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Estimating pup production of Northwest Atlantic Harp Seals, *Pagophilus groenlandicus*: Results of the 2008 surveys

Estimation de la production de petits chez les phoques du Groenland de l'Atlantique Nord Ouest, *Pagophilus groenlandicus* : Résultats des relevés de 2008

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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. Surveys of 5 whelping concentrations were conducted between 1 and 16 March resulting in estimated pup production of 287,000 (SE=27,600, CV 9.6%) in the Southern Gulf and 176,800 (SE=22,800, CV=12.9%) in the Northern Gulf (rounding to the nearest hundred). A small concentration at the Front was estimated to contain 23,400 (SE=5,500, CV=23.5%) pups. The visual survey of the Main concentration at the Front resulted in an estimated pup production of 589,400 (SE=49,500, CV=8.4%) while a photographic survey estimated 1,161,600 (SE=112,300, CV=9.7%) pups. Using the photographic estimate of the Main concentration resulted in an estimate of total pup production in 2008 of 1,648,800 (SE=118,000, CV=7.2%); using the visual estimate for the Main patch resulted in an estimate pup production of 1,076,600 (SE=61,300, CV=5.7%).

Key words: harp seal, *Pagophilus groenlandicus*, pup production, survey, abundance, birth distribution, 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. Les relevés des concentrations effectués entre le 1er et le 16 mars dans cinq aires de mise bas montrent que 287 000 (ET = 27 600, CV = 9,6 %) blanchons sont nés dans la partie sud du golfe et 176 800 (ET = 22 800, CV =12,9 %) ont vu le jour dans la partie nord du golfe (arrondi à la centaine près). Une petite concentration sur le front aurait eu une population de 23 400 (ET = 5 500, CV = 23,5 %) petits. Selon le relevé visuel de la concentration principale, sur le front, 589 400 (ET = 49 500, CV = 8,4 %) petits seraient nés, tandis que d'après le relevé photographique, il y en aurait eu 1 161 600 (ET = 112 300, CV = 9,7 %). À partir de l'estimation photographique de la concentration principale, on estime que la production totale de petits en 2008 se chiffrait à 1 648 800 (ET = 118 000, CV = 7,2 %) petits. Par ailleurs, l'estimation visuelle des aires de mise bas principales donnait une production de 1 076 600 (ET = 61 300, CV = 5,7 %) petits.

Mots clés : phoque, *Pagophilus groenlandicus*, production de petits, relevé, abondance, répartition des naissances, Nord-Ouest de l'Atlantique, photographie numérique

INTRODUCTION

Harp seals, *Pagophilus groenlandicus*, are the most abundant marine mammal in the northwest Atlantic. Each year 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. The size of the Northwest Atlantic harp seal, 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). 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. 1986). 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).

Northwest Atlantic harp seals are hunted throughout their range for commercial and subsistence needs. Highly controversial, the commercial harvest in Canada has taken place since the 1700's with the largest harvests, on the order of 700,000 animals, being taken in the mid 1800's. Measures to limit hunting were first undertaken in 1883 with the passage of the Seal Fishery Amendment Act by the General Assembly of Newfoundland, which set opening dates of 1 March for sailing ships and 10 March for steamers to travel to the herd (Sergeant 1991). In 1971, the Canadian Government introduced the first quotas to limit the hunt. Throughout the mid to late 1970s catches in Greenland and Canada ranged from 156,000 to 191,000 (Stenson 2009). Although Greenland catches increased, overall catches fell in the mid 1980s due to a decline in Canadian catches as a result of the ban on the importation of whitecoat pelts into the European Economic Community. In 1996, however, reported Canadian catches increased significantly due to a renewed interest in seal pelts. Annual catches, consisting primarily of young of the year, increased to an average of 272,600 between 1996 and 2006. Beginning in 2007, catches declined due to ice conditions and weak markets, reaching a low of 74,400 in 2009. Since 1980, Greenland catches increased relatively steadily to a peak of approximately 100,000 in 2000. Since then catches averaged a little over 80,000.

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.

Here we estimate the number of harp seal pups born in the Gulf of St. Lawrence and off the northeast coast of Newfoundland in 2008 using visual and photographic aerial surveys similar to those used previously. This information, along with recent information on catches (Stenson 2009) and reproductive rates (Stenson et al. 2009) will be incorporated into a model to determine current population size and to provide advice on catch levels for 2010.

METHODS

IDENTIFICATION OF WHELPING AREAS

Whelping concentrations (`patches') were located using fixed-wing and helicopter reconnaissance surveys of areas historically used by harp seals. At the Front and in the northern Gulf of St. Lawrence, fixed-wing reconnaissance flights were conducted almost daily from 5 to 22 March (Fig. 1). Generally, 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, to the seaward edge between 48°40'N and 53°56'N at the Front and between the Strait of Belle Isle (~50°50'N) and 49°50'N in the northern Gulf. Ice conditions appeared relatively good at the Front during the 2008 breeding season, with more extensive ice coverage than seen during the 1999 and 2004 harp seal surveys, although ice thickness appeared to be less than normal.

In the southern Gulf, reconnaissance surveys of areas traditionally used by harp seals were flown from 29 February to 19 March. Information on the location of whelping seals was gathered during helicopter reconnaissance flights and fixed-wing overflights conducted by Fisheries and Oceans Conservation and Protection Branch, as well as from the commercial seal observation industry helicopters. Flights covered the entire southern Gulf from the New Brunswick coast to Cape Breton and from the Laurentian Channel south to Prince Edward Island.

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. In the northern Gulf, the total ice pack was limited and the southward drift of the large pans of sea ice was relatively slow. Therefore, beacons were not deployed.

ESTIMATES OF ABUNDANCE

Visual surveys

Visual aerial surveys 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.

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.

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 Gulf surveys were flown at an altitude of 198 m and airspeed of 110 knots. During image post-processing in the field, it was discovered that there was some image smearing as the camera system (usually operated at an altitude of ~10,000 m) could not compensate as well for aircraft motion when flying at the lower altitude. Subsequently the operational altitude was increased and the system produced higher quality images. At an altitude of 198 m, both cameras yielded image footprints on the ice of 147 m along the flight line and 207 m across the flight line - which equals a photographic area of 0.030429 km^2 on the ice surface. At 330 m, the area covered was 245 m along the flight line and 345 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.

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. Furthermore, the digital image has the ability to use pan-sharpened colour in its reproduction cycle so the ability to use colour discrimination is enhanced relative to monochromatic prints. This is particularly important when the pups' coats have yellowish/brownish tints as these do not contrast well in monochromatic film images but do show contrast in polychromatic digital images.

Each digital image was high resolution and close to 400 MB in file size. We reviewed several non-processed images following each flight day to ascertain how well the system was working and to adjust camera settings as needed on subsequent surveys. Compared to large-format film cameras used on previous surveys, the digital cameras took far more (but slightly smaller) images per flight (up to 7,000 frames).

Surveys were flown at an altitude of 198 m in the southern Gulf and 330 metres in the northern Gulf and at the Front. Each image was georeferenced using integrated onboard GPS systems, allowing the location and footprint of each image to be determined to within less than 2 cm. In all photographic surveys there was no image overlap. The images were shot by the survey cameras using a computer model whereby the camera was triggered when the centre of the camera was over a specific point on the earth (rather than the intervalometer method used in previous harp seal surveys). While this means that ideally all images would have the same size and inter-image spacing, the aircraft did slew and change altitude slightly with wind conditions, so the images could be rotated slightly and be of slightly different area; this variation was relatively small and accounted for when calculating line lengths.

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 (see below).

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. The camera operator inserted a "mark" code into the photographs' metadata when seals were encountered so that readers would initially only read those frames where it was likely there were pups. Such marked frames accounted for 50.3% of all photographs taken (16,920 marked out of 33,655 frames shot for the entire harp seal survey). If the last marked frames on a transect contained pups, further "unmarked" frames were read until several empty frames indicated that the transect extended past the boundary of the whelping patch. 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.

Gulf surveys

The Gulf harp seal herd was photographed on March 4th and March 7th, with a total of 8,144 frames being shot. All photographic transects were oriented in a north-south direction.

Front surveys

Photographic surveys at the Front we carried out on March 12th, 15th, and 16th while the Mecatina concentration was surveyed on 15 and 17 March. A total of 23,206 frames were shot with almost half (11,115 frames) being taken on the 16 March survey of the large Front herd. All photographic transects were oriented in an east-west direction.

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 were examined by five (5) readers, 2 for the southern Gulf surveys and 3 for the Front and northern Gulf. 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 using two different methods. The first method was described by Salberg *et al* (2008). The measurement error for each photo was estimated by:

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

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*.

