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Estimating Pup Production of Northwest Atlantic Harp Seals, *Pagophilus groenlandicus,* in 2012

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Photographic and visual aerial surveys were conducted off Newfoundland and in the southern Gulf of St. Lawrence to determine pup production of Northwest Atlantic harp seals in 2012. Repeated surveys of three whelping concentrations were carried out between 27 February and 16 March. Visual surveys in the southern Gulf resulted in pup production estimates ranging from 117,600 (SE=31,800) to 137,300 (SE=48,400) animals, after correcting estimates for pups born after the surveys were flown. Photographic estimates varied from a low of 71,300 (SE=9,000) from a survey flown on 4 March to 111,500 (SE=20,000) pups from a survey flown on 2 March. The 4 March estimate is considered to be negatively biased because a significant number of pups appeared to be outside of the survey area. Mortality of pups may also have occurred between the two surveys. Excluding the 4 March survey, estimated pup production in the southern Gulf was 115,500 (SE=15,000) animals. Multiple photographic surveys of seals that pupped on ice that was originally in the Strait of Belle Isle and at the Front resulted in estimates of 74,100 (SE=12,400) and 601,400 (SE=66,900) pups, respectively. Combining the number of pups found in all three areas resulted in an estimated total pup production of 790,000 (SE=69,700, CV=8.8 %). This estimate is approximately half of the estimated number of pups born in 2008, likely due to lower reproductive rates in 2012 compared to 2008. Only 15 % of the pups were born in the southern Gulf where years of poor ice conditions have been increasing in frequency over the past decade. Ice conditions observed during 2012, were similar to those observed in 1969, 2010, and 2011 and are among the worst on record. This continuing trend of poor ice conditions has serious implications for survival of harp seal pups and the longer-term persistence of breeding seals in the southern Gulf of St Lawrence.

Key words: harp seal, *Pagophilus groenlandicus*, pup production, survey, abundance, birth distribution, Northwest Atlantic, ice conditions

Estimation de la production de petits chez les phoques du Groenland (*Pagophilus groenlandicus*) du Nord-Ouest de l'Atlantique en 2012

RÉSUMÉ

Des relevés aériens photographiques et visuels ont été effectués en 2012 au large des côtes de Terre-Neuve et dans le sud du golfe du Saint-Laurent pour déterminer la production de petits chez les phoques du Groenland du Nord-Ouest de l'Atlantique. Des relevés répétés de trois concentrations de mises bas ont été effectués entre le 27 février et le 16 mars. Les relevés visuels dans le sud du golfe du Saint-Laurent ont permis d'estimer la production de petits entre 117 600 (ET = 31 800) et 137 300 (ET = 48 400) veaux, après que les estimations eurent été corrigées en y intégrant les petits nés après les relevés. Les estimations photographiques ont varié de 71 300 petits (ET = 9 000) lors d'un relevé effectué le 4 mars à 111 500 petits (ET = 20 000) lors d'un relevé effectué le 2 mars. On considère que l'estimation du 4 mars présente un biais négatif, car un nombre important de petits semblaient être à l'extérieur de la zone de relevé. Un certain nombre de petits ont également pu mourir entre les deux relevés. Si l'on ne tient pas compte du relevé du 4 mars, la production de petits dans le sud du golfe du Saint-Laurent était estimée à 115 500 veaux (ET = 15 000). Les nombreux relevés photographiques de phoques mettant bas sur la glace effectués à l'origine au-dessus du détroit de Belle Isle et dans la zone du Front ont permis d'établir des estimations de production de 74 100 (ET = 12 400) et 601 400 (ET = 66 900) petits, respectivement. En combinant le nombre de petits présents dans les trois zones, on a pu estimer la production totale de petits à 790 000 (ET = 69 700, CV = 8,8 %). Cette estimation représente environ la moitié de l'estimation du nombre de petits nés en 2008, probablement en raison d'un taux de reproduction plus faible en 2012 qu'en 2008. Seulement 15 % des petits sont nés dans le sud du golfe, où la fréquence des années de mauvais état des glaces a augmenté au cours de la dernière décennie. L'état des glaces observé au cours de l'année 2012 était semblable à ceux observés en 1969, 2010 et 2011 et figure parmi les pires jamais enregistrés. Cette tendance continue de mauvais état des glaces a de graves répercussions sur la survie des petits du phoque du Groenland et sur la persistance à long terme de phoques reproducteurs dans le sud du golfe du Saint-Laurent.

Mots clés : phoque du Groenland, *Pagophilus groenlandicus*, production de petits, relevé, abondance, répartition des naissances, Nord-Ouest de l'Atlantique, état des glaces.

INTRODUCTION

Northwest Atlantic (NWA) harp seals, *Pagophilus groenlandicus*, are hunted throughout their range for commercial and subsistence needs. The Canadian/Newfoundland commercial harvest has operated under various forms since the 1700's with the largest harvests, on the order of 700,000 animals, being taken in the early to mid 1800's. The General Assembly of Newfoundland, first established measures to limit hunting by setting 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. Since then the annual number of seals that can be hunted has been set based upon estimates of abundance.

Each year NWA harp seals give birth on the pack 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. However, the entire population is not present at one time and so total abundance is estimated using a model that incorporates information on pup production, removals from the population, general ice conditions and variations in age-specific reproductive rates (Hammill and Stenson 2011, Hammill et al. 2012). Information on reproductive rates, removals from the population and ice conditions are collected annually, while surveys to estimate pup production are completed every 4-5 years.

Since the implementation of harvest quotas, the population has increased from approximately 2 million animals in 1971 to a projected 7.1million (95 % CI=5.9 to 8.3 million) in 2012, with the most rapid increase occurring from about 1982 until 1998 (Hammill et al. 2012).

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 NWA harp seals at 4-5 year intervals. Pup production was estimated to be 578,000 (SE = 39,000) in 1990 (Stenson et al. 1993), increasing to 1.6 million (SE=110,000) in 2008 (Stenson et al. 2011).

