for each catch option; the first assuming 0% pups in the catch, and the other using the average pup proportion in 2015-2019 (55.6%). The catch level that would reduce the population size to N70 with probability 0.8 over a 15-years period is found by finding the catch level that has N70 just included in the 80% confidence interval of the 15-year prediction of the total population size.

The estimates for the various catch options are given in Table 5. Current catch level indicates an increase in the 1+ population of 28% the next 15 years. The equilibrium catch level is 8 422 (100% 1+ animals). If pups are hunted two pups balance one 1+ animal. A catch level of 11 505 animals (100% 1+) will bring the population size down to N70 with probability 0.8 within 15 years.

DISCUSSION

Our results suggest that the addition of the relatively low pup production estimate from 2018 (54 181, CV=0.17) results in markedly different population trajectories (Fig. 3) and estimates of both historical, current and future population sizes (Table 4), compared to those presented in ICES (2016). While Øigård and Haug (2016) estimated that the Greenland Sea population increased from a mid 1970s size of approximately 35% of its level in 2016, our results indicate a much more modest increase from a mid 1970's size of about 71% of current estimated population size in 2019. This is due to both a higher mid-1970s population estimate in the new runs (305 107 compared to 235 700) and a lower current population estimate in the new runs (2019 population estimate of 426 808 compared to 2016 estimate of 640 494). This suggests that the difference between the slower population growth rate of Greenland Sea harp seal population and the faster growth rate of the Northwest Atlantic is even larger than previously identified.

It may be that the population dynamics of the Greenland Sea harp seals is similar to that of the Barents Sea / White Sea population. That other Northeast Atlantic population appears to have undergone a slow increase of the population from the mid 1970s (Skaug *et al.*, 2007) to a peak during the early 2000s, followed by a recent dramatic pup production decrease resulting in a current estimated total abundance of approximately 1.4 million individuals (ICES, 2014). Given that the two Northeast Atlantic harp seal populations exploit common feeding grounds in the northern Barents Sea during their most intensive feeding period from July to November (Folkow *et al.*, 2004; Nordøy *et al.*, 2008), it may not be surprising that they should exhibit similar population trends. While problems due to drift ice retreat appear to affect all three populations (ICES, 2011), the ecological and environmental conditions faced by seals in the Northeast and Northwest Atlantic are very different. Barents Sea / White Sea harp seals have been observed to exhibit poorer body condition in recent years than 10-15 years ago (Øigård *et al.*, 2013), presumably due to possible links between the abundance of fish species such as cod Gadus morhua, polar cod Boreogadus saida, and capelin Mallotus villosus, which are competing with harp seals for prey. Lower abundance of pelagic crustaceans (krill and amphipods) may also have contributed to the observed lower harp seal body condition in the Barents Sea (Øigård *et al.*, 2013). Similar body condition data are not available for the Greenland Sea harp seal population at present. While the stocks of fish in the Barents Sea, cod in particular, are at record high levels at present (Bogstad *et al.*, 2015), the situation is the opposite in the Northwest Atlantic, where cod has been almost completely absent over the past two decades (Link *et al.*, 2009; Hutchings and Rangeley, 2011). Thus, it seems possible that less seal-fish competition in the Northwest Atlantic may have promoted more favourable growth conditions for the harp seal population in that area (a predator pit effect, see Link *et al.*, 2009) as compared to harp seals in the Northeast Atlantic.

REFERENCES

Biuw, M., Øigård, T. A., Nilssen, K. T., Stenson, G., and Haug, T. 2019. Estimation of pup production of harp and hooded seals in the Greenland Sea in 2018. WGHARP, WP SEA 247.

Bogstad, B., Gjøsæter, H., Haug, T., and Lindstrøm, U. 2015. A review of the battle for food in the Barents Sea: cod vs. marine mammals. Front. Ecol. Evol., 3.

Folkow, L. P., Nordøy, E. S., and Blix, A. S. 2004. Distribution and diving behaviour of harp seals (Pagophilus groenlandicus) from the Greenland Sea stock. Polar Biol., 27: 281–298.

Frie, A. K., Potelov, V. A., Kingsley., M. C. S., and Haug., T. 2003. Trends in age-at-maturity and growth parameters of female Northeast Atlantic harp seals, Pagophilus groenlandicus (Erxleben, 1777). ICES J. Mar. Sci., 60: 1018–1032.

Hammill, M. O., and Stenson., G. B. 2010. Abundance of Northwest Atlantic harp seals (1952-2010). DFO CSAS Res, 114: 12.

Haug, T., Stenson, G. B., Corkeron, P. J., and Nilssen., K. T. 2006. Estimation of harp seal (Pagophilus groenlandicus) pub production in the North Atlantic completed: Results from surveyws in the Greenland sea in 2002. ICES J. Mar, 63: 95–104.

Haug., T., Biuw, M., and Zabavnikov, V. 2019. Norwegian and Russian catches of harp and hooded seals in the Northeast Atlantic in 2017-19. WGHARP, WP SEA 249.

Hutchings, J. A., and Rangeley, R. W. 2011. Correlates of recovery for Canadian Atlantic cod (Gadus morhua). Can. J. Zool., 89: 386–400. http://www.nrcresearchpress.com/doi/10.1139/z11-022.

ICES. 2009. ICES WGNAS REPORT 2009 Report of the Working Group on North Atlantic Salmon (WGNAS) Copenhagen , Denmark International Council for the Exploration of the Sea: 47pp.

ICES. 2011. ICES WGHARP REPORT 2011 Report of the Working Group on Harp and Hooded Seals (WGHARP), 15-19 Aug, 2011, St Andrews, Scotland.: 15–19. St Andrews, Scotland. http://www.ices.dk/sites/pub/Publication Reports/Expert Group Report/acom/2011/WGHARP/WGHARP 2011.pdf.

ICES. 2013. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 30 Aug-3 Sept. 2005, St.Johns, Newfoundland, Canada.: 48 pp.

ICES. 2014. Report of the ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP): 58pp.

ICES. 2016. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 26-30 Sept. 2016, ICES Headquarters, Copenhagen, Denmark.: 85 pp.

Kristensen, K., Nielsen, A., Berg, C. W., Skaug, H., and Bell, B. 2016. TMB: Automatic Differentiation and Laplace Approximation. J. Stat. Softw., 70. http://arxiv.org/abs/1509.00660%0Ahttp://dx.doi.org/10.18637/jss.v070.i05.

Link, J. S., Bogstad, B., Sparholt, H., and Lilly, G. R. 2009. Trophic role of Atlantic cod in the ecosystem. Fish Fish., 10: 58–87.

Nordøy, E. S., Folkow, L. P., Potelov, V., Prischemikhin, V., and Blix, A. S. 2008. Seasonal distribution and dive behaviour of harp seals (Pagophilus groenlandicus) of the White Sea-Barents Sea stock. Polar Biol., 31: 1119–1135.

R Core Team. 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

Skaug, H. J., Frimannslund, L., and Øien., N. I. 2007. Historical population assessment of Barents Sea harp seals (Pagophilus groenlandicus). ICES J. Mar, 64: 1356–1365.

Stirling, I. 2005. Reproductive rates of ringed seals and survival of pups in Northwestern Hudson Bay, Canada, 1991-2000. Polar Biol., 28: 381–387.

Øien, N., and Øritsland., T. 1995. Use of mark-recapture experiments to monitor seal populations subject to catching. Whales, Seals, Fish Man: 35–45.

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. Northwest Atl. Fish. Sci., 42: 103–123.

Øigård, T. A., Lindstrøm, U., Haug, T., Nilssen, K. T., and Smout, S. 2013. Functional relationship between harp seal body condition and available prey in the Barents Sea. Mar. Ecol. Prog. Ser., 484: 287–301.

Øigård, T. A., Haug, T., and Nilssen, K. T. 2014. From pup production to quotas: Current status of harp seals in the Greenland Sea. ICES J. Mar, 71: 537–545.

Øigård, T. A., and Haug, T. 2016. The 2017 abundance of harp seals (Pagophilus groenlandicus) in the Barents Sea / White Sea. WGHARP, WP SEA 239.

Table 1. Estimates of proportions of mature females (pi,t). The P1 estimates are from the period 1950-1990 (ICES, 2009), the P2 estimates are from 2009 (ICES, 2011) and the P3 estimates are from 2014 (Frie, 2016).

Age	1y	2y	3y	4y	5y	6y	7y	8y	9y	10y	11y	12y	13y
p_1	0.00	0.00	0.06	0.29	0.55	0.74	0.86	0.93	0.96	0.98	0.99	1.00	1.00
p_2	0.00	0.00	0.00	0.00	0.06	0.28	0.55	0.76	0.88	0.95	0.98	0.99	1.00
p_3	0.00	0.00	0.00	0.00	0.33	0.71	0.89	0.96	0.99	0.99	1.00	1.00	1.00

Table 2. Estimates of proportion of Greenland Sea harp seal females giving birth. Data from (ICES, 2011) and (Frie, 2016).

Year	Fecundity	SD
1964	0.92	0.04
1978	0.88	0.03
1987	0.78	0.03
1990	0.86	0.04
1991	0.83	0.05
2008	0.80	0.06
2009	0.81	0.03
2014	0.91	0.03

Table 3. Estimates of Greenland Sea harp seal pup production (ICES 2011, Øigård et al., 2010, Øigård et al., 2019). Data from 1983-1991 are mark-recapture estimates; those from 2002, 2007, 2012 and 2018 are from aerial surveys.

Year	Estimated number of pups	CV
1983	58 539	0.104
1984	103 250	0.147
1985	111 084	0.199
1987	49 970	0.076
1988	58 697	0.184
1989	110 614	0.077
1990	55 625	0.077
1991	67 274	0.082
2002	98 500	0.179
2007	110 530	0.250
2012	89 590	0.137
2018	54 181	0.170

Table 4. Estimated and derived mean values and standard deviations of the parameters used in the model for Greenland Sea harp seals. N70 is 70% of Nmax, Nlim is 30% of Nmax.

Parameter	Mean	SD
N_{1946}	369 522	29 505
M_0	0.24	1.09
M_{1+}	0.14	0.16
$N_{0,2019}$	66 407	7 552
$N_{1+,2019}$	360 400	52 120
$N_{Total,2019}$	426 808	58 063
D_{1+}	1.28	0.08
$N_{Total,2035}$	553 514	107 662
N70	370 266	105 665
Nlim	142 189	-

Table 5. Catch options with relative 1+ population size (D1+) in 15-years (2035) for harp seals in the Greenland Sea.

Catch option	Percent pups	Pup catch	1+ catch	Total catch	D_{1+}		
					2.5%	Mean	97.5%
Current level	55.6%	1 578	1 259	2 837	1.12	1.28	1.4
Equilibrium	55.6%	6 319	5 042	11 361	0.79	1.00	1.2
Equilibrium	0%	0	8 422	8 422	0.79	1.00	1.2
Reduce to N_{70}	55.6%	8 770	6 998	15 768	0.62	0.85	1.1
Reduce to N_{70}	0%	0	11 505	11 505	0.61	0.86	1.1

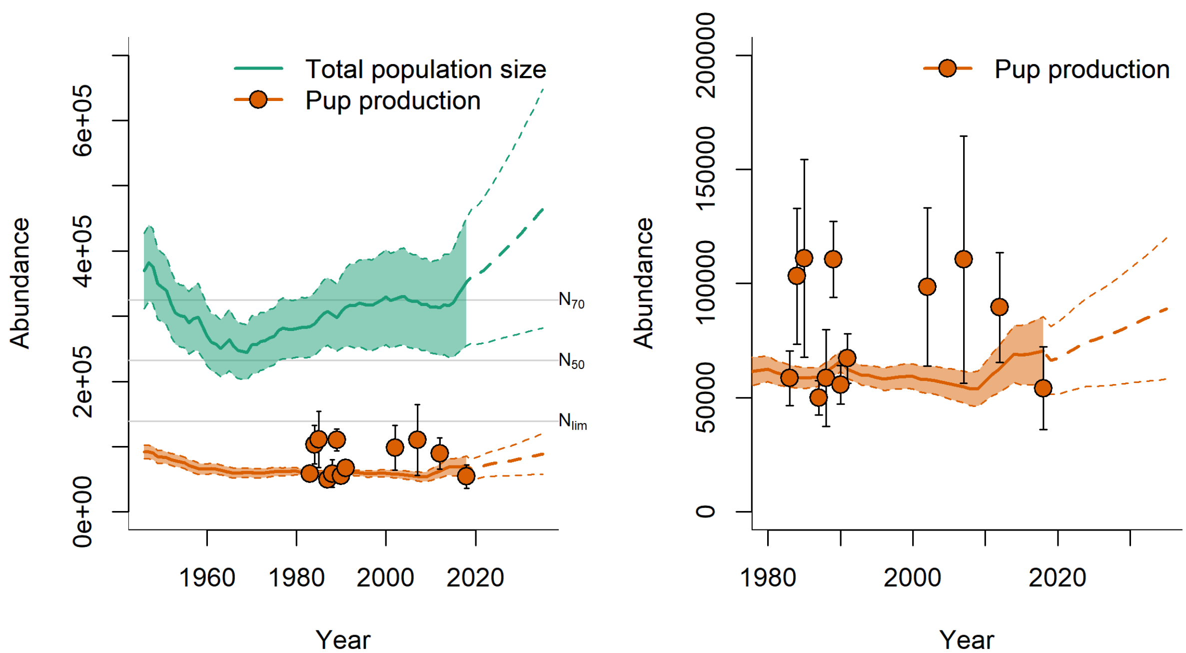

Figure 1: Modelled population trajectories for Greenland Sea harp seal pups and adults (full lines), 95% confidence intervals (shaded areas) and future projections (dashed lines). N70, N50, and Nlim denote the 70%, 50%, and 30% of the historical maximum population size, respectively. Observed pup production estimates are indicated by filled circles.