The second method was used previously by Stenson et al (2002, 2003, 2005):

$$V_j^m = \sum_{z=1}^{Z} var(b) n_{jk}^2 \qquad (5)$$

The measurement error for the whole survey *i* was estimated by:

$$V_i^m = W_i^2 \sum_{j=1}^{J_i} \sum_{k=1}^{Pj} V_{j,k} \qquad (6)$$

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). The number of pups for the i^{th} survey was estimated by:

$$N_i = W_i \sum_{j=1}^{J_i} x_i \qquad (7)$$

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

For photographic surveys where frames did not overlap

$$x_j = \frac{l_j \sum_{z=1}^{Pj} n_{j,k}}{f_j P_j} \qquad (8)$$

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

$$N_i = W_i \left[x_{i1}/2 + \sum_{j=2}^{J_i - 1} x_{ij} + x_{iJ_i}/2 \right] \qquad (9)$$

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):

$$V_i^s = \frac{W_i J_i}{2(J_i - 1)} \left(W_i - \frac{\sum_{j=1}^{J_i} F_j}{\sum_{j=1}^{J_i} l_j} \right) \sum_{j=1}^{J_i - 1} \left(\frac{l_j}{F_j} n_j - \frac{l_{j+1}}{F_{j+1}} n_{j+1} \right)^2 \qquad (10)$$

If transect spacing changed, the variance of each area of homogeneous transect spacing was given by

$$V_i^s = \frac{W_i (W_i - \frac{\sum_{j=1}^{J_i} F_j}{\sum_{j=1}^{J_i} l_j})}{2} \sum_{j=1}^{J_i - 1} \left(\frac{l_j}{F_j} n_j - \frac{l_{j+1}}{F_{j+1}} n_{j+1} \right)^2 \qquad (11)$$

For consistency with past surveys (Stenson *et al* 2002, 2003, 2005), we also estimated the survey variance using the methods described by Kingsley et al. (1985).

$$V_i^s = \frac{W_i(W_i-1)J_i}{2(J_i-1)} \sum_{j=1}^{J_i-1} (x_j - x_{j+1})^2 \qquad (12)$$

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:

$$N_i = ((N_1 \times V_2) + (N_2 \times V_1)) / (V_1 + V_2) \qquad (13)$$

and its error variance:

$$V_i = (V_1 \times V_2) / (V_1 + V_2) \qquad (14)$$

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:

$$N_i = N_{uncor} / P_i \qquad (15)$$

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):

$$V_i = N_{uncor}^2 \times V_p / P_i^4 + V_n / P_i^2 \qquad (16)$$

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). 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, and is described in detail by Stenson et al. (2003).

RESULTS

IDENTIFICATION OF WHELPING AREAS

Ice cover was considered to be 'normal' in the southern Gulf and reconnaissance flights located harp seals off the northwest coast of the Magdalen Islands (Fig. 1). Satellite-linked beacons were deployed by S. Prinsenberg (DFO-Dartmouth, NS) in the patch at the beginning of March and their drift was monitored daily (Fig. 2).

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. 3).

A dense concentration of seals (Mecatina) was located in the northern Gulf of St. Lawrence on 11 March at 51°10'N 57°50'W (Fig. 1).

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 3% (Table 1). There was very little difference between the counts of the five individual readers for each of the 250 images examined.

Estimates of Pup Production Based on Visual and Photographic Surveys

Southern Gulf

In the southern Gulf, the herd was delimited and visual surveys were flown on 1 and 4, 5 March (Fig. 4). A total of 3,129 pups were counted on the 15 north-south transects flown on 1 March (Table 2). The complete patch could not be surveyed on 4 March and as a result, three additional lines were completed on 5 March taking into account ice drift as indicated by the beacons. A total of 93 seals were counted on the additional three lines out of a total of 4,103 pups counted on the 15 east-west transects flown 4 March (Table 3). Visual estimates from the two surveys were 293,454 (SE=42,371; CV=14%) and 276,572 (SE=48,005; CV=17%) pups for the 1 and 4, 5 March surveys respectively.

Photographic surveys were flown on 4 and 7 March (Table 4, Fig. 5). A total of nine north-south lines were flown on 4 March, but visibility was poor with freezing rain. Lines 5 and 9 were not processed due to poor conditions encountered during the survey. Of the remaining seven lines, there were a total of 2,640 images, of which 43 were excluded because they were not readable. A total of 5,994 pups were counted, resulting in an estimate of 254,222 (SE=33,370; CV=13%). When the area covered by the 4 March photographic survey is compared with the 4 March visual survey, the western ends of the visual survey lines extend past the region covered by the photographic survey. In fact this area would have been covered by the two lines that were not processed. Line 8 from the 4 March visual survey also extends into the zone that would have been covered by lines 5 and 7, but does not overlap with any other lines flown on the 4 March photographic survey. A total of 31,683 pups were estimated to be on this line indicating that the 4 March photographic survey is an under-estimate. As a result, this estimate was not included in the final estimates for this area. A complete photographic survey was completed on 7 March. A total 9,618 seals were photographed on 2,082 photographs and the estimated total number of seals was 263,303 (SE=38,762, CV=15%). Using the previous method of estimating variance resulted in a SE = 38,763.

Front

A visual survey of the Main concentration at the Front was carried out on 10 March (Table 5, Fig. 6). 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%).

A photographic survey of the Main concentration was carried out on 16 March. Following the visual survey on 12 March, the concentration had drifted southward and spread considerably (Fig. 7). A total of 77,256 pups were counted on 5,826 photographs taken along 29 transects (Table 6). Correcting for mis-identified pups resulted in a total estimated pup production of 1,161.597 (SE=112,340, CV=9%). Using the previous method (Kingsley et al 1985) of estimating variance resulted in a slightly smaller estimate of SE=108,235 (CV=9%)

A visual survey of Patch W was carried out on 12 March. A total of 200 pups were counted on 13 transects flown 1.1 km apart (Table 7, Fig. 6). Pup production in this group was estimated to be 3,893 (SE=820 CV=21%). The second small patch (D) was surveyed on 15 March. Pup production was estimated to be 18,728 (SE=7,499, CV=40%) based on 634 pups counted along eight (8) transect spaced 1.85 km apart (Table 8, Fig. 6).

A photographic survey that included both of these small groups was flown on 15 March (Table 9, Fig. 7). Seven (7) transects, spaced 1.85 km apart, resulted in a count of 3,612 pups on 513 photographs. The estimated pup production in this area was 23,728 (SE=8,101, CV=34%).

Northern Gulf

Two photographic surveys of the northern Gulf (Mecatina) whelping concentration were successfully completed on 15 and 17 March (Fig. 8). The 15 March survey consisted of 15 east–west transects spaced at 3.7 km and 1.85 km apart (Table 10) while 16 transects were flow on 17 March with similar spacing (Table 11). On 15 March, 29,342 pups were identified on 1,334 photographs, while on 17 March 25,478 pups were identified on 1,602 photographs. The resulting estimates of pup production for this concentration on 15 and 17 March were 185,636 (SE=40,821, CV=22%) and 172,948 (SE=27,451, CV=16%), respectively. Averaging these two estimates resulted in an estimated pup production in the northern Gulf of 176,761 (SE=22,779, CV =13%).

Modelling the Temporal Distribution of Births

Estimates of the proportion of pups in each of the developmental stages were obtained from the southern Gulf and Front whelping patches, although stage surveys were not conducted in the northern Gulf (Table 12). Staging surveys were repeated over the entire pupping and nursing period. In the southern Gulf, 11 stage surveys were completed over the single patch of animals located. At the Front, four surveys were flown over Patch W and six staging surveys over each of the Main and D patches. In the Gulf, the estimated proportion of pups that were born at the time of the 1 March survey was 0.927 (SE=0.02359). This increased to 0.993 (SE=0.005) for the 4-5 March survey. No correction was applied to the 7 March photographic survey.

At the Front, the estimated proportion of births was ≥0.999 for the surveys flown over the Main patch and the photographic survey of Patch W, and 0.997 for the visual survey of Patch W. The estimated proportion of births for the visual survey of Patch D was 0.976 (Table 12). A correction for pups that had not been born at the time of the survey was applied to the visual survey of Patch D only.

Generally, pupping appeared to be 2 to 3 days earlier than in previous surveys in both the Gulf and at the Front (Fig. 9). For example, it was estimated that 90% of pupping was completed by 6 March in the Main concentration at the Front in 2008 compared to 8 March in 2004.

Although no data were available to determine the timing of births in the Northern Gulf, timing of pupping in this area appears to be similar to that of the Front (Stenson, pers. obs). Considering that pupping was well advanced in all other areas by the time of the surveys, it is unlikely that any correction for late pupping would be required.

ESTIMATING TOTAL 2008 PUP PRODUCTION

Adjusting the visual survey estimates in the southern Gulf account for births that had occurred after the survey had been flown resulted in a visual estimate of 315,542 (SE=46,258) and 279,365 (SE=48,508) for 1 and 4 March respectively. No correction was applied to the 7 March

survey which had an estimate of 263,303 (SE=38,762). Averaging these estimates resulted in an estimated up production in the Southern Gulf of 287,033 (SE=27,561, CV 9.6%) (Table 14).

Correcting for pups that had not been born prior to the survey resulted in a corrected estimate of 19,181 (SE=7,426, CV=39%) in Patch D at the Front (Table 14). Adding this estimate with the visual estimate for Patch W and combining with the photographic estimate of both groups resulted in an averaged estimate for this area of 23,381 (SE = 5,492, CV=23.5%). Using the method to estimate variance outlined by Kingsley *et al* (1985) results in an estimate of SE=5,443 (CV=23%).

Combining the estimates of the southern Gulf, the northern Gulf (172,482, SE=22,287) and small group at the Front with the photographic estimate of the Main concentration resulted in an estimate of total pup production (rounded to the nearest hundred) in 2008 of 1,648,800 (SE=118,00, CV=7.2%) (Table 14). Using the visual estimate for the main patch instead of the photographic results in an estimate pup production of 1,076,600 (SE=61,300, CV=5.7%).

DISCUSSION

The methods used in this survey are very similar to those used during the 1990, 1994, and 1999 surveys (Stenson et al. 1993, 2002, 2003, 2005). The basic design involves detecting concentrations of whelping animals, estimating the number of animals present on the ice, and correcting these estimates for any births that may have occurred after the counting surveys have been flown. As in previous studies, both photographic and visual surveys were flown to estimate the numbers of seal pups present on the ice.