Harp seals rely on pack ice to haul out on, to give birth and nurse their young, and to moult. They rarely haul out on land. Females begin pupping in late February in the Gulf and in early March at the Front (Sergeant 1991). Field observations suggest that whelping normally occurs on ice pans that are extensive and thick enough to persist. It must resist destruction from storm activity, but at the same time, not be so extensive as to prevent adults from entering the water during the lactation period (Bajzak et al. 2011). The ice chosen by females at the beginning of the whelping season is crucial because mobility of the pup is severely restricted. Newborn animals need stable ice to allow them time to develop sufficient blubber for insulation and to rest. After nursing for approximately 12 days the young of the year (YOY) are weaned, while the adults mate and disperse. Although the YOY spend an increasing amount of time in the water, they appear to continue to need a solid surface to haul out on and rest, particularly after weaning, and remain with the ice for several weeks (Sergeant 1991). This extended association with ice appears to be related to additional physiological development as the YOY make the transition from a "terrestrial" animal to a marine mammal (Burns et al. 2010). Consequently, the presence of stable pack ice is important in the early development of the young seal.

Using the survey estimates up to 2008 and catch data to 2012, Hammill et al (2012) estimated that the population would be about 7.1 million (SE=625,000) animals in 2012, with a pup production of 1.5 million (SE=282,000) animals, although some runs suggested a slightly lower population of 6.9 (SE=730,000) million animals and a pup production as low as 847,000 (SE=303,000) (Hammill et al 2012, unpublished).

Here we estimate the number of harp seal pups born in the Gulf of St. Lawrence and off the northeast coast of Newfoundland in 2012 using the same approach to visual and photographic aerial surveys as used previously.

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 5-16 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 48^0 40'N and 55^0 20'N at the Front and between the Strait of Belle Isle (~51^0 50'N) and the southern edge of the ice at approximately 50^0 50'N in the northern Gulf.

In the southern Gulf, reconnaissance surveys of areas traditionally used by harp seals were flown from 27 February to 10 March. Information on the location of whelping seals was gathered during helicopter reconnaissance flights and fixed-wing overflights conducted by DFO 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.

ESTIMATES OF ABUNDANCE

Visual surveys

Visual aerial surveys were flown, using a MMB 206 helicopter in the Gulf flying at an altitude of 45.7 m. 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. Total strip width was 60 m. 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 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 were flown on 27 February, and 1 and 2 March.

Photographic survey

Fixed-wing aerial photographic surveys were flown using one aircraft in the southern Gulf (Piper Navajo) and two aircraft (Piper Navajo and Rockwell Turbo Commander 690) 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 a hydraulically-actuated motion compensation frames designed to minimize the effects of aircraft pitch, roll, and yaw. The two digital camera's 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.

With the exception of the 15 March Pistolet Bay survey of the Straits concentration which was flown at 400 m, all surveys were flown at an altitude of 300 m and an airspeed of 110 knots. At an altitude of 330 m, both cameras yielded image footprints on the ice of approximately 215 m along the flight line and 325 m across the flight line. At 400 m, the photos were approximately 265m x 410m. The exact size of the area covered was estimated from the georeferenced file to ensure accuracy. The digital camera had a resolution of approximately 2.4 cm for objects on the ground when flown at 330 m. 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.

Sequential frames were shot along transect lines, spaced at 1.85 to 14.8 km (1 – 8 nmi) apart depending on the configuration of the seal patch. The surveys were designed to collect imagery with no overlap along a transect. However, in rare instances, overlap occurred. If so, seals were only counted on one frame to ensure that no pups were counted twice. Coverage along a line was generally between 70 % and 75 % in the Gulf and during the 10 March survey of the Straits. Coverage was 90-97 % for the remaining surveys. If transect spacing changed within a survey, at least three adjacent lines at equal spacing were obtained to allow for estimating the variance (see below).

Transect lines were identified based upon ongoing reconnaissance flights and estimated ice drift. The limits of the survey area were modified during the photographic surveys based upon current observations. 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. Most 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 14 km to ensure no more seals were present further along the transect line.

The 'Gulf' harp seal herd was photographed on March 2th and March 4th, with a total of 5,158 frames being shot. All photographic transects were oriented in an east-west direction.

Photographic surveys of the 'Front' concentration were carried out on 14 and 16 March, while the 'Straits' concentration was surveyed on 10 and 15 March. A total of 32,753 frames were shot of which 18,935 frames were read. With the exception of the 14 March Pistolet Bay survey which was flown in a north-south direction, photographic transects were oriented in an east-west direction.

A total of total of 37,913 frames were shot during the 2012 harp seal survey. This compares with 32,227 in 2008. This is a 15 % increase in imagery in 2012, with a 29 % increase in frames shot at the Front and a 42 % reduction in frames shot in the small Gulf patch.

<u>Correction for reader errors</u>

The imagery was geo-referenced 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, two (2) for the southern Gulf surveys and three (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 reader were examined by all readers and compared to determine a `best estimate' of the number of pups present. A correction factor for each reader was estimated as:

$$y_k = a + bn_k + u_k \quad (1)$$

Where n_k is the initial count of the kth photograph, *a* is the intercept, *b* is the slope, and u_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. Because survey and ice conditions were similar for each survey, individual photo counts were corrected using the appropriate estimates for the individual reader.

$$\hat{n}_k = \hat{b}n_k \quad (2)$$

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

$$V_k^m = \hat{\sigma}^2 + var(\hat{b})n_k^2 \quad (3)$$

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:

$$V_i^m = W_i^2 \left[\sum_{j=1}^{J_i} \left(\frac{l_j}{F_j}\right)^2 P_j\hat{\sigma}^2 + var(\hat{b}) \left(\sum_{j=1}^{J_i} \frac{l_j}{F_j} \sum_{k=1}^{P_j} n_k \right)^2 \right] \quad (4)$$

Where:

F_j is the total length of photos on a transect (i.e. $F_j = \sum_{k=1}^{P_j} f_{j,k}$ where $f_{j,k}$ *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. The basic survey design and analyses has remained the same since the survey were first flown in 1990 with only some slight modifications (Stenson et al. 1993, 2002, 2003, 2005, 2011). The number of pups for the *i*th survey was estimated by:

$$N_i = W_i \sum_{j=1}^{J_i} x_j \quad (5)$$

Where:

