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Estimated pup production of harp seals *Pagophilus groenlandicus* in the White Sea, Russia, in 2000

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Since the 1960s pup production of harp seals *Pagophilus groenlandicus* in the White Sea was estimated from aerial photographic surveys of visible adult females on the ice. Adult abundance estimations were underestimated because an unknown number of females were in the water during the survey. The absence of a reliable estimation of pup production constrained management initiatives. Aerial photographic surveys of whelping harp seals were conducted in the White Sea 10–12 March 2000. Using a systematic strip transect survey design approach, the number of pups present was estimated as 294 914 with a standard error (s.e.) of 36 168. When pups caught by Russian sealers in the White Sea before the aerial surveys (30 729 pups) were included the total estimated number of pups was 325 643 (s.e. 36 168), whereas the number of adult harp seals was 215 943 (s.e. 22 630). The pup estimate was not corrected for pups born after the survey, but this was not considered to be significant. The new estimation of pup production is higher than thought earlier.

Keywords: aerial surveys, pup production, harp seals, White Sea.

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Introduction

The harp seal *Pagophilus groenlandicus* is an abundant north Atlantic ice-breeding phocid, separated into three assumed stocks based on their whelping locations: the Northwest Atlantic stock, the Greenland Sea stock and the Barents Sea/White Sea stock (Sergeant, 1991). The Barents Sea/White Sea stock, whose whelping grounds are located in the White Sea, has been subjected to extensive Norwegian and Russian commercial hunting since the 1870s. Although historical estimates of abundance were not available by the time catch regulations were implemented in the early 1960s, this hunt may have reduced the stock to a historical low (Khuzin, 1972; Sergeant, 1991). Retrospective cohort analyses based on Norwegian catch data suggested that the stock was increasing approximately 5% per year in the late 1970s (Benjaminsen, 1979), while Norwegian and Russian age composition data and Russian aerial surveys of whelping females tended to indicate reduced recruitment in some years during the 1980s and early 1990s (Ulltang and Øien, 1988; ICES, 1990, 1992, 1993, 1994; Kjellqwist *et al.*, 1995; Timoshenko, 1995).

Because of uncertainties in the assumptions required when estimating abundance from catch-at-age data, sequential population models and mark-recapture data, independent estimates of pup production have been recommended (e.g. ICES, 1990, 1992, 1993, 1994; NAFO, 1995) and used for determining population size of harp seals both in the Northwest Atlantic (e.g. Stenson *et al.*, 1993, 1997, 2002, 2003) and in the Greenland Sea (Øritsland and Øien, 1995). The status of the stocks is subsequently assessed by fitting population models to independent estimates of pup production (e.g. Healey and Stenson, 2000; ICES, 2001). In the period 1963–1991, annual pup production was estimated from aerial photographic surveys of adult harp seal females on the ice during the whelping period that suggested an annual pup production of approximately 140 000 by 1990 (see ICES, 1992, 1993). However, it was known that 45–50% of the females may have been in the water during the surveys (Popov, 1966), and therefore were not counted. Later studies of lactating female attendance patterns (Lydersen and Kovacs, 1993; Perry and Stenson, DFO, Northwest Atlantic Fisheries Centre, St. John's, Newfoundland, Canada, pers. comm.) in the Northwest Atlantic indicate that the proportion of females on the ice varies with time of day and weather conditions, illustrating further the difficulties involved in assessing the pup production by counting adult females without determining appropriate correction factors. Also, studies of the temporal distribution of births (Potelov, unpublished data) have shown that up to 50% of the females may have whelped later than the period usually chosen for the conduction of the adult female surveys. As a result, the Russian aerial surveys of adult females likely underestimated the pup production considerably.