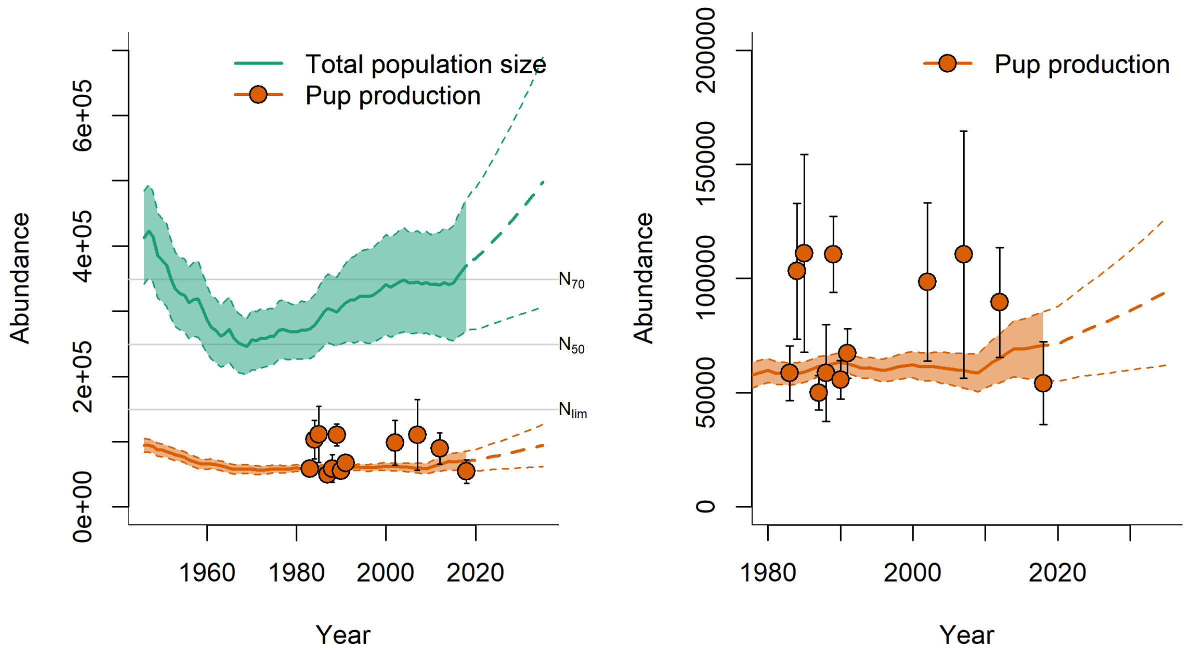

Figure 2: Modelled population trajectories for Greenland Sea harp seal pups and adults using mean Fecundity throughout time series

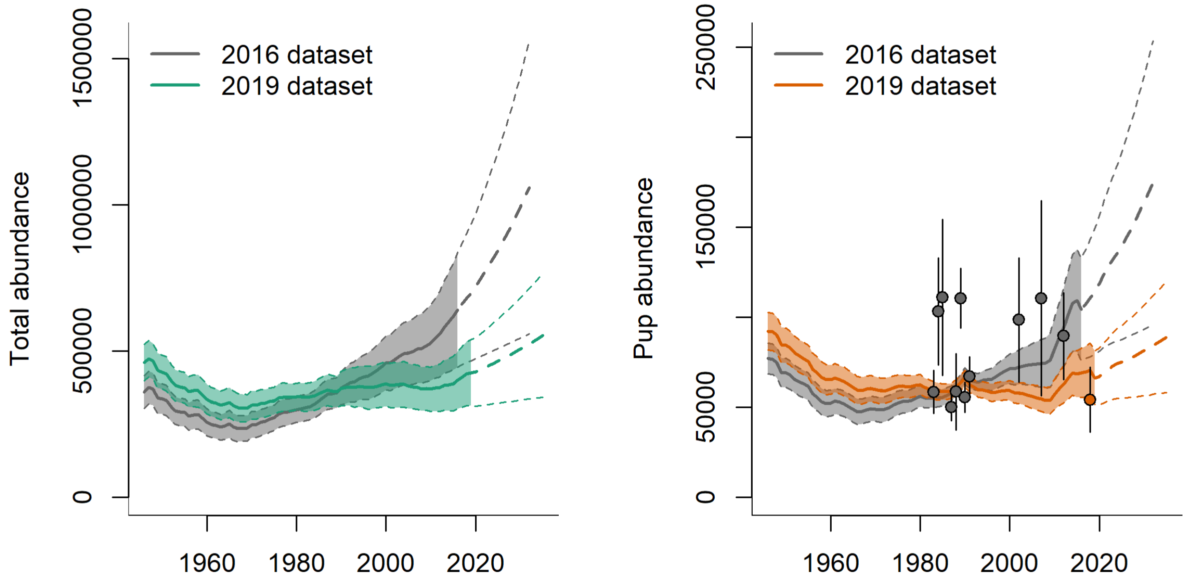

Figure 3: Comparison of estimated pup abundance trajectories based on data available in 2016 and 2019

WP SEA 251

ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS

IMR, TROMSØ, NORWAY, 2-6 SEPTEMBER 2019

The 2019 abundance of harp seals (*Pagophilus groenlandicus*) in the Barents Sea / White Sea

Martin Biuw[1], Anne Kirstine Frie[1], Martin Kristiansen[1], Michael Poltermann[1], Tor Arne Øigård[2], and Tore Haug[1]

[1]Institute of Marine Research, Fram Centre, PO Box 6606 Langnes, NO-9296 Tromsø, Norway

[2]Norwegian Computing Centre, PO Box 114 Blindern, NO-0314 Oslo, Norway

ABSTRACT

Russian aerial surveys of Barents Sea / White Sea harp seal pups during the period 1998-2013 indicate a reduction in pup production after 2003. The model currently used in the management of the Barents Sea / White Sea harp seal population is a deterministic age-structured population dynamics model and it assumes that extensive knowledge of reproduction rates are available. Due to scarcity of historical data on fecundity the current management model provides a poor fit to the pup production data for the harp seal population and the uncertainties are likely to be underestimated. The model estimates a 2019 abundance of 1 338 284 (1 151 921 – 1 524 647) 1+ animals and 253 461 (220 347 – 286 575) pups, yielding a total estimate of 1 591 745 (1 373 695 – 1 809 794) seals. Current catch levels indicated an increase in the 1+ population of 49% over the next 15 years. The equilibrium catch level was estimated to be 39 804 seals (100% 1+ animals). If pups are hunted two pups balance one 1+ animal. The PBR removals were estimated to be 45 009 seals (16% pups) using a recovery rate of Fr = 0.5. At this recovery rate the model predicts a slight population increase over the next 15 years. To be consistent with the previous assessment done in 2016, we also estimated the PBR catch level with a smaller recovery rate of Fr = 0.25. Using this recovery rate the PBR removals were estimated to be 22 505 (16% pups), and the model predicted a significant population increase over the next 15 years. No conversion factor between pups and adults exists for the PBR catch level.

INTRODUCTION

Russian aerial surveys of Barents Sea / White Sea harp seal pups during the period 1998-2013 seems to indicate a reduction in pup production after 2003 (ICES, 2009, 2011, 2014)). The most likely explanation for this change seems to be a decline in the reproductive state of females

(ICES, 2011). In the 2009 meeting, WGHARP concluded that the traditional NE Atlantic population model was unable to capture the sudden drop in pup production (ICES, 2009). The fit to the observed survey data was extremely poor and the predicted 2009 pup production was unrealistic in comparison to the observed pup production. The model used a constant maturity ogive over the entire time period. Considering the changes observed in reproductive rates in this population, WGHARP recommended that the existing model be modified to allow for non-constant reproductive rates. Therefore, at the 2011 meeting of WGHARP the model was modified to use all of the available data on reproductive rates and provided a reasonable fit to the 2010 pup production estimate, but was still not able to capture the dynamics of the observed pup production estimates. However, it provided a conservative estimate of the current population, and WGHARP felt that this model was adequate to be used to provide advice (ICES, 2011).

Given the difficulties in fitting the model to the survey-based pup production estimates from the Barents Sea / White Sea population, the WG recommended that different approaches to modify the model be explored to improve the fit to the data (ICES, 2013). The population model currently used in management of the Barents Sea / White Sea harp seal populations is a deterministic age-structured population dynamics model with 3 unknown parameters (pup mortality, mortality of 1 year and older seals, initial population size). The proportion of mature females that are pregnant, the fecundity rate, data is included in the model as a known quantity and no uncertainty around the measurements has been accounted for (ICES, 2013; Øigård *et al.*, 2014). The low dimensional parameter space and scarce available data on fecundity makes the model stiff and unable to fit to variations in the observed data well, and the resulting confidence intervals are likely to be underestimated. Øigård and Skaug (2014) have therefore suggested an improvement of the population model in order make it more flexible in capturing the dynamics of the observed pup production data. They proposed to account for the temporal variation in fecundity using a state-space approach, and assumed the fecundity to be a stochastic process that was integrated with the age-structured population dynamics of the current management model.

The new stochastic model was presented for WGHARP at the 2014 meeting and a comparison between the existing management model and the new state-space model was done. The state-space model provided a tight fit to the survey pup production estimates as it captured the sudden drop in the pup production survey estimates in 2004 and 2005, whereas the existing management model was stiff and fitted a straight line weighted slightly down towards the lower survey estimates. The WG felt that the state-space model showed some promising results and might be a step forward to modeling the population dynamics of the Barents Sea/White Sea harp seal population. However, in the current structure of this model, the model resulted in a significant increase in abundance. Considering that the most recent pup production estimate remains at a low level, the WG felt that it would be inappropriate to assume that the population will experience an increase of this magnitude and recommended the more conservative model projections provided by the existing management model to be used. This approach was applied in the most recent WGHARP meeting (ICES, 2016), and is also applied here.

MATERIALS & METHODS

Reproductive data

The population dynamics model use historical catch records, fecundity rates, age specific proportions of mature females, and estimates of pup production to estimate the population size trajectory. The current assessment includes updated reproductive data based on sampling carried out in the Barents Sea / White Sea region in 2018.

Two types of reproductive data are used in the model: information on the proportion of females that are mature at a given age (i.e., maturity ogive) and the proportion of mature females that are pregnant at a given year (i.e. fecundity rate). Estimates of age specific proportions of mature females are available for five historical periods; 1962 - 1972, 1976 - 1985, 1988 - 1993, 2006 and 2018 (Table 1; Frie *et al.*, 2003; Frie, 2019; ICES, 2009, 2013, 2016). For years with no data a linear interpolation of the age specific proportions of mature females between two periods is assumed (Fig. 1; ICES, 2013).

The model also makes use of historical values of the fecundity rates that are obtained through sampling during commercial hunt. Barents Sea / White Sea population fecundity data are available as mean estimates in the period 1990 – 1993, and from 2006 and 2011 (Table 2; Kjellqwist *et al.*, 1995; ICES, 2008; Frie, 2016, 2019). The population dynamics model assumes the observed fecundity as a known quantity as opposed to being part of the data to which the model is fit by maximum likelihood. For periods missing pregnancy rates, a linear transition was assumed, i.e., a linear transition from 0.84 in 1990 to 0.68 in 2006, from 0.68 in 2006 to 0.84 in 2011, and from 0.84 in 2011 to 0.86 in 2018. In the periods before 1990 the pregnancy rate was assumed constant at 0.84. As opposed to being part of the data to which the model is fit by maximum likelihood, these rates are treated as known quantities by the population dynamics model. When predicting population trends over the coming 15 years, the model by default uses the average of historical fecundity rates. When the most recent reproductive data from 2018 are included, this historical average is 0.827, which is substantially higher than the historical average calculated based on data available in 2016, which was 0.76 (ICES, 2016; Øigård and Haug, 2016).

Survey pup production estimates and catch history

Pup production estimates are available from surveys conducted in 1998 – 2013 (ICES, 2011, 2014). These are found in Table 3. While a new survey was conducted in 2018, this used novel drone-based photography and only covered a limited region of the available pupping area. Furthermore, these data have not yet been comprehensively analysed, and are therefoee not included in this assessment.

Catch data come from commercial hunts and distinguish between the number of pups (0-group) and the numbers of 1 year and older animals (1+) caught per year, but contain no additional information about the age composition of the catches. Catch data prior to 1946 are unreliable and they make no distinction between pups and older seals (Iversen, 1927; Rasmussen, 1957; Sergeant, 1991). Because of this we start our modelling in 1946. Catch levels for the period 1946 – 2019 are presented in ICES (2016) and Haug. *et al.* (2019).

The population model

The population model used to assess the abundance of the Barents Sea / White Sea harp seal population is identical to that used for the Greenland Sea population as well as the Greenland Sea hooded seal population and the Barents Sea / White Sea harp seal population (Skaug *et al.*, 2007; ICES, 2016).

RESULTS

Population estimates

The estimated population sizes, along with the normal priors used are presented in Table 4, and Figure 2 show the model fit to the observed pup production estimates along with the modelled total population trajectory. The model is described by only a few parameters and because of that it is very stiff. As already pointed out in the previous assessment (ICES, 2016; Øigård and Haug, 2016) the model fit to the pup production estimates is poor, and not able to capture the dynamics of the survey pup production estimates. In particular, the model does not capture the aparent drop in pup production that occurred in the mid-2000s. The modelled total population indicate that the harp seal abundance in the Barents Sea/White Sea have been decreasing from 1946 to the early 1960s, and increasing from the early 1960s to early 1980s. After that the model indicates a reduction in the population size until around 2007. From 2007 to present the model indicates an increase in the population size. The modelled total population in 2019 is estimated to be about 74% of Nmax, where Nmax is the historical maximum population size observed/estimated. Assuming annual catches at levels representing the mean catches over the last five years, the model predicts that the pup abundance will increase slightly over the next 15 years, and that the 1+ group will increase by about 49% (95% CI, 32% - 66%) over the same period. The model estimates a 2019 abundance of 1 338 284 (1 151 921 – 1 524 647) 1+ animals and 253 461 (220 347 – 286 575) pups, yielding a total estimate of 1 591 745 (1 373 695 – 1 809 794) seals.

As already discussed in the assessment carried out in 2016, the model estimates are stable for various choices of precision of the prior of M1+ and for various choices of initial values. Even though the priors for M0, and M1+ are relatively non-informative, increasing the mean of the prior to 0.33 and 0.11, respectively, caused a 3% change in the total population estimate. Since the population dynamics model assumes the observed fecundity as a known quantity as opposed to being part of the data to which the model is fit by maximum likelihood, the uncertainties in the observed fecundity rates are not accounted for. Because of this the uncertainty of the modelled abundance is likely to be underestimated.

Catch Options

Despite the updated estimates of reproductive rates, obtained from sampling carried out in 2018, the harp seal population in the Barents Sea / White Sea should still be considered as data poor. This is due to the fact that the most recent estimates of pup production are from 2013, i.e. they are 6 years old. Similar to the previous assessment, we have therefore chosen to again consider the PBR approach for estimating catch quotas. The complete set of alternative catch options considered here were therefore:

1. Current catch level (average of the catches in the period 2015 – 2019).
2. Equilibrium catches.
3. Catches that would reduce the population to N_{70} with probability 0.8 over a 15-years period.
4. Potential Biological Removals level given two options for maximum rate of increase (0.5 or 0.25), and also using an inflated coefficient of variance (0.3), compared to that estimated by the model (0.07).

When projecting future population dynamics given various quota regimes, current catch levels have normally been defined as the average catch levels of the 5 most recent years. For the most recent assessment, catch levels were set to zero for both the 0 and the 1+ group, given very low catches in the period 2012-2016 (ICES, 2016; Øigård and Haug, 2016). Commercial hunting by Norwegian vessels was resumed in the Barents Sea / White Sea area during the 2018 season, and continued into this most recent season. In this current assessment, we have therefore returned to the normal approach of using average catches over the past 5 years (Table 5). The equilibrium catch level is defined as the (fixed) annual catch level that stabilizes the future 1+ population under the estimated model. The proportion of pups in catch used was taken as the average over the past 5 years (1.9%). For the catch option designed to reduce the population size to N_{70} with probability 0.8 over a 15-years period, the catch level that has N_{70} just included in the 80% confidence interval of the 15-year prediction of the total population size was estimated. The Potential Biological Removals has been defined as:

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

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 20% percentile of the log-normal distribution. R_{max} is set at a default of 0.12 for pinnipeds. Given the still unexplained drop in pup production observed beginning in 2004 and that the pup production seem to remain low we explored a recovery factor F_r of 0.5 and 0.25. The PBR catch option assumes that the age structure of the removals is proportional to the age composition of the population (i.e. 16% based on the current population estimates). A catch consisting of a higher proportion of pups would be more conservative, but a multiplier to convert age 1+ animals to pups is inappropriate for the PBR removals.

The estimates for the various catch options using the current management model and the state-space model are given in Table 6. The equilibrium catch level is 39 804 seals (assuming 100% 1+ animals, where two pups balance one 1+ animal). The PBR removals were estimated to be 45 009 seals (16% pups) using a recovery rate of Fr = 0.5. Calculating the PBR catch level with the smaller recovery rate of Fr = 0.25, removals were estimated to be 22 505 (16% pups), and the model predicted a very slight increase in the population over the next 15 years. The PBR catch level using the current management model indicates a slight population increase of 11% (95% CI; decrease of 7% to increase of 30%) for the 1+ population over the next 15 years.

DISCUSSION

The current model used in the management of the Barents Sea / White Sea harp seals is a deterministic age-structured population dynamics model with only 3 free parameters (Øigård and Skaug, 2014). Due to scarcity of historical data on fecundity the current management model provides a poor fit to the pup production estimates, as it is unable to capture the dynamics of the survey pup production estimates of the Barents Sea / White Sea population with the sudden drop in pup production in 2004 and 2005. The existing management model treats the available data on fecundity as known quantities with no uncertainty attached. Thus, any uncertainties associated with these measurements are not taken into account. Also, the available data on fecundity is scarce. Existing data from other populations have shown that inter-annual variability in fecundity can be substantial (Stenson *et al.*, 2014). It is therefore reasonable to expect the confidence intervals from the current management model to be underestimated. For management purposes it is important that uncertainties around future predictions are realistic.

