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How many harp seal pups are there? Additional results from the 2008 surveys

Combien y a-t-il de jeunes phoques du Groenland? Résultats supplémentaires des relevés de 2008

G.B. Stenson[1], M.O. Hammill[2] and J.W. Lawson[1]
[1]Fisheries and Oceans Canada
Science Branch
PO Box 5667
St. John's, NL Canada A1C 5X1

[2]Fisheries & Oceans Canada
Science Branch
PO Box 1000
Mont Joli, QC Canada G5H 3R4

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ABSTRACT

Photographic and visual aerial surveys to determine current pup production of Northwest Atlantic harp seals were conducted off Newfoundland and in the Gulf of St. Lawrence during March 2008. While multiple surveys in the Gulf of St. Lawrence and off southern Labrador provide similar results, visual and photographic surveys of the largest concentration taken on 10 and 16 March, respectively, resulted in estimates that were significantly different (589,400 (SE=49,500 vs. 1,161,600 SE=112,300). A second, lower coverage, photographic survey carried out on 12 March was analyzed in an attempt to reconcile the difference. Nine transects, spaced 14.8 km apart, were flown during this survey, resulting in an estimated pup production of 1,026,997 (SE=280,445, CV=27%). Averaging the two photographic surveys of the Main concentration at the Front resulted in an estimated pup production of 1,142,985 (SE=104,284, CV=9%). Combining this estimate with previously reported estimates of pup production in the southern Gulf (287,033, SE=27,561), the northern Gulf (172,482, SE=22,287), and small group at the Front (23,381, SE = 5,492), resulted in an estimate of total pup production (rounded to the nearest hundred) in 2008 of 1,630,300 (SE=110,400, CV=6.8%). This is significantly higher than estimated previously and is inconsistent with previous predictions obtained from the harp seal population model. Incorporating reproductive rates obtained from annual samples directly into the model may provide some explanation for the large increase in estimates of pup production.

Key words: harp seal, *Pagophilus groenlandicus*, pup production, survey, abundance, Northwest Atlantic, digital photography.

RÉSUMÉ

Des relevés aériens photographiques et visuels ont été effectués au large des côtes de Terre-Neuve et dans le golfe du Saint-Laurent au cours du mois de mars 2008 afin de déterminer la production actuelle de petits chez les phoques du Groenland de l'Atlantique Nord-Ouest. Alors que de multiples relevés dans le golfe du Saint-Laurent et au large de la côte sud du Labrador fournissent des résultats semblables, des relevés visuels et photographiques de la plus grande concentration pris le 10 et le 16 mars, respectivement, ont donné des estimations nettement différentes (589 400 (erreur type = 49 500 c. 1 161 600, erreur type = 112 300). Un deuxième relevé photographique d'une zone réduite réalisé le 12 mars a été analysé pour tenter de rapprocher la différence. Neuf transects, à intervalles de 14,8 km, ont été survolés pendant ce relevé, donnant une production estimée de jeunes phoques de 1 026 997 (erreur type = 280 445, coefficient de variation = 27 %). En moyennant les deux relevés photographiques de la concentration principale sur le front a donné une production estimée de jeunes phoques de 1 142 985 (erreur type = 104 284, coefficient de variation = 9 %). Combiner cette estimation aux estimations déjà publiées de la production de jeunes phoques dans le Sud du golfe (287 033, erreur type = 27 561), le Nord du golfe (172 482, erreur type = 22 287) et un petit groupe sur le front (23 381, erreur type = 5,492), a donné une estimation de la production totale de jeunes phoques (arrondi à la centaine la plus près) en 2008 de 1 630 300 (erreur type = 110 400, coefficient de variation = 6,8 %). Cette estimation est considérablement plus élevée que les estimations précédentes et va à l'encontre des prévisions précédentes obtenues du modèle de la population de phoque du Groenland. Le fait d'inclure les taux de reproduction obtenus des échantillons annuels directement dans le modèle peut expliquer l'augmentation considérable des estimations de la production de jeunes phoques.

Mots clés : phoque du Groenland, *Pagophilus groenlandicus*, production de jeunes phoques, relevé, abondance, Atlantique Nord-Ouest, photographie numérique.

INTRODUCTION

Northwest Atlantic harp seals, *Pagophilus groenlandicus*, are seasonal migrants that winter in southern Canadian waters and summer in Arctic waters of eastern Canada and Greenland. Each spring they give birth on the ice off the coast of southern Labrador/northeast Newfoundland ('The Front'), and in both the southern ('The Gulf') and northern ('Mecatina') Gulf of St. Lawrence. As the most abundant marine mammal in the north Atlantic, they are hunted for both commercial and subsistence purposes in Canada and Greenland (Stenson et al 2009).

Sustainable management of this population requires accurate estimates of population size. Because total abundance of harp seals cannot be estimated directly due to their large range and age/sex segregation in seasonal distribution, the population is estimated using a model that incorporates information on pup production, removals from the population, and variations in age-specific reproductive rates (Hammill and Stenson 2008, 2009). Prior to 1990, annual pup production was estimated using a variety of methods including variations on a sequential population analysis approach, mark-recapture and aerial surveys (Sergeant 1975; Benjaminsen and Øritsland 1975; Winters 1978; Cooke 1985; Lavigne et al. 1982; Bowen and Sergeant 1983). A review of the different estimates concluded that pup production in 1978 was in the order of 300,000-350,000 (Anon. 1981). Since 1990, aerial surveys have been flown to determine pup production of northwest Atlantic harp seals at 4-5 year intervals. In 1990, pup production was estimated to be 578,000 (SE=39 000) (Stenson et al. 1993). Subsequent surveys flown in 1994 and 1999 suggested that pup production had increased to 702,900 (SE=63,600) and 997,900 (SE=102 100), respectively, and then stabilized. Pup production was estimated to be 991,400 (SE=58,200) in 2004 (Stenson et al. 2002, 2003, 2005).