The lack of updated, reliable pup production estimates have been an obstacle in the assessment and management of the Barents Sea/White Sea stock of harp seals. Without an appropriate correction factor, pup production could not be properly estimated from the proportion of females present on the ice in the whelping period, and an alternative method had to be sought. After 1991, following ICES recommendations, airplane surveys of the whelping grounds of harp seals in the White Sea were conducted using strip transect methods (ICES, 1999, 2001). In 1997–2000, helicopter surveys were performed concurrently to develop a standardized survey design aimed to estimate both the pup production and the abundance of adults on the whelping grounds in the White Sea. The survey design was based on techniques developed in Canada and Norway to estimate pup production of harp and hooded *Cystophora cristata* seals in the Northwest Atlantic (Hammill *et al.*, 1992; Stenson *et al.*, 1993, 1997, 2002, 2003) and in the Greenland Sea (Øritsland and Øien, 1995; ICES, 1998, 1999). Pilot studies were performed in 1997 and 1998 (see ICES, 1998, 1999), and a full scale survey was conducted in March 2000; this paper presents results from the helicopter 2000 survey.

Materials and methods

Reconnaissance surveys

Whelping concentrations were located using fixed-wing and helicopter reconnaissance surveys of areas historically used by harp seals in the White Sea. Three fixed-wing (L-410) surveys conducted on 24 and 27 February and 3 March delineated the western and southern borders of the whelping grounds. Flights were generally flown at altitudes of 150–200 m, and speeds of 200–270 km h^{-1} at systematic north–south transect with intervals of 10′ or 20′ longitude or in zigzag pattern from Kola coast ice edge to south (Basin) or east (Gorlo) edge of suitable ice. On 9 March, a helicopter (MI-8) reconnaissance flight at altitudes of 150–250 m, and at speeds of 150–180 km h^{-1} in the areas north of Gorlo to Voronka determined the northern border of the whelping grounds. The observed whelping grounds were more or less one large patch along the southeastern part of the Kola coast (Figure 1).

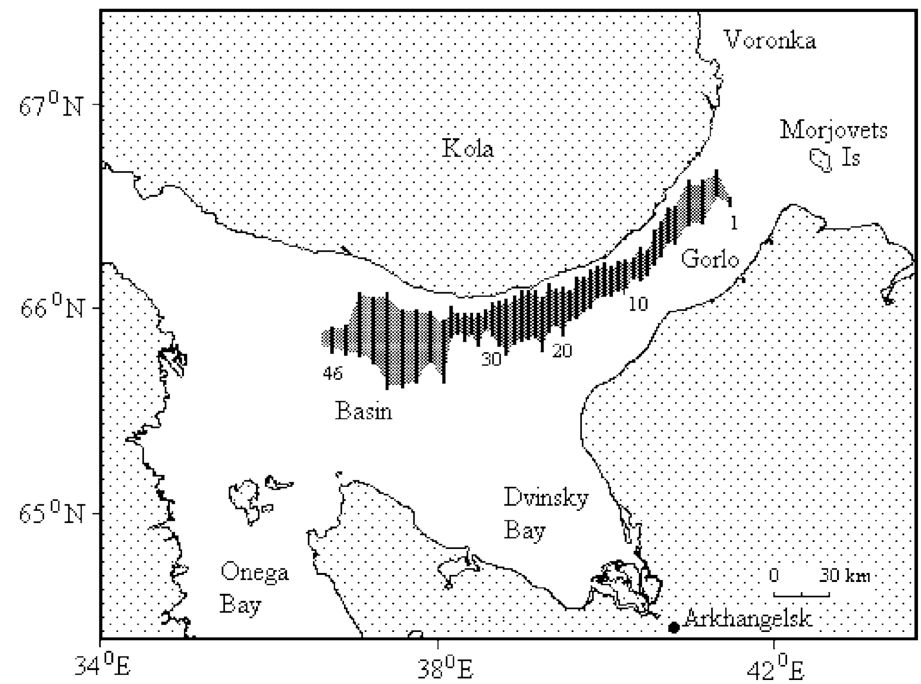

Figure 1. Position of photographic transects in the White Sea, flown with an MI-8 helicopter on 10–12 March 2000, providing a complete coverage of the survey area. The transects are numbered 1–46 from east to west.