The equilibrium catch quota presented in this report (39 971) is substantially higher that that estimated based on data available in 2016 (ICES, 2016; Øigård and Haug, 2016), which was 10 090 seals. This difference is largely explained by the high fecundity rate observed in 2018 (0.91), and the resulting increase in the average fecundity rate useed for predictions. In the 2016 assessment, this historical average was 0.76, while including the 2018 estimate gives and average historical fecundity rate of 0.822.

The precision of the 2019 model estimate is fairly high with a CV of 0.07. For reasons mentioned earlier we believe the uncertainty of the current management model is underestimated. Because of this a CV of 0.07 is likely to be too low. Increasing the CV when calculating the PBR catch level, i.e., increasing the uncertainty about the model estimate of the 2019 abundance, will lower the PBR catch quota. Increasing the CV to 0.30 resulted in an increase in the 1+ population of 18% (95% CI; decrease of 0% to increase of 36%) over the next 15 years. However, note that the confidence limits around these projected population changes are relatively wide. To ensure a 95% confidence in a non-negative change, the recovery rate had to be set to 0.25 (see Table 6). These results are substantially different from those presented in the most recent assessment (ICES, 2016; Øigård and Haug, 2016), despite the fact that the only additional data included in this assessment are updated reproductive data from 2018, However, it should be noted that the substantial differences in projected pup productions based on 2016 data and 2019 data (see Fig. 3) can be explained by the lack of pup production estimates after 2013. In analyses carried out in 2016, these 2013 data were relatively recent, and therefore helped to constrain model estimates for the most recent period. These 2013 pup production estimates are now 6 years old, leading to a lack of constraining data during model fits. This highlights the importance of ensuring regular and timely collection of all input dsata required for the model to provide reliable population estimates.

Previous conclusions by ICES (2011, 2013, 2014, 2016) have been that the population models used so far in the management of the Barents Sea / White Sea harp seal population have given poor fit to available data, and they were in particular unable to capture the dynamics of the survey-based pup production estimates. They may have overestimated the future fecundity and underestimated the impact of catches, and it has been recommended that different approaches to modify the model be explored to improve the fit to data. A new state-space model presented for the WG in 2014 (ICES, 2014) provided an alternative that provided a better fit to data. The modelling results also documented an obvious deficiency of data from the Barents Sea / White Sea harp seal population. It demonstrated that there is a problem not having temporal overlapping observations for highly relevant variables such as reproductive rates and pup production estimates. The existing management model and the proposed state-space model predicted different population trajectories and some of the estimated catch options obtained resulted in a decline in the population over the next 15 years. This was of considerable concern for the WG who suggested that the most conservative option be chosen. Despite the poor fit of the management model to the dynamics of the pup production estimates the confidence intervals of the model overlap with the uncertainty of the pup production estimates for the four of the last five surveys, and the model estimates of pup production for these years are not statistically significantly different (on a 5% level) from pup production estimates based on actual pup counts. As the current management model provided a reasonably good fit to the most recent pup production estimates, and had the most conservative future projections, this model was chosen for providing advice in 2014 (ICES, 2014) and in 2016 (ICES, 2016). We have continued to use this model for providing advice for setting catch quotas in 2019 for the Barents Sea / White Sea harp seal population. However, we strongly suggest that further developments of the population model are undertaken, and specifically that some parameters that are now treated as observed without uncertainty (e.g. fecundity) are included as random (partially observed) effects to be fitted by the model.

REFERENCES

Frie, A. K., Potelov, V. A., Kingsley., M. C. S., and Haug., T. 2003. Trends in age-at-maturity and growth parameters of female Northeast Atlantic harp seals, *Pagophilus groenlandicus* (Erxleben, 1777). ICES J. Mar. Sci., 60: 1018–1032.

Frie, A. K. 2016. A 2014 update and reassessment of reproductive parameters of Northeast Atlantic harp seals (*Pagophilus groenlandicus*). WGHARP, WP SEA 246: 13pp.

Frie, A. K. 2019. A 2019 update and reassessment of reproductive parameters of Northeast Atlantic harp seals (*Pagophilus groenlandicus*). WGHARP, WP SEA 252: 13pp.

Haug., T., Biuw, M., and Zabavnikov, V. 2019. Norwegian and Russian catches of harp and hooded seals in the Northeast Atlantic in 2017-19. WGHARP, WP SEA 249.

ICES. 2008. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 27-30 Aug. 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 (WGHARP) 24-27 August 2009, ICES Headquarters, Copenhagen , Denmark. ICES CM 2009 / ACOM 17: 51pp.

ICES. 2011. ICES WGHARP REPORT 2011 Report of the Working Group on Harp and Hooded Seals (WGHARP), 15-19 Aug, 2011, St Andrews, Scotland. ICES CM 2011 / ACOM 22: 78pp. St Andrews, Scotland. http://www.ices.dk/sites/pub/Publication Reports/Expert Group Report/acom/2011/WGHARP/WGHARP 2011.pdf.

ICES. 2013. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 26-30 Aug 2013, PINRO, Murmansk, Russia. ICES CM 2013 / ACOM 20: 48 pp.

ICES. 2014. Report of the ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 17-21 November 2014, Quebec City, Quebec, Canada. ICES CM 2014 / ACOM 20: 62pp.

ICES. 2016. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP), 26-30 Sept. 2016, ICES Headquarters, Copenhagen, Denmark. ICES CM 2016 / ACOM 21: 85pp.

Iversen, T. 1927. Drivis og selfangst. Årsber. Vedk. Norges Fisk., 1927: 1–84.

Kjellqwist, S. A., Haug, T., and Øritsland, T. 1995. Trends in age-composition, growth and reproductive parameters of Barents Sea harp seals, *Phoca groenlandica*. ICES J. Mar. Sci., 52: 197–208.

Rasmussen, B. 1957. Exploitation and protection of the East Greenland seal herds. Nor. Hvalfangsttidende, 46: 45–59.

Sergeant, D. E. 1991. Harp seals, man and ice. Can. Spec. Publ. Fish, 114: 1–153.

Skaug, H. J., Frimannslund, L., and Øien., N. I. 2007. Historical population assessment of Barents Sea harp seals (*Pagophilus groenlandicus*). ICES J. Mar, 64: 1356–1365.

Stenson, G. B., Wakeham, D., Buren, A., and Koen-Alonso, M. 2014. Density dependent and density independent factors influencing reproductive rates in Northwest Atlantic Harp Seals, *Pagophilus groenlandicus*. DFO CSAS, Res. Doc., 2014/058: 24pp.

Øigård, T. A., Haug, T., and Nilssen, K. T. 2014. From pup production to quotas: Current status of harp seals in the Greenland Sea. ICES J. Mar, 71: 537–545.

Øigård, T. A., and Skaug, H. J. 2014. Fitting state–space models to seal populations with scarce data. ICES J. Mar. Sci., 72: 1462–1469.

Øigård, T. A., and Haug, T. 2016. The 2017 abundance of harp seals (*Pagophilus groenlandicus*) in the Barents Sea / White Sea. WGHARP, WP SEA 239.

Table 1. Estimates of proportions of mature females (pi,t). The P1 estimates are from the period 1962-1972 , P2 estimates are from 1976-1985, P3 estimates are from 1988-1993, while the P4 and P5 estimates are from 2014 and 2018 respectively (ICES 2011; Frie, 2016, 2019)

Age	2y	3y	4y	5y	6y	7y	8y	9y	10y	11y	12y	13y	14y	15y
p_1	0.00	0.01	0.17	0.64	0.90	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
p_2	0.00	0.00	0.00	0.24	0.62	0.81	0.91	0.95	0.98	0.99	0.99	1.00	1.00	1.00
p_3	0.00	0.00	0.02	0.08	0.21	0.40	0.59	0.75	0.85	0.91	0.95	0.97	0.98	0.99
p_4	0.01	0.02	0.05	0.11	0.25	0.55	0.90	0.99	1.00	1.00	1.00	1.00	1.00	1.00
p_5	0.00	0.00	0.00	0.52	0.77	0.89	0.95	0.97	0.99	0.99	0.99	1.00	1.00	1.00

Table 2. Estimates of proportion of Barents Sea / White Sea harp seal females giving birth. Data from (ICES, 2011) and (Frie, 2016, 2019).

Year	Fecundity	SD
1990	0.84	0.06
1991	0.84	0.06
1992	0.84	0.06
1993	0.84	0.06
2006	0.68	0.06
2011	0.84	0.06
2018	0.91	0.03

Table 3. Estimates of Barents Sea / White Sea harp seal pup production. Numbers and CVs are drawn from ICES (2011) and ICES (2014).

Year	Estimated number of pups	CV
1998	286 260	0.150
2000	322 474	0.098
2000	339 710	0.105
2002	330 000	0.103
2003	328 000	0.181
2004	231 811	0.190
2004	234 000	0.205
2005	122 658	0.162
2008	123 104	0.199
2009	157 000	0.108
2010	163 032	0.198
2013	128 786	0.237

Table 4. Estimated and derived mean values and standard deviations of the parameters used in the model for Barents Sea / White Sea harp seals. Nmax is the historically largest total population, N70 is 70% of Nmax, Nlim is 30% of Nmax, and Nmin is the estimated population size using 20th percentile of the log-normal distribution.

Parameter	Mean	SD
N_{1946}	1 728 344	141 686
M_0	0.27	0.25
M_{1+}	0.13	0.05
$N_{0,2019}$	253 460	16 894
$N_{1+,2019}$	1 338 284	95 083
$N_{Total,2019}$	1 591 744	111 249
D_{1+}	1.49	0.09
$N_{Total,2035}$	2 433 237	295 221
N_{70}	1 425 876	266 477
N_{lim}	644 315	266 476
N_{max}	2 147 718	-
N_{min}	1 500 307	-

Table 5. Catches of 0 and 1+ seals from the Barents Sea / White Sea harp seal population during the most recent 5 years. Data from Haug & Zabavnikov (2016, 2019)

Year	Pup catch	1+ catch	Percent pups
2015	0	0	-
2016	0	28	0%
2017	0	1	0%
2018	21	2 220	0.9%
2019	34	568	5.6%
Mean	11	563	1.9%

Table 6. Catch options with relative 1+ population size (D1+) in 15-years (2035) for harp seals in the Barents Sea / White Sea.

					D_{1+}		
Catch option	Percent pups	Pup catch	1+ catch	Total catch	2.5%	Mean	97.5%
Current level	1.9%	11	563	574	1.32	1.49	1.66
Equilibrium	0%	0	39 804	39 804	0.80	1.00	1.19
Reduce to N_{70}	0%	0	49 967	49 967	0.67	0.87	1.07
$PBR_{Fr=0.50}$	15.9%	7 167	37 842	45 009	0.92	1.11	1.30
$PBR_{Fr=0.25}$	15.9%	3 584	18 921	22 505	1.12	1.30	1.48
$PBR_{Fr=0.50,\ CV=0.3}$	15.9%	5 939	31 356	37 295	1.00	1.18	1.36

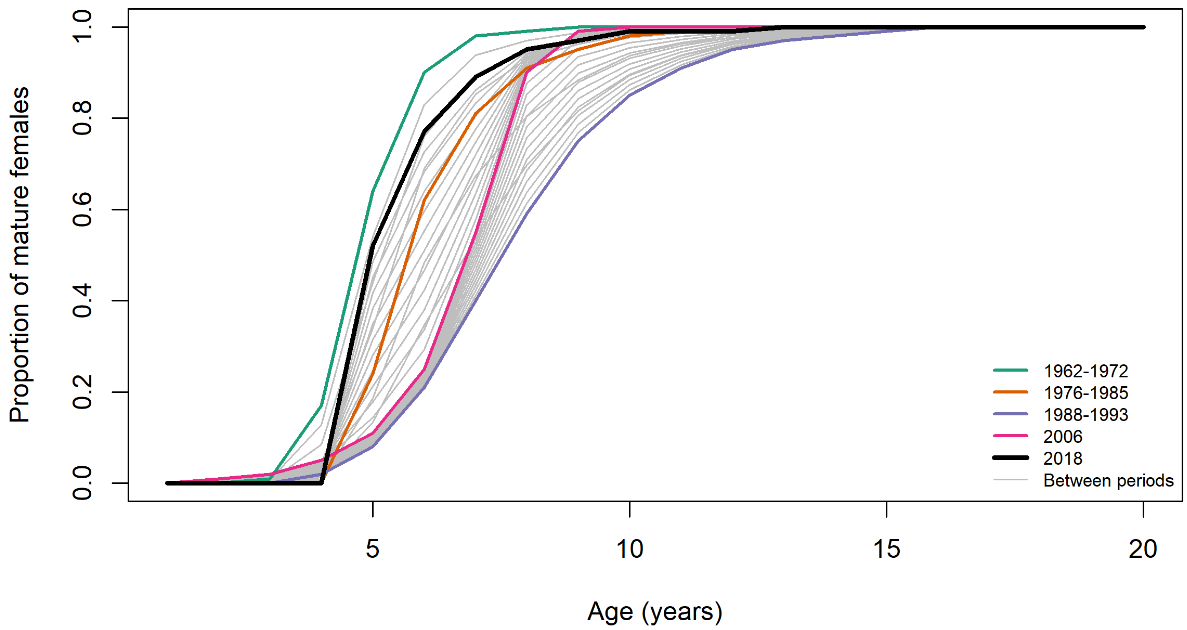

Figure 1: Proportion of mature females among Barents Sea / White Sea harp seals in four periods. Values are taken from Table 1.

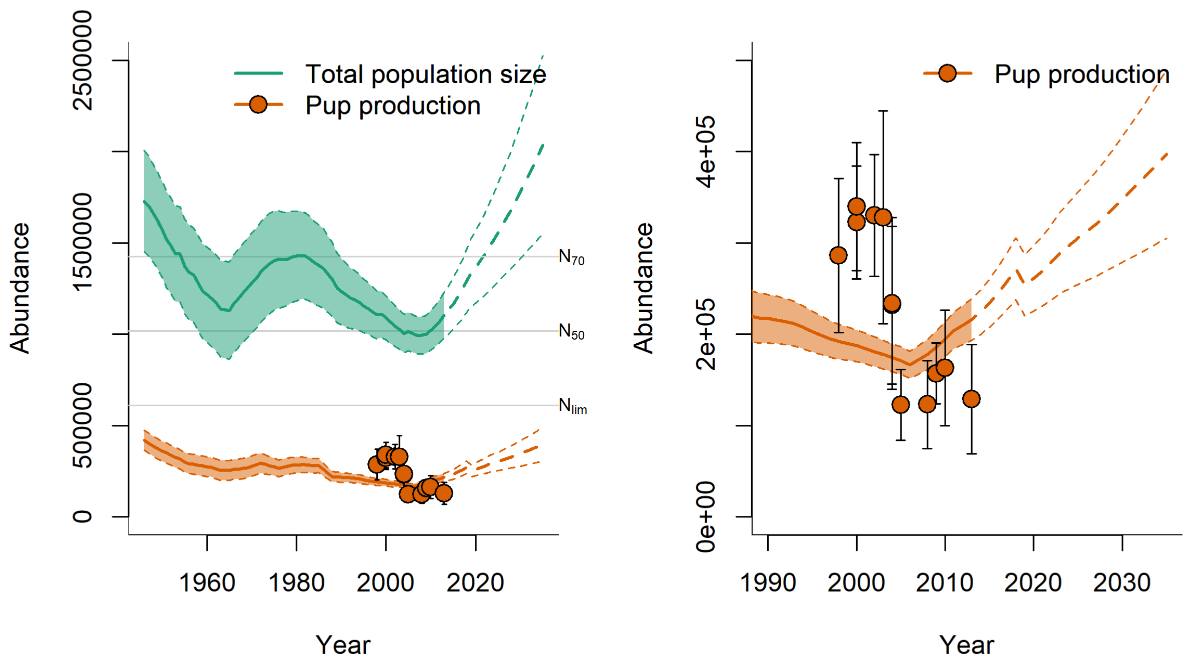

Figure 2: Modelled population trajectories for Barents Sea / White Sea harp seal pups and adults (full lines), 95% confidence intervals (shaded areas) and future projections (dashed lines). N70, N50, and Nlim denote the 70%, 50%, and 30% of the historical maximum population size, respectively. Observed pup production estimates are indicated by filled circles.