Using the survey estimate up to 2004 and catch data to 2008, Hammill and Stenson (2008) estimated that pup production has been relatively stable since 2004 due to the high level of catches of young seals since 1996. They predicted that pup production in 2008 would be similar to that seen in 2004 at approximately 1 million animals. Stenson et al. (2009) presented the results of photographic and visual surveys carried out in March 2008 to determine pup production at the Front and in the Gulf. Multiple surveys were carried out in all areas. In the Southern Gulf, visual and photographic surveys resulted in similar estimates of pup production (287,000, SE=27,600, CV 9.6%) that were consistent with previous surveys. Estimates obtained from two photographic surveys in the northern Gulf were also similar (average = 176,800, SE=22,800, CV=12.9%), but higher than seen previously. Photographic and visual surveys also provided similar results for a small concentration at the Front (23,400, SE=5,500, CV=23.5%). However, the visual survey of the largest ('Main') concentration at the Front carried out on 10 March resulted in an estimated pup production of 589,400 (SE=49,500, CV=8.4%) which was approximately half of the estimated obtained from a photographic survey carried out on 16 March (1,161,600, SE=112,300, CV=9.7%). Although Stenson et al. (2009) explored a number of possible reasons for this discrepancy, neither survey could be rejected and the National Marine Mammal Peer Review Committee (NMPRC) concluded that the results could not be reconciled (DFO 2009). Thus, there is considerable uncertainty as to the number of harp seal pups born in 2008; using the photographic estimate of the Main concentration resulted in an estimate of total pup production of 1,648,800 (SE=118,000, CV=7.2%) while using the visual estimate for the Main patch resulted in an estimate pup production of 1,076,600 (SE=61,300, CV=5.7%) (Stenson et al. 2009).

A second photographic survey of the Main concentration at the Front was carried out on 12 March, 2008. This survey had much lower coverage than the other two surveys, so the results were not presented in Stenson et al. (2009). However, given the discrepancy between the visual

and photographic surveys of this group, it was important to analyse this survey to determine if it could provide additional information that would allow us to determine how many pups were born in this concentration. The objective of this paper is to present the results of the 12 March survey and provide an estimate of total pup production for Northwest Atlantic harp seals in 2008.

METHODS

The general survey design was described in Stenson et al. (2009). A brief summary is provided below.

IDENTIFICATION OF WHELPING AREAS

Gulf and Front whelping concentrations (`patches') were located using fixed-wing and helicopter reconnaissance surveys of areas historically used by harp seals carried out between 29 February and 22 March. Repeated systematic east-west transects, spaced 18.5 km apart, were flown at an altitude of approximately 230 m, and extended from the shoreline or coastal edge of the ice pack seaward to the outer edge of the pack. Information on the location of whelping seals was also obtained during helicopter reconnaissance flights, fixed-wing overflights conducted by Fisheries and Oceans Conservation and Protection Branch and, in the Gulf, from the commercial seal observation industry helicopters. All suitable ice was examined.

All areas were searched repeatedly to minimize the chance of missing whelping concentrations. Once located, VHF and/or satellite-linked beacons were deployed within each whelping concentration to monitor their movements as the pack ice drifted during the survey period

ESTIMATES OF ABUNDANCE

Visual surveys

Visual aerial surveys of whelping concentrations in the southern Gulf and at the Front were flown at an altitude of 45.7 m, using one MMB 206 helicopter in the Gulf and two MMB 105 helicopters at the Front. Two observers seated in the rear of each of these helicopters counted all pups within a pre-measured strip on each side of the aircraft. Strip widths were checked at the end of the surveys to ensure accurate estimates of the area examined. In the Gulf, the total strip width was 60 m for the survey flown on 1 March and 47 m for the survey flown on 4 March, while at the Front, the strip width was 60 m for one helicopter and 65 m for the second. Due to the higher winds, strip widths at the Front were corrected for the degree of crab encountered on each line (as measured by the pilot). Correct altitude and transect spacing were maintained using a radar altimeter and GPS navigation systems, and strip widths were confirmed at the end of the survey period.

Pup counts were recorded in flight using a laptop system for each observer. The laptops ran a custom survey software which was linked to GPS receivers so that each pup entry was associated with a GPS-based time and location value. The software stored a summary of the pup counts for each transect, along with information on transect number, observer identity, weather and other survey variables.

Visual surveys of the southern Gulf whelping concentration were carried out on 1 and 4 March. Surveys of two small concentrations at the Front were carried out on 12 and 15 March while the

Main concentration at the Front was surveyed visually on 10 March. No visual surveys were carried out in the northern Gulf.

Photographic surveys

Fixed-wing aerial photographic surveys were flown using one aircraft in the southern Gulf (Piper Navajo) and two aircraft (Piper Navajo and Piper Aztec) at the Front. Each aircraft was equipped with a single, downward-facing Vexcel digital camera, coupled to a high-capacity hard disc array. The cameras were fitted with lenses of 100 mm focal length, and mounted in hydraulically-actuated motion compensation frames designed to minimize the effects of aircraft pitch, roll, and yaw. The two digital cameras employed on this project had slightly different CCD sensor pixel-size spacing: 7.2 µm per pixel versus 9.0 µm per pixel. The ground image "footprint", however, remained the same because the overall image CCD sensor footprint was the same for each camera. The CCD sensors collected black and white, and colour information.

The digital camera had a resolution of ~2.4 cm for objects on the ground when flown at 200-300 m, which is equal to, or slightly more than, twice the size of a photographic film. However, when the digital images were viewed in a large-format computer screen environment which allowed easy enlargement of the display scale, harp seal pups were readily identifiable.

Surveys were flown at an altitude of 198 m in the southern Gulf, and 330 m in the northern Gulf and at the Front. At 330 m, each image covered an area of 245 m along the flight line and 345 m across the flight line (area = 0.084525 km^2). The exact size of the area covered was estimated from the georeferenced file to ensure accuracy and account for slight changes in attitude. Images were georeferenced using integrated onboard GPS systems and the camera was triggered when the centre of the camera was over a specific point on the earth in order to obtain approximately 90% coverage along the transect.

Sequential frames were shot along non overlapping transect lines, spaced at 1 to 8 miles apart depending on the configuration of the seal patch. As in previous surveys, at least three adjacent lines at equal spacing were obtained to allow for estimating the variance using sequential differences.

Cameras were turned on before seals were encountered on a transect line and turned off if no seals were observed for an extended period along a transect line or open water was encountered. In these cases, an observer with a forward view ensured that the camera was turned on before seals or suitable ice were encountered again. Usually, the cameras were left running for the entire length of a transect line. Most of the transects ended when land was encountered or suitable ice was no longer available. Some transects ended earlier if seals had not been encountered for an extended period and no seals were present on adjacent transects. However, in these cases, flights were continued for at least 8 km to ensure no more seals were present further along the transect line.