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

For photographic surveys where frames did not overlap

$$x_j = \frac{l_j \sum_{k=1}^{P_j} \hat{n}_{j,k}}{F_j} \quad (6)$$

If transect spacing changed within the survey area, each area of homogeneous transect spacing was treated as a separate survey (Kingsley et al. 1985) with the estimated number of pups given by

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

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):

$$V_i^s = \frac{W_i J_i}{2(J_i - 1)} \left(W_i - \frac{\sum_{j=1}^{J_i} F_j}{\sum_{j=1}^{J_i} l_j} \right) \sum_{j=1}^{J_{i-1}} \left(x_j - x_{j+1} \right)^2 \quad (8)$$

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

$$V_i^s = \frac{W_i \left(W_i - \frac{\sum_{j=1}^{J_i} F_j}{\sum_{j=1}^{J_i} l_j} \right)}{2} \sum_{j=1}^{J_{i-1}} \left(x_j - x_{j+1} \right)^2 \quad (9)$$

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:

$$N_i = ((N_1 \times V_2) + (N_2 \times V_1)) / (V_1 + V_2) \quad (10)$$

and its error variance:

$$V_i = (V_1 \times V_2) / (V_1 + V_2) \quad (11)$$

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 (6) age-dependent morphometric and pelage-specific stages was determined repeatedly throughout the whelping period (Stenson et al. 1993, 2002, 2003, 2005, 2011). 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, SD =0.49 *n* = 106), Thin Whitecoats (μ = 4.42 d, SD = 0.70, *n* = 26), Fat Whitecoats (μ = 11.39 d, SD= 1.22, *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).

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:

$N_i = N_{uncor}/Q_i$ (12)

Where:

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

Q_i = the proportion of births estimated to have occurred prior to survey *i*.

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

$V_i = \left(N_{uncor}^2 \times V_p/Q_i^4\right) + V_n/Q_i^2$ (13)

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.

RESULTS

IDENTIFICATION OF WHELPING AREAS

Total ice cover, and particularly first-year ice cover, in the southern Gulf of St. Lawrence was very low in March 2012 (Fig 1). The total ice present was greater than the previous two years but still well below the average for the area. Seals on whelping ice were located south and southwest of the Magdalen Islands on February 26 (Fig. 2). During the whelping season, the initial drift was to the south and west (Fig. 3). Strong southerly winds resulted in northward drift between 3 and 4 March. Ice conditions degraded, with pans breaking up rapidly. Drowned whitecoats were observed in the water after the survey had ended.

Total ice at the Front was also better than the previous 2 years, but below the long term average (Fig. 1). It was similar to the average ice extent seen over the past decade. One large whelping concentration was identified at the Front (Fig. 2). This group was first located on 5 March northeast of Black Tickle at approximately 53^0 40'N 55^0 10'W. Considerable ice movement occurred during the survey period due to strong winds and currents resulting in a relatively low density of seals scattered in bands over an area that was approximately 200 km north-south and 130 km east-west. Movement of this concentration was monitored through the use of four (4) satellite linked GPS transmitters (Fig. 4).

A concentration of seals (referred to as the 'Straits') was located in the northern Gulf of St. Lawrence on 6 March with the northern edge being at the southern entrance of the Strait of Belle Isle at 51^0 30'N 54^0 28'W (Fig. 2). Strong southerly winds forced the ice the seals were on northward towards Belle Isle (Fig. 4). Winds and currents subsequently split this group with some being trapped along the northern coast of Newfoundland in the Pistolet Bay area while the rest drifted down the east coast of the peninsula towards the Grey Islands. A small number of pups remained along the west coast of Belle Isle.

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 1.2 % (Table 1). There was very little difference between the counts of the 5 readers for all of the 250 images examined.

Survey Estimates

Southern Gulf

In the southern Gulf, the herd was delimited and visual surveys were flown on 27 February, 1 and 2 March. Total of 1,705 pups were counted on the 10 north-south transects flown on 27 February (Table 2, Fig. 5). The total estimated number of pups present on the ice on 27 February was 77,171 (SE=9,544, CV=12 %). A second survey, consisting of a combination of east west and north-south transects, was flown on 1 March (Fig. 6). A total of 1,724 seals were recorded along 16 transects flown (Table 3). Estimated pup production was 121,082 (SE=39,704; CV=33 %). A third visual survey was flown on 2 March (Fig. 7) with a total of 843 seals were counted along 11 lines, resulting in an estimated 104,082 (SE=39,992; CV=38 %) pups (Table 4).

Photographic surveys were flown on 2 and 4 March. Generally, photographic coverage along a transect line was 70-75 %. On 2 March, 18 transects were completed, with 6,703 pups detected on 2,932 images. Accounting for coverage along the transects and transect spacing, the estimated pup production was 103,168 animals (SE=15,704, CV=15 %)(Table 5, Fig. 8). On 4 March, 4,468 pups were detected on 2,466 images along 12 transects resulting in an estimated pup production of 69,530 (SE=8,272; CV=12 %) animals (Table 6, Fig. 9).

Straits/Northern Gulf

The whelping concentration that was originally located in the Strait of Belle Isle was surveyed on 10 March (Fig. 10). The survey consisted of 22 east–west transects spaced at 3.7 km apart, separated into two sections by an area of open water (Table 7). A total of 4,603 pups were identified on 2,323 photographs, resulting in an estimated pup production of 74,048 (SE=15,280, CV=21 %). By 15 March, this group had split into three groups. Twenty-two (22) north-south transects were flown in the Pistolet Bay area. An estimated 13,217 (SE=2,221, CV=17 %) pups were present in this area based upon 2,760 pups found on 1,103 photos (Table 8, Fig. 11). Pup production along the eastern coast of the peninsula (Grey Islands) was estimated based upon nine (9) east-west transects. A total of 2,659 pups were counted on 1,371 photos for an estimated pup production of 60,537 (SE=21,103, CV=35 %) (Table 9, Fig. 11). A small group of pups were trapped on ice along the shore of Belle Isle. A total count of these animals resulted in an additional 521 pups. Combining the three estimates resulted in a total pup production of 74,276 (SE=21,220, CV=29 %) for 15 March.

Averaging the 10 and 15 March estimates resulted in an estimated pup production in the Straits area of 74,126 (SE=12,400, CV =17 %).