One difference between this and previous surveys is the manner in which we estimated the error associated with the reader corrections. Salberg et al. (2008) proposed a method that better incorporates the uncertainty associated with these corrections. Although this increased the variance of the estimates, the difference was generally small, likely as a result of the small and precise corrections required using the digital images.

The major difference in this survey is the use of the digital camera system during the photographic surveys. This system provided very high quality colour images and allowed us to use a GIS system to locate and identify pups. The digital images also allowed for post-processing that improves the image quality for those taken under poor lighting conditions. As a result, usable photographs could be obtained under a much wider range of light and weather conditions, increasing the likelihood of a successful survey. At a given altitude, however, the footprint of the digital images is smaller than that obtained from conventional photography, resulting in less coverage and/or more images to read. We were able to compensate by flying higher to increase the area covered by each image although the total number of photos read was greater than in previous surveys. Increasing the altitude was also necessary to improve performance of the camera which had difficulties compensating for the relative movement of the ice surface below the aircraft while photographing at lower altitudes.

The photographic component of this survey is extensive, and produced thousands of photographs that were examined by several readers. Because multiple readers were involved, with various levels of experience, a series of photographs were read by all readers. Seal pups were identified on the photographs by marking on acetates or inserting georeferenced notations on the digital images. These pups were then examined to confirm if they were seals or not. This final verification is used to obtain a ‘true’ estimate of seals present on the ice and to

develop a factor that can be used to correct the counts of each reader with respect to the 'true' count. Over time this calibration has evolved from a general calibration obtained by pooling all surveys (e.g. 1990 survey, Stenson et al. 1993), to reader specific corrections (e.g., 1994 survey, Stenson et al 2002) to reader and patch specific corrections (e.g., 1999 and 2004 surveys, Stenson et al 2003, 2005). The 1990 survey was flown using a standard large format film camera. Reader corrections involved an average adjustment of about 20%. During the 1994 and 1999 surveys a motion compensation mechanism was included as part of the photographic platform with the objective of improving image quality and therefore detection of seals. Improvements in image quality would be expected to result in a reduction in the reader correction factors which appears to have been achieved with a reduction in the average reader correction to 12% and 6% for 1994 and the 1999 surveys respectively. In 1999, only 1 out of 9 reader corrections had a significant intercept. For the 2004 survey, the imagery from the southern Gulf survey was not readable. Using only readers from the Front, who tend to be more experienced, none of the intercepts were significant, but photographic counts were corrected on average by 8%. The 2008 survey was flown using digital cameras for the first time. The high quality of the imagery resulted in much lower reader corrections compared to previous surveys averaging <3%.

Experiments comparing conventional black and white prints and a camera that was restricted to ultra violet wavelengths where harp seal pups appear black, concluded that comparable numbers of pups were counted under the two systems if flying altitudes were less than 700 ft (Ni and Stenson unpublished data; Stenson et al 1993). Highly-experienced readers tend to have relatively small correction factors suggesting that with training, readers can find most of the pups present on high-quality photographs. With the improved images we obtained using digital photographs, inexperienced readers had similarly small corrections. Preliminary results of a study to compare the presence of pups identified on print and digital images obtained concurrently in 2009, indicate that the difference in counts using the two methods is minor (Stenson and Lawson, unpublished data). Approximately 95% of the pups identified on the digital images taken at 198 m were also seen on the conventional prints used in the past surveys while ~1% of the pups were located on the prints but not seen on the digital images. The difference between these two methods is consistent with the difference in the corrections applied for reader mis-identifications, suggesting that the corrected results obtained from the two camera systems are directly comparable.

As in previous surveys, we corrected the survey estimates for births that occurred after the survey flights. If the distribution of harp seal births over the pupping season is assumed to follow a Normal distribution, the parameters of this distribution can be estimated relatively easily from the frequencies of three age-dependent stages. The resulting estimates of the proportion of pups present on the ice at the time of a survey tend to be higher, and hence more conservative than using more complex methods that also make assumptions about the starting date for pupping (e.g. Myers and Bowen 1989, Stenson et al. 2003). The correction factors applied in 2008 were very small since most of the pupping had occurred prior to our surveys being flown. In fact, the timing of pupping appeared to be earlier in 2008 than in previous years. Pupping was two to three days earlier in the Gulf (Fig. 9) compared to 2004 and 1999. A similar advancement in pupping was observed at the Front. In most years the largest whelping concentrations are first located near Cartwright, Labrador (~53^{o} 30'N) in the first week in March. In 2008, however, the large concentration was first encountered at 52^{o} 17'N on 7 March by which time a large number of births had occurred. It is possible that pupping began in the traditional area further north earlier than usual and that these animals had drifted southward to the location where we located them. The staging surveys covered the areas of both the visual and photographic surveys and relatively few newborn/yellow pups were seen after 7 March.

The staging model estimated that 90% of births had occurred by 6 March in this group which is at least 2 days earlier than estimated for previous survey years. The reason for the earlier pupping is not known although the Gulf data suggests that this may be part of an overall trend leading to a change in the timing of births (Fig. 9).

The major uncertainty associated with this study is the significance of the large photographic survey estimates of the Front and Mecatina concentrations, and the reason for the differences between the visual and photographic survey of the Main concentration. The visual and photographic surveys in the southern Gulf resulted in very similar estimates of pup production. Although the photographic survey on 4 March was incomplete, if the 31,000 pups seen during the visual survey of the area outside of the photographic transects are added to these results, pup production would be in the order of ~285,000. This is similar to the number of pups estimated in the southern Gulf during the 2004 survey (Table 15, Stenson et al 2005). In the northern Gulf, however, two photographic surveys were carried out and resulted in very similar estimates of pup production (181,100, SE=39,800 and 168,700, SE=26,900). These estimates are approximately double the 82,600 (SE=22,500) and 89,600 (SE=22,500) estimated in 1999 and 2004, respectively (Stenson et al 2003, 2005). The proportion of pupping that takes place in the northern Gulf varies considerably from year to year (Table 15), often due to drift of pups through the Strait of Belle Isle (e.g., Stenson et al 2003, 2005). However, this generally happens in years when pupping occurred close to the Labrador shore which was not observed in 2008. In fact, there was no indication of pupping in the Strait area that could have contributed to this estimate prior to locating the Mecatina patch.

The photographic survey of the Main concentration at the Front resulted in an estimate of pup production that was significantly larger than that obtained from the visual survey (1,161,600, SE=112,300 versus 589,400, SE=49,500). This photographic estimate was much larger than observed previously (see Table 15) and in fact, larger than the entire pup production estimated in 2004 (Stenson et al 2005). Both of the surveys appeared to be well carried out and resulted in precise estimates.

One possibility for the differences between the visual and photographic surveys is that the photographic estimate is correct and that the visual estimate was an underestimate. This could occur if a large concentration of pups were missed or born after the visual survey (10 March) was flown, or if the observers were overwhelmed. However, the majority of pups at the Front are usually born before 9 March and the staging surveys, which appeared to cover all of the areas pups were observed in both surveys, did not indicate a significant number of late births. Also, extensive reconnaissance carried out 8-10 March in the area of the Main patch did not locate any large concentrations of pups although small groups such as Patches D and W were located. Comparison of the counts between the highly experienced observers and less experienced, and counts from observers on the opposite sides of the helicopters, did not indicate any difference between observer counts. The time between recording pups indicated that observers had more and 1 second between counts in over 80% of all observations. Again there was no difference between observers suggesting that the difference can not be accounted for by observer ability to count.

The other possibility is that the photographic survey results are an overestimate. In order to explore this likelihood, we re-examined all aspects of this survey (e.g., coverage pattern, image sizes, effort calculations, pup identification error, georeferencing approaches) with no indication of error. The file was checked to ensure that there were no duplicate images and all five (5) readers examined a subset of 250 randomly-chosen images from different surveys (also used to estimate the reader corrections) to ensure that seals were correctly identified. In all cases, the

counts of individual photographs were extremely close. An additional 50 images taken during the Main survey were re-examined and counted manually to ensure that the program used to tabulate counts was correct. Total counts recorded during the readings and calculated from the GIS system were compared and found to be identical. The footprint of the photographs were re-calculated independently by the survey company and another GIS expert and found to be accurate. Objects of known size were measured using the georeferencing system of the survey photographs and found to be within 2 cm of their actual size. Finally, the placement of the photographs in space was examined. The starting and ending positions of each transect determined from the analysis file were consistent with the flight logs and the flight track obtained from an independent GPS monitored by the DFO observer onboard.

A preliminary, low coverage, photographic survey of the Main patch was carried out on 12 March. The images were obtained as a back-up and were not examined since the 16 March survey had significantly better coverage. We are currently reading these photographs to provide a third estimate that may allow us to determine which of the two current estimates are correct.

Without being able to determine if the visual or photographic survey estimates of the Main concentration should be accepted, it is difficult to make a conclusion about the estimate of current pup production. If the photographic survey is accepted as the true estimate of pup production at the Front, total production has increased from 997,900 (SE=102,100) in 1999 and 991,400 (SE=58,200) in 2004 to 1.6 million (SE=117.900). This is not consistent with our current understanding of the population dynamics of this population which predicted that pup production would remain around 1 million (Hammill and Stenson 2008) due to a high level of hunting over the past 15 years. If, on the other hand, the visual survey estimate is accepted, total pup production is estimated to be 1,072,300 (SE=61,100), suggesting that pup production has remained stable over the past decade. The photographic estimate is almost exactly double the visual survey estimate. If it is assumed that the photographic estimates at the Front and in the Northern Gulf should be reduced by half, total pup production would be 985,700 (SE = 59,200, CV=6%). Although the estimate of pup production in 2008 is still uncertain, all of these estimates indicate that 2008 pup production is similar to, or higher than, seen over the past decade.