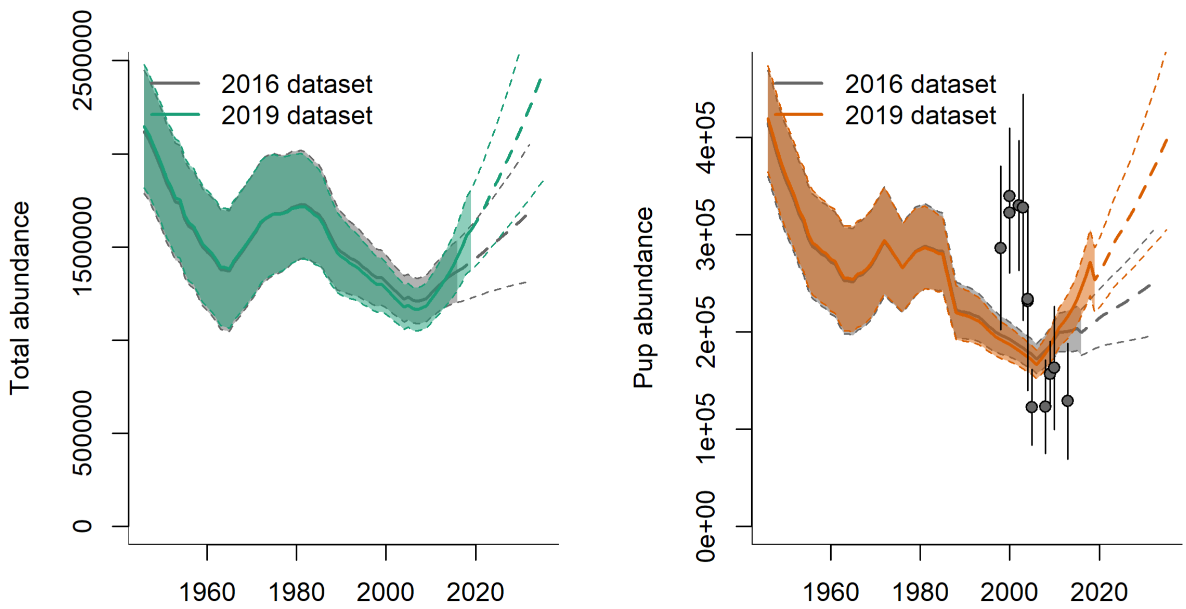

Figure 3: Comparison of estimated total and pup abundance trajectories based on data available in 2016 and 2019

WP SEA 252

Joint ICES/NAFO/NAMMCO Working Group on Harp and Hooded Seals

FRAM center, Tromsø, Norway, 2-6 September 2019

A 2018 update and reassessment of reproductive parameters of Northeast Atlantic harp seals (*Pagophilus groenlandicus*)

Anne Kirstine Frie[1]

[1] Institute of Marine Research, PO Box 6404, N-9294 Tromsø, Norway

Abstract

Mean age of maturity (MAM) for Barents/White Sea harp seals was estimated at 6.9±0.9 years for a sample of 168 females collected during moulting in the southern Barents Sea in 2018. This is not significantly different from the previous estimate from 2006, but about a year lower than the maximum values observed for this stock in the early 1990s. In comparison with typical values for the Greenland Sea and Northwest Atlantic of 5-6 years, however, the present level of MAM for BS/WS harp seals is still high. A general near-absence of first-time ovulators in samples from the Barents Sea raises concern that values of MAM for the BS/WS harp seal stock may be affected by temporal and/or spatial sampling bias. Underestimation of age specific proportions of mature females may contribute to overestimation of population size, as it will underestimate the number of females required to produce the numbers of pups estimated by aerial surveys.

Introduction

Female reproductive rates have varied considerably over time in harp seal populations and regular updates of estimates are therefore necessary to maintain reliable inputs to population and harvest models (ICES, 2004). Monitoring of reproductive rates of Northeast Atlantic (harp seals is based on ovary analysis and has mainly focused on estimation of mean age at maturity (MAM) from age specific proportions mature based on presence/absence of *Corpora lutea* (CLs) and/or *Corpora albicantia* (CAs)(Kjellqwist et al, 1995; Frie et al, 2003). Fetus-based pregnancy rates are difficult to obtain for Northeast Atlantic harp seals, because there is no commercial hunt during the post-implantation period in autumn and winter. Also the two Northeast Atlantic stocks (Greenland Sea (GS) and Barents Sea/White Sea (BS/WS) stocks) mix to some degree during parts of the post implantation phase (Folkow et al,2004; Nordøy et al, 2008). Instead, estimation of pregnancy rates females has been based on presence or absence of a large partially luteinized *Corpus albicans* (LCA) in females caught within a few weeks after the breeding season. This method has also been used for ringed seals (Stirling, 2005) and hooded seals (Born, 1982).

Time series of ovary-based reproductive data for Northeast Atlantic harp seals have shown significant variability in both MAM and pregnancy rates within and between stocks (eg. Frie et al., 2003), suggesting a need for regular updates of these parameters for population modelling purposes. Accordingly, stocks assessed within WGHARP are considered data rich, only if the last reproductive sample is no more than 5 years old. Since the last full reproductive data set for BS/WS harp seals is from 2006, this stock has been categorized as data poor for several years. In 2018, however, a new reproductive sample was collected during a commercial sealing expedition to the East Ice moulting lairs. The present document reports the analysis results for the 2018 data set and puts it into context with previous reproductive parameters for both the BS/WS and GS harp seal stocks. The main reason for showing older results for both stocks is to highlight the problem of near-absence of first-time ovulators in reproductive samples from BS/WS harp seals. This issue was first presented in a working paper from the 2016 WGHARP meeting (Frie, 2016). Due to this feature, previous estimates of mean age at maturity (MAM) for BS/WS harp seals are virtually equal to the estimates of mean age at primiparity (MAP) i.e. the mean age at first birth (see Fig.1). In contrast, MAM for GS harp seals have always been estimated to be at least at least 1 year lower than MAP, as would be expected (see Fig.2).

Material and methods

An overview of historical and recent sampling of reproductive data in the Northeast Atlantic is given in Table 1. For the BS/WS stock only the Norwegian samples are included. This is information on parity status is not available for the Russian data previously included in estimates of MAM (e.g. Frie et al., 2003). Information on age specific proportions mature and parous for BS/WS samples over the period 1963-1993 is derived from data tables in Kjellqwist et al. (1995). Data for the period 1963-85 are double-checked with original data files.

During field work, paired sets of ovaries and lower jaws were collected from all individuals. Ovaries were preserved in 4% formalin and jaws were stored frozen until boiling and extraction of lower canines in the lab. Age determination was done by counting annual growth layer groups in the dentine of about 0.14 mm thick transverse sections cut from the thickest part of a lower canine tooth. The age is given in full years corresponding to the age in the most recent breeding season. Reproductive status was determined from the presence of ovarian corpora as revealed by sectioning the ovary into 1.5-2mm thick slices without disattaching them from the cortex of the ovary.

Ovary analysis included registration of *Corpora lutea* (CLs) of the ongoing cycle and *Corpora albicantia* from previous ovulations. Some CAs consist of a core of connective tissue surrounded by luteinized tissue and are large relative to other CAs. These were termed luteinized CAs (LCAs) and were assumed to indicate pregnancy in the previous breeding cycle. These estimates rely on the assumption that LCAs distinguishable from older CAs up to a couple of months after parturition. The same method has previously been used for ringed seals (Ian Stirling, 2005) and hooded seals (Born et al, 1982) and was also used to calculate the presently used pregnancy rate for Greenland Sea harp seals (ICES, 2001).

For calculations of MAM, the presence of any of the 4 described types of corpora was considered sign of attainment of sexual maturity. For calculations of MAP, only females with at least one CA were considered parous. Richards curves were fit to the age specific proportions mature and age specific proportions parous by a maximum likelihood method described in Frie et al (2003). MAM and MAP were both estimated by equation (1).

(1) $$MAM\ /\ MAP = w + 1 - \sum_{x=1}^{x=w} \hat{P}(x)$$

In estimates of MAM, $\hat{P}$ (x) is the estimated proportion mature at age x in the sample .In estimates of MAP, $\hat{P}$ (x) is the estimated proportion mature at age x. In both cases, *w* is the oldest age group in the sample. If $\hat{P}$ (w)=1, the expression for MAM is equivalent to DeMasters (1978) formula for MAM. If $\hat{P}$ <1, Equation (1) is based on the assumption that all animals will be mature/parous at age *w*+1.

Results

The 2018 reproductive material for BS/WS harp seals was collected during a rather extended period of the moulting season from 20 April to 13 May, 2018. Reproductive data was obtained for a total of 169 females aged 2 to 22 years. One female with a reported age estimate of 2 years was found to have a CA, indicating a previous birth. This is considered biologically unrealistic and more likely due to a technical error in age estimation, ovary analysis or data recording. This female was therefore removed from further analyses of MAM and MAP. Among the remaining 168 females, the youngest parous female was 6 years. The youngest parous females in earlier samples were 3-6 years old.

The 2018 sample contained 6 females (aged 6 and 7 years), which were first-time ovulators, i.e. only had a fresh CL and no CAs. In previous BS/WS samples the youngest first-time ovulators have also been 6 years old – even going back to the 1960s, when MAM was estimated at ~5.5 years. In the 2006 sample only two first-time ovulators were present, aged 8 and 9 years.

MAM for the 2018 sample was estimated at 6.9 ±0.9 years and MAP was estimated at 7.5±0.7 years. This is the largest difference between MAM and MAP observed for the BS/WS data set (see Fig.1) and approaches the minimum expected difference of 1 year assuming a pregnancy rate of 100% for all age classes. The latter, however, seems to be an unreasonable assumption given the historic rate of pregnancy rates for both the BS/WS and GS harp seal stocks as shown in Figs. 3 and 4, respectively. It thus seems, that first- time ovulators are still seriously under-sampled in the recent BS/WS sample.

The pregnancy rate of parous females for the 2018 sample was estimated at 0.91±0.06. This is the highest pregnancy rate among the available estimates for BS/WS harp seals, but a significant difference ($P<0.001$) could only be found in comparisons with the minimum value of 0.68 from 2006. Pregnancy rates for 1990-93 and 2011 were estimated at 0.84, but sample sizes are small and do not provide enough power to establish a significant difference with the 2018 estimate (see Fig. 3). The highest pregnancy rate for the GS stock is also 0.91 and was recorded recorded in 2014 (see Fig. 4).

Discussion

The estimated MAM for BS/WS harp seals of 6.9 years for 2018 is virtually identical to the previous estimate from 2006. These estimates are about a year lower than the maximum values observed during the early 1990s, but still high compared to previous estimates for Northeast Atlantic harp seals and Northwest Atlantic harp seals (e.g. Sjare and Stenson, 2010) which are more typically around 5 -6 years. The almost complete lack of first time ovulators in previous BS/WS samples, however, raises concern that estimates of MAM for this stock are compromised by serious sampling problems. Compared to other BS/WS samples, the 2018sample, actually has a rather high number of first-time ovulators resulting in a difference between MAM and MAP of 0.7 years and thus approaching the minimum expected value of 1. However, the data series for Greenland Sea harp seals suggest more typical differences between MAM and MAP of >1 year. This is also more in line with typical estimates of pregnancy rates of 0.8-0.9 rather than 1.0.

Potential explanations for the very low occurrence of first-time ovulators in the BS/WS samples could be that non parous harp seals from this stock either ovulate too late to be recorded or are simply less likely to be present in the traditional sampling areas.

In the first case, MAM will be overestimated, but MAP and LCA-based pregnancy rates will be unbiased. If a significant portion of the nulliparous/immature females are not present during the sampling, MAP will likely be underestimated.

Most of the samples collected in the Barents Sea moulting patches are collected in the end of March-beginning of April, which is rather early in moulting. According to Khuzin (1972) moulting in the White Sea to continues into the month of May. However, even in samples collected rather late in the season such as the 2006 sample, there are almost no first-time ovulators. Information on first time ovulators for the 1990-1993 data set are derived from information in Kjellqwist et al. (1995), which reportedly contains data from females collected during both spring, summer, autumn and winter, but does not contain any first-time ovulators. It is, however, not quite clear, which of the seasonal subsamples that were included in the ovary analysis, which only comprised data for 218 out of a total of 389 females sampled during the period 1990-93. New and more detailed analyses of historical ovary material from the BS/WS stock are underway and may shed light on questions regarding timing of ovulation and temporal occurrence of different reproductive classes in samples from the Barents Sea.

Insights on the likelihood of representative sampling may also be gained from satellite telemetry studies. This would, however, require tagging of subadult females. So far, satellite tagging of harp seals in the Northeast Atlantic has only included adult animals (Folkow et al.,2008; Nordøy et al., 2008) and young of the year (Svetochev et a., 2016). However, mark-recapture analyses based on flipper tagged harp seals in the Greenland Sea have shown evidence of temporary emigration in some cohorts of young seals, which are underrepresented in the catches until they start reproducing (Øien and Øritsland, 1995). This would seem likely to cause sampling problems for the Greenland Sea stock as well, but the available data do not show clear signs of this.

The observed difference in occurrence of first-time ovulators in the Greenland Sea and Barents Sea moulting patches could be partly driven by the different positions of these areas relative to the main summer feeding grounds, which for both stocks appear to be located along the ice edge in the Fram strait and northern Barents Sea (Folkow and Blix, 2008; Nordøy et al., 2008). For seals, coming from the southern Barents Sea, the Northern summer feeding grounds can only be reached by long-distance migration with no possibilities for haul-out. Before undertaking this migration, the seals may aim to achieve a medium level of body reserves – not emaciated after moulting, but also not too heavy for energetically optimal movement. Follicle development and ovulation in young females may also partly be condition-driven and hence the likelihood of starting the northward migration might increase as follicle development advances. Suitable condition for migration may be achieved earlier in the season in non-parturient seals, which do not have to replenish body reserves after lactation. They may therefore also finish moulting earlier and hence be able to start migration earlier than parturient females. Earlier moulting in immature seals has been suggested by Sivertsen (1941) and is a commonly held belief among sealers (Haug,T. pers.comm.). This would then suggest, that females ovulating for the first time may ovulate and mate during the northward migration. In contrast to Barents Sea harp seals, Greenland Sea harp seals may follow the ice edge from their moulting areas into summer feeding areas in the Fram Strait and Northern Barents Sea. This could allow them to feed more in the pack ice off Northeast Greenland post moulting, if prey is available. Satellite telemetry data for subadult could contribute to evaluation of this hypothesis.

References

Atkinson, S. (1997). ”Reproductive biology of seals”. Reviews of reproduction, 2: 175-194.

Born, E. W. (1982). "Reproduction in the female hooded seal, *Cystophora cristata Erxleben*, at South Greenland." J. Northwest Atlantic Fisheries Science 3(1): 57-62.

Bowen, D.W., Capstick,C.K., and Sergeant, D.E.(1981).”Temporal changes in the reproductive potential of female harp seals *Pagophilus groenlandicus*”. Canadian Journal of Fisheries and Aquatic Sciences,38:495–503.