Front

A photographic survey of the Front concentration was carried out on 14 March (Fig. 12). A total of 24,146 pups were counted on 7,375 photographs taken along 23 transects (Table 10). Correcting for mis-identified pups resulted in a total estimated pup production of 627,375 (SE=93,362, CV=15 %).

A second survey of the concentration was conducted on 16 March (Table 11, Fig. 13). Sixteen (16) transects resulted in a count of 12,302 pups on 8,184 photographs. The estimated pup production in this area was 541,196 (SE=86,050, CV=16 %), which was not significantly different from the 14 March estimate.

Modelling the Temporal Distribution of Births

Estimates of the proportion of pups in each of the developmental stages were obtained from all three whelping patches (Table 12, Fig. 14). Staging surveys were carried out over the entire pupping and nursing period. A total of eight (8) staging surveys were conducted in the southern Gulf. The estimated proportion of pups that were born at the time of the 27 February survey was 0.656 (SE=0.1579) (Table 13). This increased to 0.975 (SE=0.0426) by the time of the 4 March photographic survey. A correction for the estimate of pups born after the survey date was applied to all of the Gulf survey estimates.

In the Straits, the estimated proportion of births was ≥0.99 for both of the surveys (Table 13). Therefore, no correction for the temporal distribution of births was applied.

An estimated 94 % of the pups had been born at the Front at the time of the 14 March survey (Table 13). This had increased to 98 % by the time of the second survey, two days later. A correction for pups that had not been born at the time of the survey was applied to both of these surveys.

ESTIMATING TOTAL 2012 PUP PRODUCTION

Adjusting the visual survey estimates in the southern Gulf to account for births that had occurred after the survey had been flown resulted in visual estimates of 112,522 (SE=44,552) to 137,281 (SE=48,398) pups and photographic estimates of 71,313 (SE=9,038) and 111,533 (SE=20,046) pups (Table 14). Excluding the 4 March photographic survey which appears to be incomplete (see below) and averaging the four (4) remaining surveys results in a total gulf pup production of 115,508 (SE=15,066; CV=13 %).

Correcting the Front survey estimates for the temporal distribution of births resulted in estimates of 667,704 (SE=102,515, CV=15 %) and 552,241 (SE=88,286, CV=16 %) for the 14 and 16 March surveys, respectively (Table 14). Averaging these two surveys results in an estimate of 601,409 (SE=66,897, CV=11 %) pups at the Front.

Combining these estimates of the southern Gulf with those of the Front and Straits areas (74,126, SE=12,400, CV=17 %) resulted in an estimate of total pup production (rounded to the nearest hundred) in 2012 of 791,000 (SE=69,700, CV=8.8 %) (Table 14).

DISCUSSION

The methods used in this survey are essentially the same as those used to estimate pup production of harp seals since 1990 (Stenson et al. 1993, 2002, 2003, 2005, 2011). 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. The timing of the surveys was designed to maximize the numbers of seal pups present on the ice while still ensuring that the ice persists and the concentrations are not spread too widely. The reader's counts were standardized and corrected for missed pups. The high quality images we obtained had very good resolution at the survey altitudes used in this survey and as a result, the reader corrections were minimal.

After correcting for the timing of pupping, the visual and photograph surveys carried out in the southern Gulf of St. Lawrence between 27 February and 2 March resulted in very similar estimates of pup production. The 4 March survey, however, resulted in a much lower estimate than was obtained from the other surveys. We believe that this survey produced a negatively biased estimate because it missed some of the whelping concentration and it was likely that pup mortality may have occurred after the 2 March survey. Although the survey area was similar for both the 2 and 4 March surveys, drift of the beacon indicates that the ice shifted northward (Fig. 3). Plotting the distribution of animals on the survey lines suggests that there was some compression in the distribution of animals and that pups in the northern part of the 2 March survey may have drifted outside of the area covered by the 4 March survey (Fig. 15). Between noon on 2 March and noon on 4 March, the beacon drifted 12 miles to the north and approximately nine (9) kilometers to the east. The most northerly line flown on 4 March flew along the 47.2 degree line of latitude. Taking into account the northerly drift, eight (8) or nine (9) of the most northerly transects flown on 2 March, may have drifted north of the 47.2 degree line of latitude, and consequently would not have been covered by the 4 March survey. These lines would have accounted for nearly 40 % of the herd, or approximately 41,000 pups, which would account for the differences between the survey estimates. Some pup mortality may also have occurred between the two surveys owing to deterioration in the quality of the ice (Fig. 16). The ice charts show that the area occupied by the herd on 2 March was 90 % ice cover consisting of 50 to 80 % grey to first year ice (10 to 70 cm thick), with the remaining ice 10-15 cm thick, occurring in pans of 100 to 500 m across. On 4 March this area was 90 % ice-covered, consisting of 60 to 70 % grey to first-year ice, with the remaining ice consisting of new and grey ice (<10 cm to 15 cm thick). Although there were some large pans 100 to 2,000 m across, approximately 20 to 40 % of the area was covered by ice cakes with no apparent form and small floes 10 to 100 m across (Fig. 16). Given the clear differences in coverage and ice conditions that occurred between the 4 March survey and the 4 previous ones, it seems reasonable to assume that the March 4 survey is not representative of overall pupping and should not be included in the average estimate of total pup production.

No pupping was observed in the northern Gulf itself during these surveys. The 'Straits' concentration was first located at the southern edge of the ice in the very northern section of the Gulf. Although ice usually drifts southward through the Strait of Belle Isle, strong southerly winds pushed it northward in 2012 back through the Strait. From there it drifted with the current which took the majority of the animals to the southeast where they were surveyed on 15 March. Although reconnaissance flights continued over the Strait and northern Gulf during the survey period, no seals were seen in the area after the original group left.