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Table 1. Regression statistics used to correct for misidentified pups on photographs. Each reader read 50 photographs to develop the regression. The total number of photographs read, intercept, slope, and adjusted r^2.

Patch	Date	Reader	Photos Read	Slope (SE)	R^2	Random Error
S. Gulf	7 March	1	3,014	1.025 (.0044)	0.999	0.128
		2	1,669	1.028 (.0057)	0.998	0.162
Front Main	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 (0.002)	0.9998	0.261
W/D	15 March	5	513	1.018 (0.0028)	0.9996	0.540
Mecatina	15 March	3	953	1.004 (0.0012)	0.9997	4.052
		4	381	1.000 (0.0015)	0.9999	1.512
	17 March	5	1,602	0.996 (0.0022)	0.9998	6.313

Table 2. Number of pups counted on north-south transects and estimated pup production obtained from visual surveys of the Southern Gulf on 1 March 2008.

Transect	Start Latitude (deg)	End Latitude (deg)	Longitude (deg)	Transect Spacing (Minutes long)	Seals Counted	Estimated Pups
1	47.58	48.00	62.72	4	0	0
2	48.00	47.67	62.65	4	0	0
3	47.58	48.00	62.58	4	6	498
4	48.00	47.55	62.52	4	463	38,417
5	47.57	48.00	62.45	4	730	60,562
6	48.00	47.48	62.38	4	305	25,324
6	48.00	47.48	62.38	5	305	31,654
7	47.47	48.00	62.30	5	565	58,648
8	48.00	47.48	62.22	5	426	44,213
9	47.48	48.00	62.13	5	193	20,031
10	48.00	47.58	62.05	5	52	5,392
11	47.58	47.88	61.97	5	29	3,010
12	47.88	47.63	61.88	5	46	4,773
13	47.63	47.90	61.80	5	4	415
14	47.90	47.70	61.72	5	3	311
15	47.70	47.90	61.63	5	2	207
Total					3,129	293,454 (42,371)

Table 3. Number of pups counted on east-west transects and estimated pup production obtained from visual surveys of the Southern Gulf on 4, 5 March 2008.

Transect	Start Longitude (deg)	End Longitude (deg)	Latitude (deg)	Transect Spacing (Minutes lat)	Seals Counted	Estimated Pups
1	61.52	62.42	47.72	2.5	4	261
2	62.67	61.52	47.68	2.5	32	2,092
3	61.67	62.67	47.63	2.5	57	3,728
4	62.78	61.93	47.63	2.5	110	7,196
5	62.00	61.93	47.58	2.5	470	30,772
6	62.78	61.83	47.54	2.5	877	57,465
7	62.00	62.78	47.50	2.5	1,107	72,593
8	62.82	62.00	47.46	2.5	556	36,489
9	62.00	62.82	47.42	2.5	219	14,384
10	62.98	62.60	47.38	2.5	482	31,683
11	62.62	61.95	47.33	2.5	75.5	4,967
12	62.62	61.95	47.33	5	75.5	9,933
13	62.02	62.67	47.25	5	31	4,085
14	62.67	61.88	47.17	5	7	924
15	61.92	61.50	47.08	5	0	0
Total					4,103	276,572 (48,005)

Table 4. Number of pups counted on north-south transects obtained during an incomplete photographic survey of the Southern Gulf on 4 and a complete survey on 7 March 2008. The estimate from March 4 was considered to be an underestimate and was not in the total estimated production.

Transect 4 March	Start Latitude (deg)	End Latitude (deg)	Longitude (deg)	Transect Spacing (Min long).	Seals Counted	Estimated Pups
1	47.75	47.45	61.98	6	23	1,003
2	47.37	47.75	62.07	6	22	953
3	47.74	47.10	62.18	6	298	14,084
4	47.19	47.75	62.27	6	667	28,829
5	47.72	47.21	62.38	6	1,195	50,886
6	47.05	47.69	62.47	6	1,504	64,173
7	47.61	47.03	62.58	6	2,285	94,295
Total					5,594	254,222 (33,370)
7 March						
1	47.68	47.46	61.90	9	637	36,736
2	47.29	47.84	62.05	9	536	30,887
3	47.29	47.84	62.05	4.5	536	15,721
4	47.76	47.13	62.13	4.5	1,441	53,165
5	47.80	47.08	62.20	4.5	1,733	49,287
6	47.63	47.30	62.28	4.5	1,971	58,422
7	47.41	47.81	62.35	4.5	460	18,965
8	47.63	47.68	62.42	4.5	2	60
9	47.46	47.35	62.50	4.5	2	60
Total					9,618	263,303 (38,762)

Table 5. Number of pups counted on east-west transects obtained during visual surveys of the Main Front concentration on 10 March 2008. Strip width, 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	1039	60,464
17	51.53	54.07	55.00	1230	71,580
18	51.50	53.93	55.07	1173	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 6. 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 7. Number of pups counted on north-south transects obtained during visual surveys of Patch W at the Front on 12 March 2008. Strip width, before correcting for crab was 60 m and transect spacing was 1,130 m.

Transect	Start Latitude (deg)	End Latitude (deg)	Longitude (deg)	Seals Counted	Estimated Pups
1	52.41	52.44	53.83	0	0
2	52.46	52.40	53.85	8	162
3	52.39	52.45	53.87	24	459
4	52.41	52.46	53.88	34	650
5	52.47	52.43	53.90	3	61
6	52.43	52.48	53.92	17	331
7	52.48	52.44	53.93	4	83
8	52.44	52.51	53.95	38	725
9	52.52	52.48	53.97	29	588
10	52.48	52.53	53.98	22	423
11	52.54	52.50	54.00	8	162
12	52.50	52.54	54.02	12	229
13	52.53	52.50	54.03	1	20
Total				200	3,893 (820)

Table 8. Number of pups counted east-west transects of Patch D on 15 March 2008. Strip width, before correcting for crab, 65 m. Transect spacing was 1,850 m.

Transect	Latitude (deg)	Start Longitude (deg)	End Longitude (deg)	Seals Counted	Estimated Pups
1	51.25	54.15	53.83	0	0
2	51.27	54.23	53.79	205	6,293
3	51.28	53.67	54.23	313	9,046
4	51.30	53.70	54.20	67	1,936
5	51.32	54.18	53.83	18	539
6	51.33	53.84	54.20	13	376
7	51.35	54.14	53.77	18	539
8	51.37	53.78	54.15	0	0
Total				634	18,728 (7,499)

Table 9. Numbers of pups counted on east-west transects and estimates of total production obtained during a photograph survey of the Northern (W&D) concentration on 15 March 2008.

Transect	Latitude (deg)	Start Longitude (deg)	End Longitude (deg)	Transect Spacing (m)	No. Photos	Pups Counted	Estimated Pups
1	51.23	53.82	54.05	1,850	71	2	13
2	51.25	53.89	54.16	1,850	85	976	6,486
3	51.27	53.55	54.22	1,850	167	1,753	11,428
4	51.28	53.52	54.14	1,850	78	609	4,044
5	51.30	53.52	54.10	1,850	56	249	1,605
6	51.32	53.52	54.25	1,850	36	0	0
7	51.33	53.54	53.87	1,850	20	23	151
Total					513	3,612	23,728 (8,101)

Table 10. Number of pups counted on east-west transects obtained during a photograph survey of the Northern Gulf concentration on 15 March 2008.

Transect	Latitude (deg)	Start Longitude (deg)	End Longitude (deg)	Transect Spacing (m)	No. Photos	Pups Counted	Estimated Pups
1	50.60	57.56	57.89	3,700	84	1	12
2	50.63	57.50	57.90	3,700	113	7	84
3	50.67	57.43	57.95	3,700	136	57	697
4	50.70	57.40	57.94	3,700	153	340	4,119
5	50.73	57.45	57.90	3,700	123	1,012	12,542
5	50.73	57.45	57.90	1,800	123	1,012	6,271
6	50.75	57.45	57.82	1,800	104	2,028	11,749
7	50.77	57.37	57.85	1,800	119	6,664	41,106
8	50.78	57.40	57.76	1,800	102	7,886	46,187
9	50.80	57.42	57.79	1,800	99	3,872	24,186
10	50.82	57.37	57.60	1,800	65	3,167	18,525
11	50.83	57.35	57.56	1,800	62	1,300	8,163
12	50.85	57.25	57.78	1,800	79	1,624	9,793
13	50.87	57.42	57.62	1,800	57	301	1,753
14	50.88	57.45	57.56	1,800	31	72	448
15	50.90	57.29	57.32	1,800	7	0	0
Total					1,334	29,342	185,636 (40,821)

Table 11. Number of pups counted on east-west transects obtained during a photograph survey of the Northern Gulf concentration on 17 March 2008.