DFO (2005). "Stock Assessment of Northwest Atlantic Harp Seals (*Pagophilus groenlandicus*)”. DFO Can. Sci.Advis.Rep.2005/037

DeMaster, D.P. 1978. Calculation of the average age of sexual maturity in marine mammals. J. Fish. Res. Board Can. 35(6): 912–915. doi:10.1139/f78-148.

Folkow L.P., Nordøy, E. and Blix, A. (2008). “Distribution and dive behaviour of harp seals (Pagophilus groenlandicus) from the Greenland Sea stock. “Polar Biology, 31:1119–1135.

Frie, AK., Potelov, V.A., Kingsley, M.C.S.K. and Haug, T. 2003. “Trends in age-at-maturity and growth parameters of female Northeast Atlantic harp seals, Pagophilus groenlandicus (Erxleben, 1777)”. ICES Journal of Marine Science 60 (5): 1018-1032

Frie, A.K. 2016. A 2014 update and reassessment of reproductive parameters of Northeast Atlantic harp seals (Pagophilus groenlandicus). WPSEA 246. Joint ICES/NAMMCO Working Group on Harp and Hooded seals, ICES Head Quarters, Copenhagen, Denmark,26-30 september 2016.

ICES (2001). “Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals”. ICES CM 2001/ACFM: 08. 40 pp.

ICES (2008). “Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals”. ICES CM 2008/ACOM: 17. 59 pp.

ICES (2004). “Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals”. ICES CM 2004/ACFM: 06. 53 pp.

Khuzin, R. S. 1972. Ekologo-Morfologicheskij analiz razlichii I perspektivy promysla grenlandskogo chulenia Belomorskoi, Ian-Maienskoi i Niufaundlendskoi populjatsii (Ecological and morphological analysis of differences between the White Sea, Jan Mayen and Newfoundland harp seal populations and perspectives for their exploitation). Murmanskoe knizhnoe izdatel’stvo, Murmansk. 174 pp.

Kjellquist,S.A., Haug,T. and Øritsland,T. (1995).”Trends in age-composition, growth and reproductive parameters of Barents Sea harp seals, *Phoca groenlandica* “. ICES Journal of Marine Science, 52: 197–208.

Nordøy, E., Folkow L.P., Potelov, V., Prischemikhin V. and Blix, A. (2008). “Seasonal distribution and dive behaviour of harp seals (Pagophilus groenlandicus) of the White Sea–Barents Sea stock. “. Polar Biology, 31:1119–1135.

Øien, N., and Øritsland, T. 1995. “Use of mark–recapture experiments to monitor seal populations subject to catching”. In Whales, Seals, Fish and Man, pp. 35–45. Ed. by A. S. Blix, L. Walløe, and Ø. Ulltang. Elsevier, Amsterdam. 720 pp.

Sivertsen, E.1941. “On the bioloy of the harp seal phocagroenlandica Erxl.Investigations carried out in the White Sea 1925-37. Hvalrådets skrifter,26:1-166.

Sjare, B., and Stenson, G.B. 2010. “Changes in the reproductive parameters of female harp seals (Pagophilus groenlandicus) in the Northwest Atlantic”. ICES J. Mar. Sci. 67(2): 304–315. doi:10.1093/icesjms/fsp267.

Stirling, I. 2005. “Reproductive rates of ringed seals and survival of pups in northwestern Hudson Bay, Canada, 1991–2000”. Polar Biology, 28: 381–387.

Svetochev, N.S., Kavtsevich,N.N. and Svetocheva, O.N.2016. “Satellite tagging and seasonal distribution of harp seal (juveniles) of the White Sea-Barents Sea stock”. Czech polar reports 6(1):31-42.

Tables

Sampling of ovaries in Barents Sea moulting patches			
Platform	Year	Time interv.	N
Commercial	1963-72	March-April	237
Commercial	1976-85	March-April	127
Commercial/Scientific	1990-93	Uncertain	218
Commercial	2006	8/4-2/5	82
Commercial	2011	5/5	46
Commercial	2018	20/4-13/5	169

Table 1. Characteristics of the sampling of female reproductive organs in the Barents Sea (mainly the southern Barents Sea pack ice areas, the “East Ice”). Data for the period 1963-1993 are derived from data tables presented in Kjellqwist et al. (1995). Data for 2006 are unpublished IMR data previously analysed and presented to WGHARP.

Sampling of ovaries in Greenland Sea moulting patches			
Platform	Year	Time interv.	N
Scientific	1959-64	14-25/5 (1964)	75
Scientific	1978	23/4-6/5	174
Scientific	1987	10/5-11/6	250
Scientific	1990	20/5-8/6	99
Scientific	1991	20/4-29/5	89
Commercial	2008	1/4-24/5	56
Commercial	2009	27/4-8/5	214
Commercial	2014	30/4-7/5	197

Table 2. Characteristics of the sampling of female reproductive organs in the Greenland Sea. Samples from the period 1964 to 1991 are collected by Russian scientists and analysed in Frie et al. (2003). For the 1959-64 sample exact sampling dates are only known for 1964.

Samples from 2009 and 2014 were collected by Norwegian scientists on board commercial sealers.

Figures

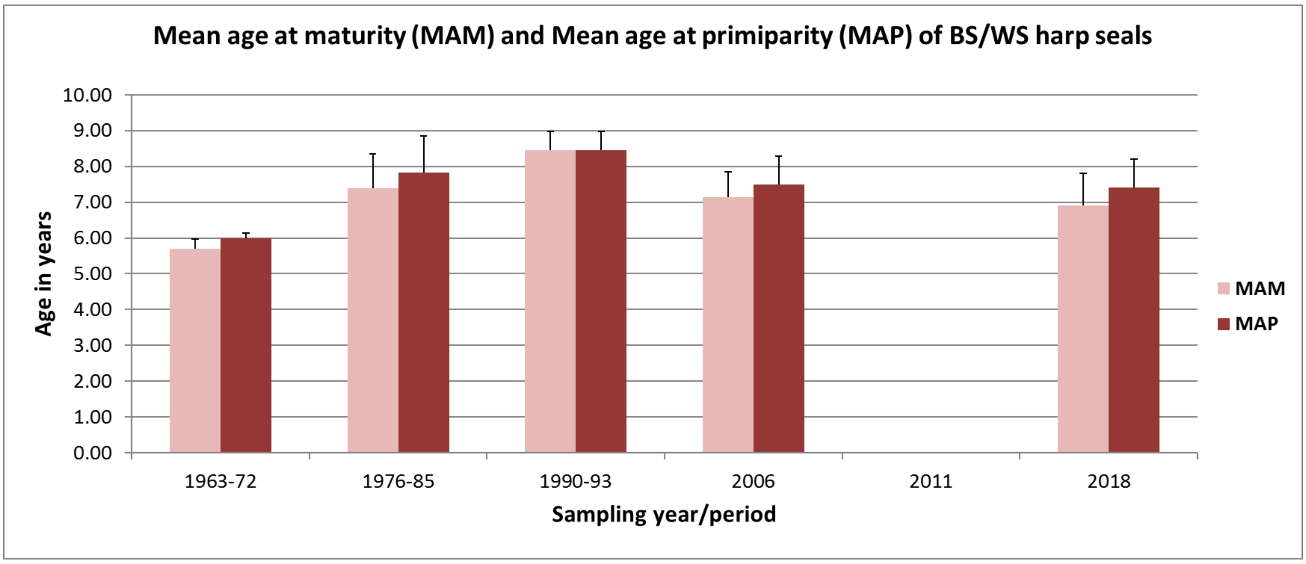

Figure 1. Mean age at maturity (MAM) and mean age at primiparity (MAP) for BS/WS harp seals based on Norwegian samples collected in moulting patches. Samples collected in 2011 consisted only of adult females and were not suitable for estimation of MAM or MAP. Error bars are 95% CIs.

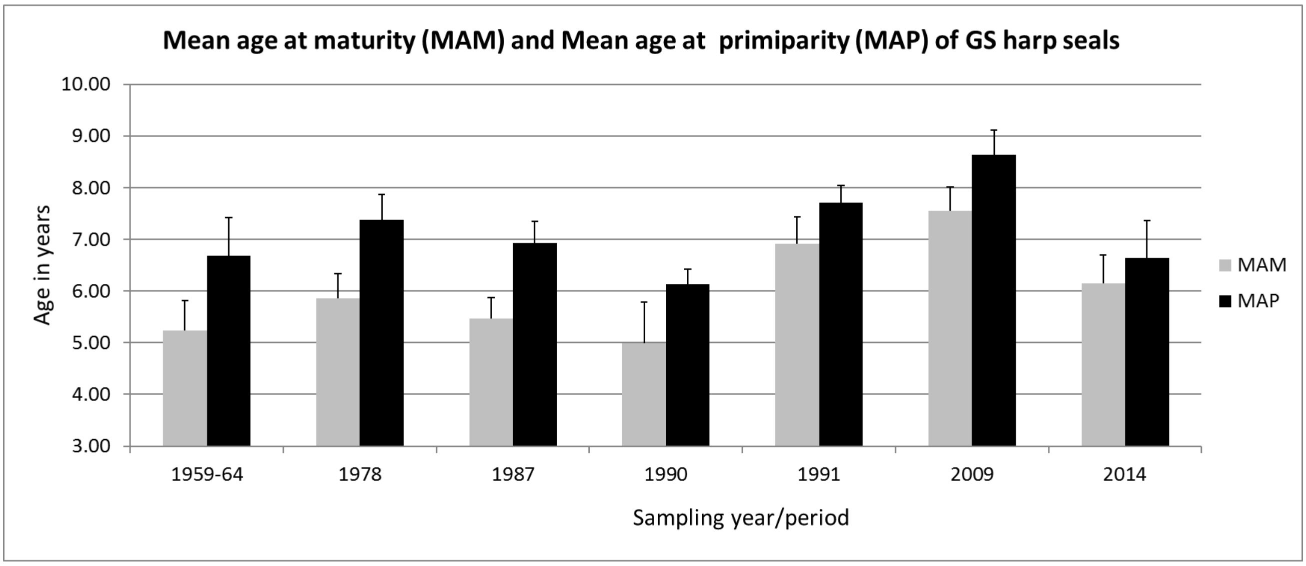

Figure 2. Mean age at maturity (MAM) and mean age at primiparity (MAP) for GS harp seals based on Russian (1959-64 to 1991) and Norwegian (2009 and 2014) samples collected in moulting patches. Error bars are 95% CIs.

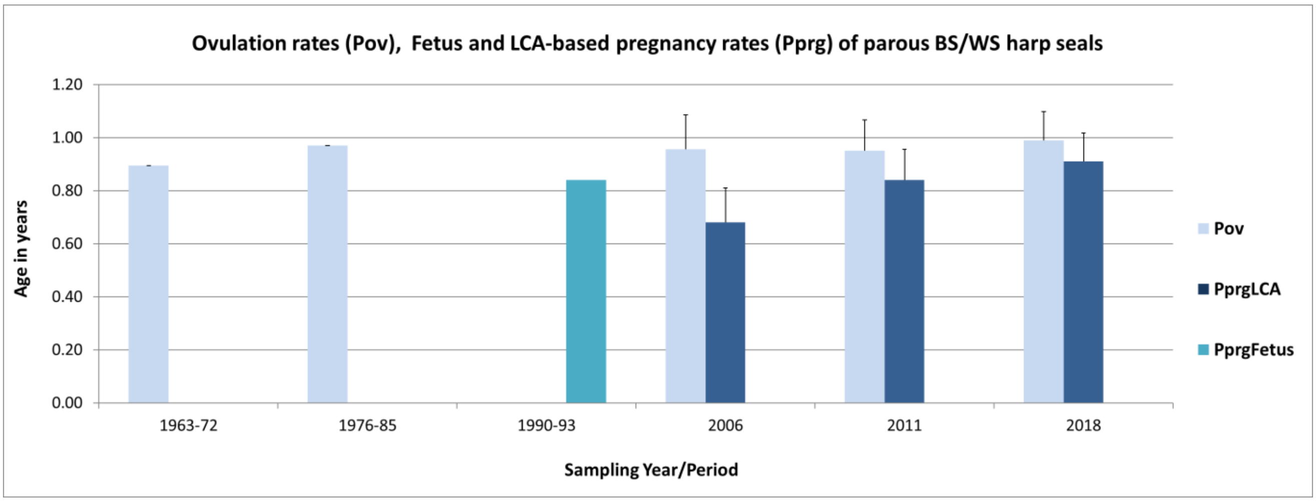

Figure 3. Ovulation rates and LCA-based pregnancy rates for BS/WS harp seals. Pregnancy rates are currently not available for 1963-72 and 1976-85. The 1990-93 is a late autumn sample and the pregnancy rate is based on presence/absence of a fetus. Error bars are 95% binomial confidence intervals.

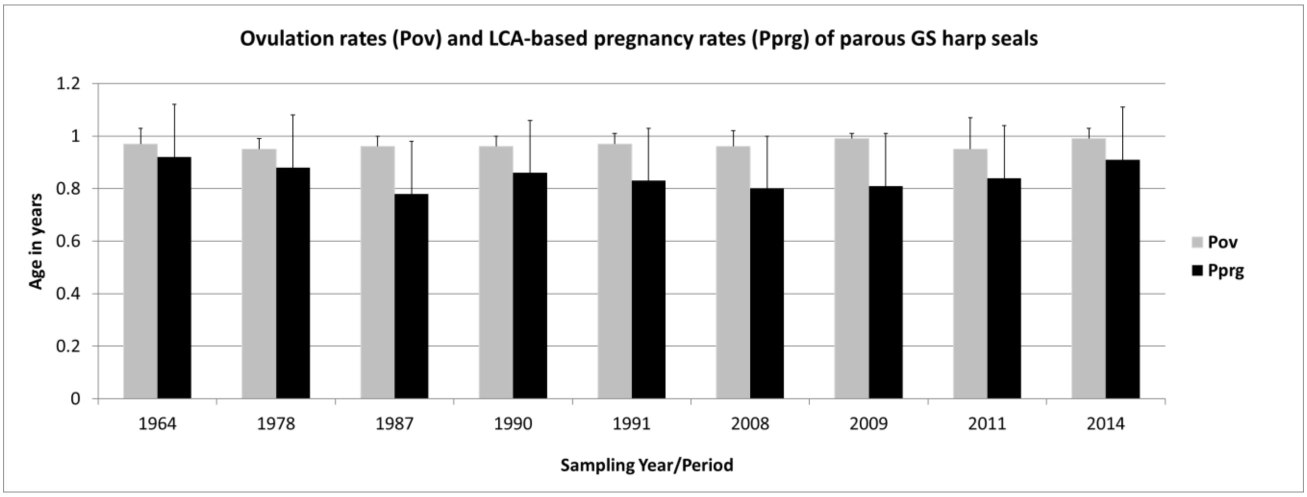

Figure 4. Ovulation rates and LCA-based pregnancy rates for GS harp seals. Error bars are 95% binomial confidence intervals.

WP SEA 253

ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS

IMR, TROMSO, NORWAY, 2-6 SEPTEMBER 2019

ANALYSIS OF THE WHITE SEA/BARENTS SEA HARP SEAL POPULATION (*Phoca groenlandica)* CALCULATED QUANTITY ESTIMATION BY COHORT MODELS IN PRESENT STAGE WHEN HUNTING IS ABSENTED

Viktor Korzhev, Vladimir Zabavnikov
Polar Branch of Federal State Budget Scientific Institution (PB FSBSI) "VNIRO" ("PINRO" of the N.M. Knipovich named - PINRO)
PINRO, Academician Knipovich st. 6, 183763 Murmansk, Russia

The harp seal of the White Sea population (*Phoca groenlandica*) is an important component in the ecosystem of the Barents and White Seas. For a long time, it was the main mammal hunting target object in Norway and Russia. At the same time, the harp seal is a predator of the highest trophic level capable of influencing the commercial stocks of fish and the main competitor of cod in capelin consumption. This paper discusses the possibility and patterns of the use of mathematical models for estimating the size of the White Sea population of the harp seal with the absence of hunting and the lack of collected biological data on the condition of seals.