With an estimated of 791,000 (SE=69,700), the 2012 pup production was approximately half of the 1.6 million (SE=117,900) estimated in 2008 (Stenson et al 2011) and slightly lower than that seen in 1999 and 2004 when pupping was estimated to be around 1 million (Stenson et al 2003, 2005). This decrease occurred in all areas although it was the greatest in the Gulf of St. Lawrence. Given the extensive flight activity by the DFO surveillance aircraft, private aircraft in the southern Gulf and our own flights, as well as the limited extent of suitable ice in some areas, it is highly unlikely that any significant concentrations of whelping animals were missed during our surveys. In the southern Gulf, suitable ice was only located in the traditional whelping area to the south of the Magdalen Islands (Bajzak et al 2011). Not only was there much less ice than normal in this area, the quality of this ice, as shown by the lack of first-year ice, was also considerably lower than normal (Fig. 16).

To ensure that no whelping concentrations were missed at the Front, reconnaissance flights were extended northward beyond 55^0N. This is north of the traditional whelping area although a group was found there in 2010 (Stenson and Hammill 2012). However, in that year, there was no suitable ice south of Grosewater Bay. In contrast, ice conditions at the Front in 2012 were similar to that seen over the past decade and not as poor as they were in either 2010 or 2011.

It is possible that animals over-wintered off southern Greenland and did not make the trip to southern areas; Rosing-Asvid (2008) reported more than 1,000 harp seal pups off southern Greenland in 2007 although it is not clear if these seals were from the Northwest Atlantic or Greenland Sea populations. To date, no reports of pupping off Greenland in 2012 have been received (Rosing-Asvid pers. comm.) and a survey of harp seals in the Greenland Sea estimated that pupping was similar, or slightly lower, than in previous years (Øigård et al 2014). Therefore, there is no reason to expect that large numbers of northwest Atlantic harp seals pupped outside of their traditional areas.

The most likely explanation for the large decline in pup production in 2012 is a reduction in pregnancy rates. The large increase in pup production seen between the 2004 and 2008 surveys (991,400 vs 1.6 million, Stenson et al. 2005, 2011) appears to have been due to the highly variable fecundity rates seen in this population. The proportion of mature females that gave birth in 2004 was less than 40 % while in 2008, it had increased to more than 70 % (Stenson and Wells 2011). In recent years, pregnancy rates have been as low as 25 % (Hammill et al 2012). Stenson et al. (2014) estimated fecundity rates in 2012 to be 65 %. However, this is based upon a very small sample (n=20) and so this estimate cannot be considered to be very reliable. Using a model that fits pup production estimates and historical reproductive data to predict total abundance and carrying capacity (K), Hammill et al (2014) predicted that pregnancy rates for seals 8 years of age and older would be approximately ~40 % in 2012. This would result in an estimated pup production of in the order of 929,000. Although the exact fecundity rate in 2012 is not known, the level of pup production we observed could be explained by pregnancy rates similar to that seen in recent years.

The rapid increase in abundance of NW Atlantic harp seals coincided with a period of over a decade of better than normal ice conditions as indicated by first year ice cover, particularly in the southern Gulf of St Lawrence (Friedlander et al. 2010; Bajzak et al. 2011). However, since the late 1990s, there has been a marked increase in the frequency of winters with poorer than average ice cover in the both the Gulf and Front areas (Fig. 1). It is difficult to predict how ice conditions will change in the future but it may result in a shift in whelping locations. Stenson and Hammill (2014) reported that very little pupping occurred in the southern Gulf of St. Lawrence in 2010 and that pupping occurred north of the traditional area of the Front that year. They attributed the movement to the late formation of ice. Although ice conditions were also poor the following year, pupping took place in the southern Gulf, presumably because ice formed at the usual time, although it did not persist. Ice formation in 2012 was similar to that of 2011(Fig. 1); these conditions resulted in females giving birth in the area, but deteriorating ice conditions persisted and may have led to elevated early mortality (Stenson and Hammill 2014).

Pup production in the southern Gulf of St Lawrence accounts, on average, for about 20 % of the total northwest Atlantic pup production (Table. 15). Although the proportion varies among years (previous range 17 to 28 %), there has been a downward trend in the Gulf contribution with only 15 % of the births in 2012 being born in the southern Gulf. Hammill et al (2012) estimate that mortality in the southern Gulf has been above average in 8 of the last 12 years due to poor ice conditions. The loss of one or two cohorts in a long-lived pinniped will not have serious implications for a population, but continued mortality is not sustainable. Gulf and Front seals are considered to be components of a single population but with a high degree of site fidelity among females (Sergeant 1991). It is possible that females that usually breed in the southern Gulf may move to the northern Gulf or Front if poor ice conditions persist, but as long as ice remains in the Gulf, some females will continue to pup there even if their young do not survive. This will have an important influence on the demographics of this population. If ice conditions continue as observed over the last decade, however, it is possible that harp seals will no longer have a significant breeding presence in the southern Gulf of St Lawrence.

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TABLES

Table 1. Regression statistics used to correct for misidentified pups on photographs. Each reader read a minimum of 50 photographs to develop the regression. Individual surveys did not differ and were combined for a single regression per reader. The total number of photographs read, intercept, slope and adjusted r^2 are presented.

Area	Reader	Photos Read	Slope (SE)	R^2	Random Error
Front	1	10,357	1.0078 (.0020)	0.9996	0.583
Front	2	5,658	1.0095 (.0044)	0.9991	0.899
Front	3	2,920	0.9987 (0.0036)	0.9994	0.309
Gulf	4	4,543	1.0113 (0.0048)	0.9995	1.595
Gulf	5	615	1.0090 (0.0028)	0.9996	1.555

Table 2. Number of pups counted on north-south transects and estimated pup production obtained from visual surveys of the Southern Gulf on 27 February 2012.

Transect	Start Latitude	Longitude	End Latitude	Transect spacing (m)	Pups counted	Estimated Pups
1	47.05	61.83	46.88	5,000	3	252.8
2	46.87	61.90	47.17	5,000	0	0.0
3	47.16	61.97	46.93	5,000	19	1,598.5
4	46.94	62.03	47.47	5,000	51.5	4,319.7
4	46.94	62.03	47.47	2,500	51.5	2,159.9
5	47.35	62.07	47.00	2,500	513	21,527.1
6	47.48	62.10	46.98	2,500	635	26,620.6
7	47.08	62.13	47.26	2,500	365	15,318.2
8	46.99	62.17	47.28	2,500	6	252.0
8	46.99	62.17	47.28	5,000	6	503.9
9	47.28	62.23	47.05	5,000	30	2,518.4
10	47.07	62.30	47.21	5,000	25	2,099.6
					Total Estimated	77,171
					SE	9,544

Table 3. Transect positions, direction, spacing, number of pups counted and estimated from visual surveys of the Southern Gulf on 1 March 2012.