Photographic surveys

Helicopter aerial photographic surveys were flown using a 30 × 30 cm format camera (AFA-42-20) equipped with a 200 mm lens and ISOPANCHROME (SWEMA, type 42) black-and-white film. A mechanism which compensated for camera motions was used. Based on trials carried out in 1997 and 1998 (ICES, 1998, 1999), all surveys were flown at an altitude of 125 m, and at a speed of 150 km h^{-1}, providing coverage of a 186.5 × 186.5 m area per photo. The chosen exposure was 1/500. Total lengths of pups were measured in mm on the developed negative and positive films, and with the chosen methodology, the image sizes of the pups were 1.4–1.8 mm. Adults ranged in image size between 3.0 and 3.5 mm. These measurements were used to identify pups in the photoanalyses. One to three photos were taken per km along the transects. Correct altitude and transect spacing were maintained using a radar altimeter and satellite navigation system (GPS).

Systematic photographic strip transect surveys of the whelping concentrations were carried out during 10–12 March 2000. The total area was surveyed once. Based on reconnaissance surveys the concentrations were divided into low and high density strata. Transects 1–5 were flown over low density strata and were spaced 7.4 km apart, while transects 6–38 covered the densest portion of the patch and were spaced 3.7 km apart (Figure 1 and Table 1). On the last survey day (12 March) weather conditions were poor. To be able to cover the entire remaining whelping ground, which included high pup densities, the transect spacing was 7.4 km for transects 39–46. The distance between the adjacent transects was decided before each flight. The start and end of each scheduled transect were decided during the flights. Each transect started when an observer with a forward view encountered the first seals and ended after the last seal was observed on the transect or none were visible on the sides of the transect. Flights proceeded at a speed and height to guarantee no part of the whelping ground was missed. The camera was turned on and turned off at the beginning and the end of transect, respectively. During each transect the camera worked constantly. To calculate length of transects, the beginning and the end position of each transect were marked by a GPS receiver linked to a computer. The surveys were carried out from east to west, i.e. opposite to the general direction of the ice drift in the area, which prevented double counting between days. This approach may have caused some underestimation which was not corrected for.

Two positive copies were made from each negative. All negative and positive photos were analysed by three readers. At the beginning the same frames were read several times by all the readers until they developed similar reading techniques. During the main reading each frame was analysed by two readers. If they came to different conclusions about the number of pups and adults, the lower estimate was used.

Table 1. Results from the photographic strip transect surveys in the White Sea conducted in the period 10–12 March 2000.

Stratum	No. of transects	Length (km)	Transect spacing	No. of photos	No. of seals on photo	
					Pups	Adults
1	1	3.89	7.4	9	2	1
1	2	13.52	7.4	28	4	2
1	3	21.95	7.4	44	7	8
1	4	23.68	7.4	40	15	25
1/2	5	19.08	7.4/3.7	38	9	0
2	6	18.15	3.7	36	127	179
2	7	18.24	3.7	35	70	90
2	8	17.35	3.7	34	88	178
2	9	12.5	3.7	25	20	27
2	10	16.3	3.7	33	21	27
2	11	9.88	3.7	18	22	56
2	12	16.85	3.7	33	29	36
2	13	15	3.7	28	49	87
2	14	15.56	3.7	30	64	96
2	15	16.42	3.7	30	95	152
2	16	16.42	3.7	34	107	129
2	17	20	3.7	30	68	136
2	18	17.16	3.7	34	53	89
2	19	21.79	3.7	40	29	27
2	20	14.41	3.7	26	36	13
2	21	24.72	3.7	39	36	23
2	22	18.64	3.7	38	29	34
2	23	25.19	3.7	45	74	54
2	24	27.78	3.7	62	108	84
2	25	23.92	3.7	42	229	166
2	26	25.74	3.7	49	156	96
2	27	26.11	3.7	47	84	47
2	28	25.87	3.7	52	44	34
2	29	24.84	3.7	50	67	67
2	30	23.68	3.7	57	10	10
2	31	16.67	3.7	50	2	36
2	32	9.78	3.7	28	4	16
2	33	16.82	3.7	47	19	27
2	34	10.49	3.7	36	43	46
2	35	14.23	3.7	45	7	10
2	36	9.48	3.7	31	14	4
2	37	15.77	3.7	46	15	16
2/3	38	33.03	3.7/7.4	90	81	42
3	39	26.73	7.4	74	123	93
3	40	38.21	7.4	130	709	361
3	41	38.9	7.4	121	756	467
3	42	50.96	7.4	149	368	226
3	43	34.39	7.4	106	481	176
3	44	28.06	7.4	81	261	56
3	45	15.16	7.4	48	21	2
3	46	12.75	7.4	38	0	0
Total		946.07		2226	4656	3551

Abundance estimation

Photographic surveys and statistical analysis of results were carried out according to methods used in similar aerial surveys of harp and hooded seals in the Northwest Atlantic (Hammill *et al.*, 1992; Stenson *et al.*, 1993, 1997, 2002, 2003).