Transect	Latitude (deg)	Start Longitude (deg)	End Longitude (deg)	Transect Spacing (m)	No. Photos	Pups Counted	Estimated Pups
1	50.43	57.68	58.11	3,700	138	0	0
2	50.47	57.59	58.02	3,700	81	0	0
3	50.50	57.63	58.16	3,700	151	2	26
4	50.53	57.47	58.08	3,700	166	3	38
5	50.57	57.53	58.08	3,700	138	3	38
6	50.60	57.46	57.97	3,700	90	3	38
7	50.63	57.57	58.08	3,700	151	116	1,478
8	50.67	57.50	58.06	3,700	164	374	4,872
8	50.67	57.50	58.06	1,800	164	374	2,436
9	50.68	57.46	57.99	1,800	171	4,890	30,999
10	50.70	57.49	58.00	1,800	166	4,352	29,006
11	50.72	57.49	57.93	1,800	141	6,030	38,161
12	50.73	57.45	57.81	1,800	116	4,677	30,593
13	50.75	57.45	57.83	1,800	124	3,110	19,811
14	50.77	57.49	57.81	1,800	110	729	4,764
14	50.77	57.49	57.81	3,700	110	729	9,529
15	50.80	57.39	57.57	3,700	56	51	672
16	50.83	57.50	57.73	3,700	75	37	485
Total					1,602	25,478	172,948 (27,451)

Table 12. Numbers of harp seal pups in individual age dependent stages in the Gulf of St. Lawrence and on the Front during February and March 2008.

	Date	Newborn	Thin white	Fat white	Ragged	Beater	Total
S. Gulf	29 February	30	42	2	0	0	74
	04 March	5	42	86	15	0	148
	05 March	14	30	84	2	0	130
	11 March	0	21	1520	98	0	1639
	12 March	0	1	158	72	1	232
	16 March	0	0	285	439	70	794
	17 March	0	0	203	630	141	974
	19 March	0	0	124	838	192	1154
	24 March	0	0	30	724	1183	1937
	25 March	0	0	1	91	291	383
	27 March	0	0	0	30	390	420
Front	Main						
	07 March	140	3216	35	0	0	3391
	09 March	39	1233	52	0	0	1324
	11 March	13	4699	645	31	0	5388
	15 March	0	120	1629	672	0	2421
	17 March	0	40	1603	6410	2	8055
	22 March	0	0	34	2098	150	2282
	Patch W						
	11 March	2	12	0	0	0	14
	12 March	0	62	59	1	0	122
	15 March	0	26	51	2	0	79
	17 March	0	8	135	38	0	181
	Patch D						
	12 March	24	1826	45	1	0	1896
	15 March	5	375	86	1	0	467
	17 March	1	25	308	45	0	379
	21 March	0	5	34	399	0	438
	22 March	0	2	6	252	2	262
	24 March	0	0	7	257	7	271

Table 13. Estimated proportions of Northwest Atlantic harp seal pups on the ice at the time of the surveys. No data were available to determine the birthing ogive for the Northern Gulf concentration.

Area	Area	Date	Estimate	Std Err
S. Gulf	Visual	1 Mar	0.927	0.023
		4 Mar	0.993	0.0051
	Photographic	4 Mar	0.993	0.0051
		7 Mar	0.9997	.00039
Front				
Main	Visual	10	0.9995	.00100
	Photographic	16	1	.00000001
W	Visual	12	0.997	.00176
D	Visual	15	0.976	0.03060
D/W	Photographic	15	0.9999	.00003

Table 14. 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		176,800	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 16	Photo	1,161,600	112,300	0.10
Total		Photo	1,648,800	118,000	0.07
		Visual	1,076,600	61,300	0.06

Table 15. Northwest Atlantic harp seal pup production estimates from aerial surveys completed since 1990. The estimates for 2008 are present assuming the visual survey of the main concentration is correct and, alternatively, assuming the photographic survey is correct.

Year	Southern Gulf	Northern Gulf	Front	Total
1990	106 000 (23,000)	4,400 (1300)	467,000 (31000)	578,000 (39 000)
1994	198 600 (24,200)	57,600 (13 700)	446,700 (57 200)	702,900 (63 600)
1999	176 200 (25,400)	82,600 (22 500)	739,100 (96 300)	997,900 (102 100)
2004	261 000 (25,700)	89,600 (22 500)	640,800 (46 900)	991,400 (58 200)
2008	287,000 (27,600)	172,600 (22,300)	612,800 (49,800)	1,072,300 (61,100)
			1,185,000 (112,474)	1,644,500 (117,900)
	Proportions			
1990	0.18	0.01	0.81	
1994	0.28	0.08	0.64	
1999	0.18	0.08	0.74	
2004	0.26	0.09	0.65	
2008	0.27	0.16	0.57	
	0.17	0.11	0.72	
Average	0.23/0.21	0.08/0.07	0.68/0.71	
SE	0.05	0.05	0.09	

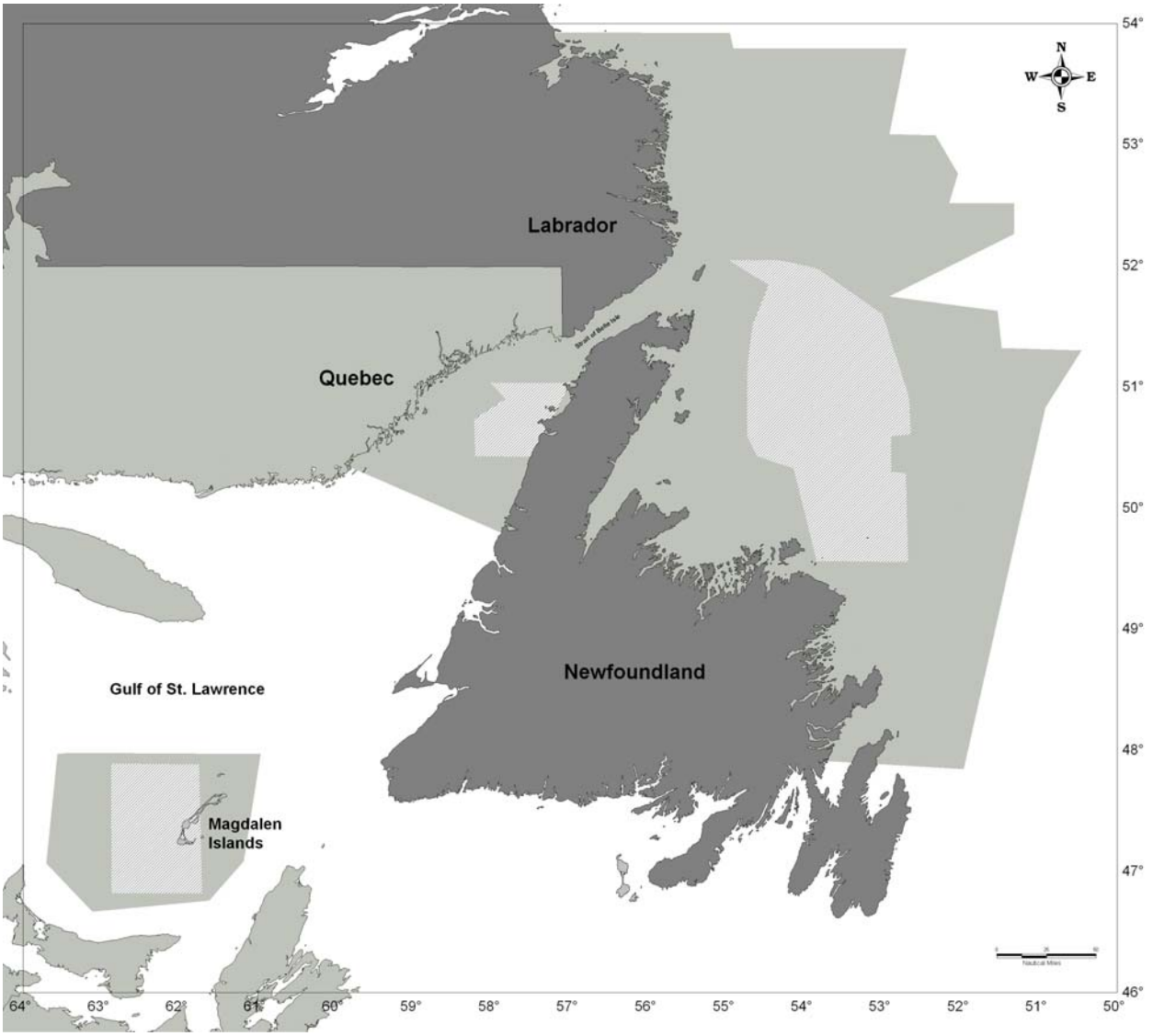

Figure 1. Ice areas examined during reconnaissance flights (light grey outlines) during the 2008 harp seal survey. Whelping concentrations are indicated by polygons with dashed pattern.