Transect	Axial	Start	Stop	Direction	Transect spacing (m)	Pups counted	Estimated pups
1	47.33	62.02	62.39	E-W	7,400	0	0
2	47.27	62.01	62.55	E-W	7,400	1	123.5
3	47.23	62.23	62.40	E-W	7,400	12	1,481.6
3	47.23	62.23	62.40	E-W	3,700	12	740.8
4	47.20	62.40	62.04	E-W	3,700	76	4,691.7
5	47.17	62.35	62.29	E-W	3,700	58	3,580.5
6	47.13	62.58	62.08	E-W	3,700	76	4,691.7
7	47.10	62.32	62.54	E-W	3,700	28	1,728.5
8	47.07	62.10	62.43	E-W	3,700	76	4,691.7
9	47.03	62.66	62.27	E-W	3,700	516	31,854.4
10	46.99	62.42	62.20	E-W	3,700	341	21,051.1
11	46.97	62.22	62.65	E-W	3,700	305	18,828.7
12	46.92	62.15	62.70	E-W	3,700	107	13,149.2
12	46.92	62.15	62.70	E-W	11,100	107	19,816.4
13	46.87	62.79	62.13	E-W	11,100	5	926.0
14	46.73	62.59	62.12	E-W	11,100	1	185.2
15	62.00	46.89	46.67	N-S	5,000	1	84.6
16	62.07	46.72	46.90	N-S	5,000	2	169.0
						Total Estimate	121,082
						SE	39,704

Table 4. Number of pups counted on east-west transects obtained during a visual survey of the Southern Gulf on 2 March, 2012.

Transect	Axial (Lat.)	Start (Long)	Stop (Long)	Direction	Transect Spacing (m)	Pups counted	Estimated pups
1	47.37	62.55	62.03	E	7,400	0	0
2	47.30	62.20	62.65	W	7,400	12	1,481.6
3	47.23	62.62	62.38	E	7,400	2	246.9
4	47.17	62.40	62.65	W	7,400	157	19,384.3
5	47.10	62.64	62.42	E	7,400	59	7,284.5
6	47.03	62.43	62.71	W	7,400	65	8,025.3
7	46.97	62.70	62.39	E	-	340	41,978.7
8	46.90	62.30	63.18	W	3,700	61	7,531.5
9	46.83	63.19	62.53	E	3,700	84	10,371.2
10	46.77	63.14	61.96	E	3,700	63	7,778.4
11	46.70	63.16	63.09	E	3,700	0	0
						Estimated Total	104,082
						SE	39,992

Table 5. Number of pups counted on east-west transects obtained during photographic surveys of the southern Gulf flown 2 March, 2012.

Line	Axial (Lat)	Start (Long)	End (Long)	Transect spacing (m)	Transect length (m)	Photos #	% cover	Pups detected	Pups on line	Weighted seals
1	47.33	62.10	62.75	7,400	48,368	172	74	4	5.5	126.7
2	47.27	62.01	62.82	7,400	60,766	216	75	29	38.9	903.2
3	47.20	62.34	62.85	7,400	38,791	138	74	207.5	282.8	6,542.5
3	47.20	62.34	62.85	3,700	38,791	138	74	207.5	282.8	3,256.8
4	47.17	62.42	62.61	3,700	15,135	54	75	407	544.9	6,243.5
5	47.14	62.38	62.59	3,700	15,976	57	73	816	1,110.3	12,998.8
6	47.10	62.43	62.60	3,700	13,728	49	75	233	312.7	3,594.9
7	47.07	62.43	62.40	3,700	15,701	56	77	78	101.8	1,166.0
8	47.03	62.60	62.39	3,700	15,982	57	72	259	361.1	4,102.9
9	47.00	62.31	62.65	3,700	26,125	93	75	1,483	1,971.8	22,204.9
10	46.97	62.35	62.74	3,700	30,069	107	75	1,017	1,353.5	15,276.3
11	46.93	62.91	62.23	3,700	52,303	186	71	848	1,193.0	14,294.9
12	46.90	62.68	62.19	3,700	37,110	132	75	206	274.0	3,089.6
13	46.87	62.25	62.71	3,700	35,119	125	70	79	113.4	1,392.9
13b	46.87	62.75	62.91	3,700	12,306	44	70	19	27.1	331.3

Line	Axial (Lat)	Start (Long)	End (Long)	Transect spacing (m)	Transect length (m)	Photos #	% cover	Pups detected	Pups on line	Weighted seals
14	46.84	62.23	63.01	3,700	59,356	211	75	154	204.3	2,304.8
15	46.83	63.20	63.02	3,700	14,291	51	74	4	5.4	61.7
16	46.80	62.91	62.31	3,700	46,105	164	69	176	253.6	3,102.6
17	46.76	63.20	62.03	3,700	89,892	319	64	56	87.9	1,168.0
18	46.74	62.40	63.09	3,700	53,122	189	64	5	7.9	104.9
19	46.70	62.02	63.18	3,700	88,606	314	71	1	1.4	16.6
Total estimated										103,168
SE										15,704

Table 6. Number of pups counted on east-west transects obtained during photographic surveys of the southern Gulf flown 4 March, 2012.