The estimated number of pups for the ith survey is given by

$$\hat{N}_i = k_i \sum_{j=1}^{J_i} x_j$$

where J_i is the number of transects in the ith survey, k_i the weighting factor for the ith survey determined by dividing the transect interval by the transect width and x_j is the number of pups on the jth transect.

For photographic surveys where frames did not overlap

$$x_j = \frac{l_j \sum_{z=1}^{f_i} t_{jz}}{f_j p_j}$$

where f_j is the number of photographs on transect line j, t_{jz} the number of seals in the zth frame on the jth transect, l_j the total transect length and p_j is the frame length.

This assumes that the distribution and density of pups on the unobserved portions were similar to those in the observed. The additional component of error that arises from this assumption was judged to be small and is included in the between-transect variability.

The estimates of error variance, based on serial differences between transects were calculated as

$$V_i = \frac{k_i(k_i - 1)J_i}{2(J_i - 1)} \sum_{j=1}^{J_i - 1} (x_j - x_j + 1)^2$$

If transect spacing changed within the survey area, each area of homogeneous transect spacing was treated as a separate survey with the estimated number of pups given by

$$\hat{N}_i = k_i \left[x_{i1}/2 + \sum_{j=2}^{J_i - 1} x_{ij} + x_i J_i/2 \right]$$

where J_i is the number of transects in the ith group, x_{ij} the number of pups counted on the jth transect in the ith group and the end transects are the limits of the survey area.

The variance estimate was given by

$$V_i = \frac{k_i(k_i - 1)}{2} \sum_{j=1}^{J_i - 1} (x_j - x_j + 1)^2$$

The total population was estimated as $\hat{N} = \sum_{i=1}^{I} N_i$ and its error variance $\hat{V} = \sum_{i=1}^{I} V_i$, where I is the number of surveys.

Results

The whelping area

The reconnaissance flight on 24 February 2000 revealed that the breeding patch was already established, but the number of whelping females was small. On 27 February and 3 March, dense whelping patches were observed in the western parts of the Basin area (west to longitude 37°40′E, see Figure 1). Females were still observed to arrive in the area. The northern border of the whelping patch was determined on 9 March (north to latitude 66°40′N). Further to the north, no seals were found as the northernmost parts of the Gorlo and Voronka areas were ice free. The whelping grounds extended in a continuous strip along the northern part of the Basin area and through the Gorlo area (approximately from 65°47′N 36°45′E in the west to 66°40′N 41°30′E in the east) (Figure 1).

The strip transect photographic surveys

A total of 46 transects were flown during the photographic surveys, which covered 1.7% of the total whelping grounds (Table 1). On 10 March, a photographic survey of the whelping grounds in the Gorlo area included 21 transects (transect space 3.7 and 7.4 km), which covered 1.5% of the surveyed area. On 11 March, the eastern part of the Basin area was covered by 16 photographed transects (transect space 3.7 km), which was 2.2% of the surveyed area. On 12 March, 9 transects (transect space 7.4 km) were flown in the western part of the Basin area, covering 1.5% of the surveyed area. A total of 2226 photos were taken during the surveys, which resulted in 4646 pups and 3551 adults counted on the frames (Table 1).

The pup production, uncorrected for births, was estimated to be 294 914 (standard error (s.e.) 36 168). When the pups taken by sealers (30 729) prior to the photographic surveys were included, the mean pup production estimate was 325 643 (s.e. 36 168). The mean number of adults was estimated to be 215 943 (s.e. 22 630). On 10 March, the number of adults was higher than the estimated number of pups but on 11–12 March the results were opposite. The ratio between pups and adults counted on the images indicated more adults than pups in the eastern areas, whereas the opposite was the case in the central and western areas (Table 2).