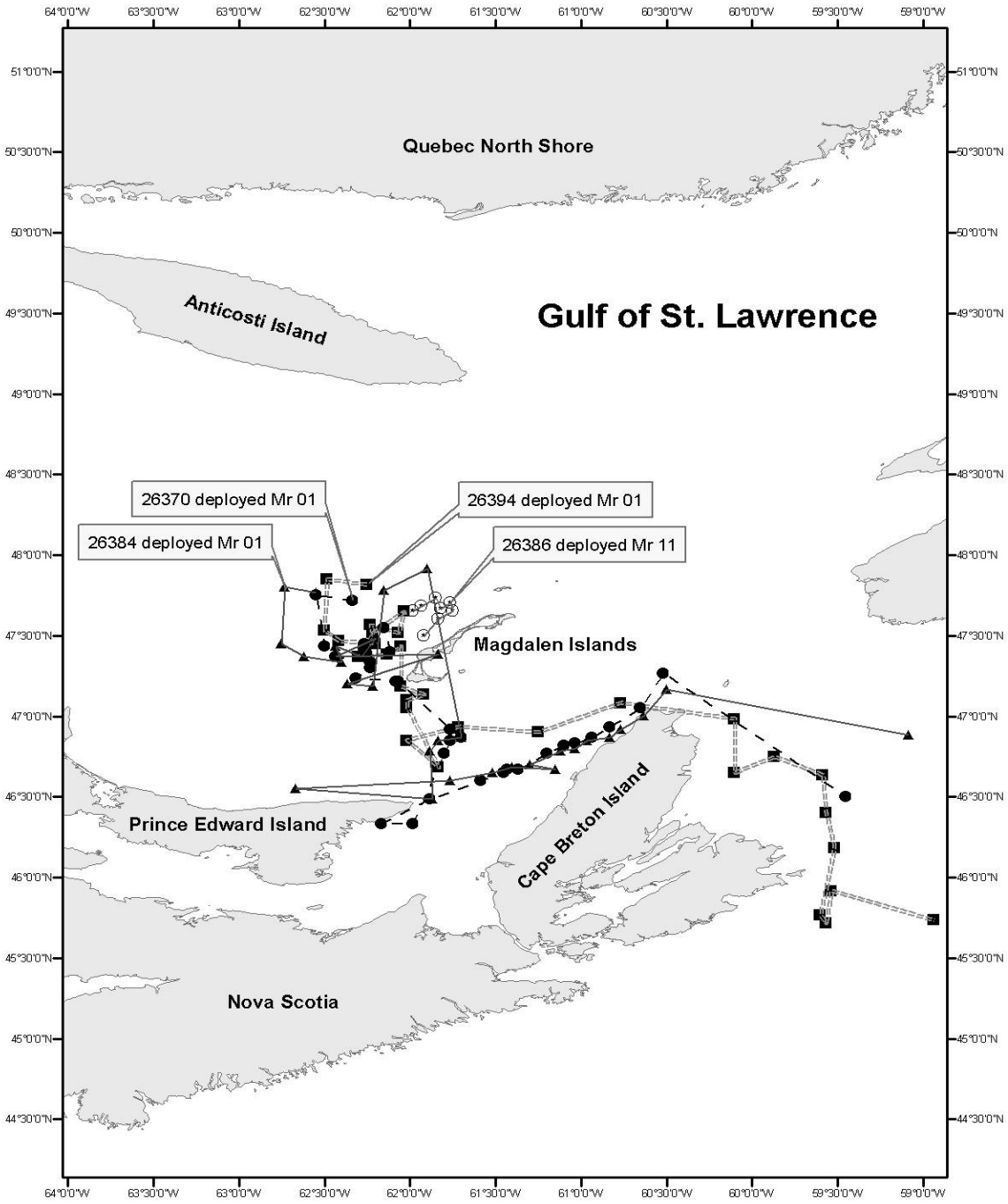

Figure 2. Movements of satellite linked beacons used to monitor movement of ice and whelping seals in the southern Gulf of St. Lawrence, March 2008.

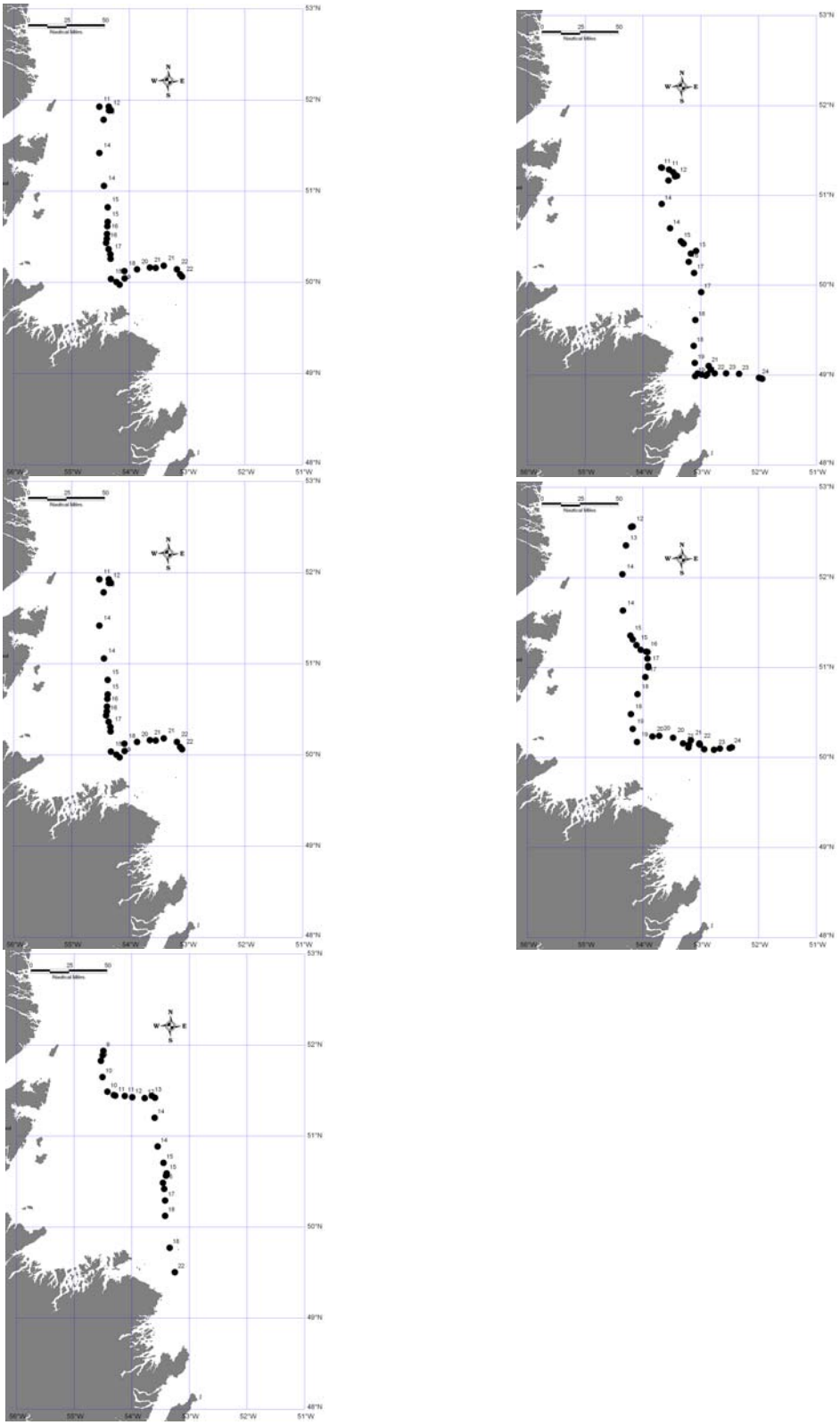

Figure 3. Movement of satellite linked GPS transmitters to monitor ice movement at the Front during the 2008 harp seal survey.

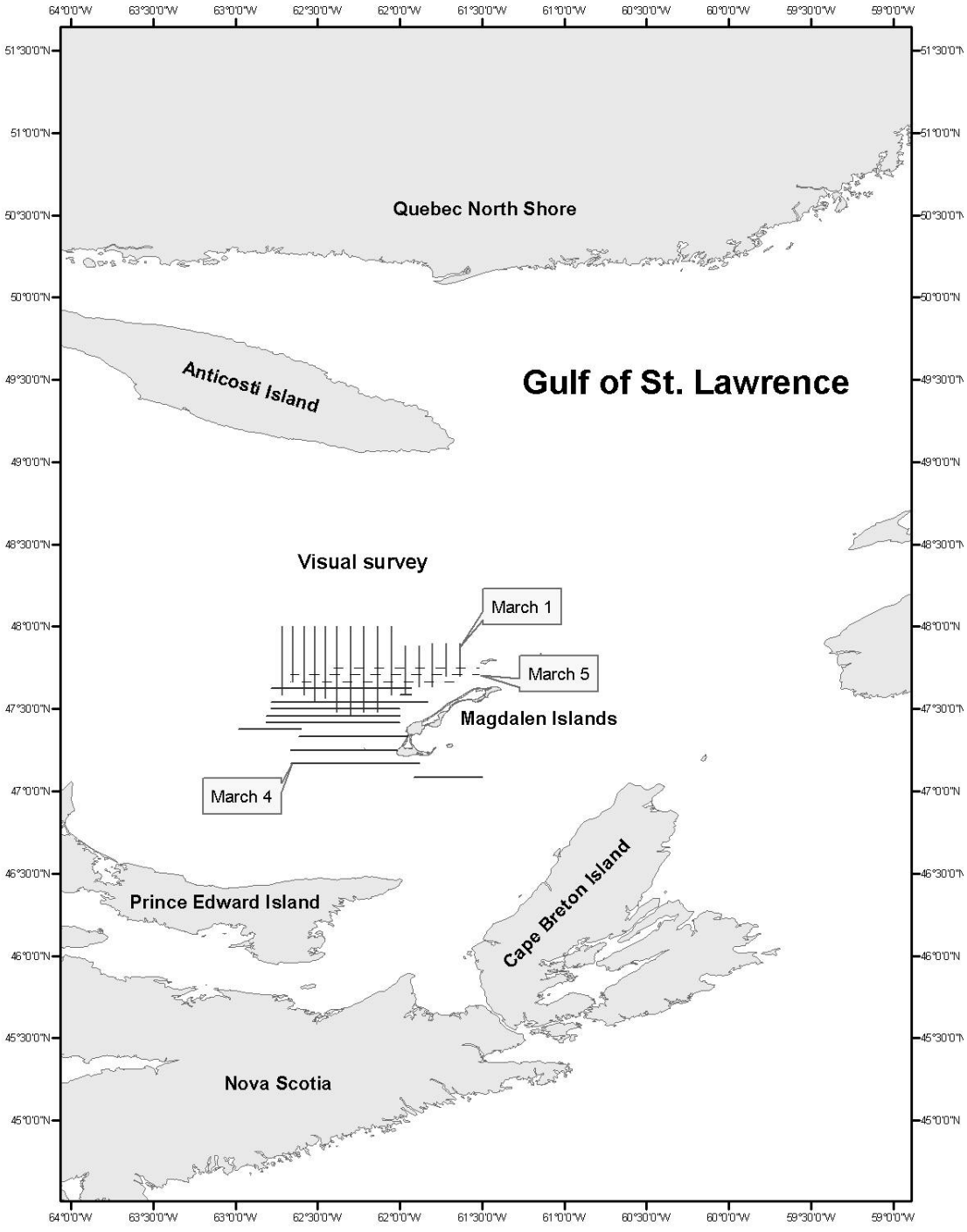

Figure 4. Location of visual survey transects flown to determine harp seal pup production in the southern Gulf of St. Lawrence on 1 (north-south lines) and 4-5 (horizontal lines) March 2008.