Line	Axial (Lat)	Start (Long)	End (Long)	Transect spacing	Transect length	Photos	%cov	Pups	Pups on line	Weighted seals
1	47.27	62.64	62.18	7,400	34,812	124	72	135	187.7	4,477.8
2	47.20	62.24	62.67	7,400	32,564	116	73	564	771.1	18,084.2
2	47.20	62.24	62.67	3,700	32,564	116	73	562	771.1	9,002.6
3	47.17	62.68	62.04	3,700	48,314	159	65	1,138	1,763.6	10,629.6
4	47.14	62.19	62.67	3,700	36,780	131	72	306	423.6	5,003.0
5	47.10	62.11	62.74	3,700	47,471	169	71	49	68.8	824.6
6	47.07	62.62	62.16	3,700	35,652	127	72	31	43.1	512.5
7	47.03	62.68	61.92	3,700	57,603	205	72	222	308.2	3,658.1
8	47.00	62.16	62.77	3,700	46,068	164	72	307	428.6	5,107.1
9	46.97	62.06	62.91	3,700	64,640	230	73	17	23.4	274.7
10	46.93	62.73	62.17	3,700	42,691	152	72	1	1.4	16.4
11	46.90	62.85	61.93	3,700	70,588	251	86	5	5.8	58.5
12	46.87	62.24	62.92	3,700	52,258	186	72	1	1.4	16.5
									Total Estimate	69,530
									SE	8,272

Table 7. Number of pups counted on E-W transects during photographic surveys in the Strait of Belle Isle, 10 March, 2012.

Line	Axial (Lat)		Start	End	Spacing	Length	Photos	%	Pups	Cor	Pups on	Weighted
	Deg	Min	Long	Long	(m)	(m)		Cover		Pups	line	Seals
1	52	1	55.16	55.65	3,700	33,552	119	72	0	0	0	0
2	51	59	55.16	55.75	3,700	40,340	143	75	187	188.5	250.6	2,856.0
3	51	57	55.26	55.61	3,700	24,506	87	72	125	126.0	174.7	2,079.3
4	51	55	55.34	55.75	3,700	28,182	100	72	634	638.9	889.1	10,610.0
5	51	53	55.16	55.75	3,700	40,332	143	72	21	21.2	29.4	349.8
6	51	51	55.17	55.75	3,700	39,761	141	72	24	24.2	33.4	396.7
7	51	49	55.06	55.75	3,700	47,682	169	72	45	45.3	62.7	742.0
1	51	45	55.08	55.61	3,700	36,942	131	73	411	414.2	570.2	6,727.3
2	51	43	55.17	55.62	3,700	31,293	111	75	69	69.5	93.1	1,069.7
3	51	41	55.08	55.58	3,700	34,964	124	73	706	711.5	977.8	11,519.3
4	51	39	55.17	55.87	3,700	48,819	173	75	727	732.6	980.5	11,240.3
5	51	37	55.10	55.94	3,700	58,348	207	73	437	440.4	601.7	7,049.9
6	51	35	55.22	55.43	3,700	14,905	53	75	2	2.0	2.7	31.0
7	51	33	55.15	55.46	3,700	21,680	77	73	38	38.3	52.3	613.6
8	51	31	55.20	55.47	3,700	18,856	67	74	264	266.0	357.8	4,131.4
9	51	29	55.15	55.49	3,700	23,098	82	73	128	130.0	177.0	2,068.5
10	51	27	55.20	55.47	3,700	19,423	69	74	297	299.3	403.1	4,662.8
11	51	25	55.21	55.51	3,700	20,833	74	73	362	364.8	500.3	5,889.6
12	51	23	55.24	55.53	3,700	19,990	71	74	93	94.7	127.7	1,478.8
13	51	21	55.23	55.54	3,700	20,557	73	73	32	32.2	44.0	516.6
14	51	19	55.37	55.53	3,700	10,944	39	74	1	1.0	1.4	15.7
15	51	17	55.33	55.62	3,700	19,707	70	74	0	0	0	0
											Total Estimate	74,048
											SE	15,280

Table 8. Number of pups counted on N-S transect during photographic surveys in Pistolet Bay (Straits), 15 March, 2012. An additional 531 pups were counted on the ice along Belle Island.

Line	Axial Lon		Start	End	Spacing	Length	Photos	%	Pups	Cor	Pups on	Weighted
-	Deg	Min	Lat	Lat	(m)	(m)	-	Cover	-	Pups	line	Seals
1	55	55.8	51.74	51.61	1,850	14,960	53	94	7	7.1	7.5	34
2	55	54.2	51.74	51.60	1,850	15,532	55	97	5	5.0	5.2	23
3	55	52.6	51.74	51.56	1,850	20,610	73	94	1	1.0	1.1	5
4	55	51	51.74	51.61	1,850	14,685	52	97	10	10.1	10.4	46
5	55	49.4	51.74	51.59	1,850	16,935	60	93	64	64.5	69.0	316
6	55	47.8	51.74	51.58	1,850	18,643	66	97	128	129.0	133.0	587
7	55	46.2	51.74	51.60	1,850	16,371	58	93	195	196.5	210.6	966
8	55	44.6	51.75	51.58	1,850	18,637	66	96	125	126.0	131.1	584
9	55	43	51.74	51.58	1,850	18,066	64	93	457	460.6	492.7	2,257
10	55	41.6	51.74	51.58	1,850	18,358	65	96	569	573.4	596.6	2,655
11	55	39.8	51.74	51.59	1,850	16,935	60	94	137	138.1	147.5	675
12	55	38.2	51.71	51.59	1,850	13,271	47	97	102	102.8	106.5	472
13	55	36.6	51.74	51.61	1,850	14,956	53	93	61	61.5	65.9	302
14	55	35	51.72	51.60	1,850	13,551	48	97	144	145.1	150.2	666
15	55	33.4	51.73	51.61	1,850	14,390	51	93	39	39.3	42.0	193
16	55	31.8	51.74	51.62	1,850	13,556	48	96	115	115.9	120.3	534
17	55	30.2	51.74	51.62	1,850	13,828	49	93	130	131.0	141.0	649
18	55	28.6	51.60	51.70	1,850	12,141	43	97	216	217.7	225.5	1,000
19	55	26.8	51.68	51.62	1,850	7,043	25	94	37	37.3	39.9	183
20	55	25.2	51.68	51.58	1,850	10,732	38	97	0	0.0	0	0
21	55	23.6	-	-	Open	Water	-	-	-	-	-	-
22	55	22	51.67	51.60	1,850	8,181	29	94	218	219.7	234.6	1,070
											Total Estimate	13,217
											SE	2,221

Table 9. Number of pups counted on E-W transect during photographic surveys near the Grey Islands (Straits), 15 March, 2012