The Southern Gulf harp seal herd was photographed on 4 and 7 March (Stenson et al. 2009). Surveys in the northern Gulf were carried out on 15 and 17 March while the northern group at the Front was surveyed on 10 March. The main concentration at the Front was photographed on 12 and 16 March.

Correction for reader errors

Digital photographs were stored on large-capacity external hard drives. During the reading process the imagery was georeferenced using the GIS software ERSI ArcMap 9.1. A virtual layer was superimposed on each photograph and pup locations were marked by clicking on each pup's image. Images obtained at the Front were examined by three (3) experienced readers. After all photographs were examined, each reader re-read a series of the photographs in sequence. Readings of photos continued until the counts from the first and second readings differed by less than 5%. If counts differed by more than 5%, the counts from the first reading were replaced by those from the second reading.

To correct for reader errors, a series of 50 randomly-selected frames from each survey were examined by all readers and compared to determine a "best estimate" of the number of pups present. The original counts (*x*) were regressed on the "'best estimate" (*y*) to determine a correction factor for each survey and reader:

$$y_{j,k} = a + bn_{j,k} + u_{j,k} \qquad (1)$$

where $n_{j,k}$ is the counts of the k[th] photograph in the j[th] transect, a is the intercept, b is the slope, and $u_{j,k}$ is a random component.

In all cases the intercept was not significantly different from zero and so the regression was repeated assuming no intercept. Each photo count was corrected using the appropriate estimates for individual survey and reader.

$$n_{j,k}^{cor} = b\, n_{j,k} \qquad (2)$$

The measurement error associated with variation about the regression (V_{meas}) was estimated for each photo by (Salberg *et al.* 2008):

$$V_{j,k}{}^{m} = \hat{\sigma}^2_{j,k} + \mathrm{var}(\hat{b}) n_{j,k}{}^{2} \qquad (3)$$

where $\hat{\sigma}^2$ is the estimate of the variance of the random component *u,* estimated as the variance of the residuals of the regression equation. The measurement error for the entire survey is:

$$V_i^m = W^2 \left[\sum_{j=1}^{J_i} \left(\frac{l_j}{F_j} \right) P_j \hat{\sigma}^2 + \mathrm{var}(\hat{b}) \left(\sum_{j=1}^{J_i} \frac{l_j}{F_j} \sum_{k=1}^{P_j} n_{j,k} \right)^2 \right]. \qquad (4)$$

where

$$F_j = \sum_{k=1}^{P_j} f_{j,k} \,,$$

$f_{j,k}$ is the length of photo *k* in transect *j*,

P_j is the total number of photographs on transect j

l_j is the length of transect *j*

$W_i = S_i / w_i$. Here S_i is the spacing between transects in Patch *i*, and w_i is the width of the transects in Patch *i*.

Survey analysis

Both visual and photographic surveys were based on a systematic sampling design with a single random start and a sampling unit of a transect of variable length. Pup production was estimated using the methods outlined in Stenson *et al*. (1993, 2002, 2003, 2005, 2009). The number of pups for the i^{th} survey was estimated by:

$$N_i = W_i \sum_{j=1}^{J_i} x_i \qquad (5)$$

where x_j is the total number of pups on the j^{th} transect.

For photographic surveys where frames did not overlap

$$x_j = \frac{l_j \sum_{z=1}^{Pj} n_{j,k}}{f_j P_j} \qquad (6)$$

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

$$N_i = W_i \left[x_{i1}/2 + \sum_{j=2}^{J_i - 1} x_{ij} + x_{iJ_i}/2 \right] \qquad (7)$$

where:

J_i = the number of transects in the i^{th} group;

X_{ij} = the number of pups counted on the j^{th} transect in the i^{th} group;

and the end transects are the limits of the survey area.

We estimated the variance of the survey based upon serial differences between adjacent transects using the method described by Salberg et al. (2008):

$$V_i^s = \frac{W_i J_i}{2(J_i - 1)} \left(W_i - \frac{\sum_{j=1}^{J_i} F_j}{\sum_{j=1}^{J_i} l_j} \right) \sum_{j=1}^{J_i - 1} \left(\frac{l_j}{F_j} n_j - \frac{l_{j+1}}{F_{j+1}} n_{j+1} \right)^2 \qquad (8)$$

The variance associated with the reader corrections (V_i^m) was added to the sampling variance (V_i^s) to obtain the total variance for a given survey (V_i).

Estimates from two surveys of the same area were combined using:

$$N_i = ((N_1 \times V_2) + (N_2 \times V_1)) / (V_1 + V_2) \qquad (9)$$

and its error variance:

$$V_i = (V_1 \times V_2) / (V_1 + V_2) \qquad (10)$$

To correct for pups that had not been born by the time of the survey, the number of pups present on the ice were corrected by:

$$N_i = N_{uncor} / P_i \qquad (11)$$

where:

N_{uncor} = the uncorrected estimate for survey *i*;

P_i = the proportion estimated to have been born prior to survey *i*.

The estimates of N_{uncor} and P_i are independent and therefore the error variance of the quotient is given by (Mood *et al.* 1974):

$$V_i = N_{uncor}^2 \times V_p / P_i^4 + V_n / P_i^2 \qquad (12)$$

where:

V_p = the variance in the proportion estimated to have been present prior to survey *i*;

V_n = the variance in the uncorrected estimate for survey *I*.

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.

Temporal distribution of births

The temporal distribution of births over the pupping season was estimated to correct the estimates of abundance for pups that were born after the survey had been flown. The proportion of pups in each of six age-dependent morphometric and pelage-specific stages was determined repeatedly throughout the whelping period (Stenson et al. 1993, 2002, 2003, 2005, 2009). A series of random, low-level (<10 m altitude) helicopter surveys were flown over each whelping concentration during which pups were classified as Newborn, Yellow, Thin Whitecoat, Fat Whitecoat, Raggedy-jacket or Beater (Stewart and Lavigne 1980). Due to the extremely short duration and subsequently small number of pups observed in the Newborn and Yellow stages these two categories were combined into a single group called Newborn. The change in proportion of Newborn, Thin Whitecoat and Fat Whitecoat pups over time was used to estimate the distribution of births. Stage durations for Newborns (μ = 2.40 d, se = 48, *n* = 106), Thin

Whitecoats (μ = 4.42 d, se = 0.138, *n* = 26), Fat Whitecoats (μ = 11.39 d, se= 0.186, *n* = 80) were obtained from Kovacs and Lavigne (1985).