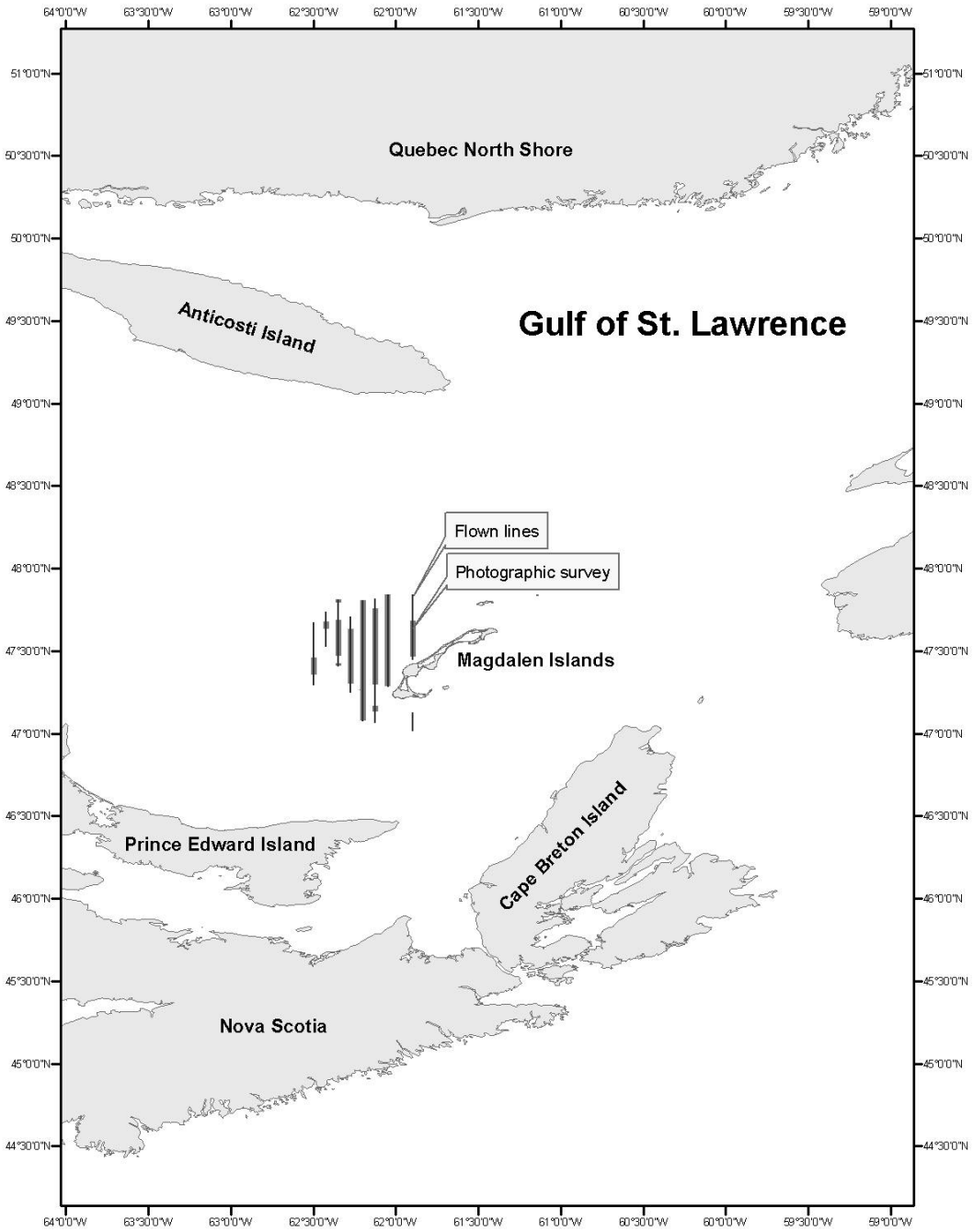

Figure 5. Location of photographic survey transects flown on 7 March 2008 to determine harp seal pup production in the southern Gulf of St. Lawrence.

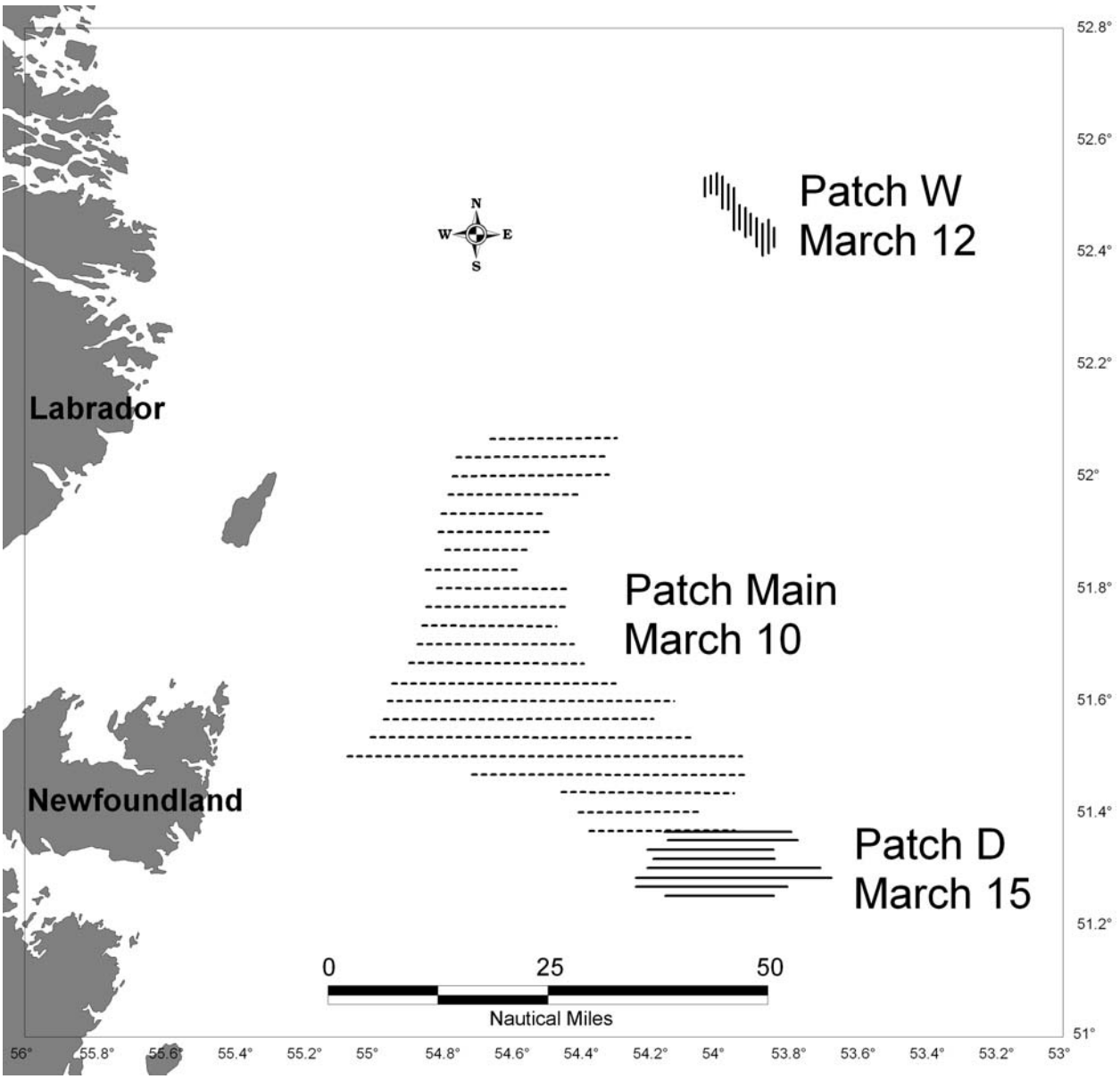

Figure 6. Visual transect lines for surveys flown in patch “Main” (March 10th). patch “W” (March 12th) and patch “D” (March 15th) during the 2008 harp seal survey.