The population model used to estimate the population of harp seals was developed in the early 2000s. It is a cohort dynamics model with a deterministic age structure. Taking into account the individual modifications made, this model has so far been used as the main one in estimating the abundance of seals at the joint ICES/NAFO Working Group on the harp and hooded seals (WGHARP). The model is described in detail in a number of documents (ICES, 2008, Korzhev, 2014). It has three unknown parameters (pup mortality, mortality of seals at the age of 1 year and older, initial or starting abundance).

The model uses two types of input data on the population reproductivity: the portion of mature females by age and year (i.e. the maturation ogive) and the portion of pregnant females in each year (i.e. the birth rate). There are very few historical data on the maturity of female seals. Using the literature sources, by averaging the data over several years, we were able to calculate only six maturation ogives for different periods including 1962-1964, 1965-1972, 1976-1985, 1988, 1990-1993, 2006, while the age of 50%-maturation of animals (and the type of maturation curves) changed significantly throughout the time period from 4.5 to 8.1 years. In order to estimate the maturity ogives of females in the years when animal maturation data are not available, linear interpolation is performed between the known data from two adjacent periods. It should be noted that over the past 11 years (2007-2017), there are no observable data on the maturity of seals. This introduces great uncertainty in the estimates of the current population size.

Even more scanty data on the change in the birth rate are available. The birth rates (F) of harp seals for the White Sea population are available for only three periods including 1990-1993, 2006 and 2011. In 1990-1993, the value of the coefficient F was estimated at 0.84, in 2006 – at 0.68 and in 2011 – at 0.84. In the model calculations, a linear decrease in the F-rate is assumed from 0.84 in 1990 to 0.68 in 2006, and again its linear growth to 0.84 from 2006 to 2011. In 1946-1990, a constant pregnancy rate of 0.84 was assumed. .

The data sets of the seal catch by years are formed based on the results of reports on commercial hunting for the years 1946-2017. In the hunting reports, the catches are divided into two groups: the catches of pups and adult animals (age 1+) by years of capture, but the reports do not contain any additional information about the age structure of catch. Therefore, to obtain a catch by age and year, it is assumed that the distribution of the catch by age is proportional to the estimated abundance of the age structure of the population in a given year. It is customary to begin the simulation period from 1946, since the data on catches prior to this year are considered unreliable. There are no data for estimating natural mortality of puppies and animals of ages 1+ by age, so it is assumed that mortality is constant within the group 1+ .

The tuning of model parameters is carried out by minimizing the sum of squares of deviations between estimates of the abundance of pups by the model and the actual abundance of pups (SSQ). The actual estimates of the abundance of pups are taken from materials of aerial surveys conducted by PINRO in 1998-2013 (ICES 2014).

Since 1968, the aerial surveys for whelping seals in the White Sea, where the number of females was counted, have been carried out. The number of not females, but puppies, was estimated using the new methods and technology. In the first years of such surveys (1998-2003), the abundance of puppies was estimated at 286-330 thousand animals, which exceeded the number of females in previous surveys by 2.5-3 times. Since 2004, the number of pups in the whelping patches began to decrease sharply, first to 234 thousand animals in 2004, then to 122-123 thousand seals in 2005 and 2008. The following two surveys of 2009 and 2010 showed a slight increase in the number of pups to 157-163 thousand, but the last survey, conducted in 2013, again showed a decrease in the number of puppies to 129 thousand animals.

Unfortunately, there is very little information about the abundance dynamics of this population. In 1951-1953, the abundance of the White Sea harp seal population was estimated at 1.3–1.5 million animals. Due to the intensive hunting of seals, the population size dropped sharply by the mid-1960s. According to Yakovenko (Yakovenko, 1967), the abundance of females at whelping patches in 1967 did not exceed 80 thousand, and the total number of animals was estimated at 400-500 thousand animals. Hunting was sharply reduced, and the abundance of harp seals gradually increased by the mid-1990s and was estimated at the level of 800 thousand animals.

Given the very scarce information on the dynamics of reproductive parameters, a sharp decline in the number of pups according to aerial surveys since 2003, a priori values of natural mortality rates, it is rather difficult to estimate the abundance of the White Sea seal population reliably by the analytical model at the present stage. Therefore, the problem was solved to estimate the uncertainties in estimating the population size, associated with the uncertainties in estimating biological parameters. We considered several options for calculating the size of the White Sea population: with constant parameters of reproduction for the entire period under consideration, and with parameters of reproduction calculated using the approaches described above.

Estimation with constant values of reproductive parameters. It was assumed that the birth rate (F) is a random variable having a normal distribution with an average of 0.84 and a standard deviation of 0.168. To estimate the standard deviation, it was assumed that the coefficient of variation was 20%. The maturation ogive of seals by age was adopted to be constant for the entire period (table).

Table - Portion of mature females by age for the harp seal of the White Sea population

Age	1	2	3	4	5	6	7	8	9	10	11+
Portion of mature females	0	0	0	0	0,1	0,18	0,35	0,6	0,7	0,94	1

It is impossible to describe the actual dynamics of the abundance of pups using a model with constant parameters (Fig. 1). In this variant of calculations, the initial abundance of animals 1+ in the starting year is estimated at 3 million animals, and the population abundance in 2018 is estimated at 1.02 (CI 0.91-1.2) million animals.

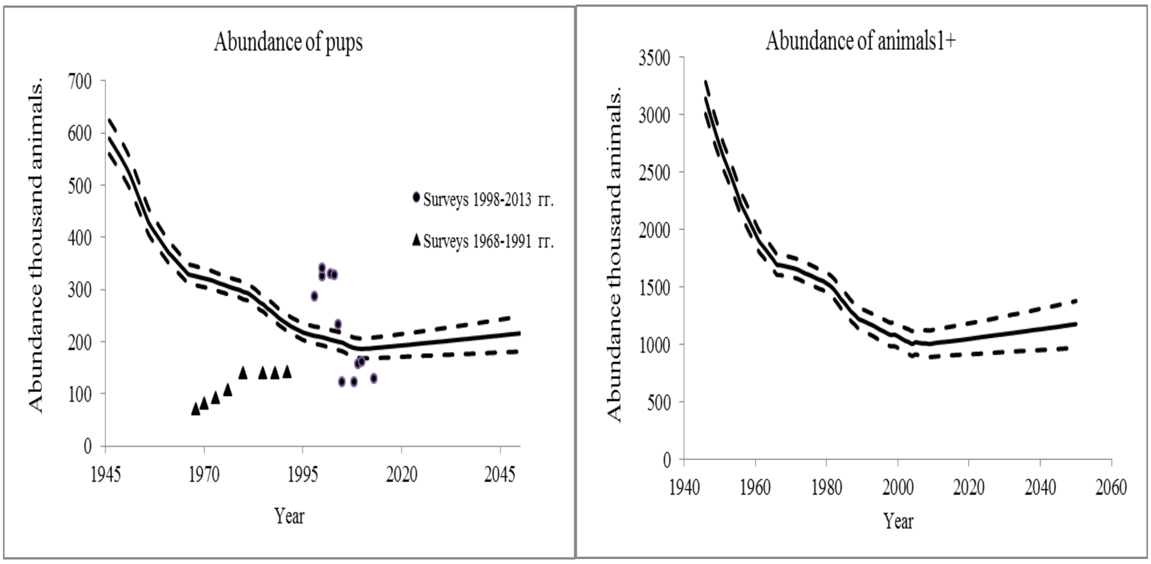

Figure 1 - Dynamics of the abundance of harp seals from the White Sea population by a cohort model with constant values of reproductivity parameters

The estimates from the model with constant reproductivity parameters do not show a sharp decline in the size of the White Sea population of the harp seal in the 1960s; and the pup estimates are 4-5 times higher than those observed in the surveys in these years. Consequently, the model does not adequately describe the provisional estimated actual population dynamics.

Using different values of the initial population, natural mortality rates and the birth rate, you can get many different population dynamics curves that have approximately the same values of the SSQ tuning criteria. In order to reduce uncertainty in the choice of values of population parameters, we assume that in the period 2008–2020, when there is no hunting, the total population size should not increase sharply. We explain this assumption by the fact that recent surveys of pups (2008–2013) when there was no hunting have insignificant fluctuations in estimates, do not have a clearly defined tendency, and may indicate some stabilization of the abundance of the White Sea harp seal population.

Reducing the initial abundance to 1.7, 1.5, and 1.2 million animals, we obtain different trajectories of the abundance curves with the similar values of SSQ. However, they all show that in the absence of hunting, the population size steadily increases. Moreover, the smaller the initial abundance, the higher the growth rate of the abundance. Modelling a sharp increase in abundance in the absence of hunting starting from 2018, causes a great distrust of the estimates. Therefore, a model with constant parameters of reproduction cannot adequately describe the dynamics of the White Sea population noted by researchers, and the use of the model is not advisable.

<u>Estimation with variable values of reproductive parameters.</u> Two options were considered.

1) Modelling with variable values of maturation parameters by age and year ($p_{i,\ j}$) and with the birth rate (F), varying according to the rules described above, and, precisely, in the years when data are known - their values are taken. For years in which data are not available, linear interpolation is used between years with known data.
2) The birth rate F is assumed to be constant and equal to 0.84 from 1960 to 2003, and for the subsequent years (2004-2013) it was chosen so that the simulated abundance of pups described well the actual abundance of pups from the surveys in 1998-2013.

According to the first variant of the calculations, the model also cannot adequately describe the changes in the abundance of recruitment in 1998-2013. But, in this case, in the dynamics of the abundance curves, one can note the manifestation of the tendencies noted earlier by the researchers, namely the decline in the population since 1946, reaching the minimum in the mid-1960s, then the changes in the abundance associated with the dynamics of catch (Fig. 2).

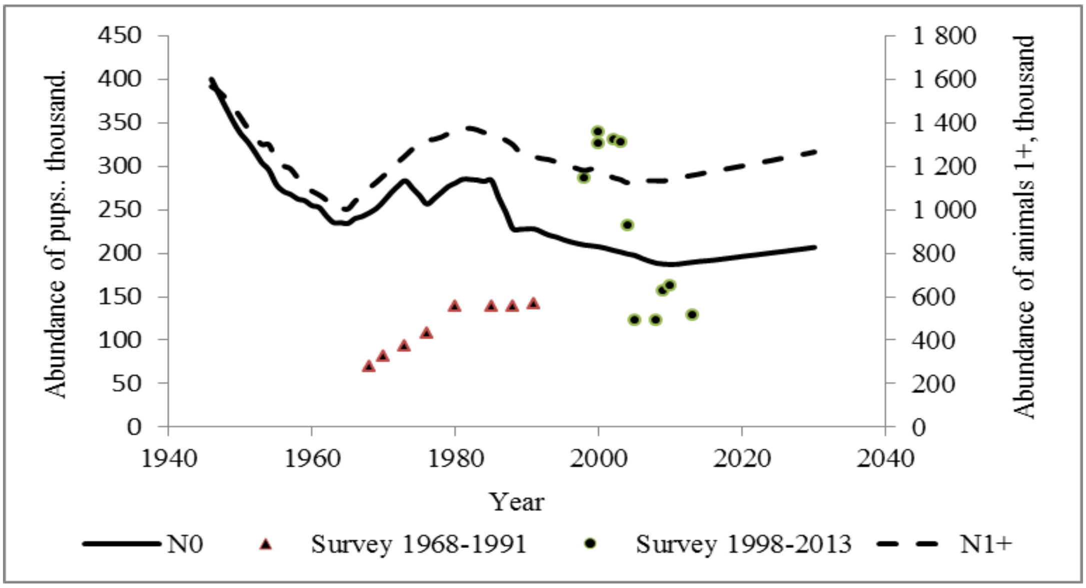

Figure 2 - Simulation of the abundance dynamics of pups and animals 1+ in harp seals of the White Sea population

This variant, the abundance of pups according to the model significantly exceeds the abundance of females that gave birth according to the surveys in 1968-1991. The current state of the population is estimated at about 1.2 million animals aged 1+ and about 200 thousand pups. According to the model, the abundance of pups exceeds that one during the last surveys of 2008-2013. (Fig. 2).

Mathematical modelling allows us to investigate how the birth rate should have changed in order to describe the changes in the abundance of pups observed from the results of aerial surveys in 1998-2013. For this, a version of the calculation in which 1960 was adopted to be starting, was made. As for the period from 1946 to 1960, nothing is known about the abundance of pups or females at whelping patches, so we did not use this period of 15 years in the calculations and tuning.

The simulation results showed the following. In order for the estimates of the abundance of pups according to the model to correspond to those ones obtained in the course of the surveys, the birth rate F_t should be changed as follows. It was constant and equal to 0.85 from 1960 to 1978, then decreased linearly to 0.65 by 1991. After 1991, the birth rate should increase to 0.89 in 2001, and then sharply decrease to 0.25 in 2005 and remain at this level until 2013. In further calculations for 2014-2030, it was assumed that the estimate F will remain at the same level (Fig. 3).

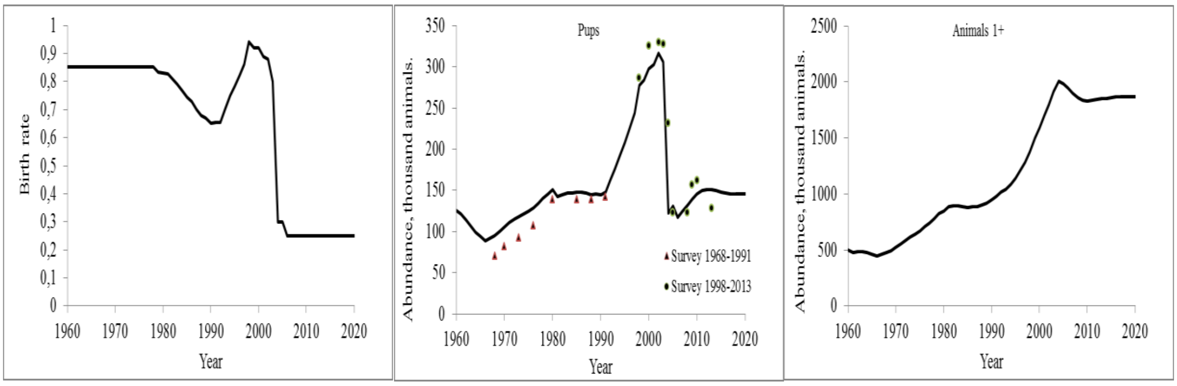

Figure 3 - Estimated dynamics of the birth rate and simulated values of the abundance of pups and adult animals of the harp seals from the White Sea population

These F-estimates seem to be very low. However, given the “unfavorable” ice conditions for whelping of harp seal females in the last period, that caused an increase in pup natural mortality, an increase in miscarriages in females; and also, assuming a tendency of change in the F_t rate for the White Sea population, the same one that was observed from 1960 to 2004 in females of the harp seal of the Newfoundling population (in 2004, their F fell to 0.44), and given the preliminary estimates of its decline to 0.3 in 2010-2011 (Sjare B., Stenson G.B. 2010), it can be assumed that our estimates of abundance and F_t for the White Sea population may be quite real. At the same time, the abundance of animals aged 1+ of the White Sea population of the harp seal for 2018 is estimated at 2.0 million, and the abundance of pups - at 156 thousand animals (Fig. 3).

Studies have shown that it is only possible to describe the dynamics of pup abundance from surveys assuming a large change in the birth rates. In this regard, at this stage, two hypotheses can be assumed: 1) the population abundance of 1+ is quite high (up to 2 million animals), but the birth rate is very low; 2) the birth rate is close to its average value, and then the number of animals 1+ is about 1 million animals. In the first case, the capture of seals can be carried out under the assumption of an increase in the birth rate. In the second case, the population is at the level of its relative stabilization (as in the 1980-1990s), and then the catch is possible at the level of 20-30 thousand animals (as it was before, and which did not lead to the depletion of the population).