The distribution of births was determined, assuming that the timing of births followed a Normal distribution, as described by Stenson et al. (2003).

RESULTS

The results of the surveys in the southern and northern Gulf (Mecatina) were presented in Stenson et al. (2009). The results of the surveys of the small groups at the Front, as well as the 10 March visual survey and 16 March photographic of the Front Main concentration were also presented. The results from the surveys of the Main concentration are repeated here in order to allow comparison with the 12 March photographic survey presented for the first time in this paper.

IDENTIFICATION OF WHELPING AREAS

Three whelping concentrations were located at the Front (Fig. 1). A large concentration (Main) was located on 7 March east of Belle Isle at 52°17'N 54°43'W. A small group (W) was found north of the large group (52°47'N 54°24'W) on 10 March. On 12 March another small group (D) was sighted a short distance to the northwest of Patch W at 52°34'N 54° 11'W. Considerable ice movement occurred during the survey period due to strong winds and currents. However, movement of the concentrations was monitored through the use of five (5) satellite linked GPS transmitters and two (2) VHF transmitters (Fig. 2), which indicated that the smaller groups remained distinct from the larger group during all surveys.

PUP PRODUCTION SURVEYS

Reader corrections

Correction factors were developed for all readers. The regressions of the 'true counts' on the individual reader counts were significant and all regressions passed through zero. The fit to the regressions was extremely good and the corrections were less than 1% (Table 1). There was very little difference between the counts of the all readers for each of the images examined.

Estimates of pup production based on visual and photographic surveys

Front: A visual survey of the Main concentration at the Front was carried out on 10 March (Table 2, Fig. 3). A total of 22 east-west transects were flown with transect spacing of 3.7 km. Observers recorded a total of 9,481 pups which resulted in an estimated pup production of 589,399 (SE=49,461, CV=8%).

One photographic survey of the Main concentrations was carried out on 12 March. Nine (9) transects were flown 14.8 km (8 nm) apart (Fig 3). A total of 19,707 pups were counted on 1,622 photographs (Table 3) resulting in an estimate of 1,026,997 (SE=280,445, CV=27%) pups.

A second photographic survey of this group was conducted on 16 March. The concentration had drifted southward following the earlier surveys and spread considerably (Fig. 3). A total of

77,256 pups were counted on 5,826 photographs taken along 29 transects (Table 4). Correcting for mis-identified pups resulted in a total estimated pup production of 1,161,597 (SE=112,340, CV=10%).

Modelling the temporal distribution of births

Estimates of the proportion of pups in each of the developmental stages were obtained during six (6) staging surveys of the Main concentrations (Table 5). Staging surveys were repeated over the entire pupping and nursing period. The estimated proportion of births was ≥0.999 for all of the surveys flown over the Main patch and therefore, no correction for pups born after the surveys was necessary (Table 6).

ESTIMATING TOTAL 2008 PUP PRODUCTION

Averaging the two photographic surveys of the Main concentration at the Front, weighting by the inverse of the variance, resulted in an estimated pup production of 1,142,985 (SE=104,284, CV=9%). Combining this estimate with those from the southern Gulf (287,033, SE=27,561), the northern Gulf (172,482, SE=22,287) and small group at the Front (23,381, SE = 5,492), resulted in an estimate of total pup production (rounded to the nearest hundred) in 2008 of 1,630,300 (SE=110,400, CV=6.8%) (Table 7).

DISCUSSION

The results of the 12 March photographic survey were very similar to those obtained from the photographic survey of the same concentration carried out 4 days later. Together these surveys indicate that pup production at the Front during 2008 was approximately 1.15 million. This is slightly higher than the total pup production estimate obtained in 2004 (991,400, SE=58,200, Stenson et al 2005). Pup production in the northern Gulf was also higher than previously seen although pup production in this area is highly variable (Stenson et al 2002, 2003, 2005). There was no difference in the number of pups born in the southern Gulf from that seen in 2004 (261,000 SE=25,700, Stenson et al. 2005).

It is not clear why the results of the visual survey carried out on 10 March were significantly lower than the photographic surveys (z=4.66, p<0.001). Visual and photographic techniques have provided similar results in all previous occasions where complete surveys were obtained (Stenson et al 1997, 2002, 2003, 2005), and were comparable in the southern Gulf and the northern patches at the Front in 2008. The techniques used in 2008 were the same as in previous surveys and involved many of the same personnel, including the lead scientist, two of the four observers and both of the pilots.

The visual survey could be an underestimate if pups were born after the visual survey was flown, the observers were overwhelmed, or if a large concentration of pups was missed. Staging surveys, which covered all of the areas surveyed, indicated that no significant pupping occurred after the 10 March survey. The complete lack of any newborns after 11 March and the very small proportion of young stages in subsequent surveys suggest that a pulse of births between the 10th and 12th surveys could not account for the 400,000 pup difference. In fact, the timing of pupping appeared to be earlier in 2008 than in previous years (Stenson et al 2009).

Two of the observers, one per helicopter, have had extensive experience, having participated in every harp and hooded seal survey since 1990. They did not indicate any differences between

this survey and previous ones with respect to pup densities. The helicopter speed was reduced prior to encountering large groups of pups and observers had more than 1 sec between counts in over 80% of all observations. Counts from highly-experienced and less-experienced observers in the same helicopter were very similar, suggesting that the difference can not be accounted for by observer ability to count.

Although it is difficult to imagine that the visual survey missed such a large number of pups, the possibility cannot be ruled out. Extensive reconnaissance was carried out between 8 and 10 March in the area of the Main patch (Fig 4). No large concentrations of pups were located although small groups such as Patches D and W were found. If additional seals were present, it may have been located to the east of the area surveyed. It is also possible that groups of seals were spread to the south on the loose pack ice. During the photographic surveys, additional transects were flown to the south as seals were encountered. These pup accounted for a large proportion of the estimate, particularly on 16 March; the estimated pup production obtained from the wide (4 and 6 nm) spaced transects at the southern edge of the concentration was just under 400,000 pups (CV=24%) which would account for most of the difference between the visual and photographic surveys.