Discussion

Previously, pup production in the White Sea was estimated from age composition data by Benjaminsen (1979) who suggested a minimum pup production of about 100 000 in 1965, which, by projection, gave an estimated pup

Table 2. Numbers of pups and adult harp seals, counted on the photos obtained from the transect photographic surveys in the White Sea, 10–12 March 2000.

Whelping ground subarea	Pup numbers on photos (seals)	Adult numbers on photos (seals)	Ratio (pups/adults)
Eastern	951	1381	0.69
Central	905	747	1.21
Western	2800	1423	1.97
Total	4656	3551	1.31

production of approximately 170 000 in 1978. Russian aerial surveys of adult females on the whelping grounds suggested an annual pup production of 140 000 (ICES, 1990, 1994) around 1990, although it is evident that this may have been an underestimate due to methodological shortcomings.

The present survey shows that current pup production is substantially higher than previously assumed. It is important to note, however, that estimates made by different methods are not necessarily comparable, and direct comparisons of the presented 2000 aerial survey results with previous results to quantify changes in pup production should in principle not be done. Nevertheless, the obtained pup production estimate of 325 643 (s.e. 36 168) compares with results obtained in an airplane full scale survey performed on the harp seal whelping patches in the White Sea in March 1998 (ICES, 1999). Using the same airplane and methodology, comparable results were also obtained in an independent airplane flown survey conducted in the White Sea on 18 March 2000. This survey, conducted by traditional strip transect methods using multiple sensors, yielded an uncorrected pup production estimate of 339 710 (s.e. 32 400) (see ICES, 2001).

The February/March 2000 ice conditions were mainly characterized by thin "grey" ice in the White Sea. The so-called "white" ice, particularly suitable for whelping females, was lacking in most of the areas typically used by the breeding seals. Large areas in the White Sea were covered with thin "grey" ice, which whelping females usually avoid. Due to the lack of suitable ice, the majority of females whelped further to the west (in the Basin area) than was normal. If possible, the entire concentration should be surveyed in one single day. However, this could not be done in 2000. The ice drift was considered insignificant except during the survey on 12 March, when western wind during the second half of the day led to a general ice drift towards the east. The photographic surveys were carried out from east to west, opposite to the general direction of the ice drift in the surveyed area, which could have caused a slight underestimation as result.

The majority of harp seal females in the White Sea whelp between 25 February and 4 March, but newborns and fresh placental remains have been observed as late as 12 March (Khuzin, 1970; Potelov, unpublished data). It is obvious that the 2000 whelping was not completely over when the strip transects were flown. Available data did not permit exact calculation of the temporal distribution of births in 2000, so the given estimate could not be corrected for births that occurred after the survey period. In the future, to correct the estimates of abundance for proportion of pups not born or those in the water at the time of survey, it is necessary to perform work on the temporal distribution of births. In addition, some pups may have been missed due to increasing ice drift in the second half of 12 March, and some pups may not have been counted on the frames in bright sunny days. The given, uncorrected pup production estimate is, therefore, likely to be an underestimate.

The ratio of pups/adult harp seals in the eastern part of the whelping area was lower than in the central and western parts. No doubt, the pup/adult ratio is subject to considerable variation as a result of the general behaviour of the seals. In certain areas, adults on the ice may well be males. This may particularly be true in the fringes of the whelping patch where males are known to cluster in small, dense groups during the nursing period (Lavigne and Kovacs, 1988). Also, both variations in weather conditions, and the time of the day the surveys were flown, are likely to affect this ratio (Lydersen and Kovacs, 1993; Perry and Stenson, DFO, Northwest Atlantic Fisheries Centre, St. John's, Newfoundland, Canada, pers. comm.). Another influence could be the fact that almost 31 000 pups were caught mainly in the eastern whelping areas prior to the surveys. Only a small part of the quota was taken in the central part, and no animals in the western part. Results from satellite tagging of harp seals in the White Sea have shown that females, whose pups are killed in sealing operations, remains on the whelping grounds for a long time (Erling Nordøy, University of Tromsø, Norway, pers. comm.). In summary, these somewhat unpredictable factors emphasize the uncertainties involved in assessing adults instead of pups in the abundance estimate surveys, therefore pup surveys are the preferable way, and the use of pup/adult ratio should not be used to estimate abundance.

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