The use of a cohort model for estimating abundance and catch forecast is currently not recommended. It is necessary to organize, where possible, systematic collection of biological data on the condition of seals. In the absence of biological data for estimating the abundance of marine mammals, it is more preferable, in our opinion, to use the production models, that is explained by their relative simplicity and minimal requirements for input data. To implement them, it is enough to have the catch data and one or more estimates of abundance (for example, on aerial surveys).

References

Anon., ICES 2008. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals, 27-30 August 2008, Tromsø, Norway. Anon., ICES CM 2009/ACOM 17. 59 pp

Anon., 2014. Report of the Working Group on Harp and Hooded Seals (WGHARP), St. Andrews, Scotland, 15-19 August 2014 // ICES CM 2014/ACOM: 21. 68 p.

Korzhev, V., 2014. Estimation of the abundance *and* management of hunting of the harp seal *Pagophilus groenlandicus* (*Phoca groenlandica* Erxleben, 1777) // Proceedings of VNIRO. V. 151. , pp. 87-94 (in Russian)

Sjare B., Stenson G.B. 2010. Changes in the reproductive parameters of female harp seals (Pagophilus groenlandicus) in the Northwest Atlantic // ICES J. Mar. Sci. Vol. 67. P. 304–315.

Yakovenko M. 1967. The White Sea population of the harp seal and its exploitation prospects. Murmansk, PINRO, proceedings XXI, 1967, pp. 6-18 (in Russian)

WP SEA 254

ICES/NAFO/NAMMCO WORKING GROUP ON HARP AND HOODED SEALS IMR, TROMSØ, NORWAY, 2-6 SEPTEMBER 2019

Updated Estimates of Harp Seal Bycatch and Total Removals of NW Atlantic Harp and Hooded Seals in Canadian waters

G. B. Stenson and P. Upward

Department of Fisheries & Oceans, Science Branch, P.O. Box 5667 St. John's, Newfoundland, Canada A1C 5X1

Hooded Seals

Under the Canadian Atlantic Seal Management Strategy (Hammill and Stenson 2007, 2009b), Northwest Atlantic hooded seals are considered to be data poor. Under this approach, TAC are set by considering a PBR approach. Prior to 2007, the TAC for hooded seals was set at 10,000 (Table 1). As a result of new data on the status of the population (Hammill and Stenson 2006) the quota was reduced to 8,200 in 2007. Hooded seals have not been assessed since 2006 and as a result, no changes have occurred in the TAC. The TAC has not actually been formally announced since 2016. The killing of bluebacks is prohibited in Canada.

Although the number of hooded seals taken in Canada has increased in recent years, the numbers are still very low. One 1 hooded seal was reported taken in each of 2015 and 2016 (Table 2). Catches increased to 12 in 2017 and 79 in 2018. The preliminary estimate of hooded seal catches in 2019 is 30 seals. These are all 1+ individuals as the hunting of bluebacks is illegal in Canada.

Harp Seals

After 2005, TACs were set annually to ensure that the population did not decline below the precautionary reference level (i.e. N_{70} or 70% of the maximum population size) within a 15 year period (e.g. Hammill and Stenson 2007, 2009; Hammill et al 2014). Using this approach, the TAC for harp seals was set at 400,000 in 2011 (Table 3). Although the harp seal population was reassessed in 2013, the quota remained the same. However, hunting of harp and hooded seals in Canadian waters has been very limited in recent years and there has been very little interest in reviewing the catch limits. Since 2017, the TAC has not actually been announced; DFO has said that they will monitor the catch 'with respect to the scientific recommendations'.

After more than a decade of high catches, harp seal catches in Canada have remained below 100,000 since 2009, averaging ~63,000 animals (Table 4). Catches declined to 35,382 (8% of the TAC) in 2015 after which they increased to 68,380 (17% TAC) in 2016 and 81,742 (20.5% TAC) in 2017. Catches declined again in the most recent years with 61,022 (15.25% TAC) seal reported taken in 2018 and a preliminary estimate of 32,038 (8% TAC) in 2019. Since the late 1990s, over 97% of the catch have been young of the year (YOY) with some years beaters accounted for 100% of the harvest. Since 2016, however, the proportion of 1+ in the catch has increased with the proportion of YOY in the catch averaging 90%.

An additional 1,000 seals are assumed to be taken in the Canadian Arctic.

Bycatch

Sjare et al. (2005) provided estimates of harp seal bycatch in the Newfoundland lumpfish fisheries from 1970 - 2003. These estimates were based upon reported landings of lumpfish roe (Table 5) and estimates of seal bycatch rates obtained from a bycatch logbook monitoring program that was carried out by DFO, Marine Mammal Section from 1989 to 2003. The data were split into three areas; Northeast Coast (NAFO areas 3K and 3L except 3Lq), South Coast (3Pn, 3Ps and 3Lq) and the West Coast (4R). Harp seal bycatch per tonne of lumpfish roe were calculated for each area based on the logbook data on the weight of lumpfish roe landed and the number of seals caught per trip (Table 6). These estimates were used to hind-cast to from 1988 to 1970 based on lumpfish roe landings over that time period and the average number of seals taken per tonne of roe from 1989 to 1991.

In our assessments, we have incorporated these estimates up to 2003 and then applied an average of the last 5 years (12,290) to the period 2004 onward. However, since 2003 there have been significant changes in the lumpfish fishery. Therefore, we felt it necessary to revisit the estimates.

In the absence of new logbook data on catch rates, we used the bycatch rates estimated by Sjare et al (2005) and updated lumpfish roe landing spanning 1970 through 2018. As in Sjare et al (2005) we used the average of the bycatch rates from 1989 to 1991 from each area to hind-cast the 1970-1988 period. We then used the average rates from 1999 to 2003 (i.e. the last 5 years) for the subsequent years.

Sjare et al. estimated the proportion of YOY seals caught from 1989 to 2000 using age class records provided by fishers over that time period. As in the Sjare et al. (2005), the average age classes from 1989 to 1991 were applied to the 1970-88 period while averages for 1996 to 2000 were applied to 2000 onward (Table 7).

Bycatch was low until the early 1990s due to limited effort in the fishery (table 8, Fig 1). However, in the mid 1990s effort increased dramatically and catches rose to over 45,000 seals. By the late 1990s, bycatch dropped dramatically. However, it rose again briefly before dropping aging in the early 2000s. Another peak (~35,000) in bycatch occurred in the mid 2000s before declining. Since 2010, bycatch has remained low. In 2018 it was estimated to be 555 seals.

In addition to estimated bycatch in the Newfoundland lumpfish fishery, we also included estimates of bycatch in the northeast US fisheries (Hayes et al 2019). Only small numbers of harp seals are caught in the US fisheries (Table 9).

References

Hammill, M. O., and Stenson, G. B. 2007. Application of the Precautionary Approach and conservation reference points to the management of Atlantic seals. ICES Journal of Marine Science, 64: 702-706.

Hammill, M. O., and Stenson, G. B. 2007. Application of the Precautionary Approach and conservation reference points to the management of Atlantic seals. ICES Journal of Marine Science, 64: 702-706.

Hammill, M. O., G. B. Stenson, A. Mosnier and T. Doniol-Valcroze. 2014. Abundance estimates of Northwest Atlantic harp seals and management advice for 2014. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/022.

Hayes, S.A., E. Josephson, K. Maze-Foley and P.E. Rosel (eds). 2019. US Atlantic and Gulf of Mexico Marine Mammal Stock Assessments – 2018. NOAA Technical Memorandum NMFS-NE-258.

Sjare, B., D. Walsh, G. B. Stenson and S. Benjamins. 2005. An update on harp seal *(Pagophilus groenlandicus*) by-catch estimates in the Newfoundland lumpfish fishery. Canadian Science Advisory Secretariat. Res. Doc. 2005/049.

Table 1. Major management measures implemented for hooded seals in Canadian waters for 1964–2019.

Year	Management Measure
1964	Hunting of hooded seals banned in the Gulf area (below 50oN), effective 1965.
1966	ICNAF assumed responsibility for management advice for northwest Atlantic.
1968	Open season defined (12 March–15 April).
1974–1975	TAC set at 15,000 for Canadian waters. Opening and closing dates set (20 March–24 April).
1976	TAC held at 15,000 for Canadian waters. Opening delayed to 22 March. Shooting banned between 23:00 and 10:00 GMT from opening until 31 March and between 24:00 and 09:00 GMT thereafter (to limit loss of wounded animals).
1977	TAC maintained at 15,000 for Canadian waters. Shooting of animals in water prohibited (to reduce loss due to sinking). Number of adult females limited to 10% of total catch.
1978	TAC remained at 15,000 for Canadian waters. Number of adult females limited to 7.5% of total catch.
1979–1982	TAC maintained at 15,000. Catch of adult females reduced to 5% of total catch.
1983	TAC reduced to 12,000 for Canadian waters. Previous conservation measures retained.
1984–1990	TAC reduced to 2,340 for Canadian waters.
1987	Change in Seal Management Policy to prohibit the commercial hunting of bluebacks and hunting from large (>65 ft) vessels (effective 1988). Changes implemented by a condition of licence.
1991–1992	TAC raised to 15,000.
1992	First Seal Management Plan implemented.
1993	TAC reduced to 8,000. Seal Protection Regulations updated and incorporated in the Marine Mammal Regulations. The commercial sale of bluebacks prohibited under the Regulations.
1995	Personal sealing licences allowed (adult pelage only).
1998	TAC increased to 10,000
2000	Taking of bluebacks prohibited by condition of license.
2007	TAC reduced to 8,200 under Objective Based Fisheries Management based on 2006 assessment
2008	Implementation of requirement to bleed before skinning as a condition of license
2009	Additional requirements implemented to ensure humane killing methods are used
2017	TAC no longer announced. Catches monitored.

Table 2. Canadian catches of hooded seals off Newfoundland and in the Gulf of St. Lawrence, Canada ("Gulf" and "Front"), 1946-2019a,b. Catches from 1995 onward includes catches under personal use licences. YOY refers to Young of Year. Catches from 1990-1996 were not assigned to age classes. With the exception of 1996, all were assumed to be 1+.

	Large Vessel Catches				Landsmen Catches				Total Catches			
Year	YOY	1+	Unk	Total	YOY	1+	Unk	Total	YOY	1+	Unk	Total
1946-50	4029	2221	0	6249	429	184	0	613	4458	2405	0	6863
1951-55	3948	1373	0	5321	494	157	0	651	4442	1530	0	5972
1956-60	3641	2634	0	6275	106	70	0	176	3747	2704	0	6451
1961-65	2567	1756	0	4323	521	199	0	720	3088	1955	0	5043
1966-70	7483	5220	0	12703	613	211	24	848	8096	5431	24	13551
1971-75	6550	5247	0	11797	92	56	0	148	6642	5303	0	11945
1976	6065	5718	0	11783	475	127	0	602	6540	5845	0	12385
1977	7967	2922	0	10889	1003	201	0	1204	8970	3123	0	12093
1978	7730	2029	0	9759	236	509	0	745	7966	2538	0	10504
1979	11817	2876	0	14693	131	301	0	432	11948	3177	0	15125
1980	9712	1547	0	11259	1441	416	0	1857	11153	1963	0	13116
1981	7372	1897	0	9269	3289	1118	0	4407	10661	3015	0	13676
1982	4899	1987	0	6886	2858	649	0	3507	7757	2636	0	10393
1983	0	0	0	0	0	128	0	128	0	128	0	128
1984	206	187	0	393d	0	56	0	56	206	243	0	449
1985	215	220	0	435d	5	344	0	349	220	564	0	784
1986	0	0	0	0	21	12	0	33	21	12	0	33
1987	124	4	250	378	1197	280	0	1477	1321	284	250	1855
1988	0	0	0	0	828	80	0	908	828	80	0	908
1989	0	0	0	0	102	260	5	367	102	260	5	367
1990	41	53	0	94[d]	0	0	636[e]	636	41	53	636	730
1991	0	14	0	14[d]	0	0	6411[e]	6411	0	14	6411	6425
1992	35	60	0	95[d]	0	0	119[e]	119	35	60	119	214
1993	0	19	0	19[d]	0	0	19[e]	19	0	19	19	38
1994	19	53	0	72[d]	0	0	149[e]	149	19	53	149	221
1995	0	0	0	0	0	0	857[e]	857	0	0	857e	857
1996	0	0	0	0	0	0	25754[e]	25754	0	22847[f]	2907	25754
1997	0	0	0	0	0	7058	0	7058	0	7058	0	7058
1998	0	0	0	0	0	10148	0	10148	0	10148	0	10148
1999	0	0	0	0	0	201	0	201	0	201	0	201
2000	2	2	0	4[d]	0	10	0	10	2	12	0	14
2001	0	0	0	0	0	140	0	140	0	140	0	140
2002	0	0	0	0	0	150	0	150	0	150	0	150
2003	0	0	0	0	0	151	0	151	0	151	0	151
2004	0	0	0	0	0	389	0	389	0	389	0	389
2005	0	0	0	0	0	20	0	20	0	20	0	20
2006	0	0	0	0	0	40	0	40	0	40	0	40
2007	0	0	0	0	0	17	0	17	0	17	0	17
2008	0	0	0	0	0	5	0	5	0	5	0	5
2009	0	0	0	0	0	10	0	10	0	10	0	10
2010	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	0	0	0	2	0	2	0	2	0	2
2012	0	0	0	0	0	1	0	1	0	1	0	1
2013	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	7	0	7	0	7	0	7
2015	0	0	0	0	0	1	0	1	0	1	0	1
2016	0	0	0	0	0	1	0	1	0	1	0	1
2017	0	0	0	0	0	12	0	12	0	12	0	12
2018	0	0	0	0	0	79	0	79	0	79	0	79
2019[g]	0	0	0	0	0	30	0	30	0	30	0	30

[a] For the period 1946–1970 only 5-years averages are given.

[b] All values prior to 1990 are from NAFO except where noted; recent years are from DFO Statistics Branch.

[c] Landsmen values include catches by small vessels (< 150 gr tons) and aircraft.

[d] Large vessel catches represent research catches in Newfoundland and may differ from NAFO values.

[e] **Statistics not split by age; commercial catches of bluebacks are not allowed**

[f] **Number of YOY based upon seizures of illegal catches**

[g] **Preliminary data**

Table 3. Major management measures implemented for harp seals in Canadian waters, 1961–2019.