Total pup production in 2008 was estimated to be 1.63 million (SE=110,400). This is significantly higher than previously estimated and is inconsistent with the predictions from the population model obtained using previous survey estimates and smoothed reproductive rates (Hammill and Stenson 2008, 2009). Hammill and Stenson (2009) did note, however, that this high estimate could be accounted for if pregnancy rates were exceptionally high (>90%) in 2008, i.e., similar to that seen during the 1970s. However, examination of reproductive tracts collected just prior to the survey indicates that while fecundity rates are higher then the recent average, they are not sufficient to explain the number of pups seen (Stenson and Wells 2011).

The model used to estimate total abundance of harp seals and predict future pup production uses annual estimates of age-specific reproductive rates (e.g., Hammill and Stenson 2008, 2009). Previously, the reproductive data were smoothed in order to account for data gaps and small sample sizes (Stenson and Hammill 2009). Using these data, the population model can not be fit to the 2008 estimate of pup production (Hammill and Stenson 2009). However, annual pregnancy rates are highly variable, particularly in recent years, with the percentage of mature animals being pregnant ranging from 40 to 75% (Sjare and Stenson 2010, Stenson and Hammill 2009, Stenson and Wells 2010). By smoothing the annual estimates, we assume that the interannual variation reflect sampling error rather than true variability. Assuming that the samples may, in fact, be monitoring highly variable responses to changes in annual conditions, results in a very different population trajectory that may explain the survey estimates (Hammill and Stenson, 2011). If so, it is critical to adequately monitor annual reproductive rates in order to determine the population dynamics of Northwest Atlantic harp seals and understand future survey results.

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Table 1. Regression statistics used to correct for misidentified pups on photographs taken during surveys of the Main harp seal concentration off Newfoundland. Each reader examined 50 photographs per survey to develop the regression. The total number of photographs read, intercept, slope, and adjusted r^2 are presented in the table.

Date	Reader	Photos Read	Slope (SE)	R^2	Random Error
12 March	3	363	1.020 (0.0047)	0.9989	2.281
	4	607	1.001 (0.0023)	0.9997	0.570
	5	652	1.006 (0.0029)	0.9996	0.900
16 March	3	3,716	1.004 (0.0014)	0.9999	0.544
	4	1,629	1.004 (0.0020)	0.9998	0.529
	5	481	1.007 (0.0020)	0.9998	0.261

Table 2. Number of pups counted on east-west transects obtained during visual surveys of the Main Front concentration on 10 March 2008. Strip widths, before correcting for crab were 60 m for transect 1-13 and 65 m for transects 14 to 22. Transect spacing was 3,700 m.

Transect	Latitude (deg)	Start Longitude (deg)	End Longitude (deg)	Seals Counted	Estimated Pups
1	52.07	54.29	54.65	201	12,832
2	52.04	54.32	54.75	85	5,281
3	52.01	54.31	54.76	117	8,808
4	51.97	54.39	54.77	133	8,263
5	51.93	54.49	54.80	155	9,595
6	51.90	54.48	54.80	182	14,651
7	51.87	54.54	54.78	117	7,243
8	51.83	54.57	54.84	346	26,047
9	51.80	54.43	54.81	167	12,572
10	51.77	54.43	54.84	186	11,647
11	51.73	54.46	54.85	156	11,108
12	51.70	54.41	54.86	582	36,160
13	51.67	54.38	54.89	893	67,226
14	51.63	54.29	54.93	890	51,793
15	51.60	54.12	54.95	684	39,536
16	51.57	54.18	54.96	1,039	60,464
17	51.53	54.07	55.00	1,230	71,580
18	51.50	53.93	55.07	1,173	67,801
19	51.47	53.92	54.71	540	31,823
20	51.43	53.95	54.45	455	26,300
21	51.40	54.05	54.40	146	8,439
22	51.37	53.95	54.37	4	231
Total				**9,481**	**589,399 (49,461)**

Table 3. Numbers of pups counted on east-west transects and estimates of total production obtained during a photograph survey of the Main Front concentration on 12 March 2008. Transect spacing was 14.8 km.

Transect	Latitude (deg)	Start Longitude (deg)	End Longitude (deg)	No. Photos	Pups Counted	Estimated Pups
1	50.90	53.08	53.14	17	63	3,085
2	51.03	53.31	53.62	84	19	982
3	51.17	53.34	54.57	226	3,051	155,302
4	51.30	53.42	54.60	280	6,514	341,748
5	51.43	53.18	54.32	363	6,149	319,603
6	54.57	52.92	54.22	255	986	51,961
7	51.70	53.94	54.44	132	1,205	63,109
8	51.83	53.93	54.44	162	919	49,161
9	51.97	53.98	54.30	103	801	42,045
Total				**1,622**	**19,707**	**1,026,997 (280,436)**

Table 4. Numbers of pups counted on east-west transects and estimates of total production obtained during a photograph survey of the Main Front concentration on 16 March 2008.

Transect	Latitude (deg)	Start Longitude (deg)	End Longitude (deg)	Transect Spacing (m)	No. Photos	Pups Counted	Estimated Pups
1	49.62	52.75	53.70	11,100	271	0	0
2	49.72	52.75	53.38	11,100	166	7	257
3	49.82	52.87	53.42	11,100	158	753	26,808
4	49.92	52.75	53.25	11,100	146	115	4,153
5	50.02	52.81	53.42	11,100	175	2,288	80,673
6	50.12	52.76	53.52	11,100	199	1,839	66,582
6	50.12	52.76	53.52	7,400	199	1,839	44,388
7	50.18	52.83	53.77	7,400	269	5,803	136,830
8	50.25	52.83	53.71	7,400	250	1,424	33,331
8	50.25	52.83	53.71	3,700	250	1,424	16,665
9	50.28	52.89	53.79	3,700	255	4,227	50,780
10	50.32	53.00	53.88	3,700	252	3,874	45,192
11	50.35	53.00	53.75	3,700	216	5,271	64,496
12	50.38	53.09	54.03	3,700	267	4,572	54,791
13	50.42	53.13	53.89	3,700	211	3,835	46,976
14	50.45	53.25	53.81	3,700	152	4,496	55,348
15	50.48	53.00	54.41	3,700	357	5,111	61,961
16	50.52	53.00	54.39	3,700	366	7,309	88,577
17	50.55	53.06	53.28	3,700	394	8,450	103,194
18	50.58	53.00	54.36	3,700	262	3,070	37,295
19	50.62	52.83	54.48	3,700	341	2,646	32,616
20	50.65	52.87	54.41	3,700	359	2,473	30,262
21	50.68	52.87	54.39	3,700	289	2,840	33,713
22	50.72	52.85	54.37	3,700	173	1,858	24,282
23	50.75	52.87	53.12	3,700	37	885	11,420
24	50.78	52.79	53.14	3,700	92	423	5,403
25	50.82	52.82	53.08	3,700	57	77	1,035
26	50.85	52.95	53.02	3,700	19	3	38
27	50.88	52.79	52.97	3,700	47	209	2,776
28	50.92	52.75	53.04	3,700	39	120	1,567
29	50.95	52.75	52.78	3,700	7	15	188
Total					**5,826**	**77,256**	**1,161,597 (112,340)**