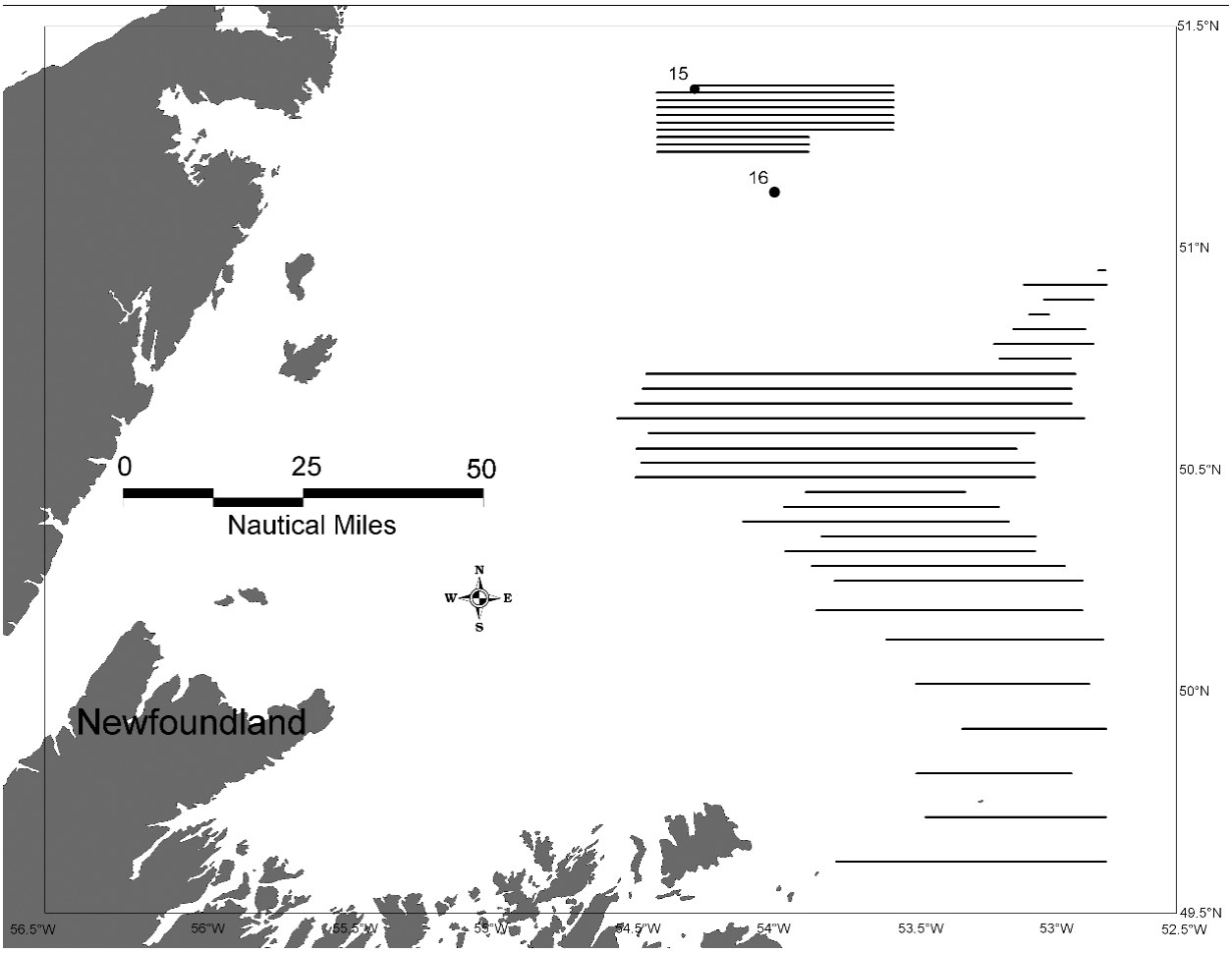

Figure 7. Photographic transect lines for surveys flown on March 15th (northern group of lines) and 16th (southern group of lines) during the 2008 harp seal survey. The position of ROMM 8 is indicated (black circles) for the two survey dates.

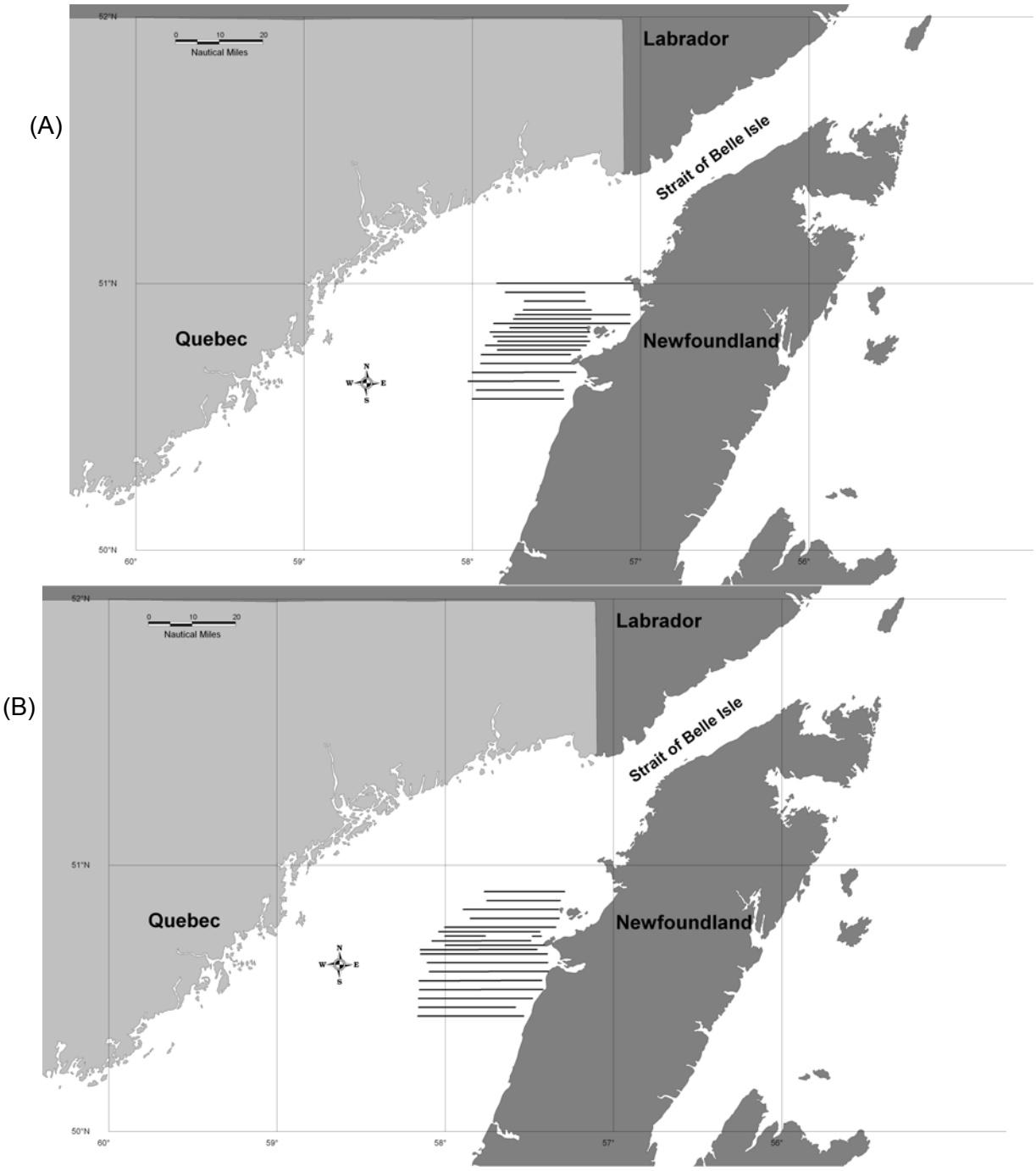

Figure 8. Photographic transect lines for surveys flown at the Mecatina whelping patch in the northern Gulf on March 15th (A) and March 17th (B) during the 2008 harp seal survey.

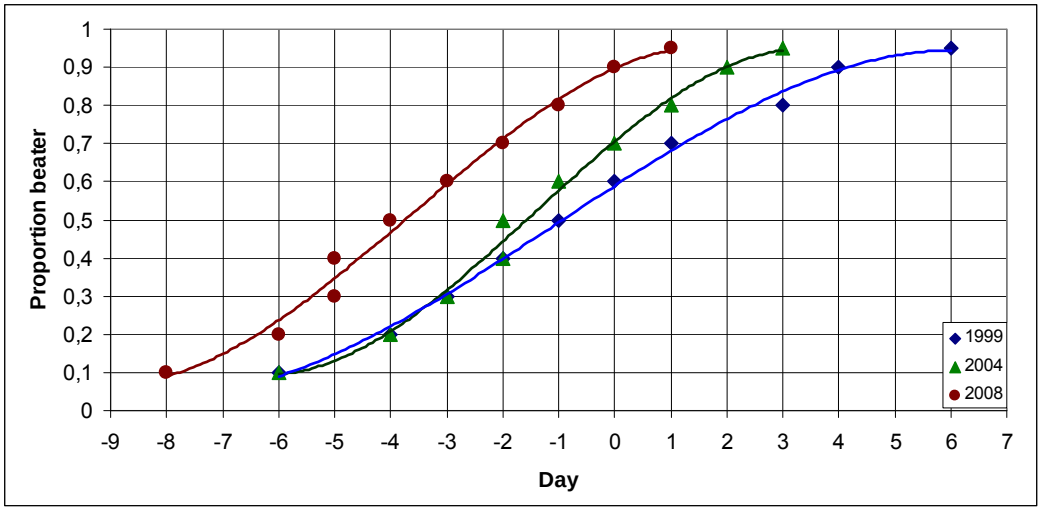

Figure 9. Proportion of animals pupped in the southern Gulf during 3 survey years, where day 1 is 1 March.