Year	Management Measure
1961	Opening and closing dates set for the Gulf of the St. Lawrence and Front areas.
1964	First licensing of sealing vessels and aircraft. Quota of 50,000 set for southern Gulf (effective 1965).
1965	Prohibition on killing adult seals in breeding or nursery areas. Introduction of licensing of sealers. Introduction of regulations defining killing methods.
1966	Amendments to licensing. Gulf quota areas extended. Rigid definition of killing methods.
1971	TAC for large vessels set at 200,000 and an allowance of 45,000 for landsmen.
1972 – 1975	TAC reduced to 150,000, including 120,000 for large vessel and 30,000 (unregulated) for landsmen. Large vessel hunt in the Gulf prohibited.
1976	TAC was reduced to 127,000.
1977	TAC increased to 170,000 for Canadian waters, including an allowance of 10,000 for northern native peoples and a quota of 63,000 for landsmen (includes various suballocations throughout the Gulf of St. Lawrence and northeastern Newfoundland). Adults limited to 5% of total large vessel catch.
1978–1979	TAC held at 170,000 for Canadian waters. An additional allowance of 10,000 for the northern native peoples (mainly Greenland).
1980	TAC remained at 170,000 for Canadian waters including an allowance of 1,800 for the Canadian Arctic. Greenland was allocated additional 10,000.
1981	TAC remained at 170,000 for Canadian waters including 1,800 for the Canadian Arctic. An additional allowance of 13,000 for Greenland.
1982–1987	TAC increased to 186,000 for Canadian waters including increased allowance to northern native people of 11,000. Greenland catch anticipated at 13,000.
1987	Change in Seal Management Policy to prohibit the commercial hunting of whitecoats and hunting from large (>65 ft) vessels (effective 1988). Changes implemented by a condition of licence.
1992	First Seal Management Plan implemented.
1993	Seal Protection Regulations updated and incorporated in the Marine Mammal Regulations. The commercial sale of whitecoats prohibited under the Regulations. Netting of seals south of 54°N prohibited. Other changes to define killing methods, control interference with the hunt and remove old restrictions.
1995	Personal sealing licences allowed. TAC remained at 186,000 including personal catches. Quota divided among Gulf, Front and unallocated reserve.
1996	TAC increased to 250,000 including allocations of 2,000 for personal use and 2,000 for Canadian Arctic.
1997	TAC increased to 275,000 for Canadian waters.
2000	Taking of whitecoats prohibited by condition of license
2003	Implementation of 3 year management plan allowing a total harvest of 975,000 over 3 years with a maximum of 350,000 in any one year.
2005	TAC reduced to 319,517 in final year of 3 year management plan
2006	TAC increased to 335,000 including a 325,000 commercial quota, 6,000 original initiative, and 2,000 allocation each for Personal Use and Arctic catches
2007	TAC reduced to 270,000 including 263,140 for commercial, 4,860 for Aboriginal, and 2,000 for Personal Use catches
2008	TAC increased to 275,000 including a 268,050 for commercial, 4,950 for Aboriginal and 2,000 for Personal Use catches Implementation of requirement to bleed before skinning as a condition of licence
2009	TAC increased to 280,000 based upon allocations given in 2008 plus an additional 5,000 for market development Additional requirements related to humane killing methods were implemented
2010	TAC increased to 330,000
2011	TAC increased to 400,000
2017	TAC no longer announced. Catches monitored

Table 4. Reported Canadian catches of Harp seals off Newfoundland and in the Gulf of St. Lawrence, Canada ("Gulf" and "Front"), 1946–2019a,b. Catches from 1995 onward include catches under the personal use licences. YOY = Young of Year.

	Large Vessel Catch				Landsmen Catch[c]				Total Catches			
Year	YOY	1+	Unk	Total	YOY	1+	Unk	Total	YOY	1+	Unk	Total
1946-50	108256	53763	0	162019	44724	11232	0	55956	152980	64995	0	217975
1951-55	184857	87576	0	272433	43542	10697	0	54239	228399	98273	0	326672
1956-50	175351	89617	0	264968	33227	7848	0	41075	208578	97466	0	306044
1961-65	171643	52776	0	224419[d]	47450	13293	0	60743	219093	66069	0	285162
1966-70	194819	40444	0	235263	32524	11633	0	44157	227343	52077	0	279420
1971-75	106425	12778	0	119203	29813	12320	0	42133	136237	25098	0	161336
1976	93939	4576	0	98515	38146	28341	0	66487	132085	32917	0	165002
1977	92904	2048	0	94952	34078	26113	0	60191	126982	28161	0	155143
1978	63669	3523	0	67192	52521	42010	0	94531	116190	45533	0	161723
1979	96926	449	0	97375	35532	27634	0	63166	132458	28083	0	160541
1980	91577	1563	0	93140	40844	35542	0	76386	132421	37105	0	169526
1981d	89049	1211	0	90260	89345	22564	0	111909	178394	23775	0	202169
1982	100568	1655	0	102223	44706	19810	0	64516	145274	21465	0	166739
1983	9529	1021	0	10550	40529	6810	0	47339	50058	7831	0	57889
1984	95	549	0	644[e]	23827	7073	0	30900	23922	7622	0	31544
1985	0	1	0	1[e]	13334	5700	0	19034	13334	5701	0	19035
1986	0	0	0	0	21888	4046	0	25934	21888	4046	0	25934
1987	2671	90	0	2761	33657	10356	22	44035	36350	10446	0	46796
1988	0	0	0	0	66972	13493	13581	94046	66972	27074	0	94046
1989	1	231	0	232[e]	56345	5691	3036	65072	56346	8958	0	65304
1990	48	74	0	122[e]	34354	23725	1961	60040	34402	25760	0	60162
1991	3	20	0	23[e]	42379	5746	4440	52565	42382	10206	0	52588
1992	99	846	0	945[e]	43767	21520	2436	67723	43866	24802	0	68668
1993	8	111	0	119[e]	16393	9714	777	26884	16401	10602	0	27003
1994	43	152	0	195[e]	25180	34939	1065	61184	25223	36156	0	61379
1995	21	355	0	376[e]	33615	31306	470	65391	34106	31661	0	65767
1996	3	186	0	189[e]	184853	57864	0	242717	184856	58050	0	242906
1997	0	6	0	6[e]	220476	43728	0	264204	220476	43734	0	264210
1998	7	547	0	554[e]	0	0	282070	282070	7	547	282070	282624
1999	26	25	0	51[e]	221001	6769	16782	244552	221027	6794	16782	244603
2000	16	450	0	466[e]	85035	6567	0	91602	85485	6583	0	92068
2001	0	0	0	0	214754	11739	0	226493	214754	11739	0	226493
2002	0	0	0	0	297764	14603	0	312367	297764	14603	0	312367
2003	0	0	0	0	280174	9338	0	289512	280174	9338	0	289512
2004	0	0	0	0	353553	12418	0	365971	353553	12418	0	365971
2005	0	0	0	0	319127	4699	0	323826	319127	4699	0	323826
2006	0	0	0	0	346426	8441	0	354867	346426	8441	0	354867
2007	0	0	0	0	221488	3257	0	224745	221488	3257	0	224745
2008	0	0	0	0	217565	285	0	217850	217565	285	0	217850
2009	0	0	0	0	76668	0	0	76668	76668	0	0	76668
2010	0	0	0	0	68654	447	0	69101	68654	447	0	69101
2011	0	0	0	0	40371	18	0	40389	40371	18	0	40389
2012	0	0	0	0	71319	141	0	71460	71319	141	0	71460
2013	0	0	0	0	94,310	3,612	0	97,922	94,310	3,612	0	97,922
2014	0	0	0	0	59,616	50	0	59,666	59,616	50	0	59,666
2015	0	0	0	0	35,302	80	0	35,382	35,302	80	0	35,382
2016	0	0	0	0	51,854	7,087	9,419[f]	68,360	51,854	7,087	9,419	68,360
2017	0	0	0	0	58,234	10,062	13,446[f]	81,742	58,234	10,062	13,446	81,742
2018	0	0	0	0	53,222	4,728	3,072[f]	61,022	53,222	4,728	3,072	61,022
2019	0	0	0	0	0	0	32,038[fg]	32,038	0	0	32,038	32,038

a For the period 1946-1975 only 5-years averages are given.

b All values prior to 1990 are from NAFO except where noted, recent data from DFO Statistics Branch.

c Landsmen values include catches by small vessels (< 150 gr tons) and aircraft.

d NAFO values revised to include complete Quebec catch (Bowen, W.D. 1982)

e Large vessel catches represent research catches in Newfoundland and may differ from NAFO values

f Unspecified catches will be assigned to age class at a later date

g Preliminary data

Table 5. Reported landings (tonnes) of lumpfish roe in Newfoundland 1970-2018

Year	NE Coast	S Coast	W Coast
1970	23,162	726	705
1971	99,706		56,212
1972	201,316		3,170
1973	152,561	627	427
1974	60,338		
1975	94,051	5	26
1976	190,811	501	129,456
1977	401,397		104,933
1978	766,821	102,092	131,156
1979	633,020	244,617	103,454
1980	110,078	453,407	29,825
1981	164,785	635,551	93,356
1982	100,463	591,834	107,972
1983	151,323	734,994	181,662
1984	231,243	510,540	196,960
1985	549,130	514,064	162,420
1986	895,991	651,510	
1987	2,179,913	826,281	77
1988	1,614,327	673,062	
1989	1,582,922	746,845	
1990	835,161	336,104	
1991	1,043,345	1,045,286	100
1992	1,438,489	506,798	363
1993	869,547	1,566,793	179,279
1994	492,958	1,023,444	77,062
1995	233,423	816,312	140,355
1996	369,441	752,031	347,489
1997	378,163	1,631,922	475,868
1998	172,014	965,979	400,716
1999	546,648	1,599,345	665,496
2000	865,475	922,361	261,565
2001	488,299	289,587	125,875
2002	140,454	15,300	21,536
2003	152,130	362,009	47,761
2004	746,359	939,011	96,130
2005	559,392	561,952	146,947
2006	284,540	707,379	106,221
2007	200,517	185,768	56,922
2008	157,712	26,776	101,547
2009	65,637	2,735	9,959
2010	91,295	10,844	50,996
2011	51,855	272	32,927
2012	50,185	706	61,607
2013	87		5,363
2014	4,969		34,978
2015	4,698		28,577
2016	5,504	817	13,347
2017	1,838	1,865	3,371
2018	8,314	508	12,642

Table 6. Number of harp seals caught per tonne of lumpfish roe. Taken from Sjare et al (2005). Catch rates applied from 2003-2018 are the average of the final 5 years (1999-2003).

Year	NE Coast	S Coast	W Coast
Pre 1989	3.03	5.21	3.97
1989	3.71	3.71	3.71
1990	1.69	4.04	6.59
1991	2.63	5.70	4.06
1992	12.72	9.34	11.75
1993	15.91	4.34	35.37
1994	34.26	22.04	94.70
1995	32.47	10.14	28.80
1996	40.61	12.35	15.14
1997	21.23	3.59	10.28
1998	2.90	2.90	2.90
1999	18.30	1.86	4.67
2000	8.96	2.62	5.07
2001	11.50	22.85	61.62
2002	51.54	53.14	69.24
2003	20.75	6.03	2.20
Post 2003	22.21	17.30	28.56

Table 7. Proportion of harp seal by-catch that consisted of YOY harp seals from the northeast, south and west coast regions of Newfoundland from 1970 to 2018, based upon Sjare et al (2005). Proportion of YOY prior to 1989 are the mean of 1989-91 estimates for each region; estimates for post 2000 are the mean of estimates 1996-2000.

Year	NE Coast	S Coast	W Coast
Pre 1989	0.77	0.92	0.93
1989	0.90	0.95	0.95
1990	0.60	0.83	0.85
1991	0.80	0.99	0.99
1992	0.66	0.96	0.92
1993	0.60	0.77	0.90
1994	0.48	0.95	0.90
1995	0.38	0.93	0.79
1996	0.16	0.56	0.62
1997	0.47	0.92	0.92
1998	0.73	0.82	0.73
1999	0.41	0.90	0.97
2000	0.79	1.00	1.00
Post 2000	0.51	0.84	0.85

Table 8. Estimated bycatch of harp seals in the Newfoundland lumpfish fishery, 1920-2018.

	Northeast Coast			South Coast			West Coast			Total		
Year	YOY	1+	Total	YOY	1+	Total	YOY	1+	Total	YOY	1+	Total
1970	54	16	70	3	0	4	3	0	3	60	17	77
1971	233	69	302	-	-	-	208	16	223	440	85	525
1972	470	140	610	-	-	-	12	1	13	481	141	623
1973	356	106	462	3	0	3	2	0	2	361	107	467
1974	141	42	183	-	-	-	-	-	-	141	42	183
1975	219	66	285	0	0	0	0	0	0	220	66	285
1976	445	133	578	2	0	3	478	36	514	926	169	1,095
1977	936	280	1216	-	-	-	387	29	417	1,324	309	1,633
1978	1,789	534	2323	489	43	532	484	36	521	2,763	613	3,376
1979	1,477	441	1918	1,172	102	1,274	382	29	411	3,031	572	3,603
1980	257	77	334	2,173	189	2,362	110	8	118	2,540	274	2,814
1981	384	115	499	3,046	265	3,311	345	26	371	3,775	406	4,181
1982	234	70	304	2,837	247	3,083	399	30	429	3,470	347	3,817
1983	353	105	459	3,523	306	3,829	671	50	721	4,547	462	5,009
1984	540	161	701	2,447	213	2,660	727	55	782	3,714	429	4,143
1985	1,281	383	1664	2,464	214	2,678	600	45	645	4,345	642	4,987
1986	2,090	624	2715	3,123	272	3,394	-	-	-	5,213	896	6,109
1987	5,086	1,519	6605	3,961	344	4,305	0	0	0	9,047	1,864	10,910
1988	3,766	1,125	4891	3,226	281	3,507	-	-	-	6,993	1,406	8,398
1989	5,285	587	5873	2,632	139	2,771	-	-	-	7,918	726	8,643
1990	847	565	1411	1,127	231	1,358	-	-	-	1,974	795	2,769
1991	2,195	549	2744	5,899	60	5,958	0	0	0	8,094	608	8,703
1992	12,076	6,221	18298	4,544	189	4,733	4	0	4	16,624	6,411	23,035
1993	8,301	5,534	13834	5,236	1,564	6,800	5,707	634	6,341	19,244	7,732	26,975
1994	8,107	8,782	16889	21,429	1,128	22,557	6,568	730	7,298	36,103	10,640	46,743
1995	2,880	4,699	7579	7,698	579	8,277	3,193	849	4,042	13,771	6,127	19,899
1996	2,400	12,603	15003	5,201	4,087	9,288	3,262	1,999	5,261	10,863	18,688	29,552
1997	3,773	4,255	8028	5,390	469	5,859	4,501	391	4,892	13,664	5,115	18,779
1998	364	135	499	2,297	504	2,801	848	314	1,162	3,510	953	4,462
1999	4,101	5,902	10004	2,677	297	2,975	3,015	93	3,108	9,793	6,293	16,086
2000	6,126	1,628	7755	2,417	-	2,417	1,326	-	1,326	9,869	1,628	11,497
2001	2,864	2,752	5615	5,558	1,059	6,617	6,593	1,163	7,756	15,015	4,974	19,989

2002	3,692	3,547	7239	683	130	813	1,267	224	1,491	5,642	3,901	9,543
2003	1,610	1,547	3157	1,834	349	2,183	89	16	105	3,533	1,912	5,445
2004	8,454	8,123	16577	13,646	2,599	16,245	2,334	412	2,745	24,433	11,134	35,567
2005	6,336	6,088	12424	8,166	1,555	9,722	3,567	630	4,197	18,070	8,273	26,343
2006	3,223	3,097	6320	10,280	1,958	12,238	2,579	455	3,034	16,081	5,510	21,591
2007	2,271	2,182	4453	2,700	514	3,214	1,382	244	1,626	6,353	2,940	9,293
2008	1,786	1,716	3503	389	74	463	2,465	435	2,900	4,641	2,226	6,866
2009	743	714	1458	40	8	47	242	43	284	1,025	765	1,790
2010	1,034	994	2028	158	30	188	1,238	218	1,456	2,430	1,242	3,672
2011	587	564	1152	4	1	5	799	141	940	1,391	706	2,097
2012	568	546	1115	10	2	12	1,496	264	1,759	2,074	812	2,886
2013	1	1	2	-	-	-	130	23	153	131	24	155
2014	56	54	110	-	-	-	849	150	999	905	204	1,109
2015	53	51	104	-	-	-	694	122	816	747	174	920
2016	62	60	122	12	2	14	324	57	381	398	119	518
2017	21	20	41	27	5	32	82	14	96	130	40	169
2018	94	90	185	7	1	9	307	54	361	408	146	555

Table 9. Estimated bycatch of harp seals in the northeast US. Estimated bycatch 2017-2019 is the average of estimates 2012-2016. (from Hayes et al 2019)

Year	Bycatch
1994	861
1995	694
1996	89
1997	269
1998	95
1999	81
2000	24
2001	75
2002	0
2003	0
2004	303
2005	35
2006	65
2007	157
2008	414
2009	485
2010	285
2011	17
2012	0
2013	22
2014	57
2015	119
2016	85
2017	57
2018	57
2019	57

Fig 1. Estimated bycatch of harp seals in the Newfoundland lumpfish fishery