Table 5. Numbers of harp seal pups in individual age dependent stages on the Front during March 2008.

Date	Newborn	Thin white	Fat white	Ragged	Beater	Total
07 March	140	3,216	35	0	0	3,391
09 March	39	1,233	52	0	0	1,324
11 March	13	4,699	645	31	0	5,388
15 March	0	120	1,629	672	0	2,421
17 March	0	40	1,603	6,410	2	8,055
22 March	0	0	34	2,098	150	2,282

Table 6. Estimated proportions of Northwest Atlantic harp seal pups on the ice at the time of the surveys.

Survey	Date	Estimate	Std Err
Visual	10	0.9995	.001
Photographic	12	1	<.0001
	16	1	<.0001

Table 7. Estimated pup production and standard errors of northwest Atlantic harp seals during March 2008. The 1 March survey of the Southern Gulf and the 15 March survey of Patch D were corrected for the birthing ogive. All estimates are rounded to the nearest hundred.

Area	Date	Method	Estimate	Std Err	CV
S. Gulf	1	Visual	315,500	46,300	0.15
	4/5	Visual	279,400	48,500	0.17
	7	Photo	263,300	48,600	0.18
	Averaged		**287,000**	**27,600**	**0.10**
Mecatina	March 15	Photo	185,600	40,800	0.22
	March 17	Photo	172,900	27,500	0.16
	Averaged		**176,900**	**22,800**	**0.13**
W	March 12	Visual	3,900	820	0.21
D	March 15	Visual	19,200	7,400	0.39
W+D	Combined		23,100	7,500	0.32
Northern	March 15	Photo	23,700	8,100	0.34
	Averaged		**23,400**	**5,500**	**0.23**
Front	March 10	Visual	589,400	49,500	0.08
	March 12	Photo	1,027,000	280,400	0.27
	March 16		1,161,600	112,300	0.10
	Averaged		**1,143,000**	**104,300**	**0.09**
Total			**1,630,300**	**110,400**	**0.07**

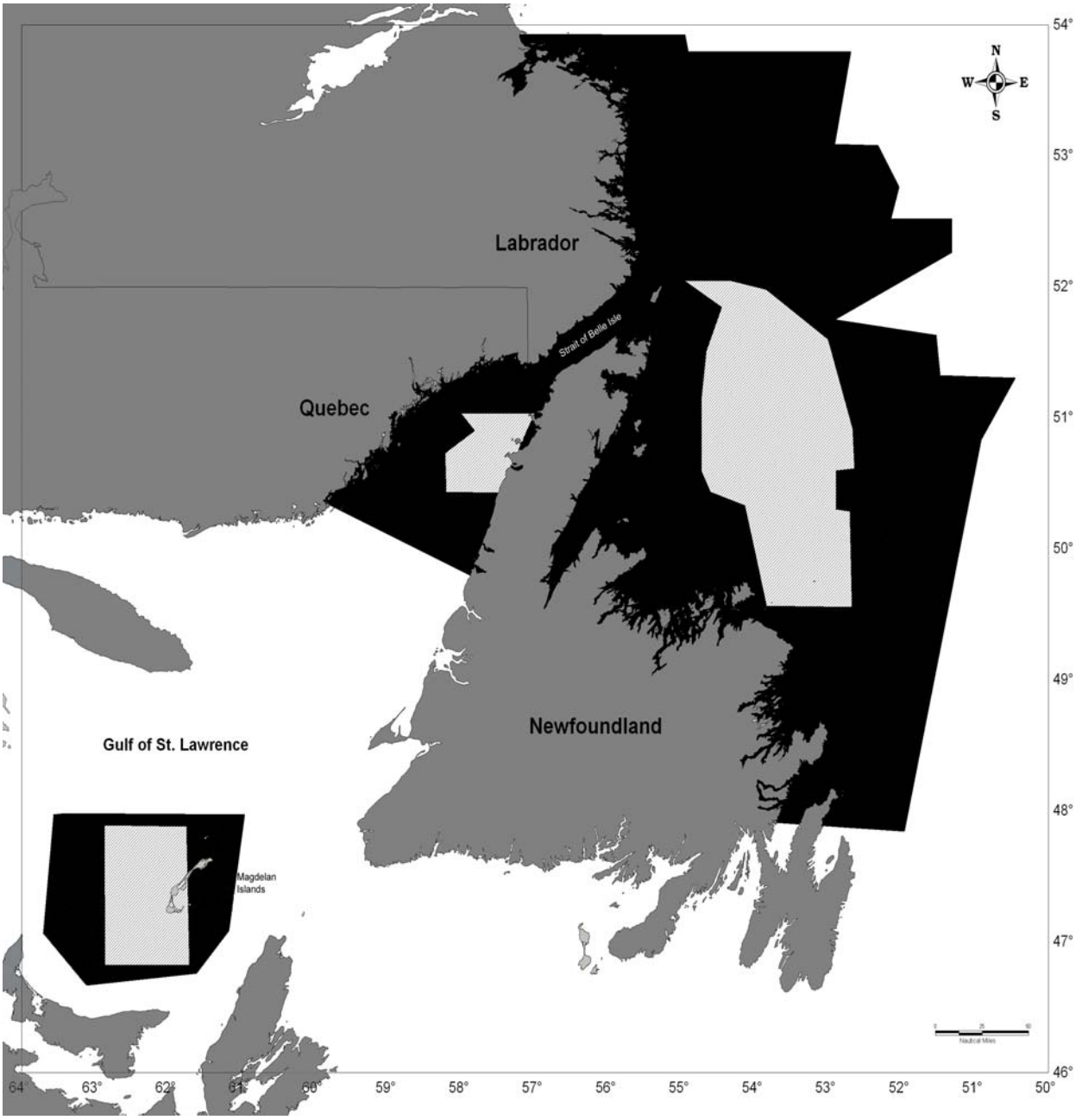

Figure 1. Ice areas examined during reconnaissance flights (black outlines) during the 2008 harp seal survey. Whelping concentrations are indicated by light grey polygons with the reconnaissance areas.

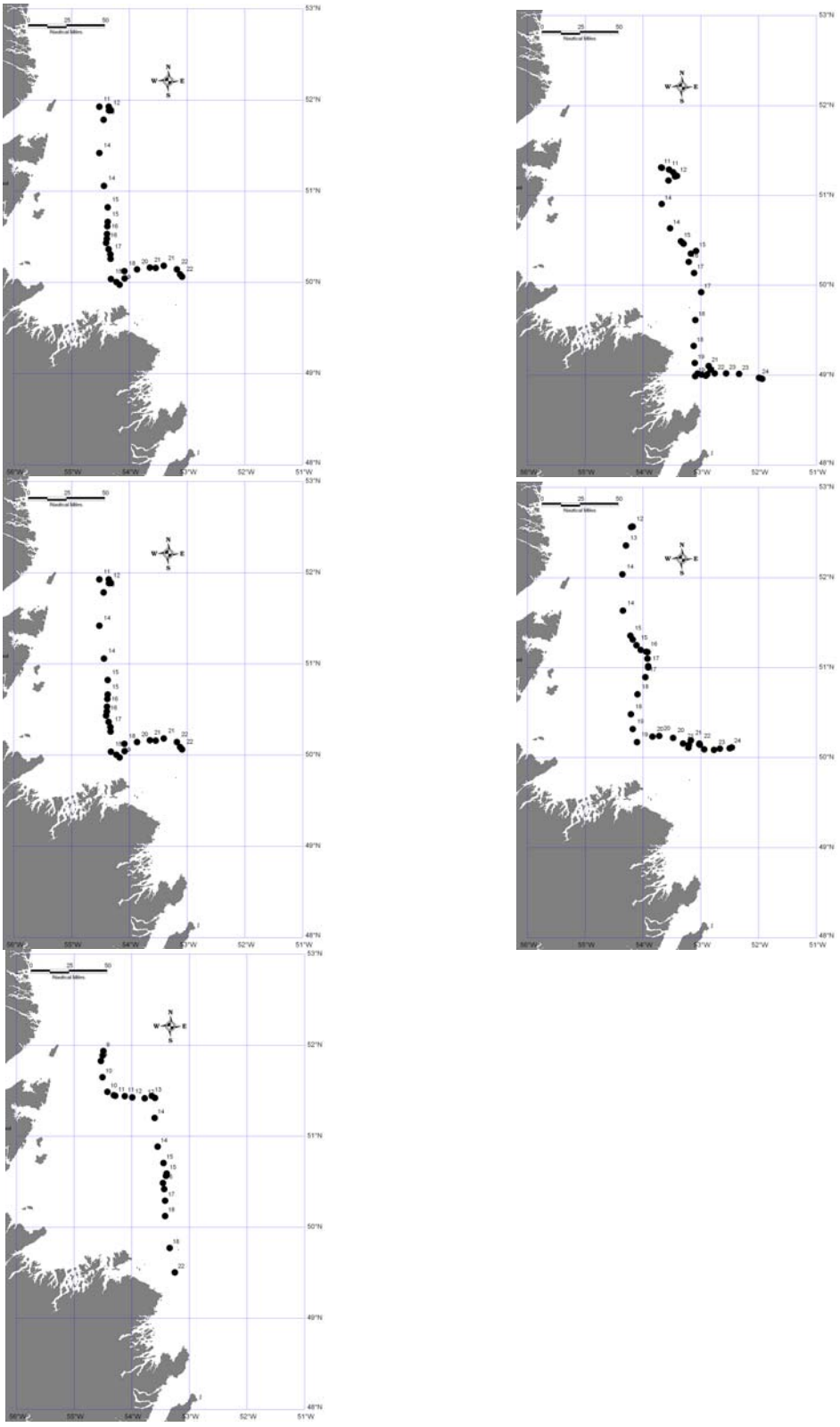

Figure 2. Movement of satellite-linked GPS transmitters to monitor ice movement at the Front during the 2008 harp seal survey.

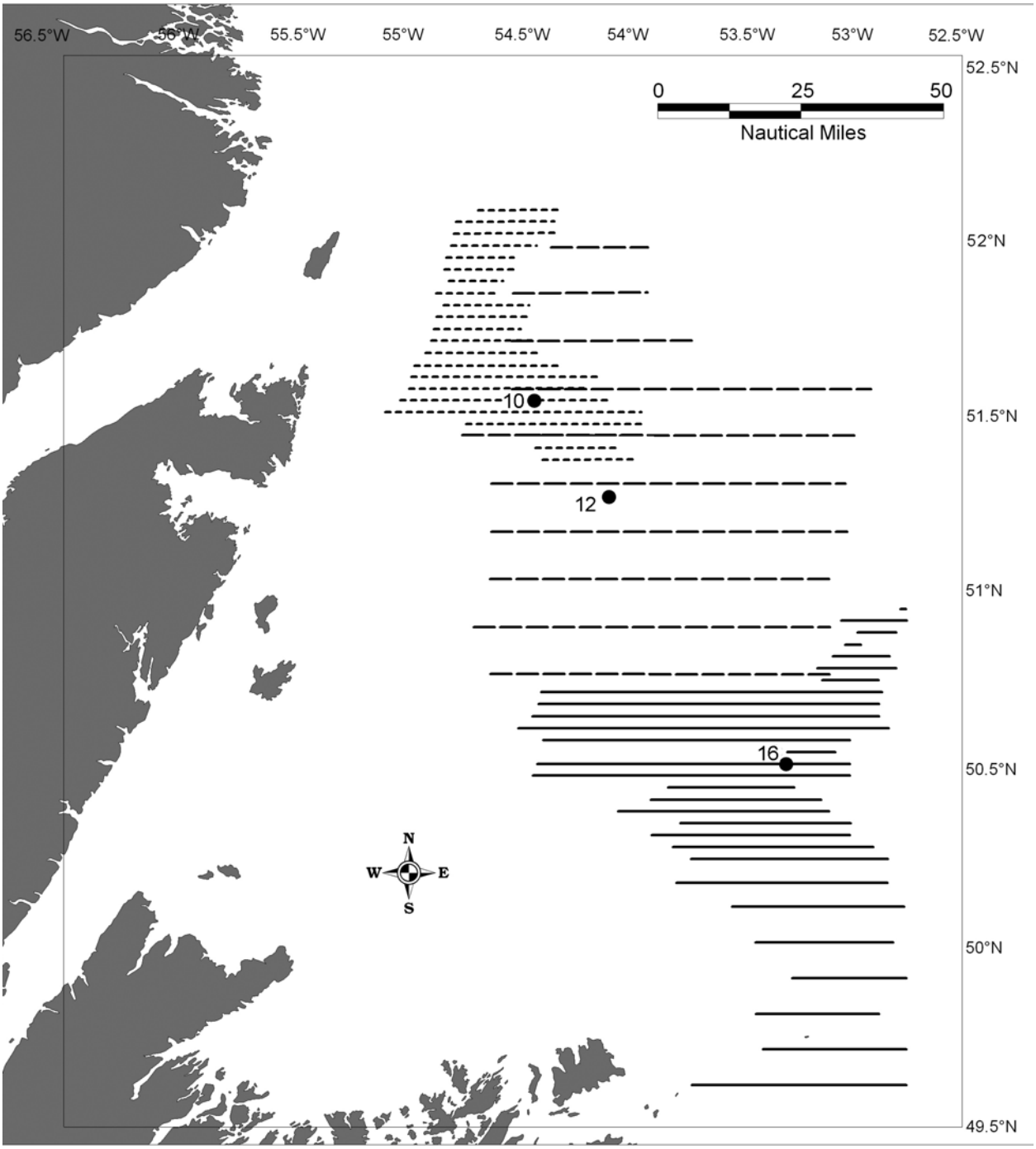

Figure 3. Transect lines flown during the March 10th visual survey (small dash), and March 12th (long dash) and 16th (solid lines) photographic surveys of the Main concentration off Newfoundland. Drift of the ice is indicated by the position of ROMM 2 (black circle) on each survey day.

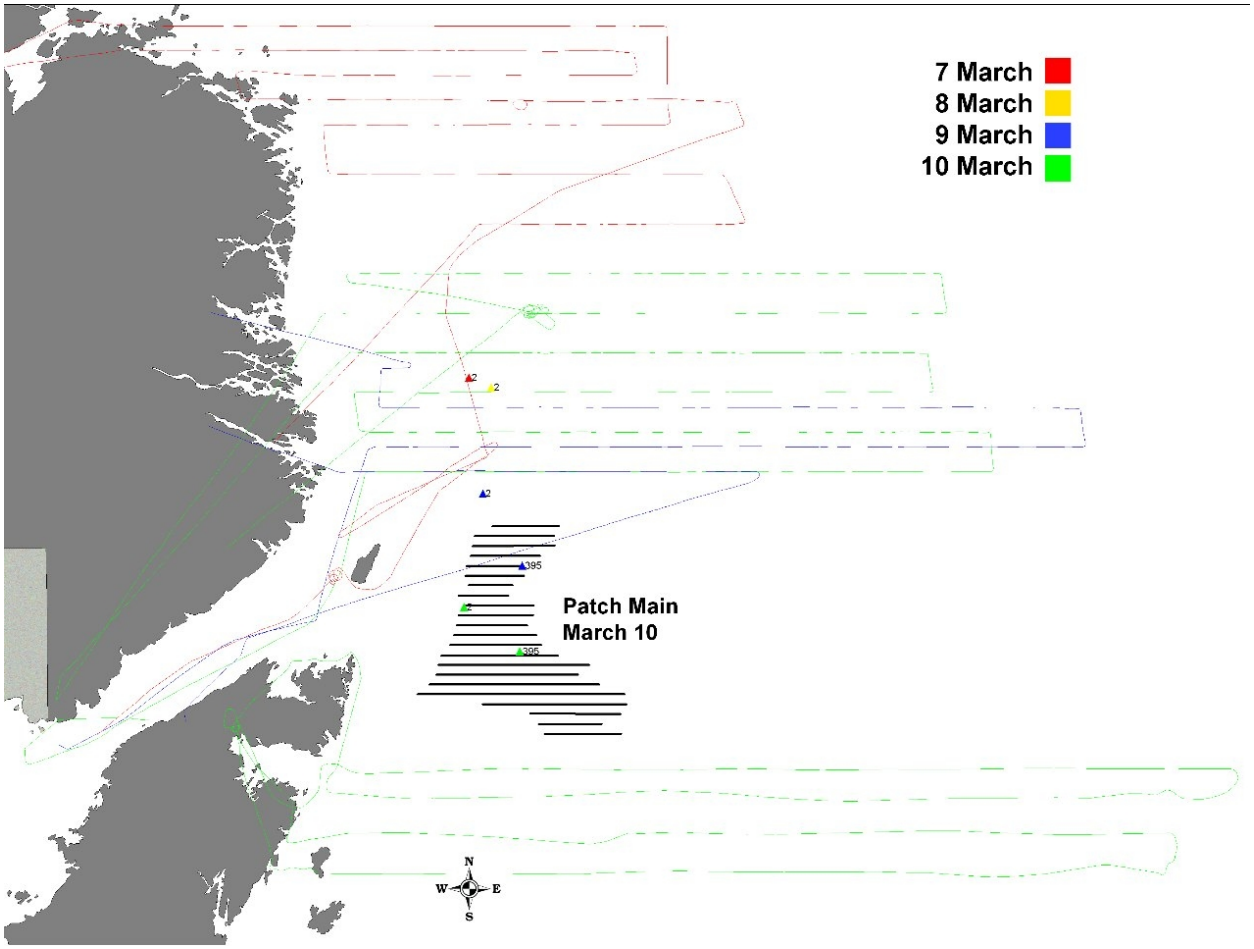

Figure 4. Reconnaissance flights carried out between 7 and 10 March north and south of the Main harp seal concentration surveyed on 10 March, 2008.