Line	Axial (Lat)		Start	End	Spacing	Length	Photos	%	Pups	Cor	Pups on	Weighted
-	Deg	Min	Long	Long	(m)	(m)	-	Cover	-	Pups	Line	Seals
1	51	1.5	55.0	55.6	7,400	38,919	173	0.99	478	482.5	489.1	10,646.4
2	50	57.5	55.0	55.6	7,400	38,918	173	0.98	81	81.8	83.7	1,838.2
3	50	53.5	55.0	55.6	7,400	21,600	96	0.98	338	341.2	347.8	7,604.0
4	50	49.5	55.0	55.6	7,400	32,387	144	0.98	174	175.7	179.3	3,927.0
5	50	45.5	55.0	55.5	7,400	38,922	173	0.98	323	326.1	332.0	7,253.1
6	50	41.5	55.0	55.5	7,400	38,472	171	1.00	236	238.2	239.2	5,157.6
7	50	37.5	55.5	55.8	7,400	19,164	83	0.95	926	933.2	985.4	21,748.2
8	50	33.5	55.5	55.8	7,400	19,114	85	0.96	63	63.5	66.0	1,470.5
9	50	29.5	55.0	55.9	7,400	61,421	273	0.99	40	40.4	41.0	892.2
											Total Estimate	60,537
											SE	21,103

Table 10. Number of pups counted on E-W transect during photographic surveys of the Front, 14 March, 2012.

Line	Axial (Lat)		Start	End	Spacing	Length	Photos	%	Pups	Cor	Pups on	Weighted
	Deg	Min	Long	Long	(m)	(m)		Cover		Pups	Line	Seals
1	53	0	53.26	54.57	7,400	47,672	169	79	1	1.0	1.3	27.6
2	52	56	53.42	54.74	7,400	87,254	371	85	793	792.0	933.6	22,207.2
3	52	52	53.27	54.55	7,400	86,214	366	94	982	991.3	1,051.6	22,875.7
4	52	48	53.03	54.07	7,400	113,163	504	93	4,608	4,601.9	4,972.4	115,482.8
5	52	44	53.13	54.51	7,400	93,524	397	95	3,136	3,165.8	3,329.9	71,817.2
6	52	40	53.01	54.68	7,400	112,721	501	94	608	607.2	648.8	14,869.5
7	52	36	53.15	54.52	7,400	93,280	396	90	1,261	1,273.0	1,421.1	32,535.7
8	52	32	53.04	53.23	7,400	115,047	515	94	1,130	1,128.5	1,201.3	27,633.4
9	52	28	53.19	54.47	7,400	86,924	369	91	1,894	1,912.0	2,110.8	47,784.5
10	52	24	53.19	54.72	7,400	104,172	463	96	1,287	1,285.3	1,332.6	29,644.0
11	52	20	53.21	54.35	7,400	77,279	328	96	791	798.5	830.0	17,689.6
12	52	16	53.25	54.59	7,400	91,562	406	95	530	529.3	556.0	12,500.9
13	52	12	53.19	54.35	7,400	79,397	337	94	504	508.8	541.2	11,803.7
14	52	8	53.39	54.57	7,400	68,665	160	52	360	359.5	685.6	13,847.9
15	52	4	53.20	54.24	7,400	62,886	267	94	51	51.5	27.5	603.6
15	52	4	53.20	54.24	-	62,886	267	94	51	51.5	27.5	603.6
16	51	56	53.40	54.20	14,800	55,361	235	95	50	50.5	53.3	2,306.0
17	51	48	53.44	54.11	14,800	45,695	194	93	235	237.2	255.9	11,324.2
18	51	40	53.51	54.11	14,800	40,975	174	91	698	704.6	777.0	35,147.5
19	51	32	53.52	54.29	14,800	53,469	227	91	656	662.2	363.3	16,351.9
19	51	32	53.52	54.29	7,400	53,469	227	91	656	662.2	363.3	16,351.9
20	51	28	53.40	54.30	7,400	62,660	266	93	1,377	1,390.1	1,494.5	32,949.7
21	51	24	53.32	54.25	7,400	61,695	262	92	2,013	2,032.2	2,215.7	49,559.1
22	51	20	53.28	54.10	7,400	56,538	240	92	996	1,005.5	1,095.6	24,479.9
23	51	16	53.34	54.11	7,400	53,705	228	92	185	186.8	203.6	4,549.8
											Total Estimate	627,375
											SE	93,362

Table 11. Number of pups counted on E-W transect during photographic surveys of the Front, 16 March, 2012.

Line	Axial (Lat)		Start	End	Spacing	Length	Photos	%	Pups	Cor	Pups on	Weighted
-	Deg	Min	Long	Long	(m)	(m)	-	Cover	-	Pups	Line	Seals
1	52	56.00	52.58	53.94	11100	91,238	409	0.94	1	1.0	1.1	38.2
2	52	50.00	52.59	53.93	11100	90,116	404	0.91	593	597.6	653.7	22,348.6
3	52	44.00	52.34	54.49	11100	144,991	650	0.93	1,386	1,396.8	1,498.3	53,496.2
4	52	38.00	52.33	54.39	11100	139,868	627	0.94	985	992.7	525.9	18,827.9
4	52	38	52.33	54.39	22200	139,868	627	0.94	985	992.7	525.9	37,655.9
5	52	26	52.44	54.38	22200	130,870	584	0.95	621	625.8	662.2	45,092.3
6	52	14	52.44	54.47	22200	138,969	623	0.95	361	363.8	381.3	25,940.5
7	52	2	52.45	54.10	22200	112,639	478	0.96	688	693.3	720.6	46,056.4
8	51	50	52.46	54.19	22200	119,955	509	0.91	990	997.7	545.9	36,740.7
8	51	50	52.46	54.19	11100	119,955	509	0.91	990	997.7	545.9	18,370.3
9	51	44	52.60	54.24	11100	113,363	481	0.96	359	361.8	375.4	11,977.8
10	51	38	52.66	54.19	11100	106,281	451	0.93	402	405.1	437.0	14,491.6
11	51	32	52.66	54.22	11100	108,642	461	0.94	1,255	1,264.8	1,339.8	43,639.4
12	51	26	52.67	54.17	11100	103,909	441	0.93	1,757	1,770.7	1,898.4	62,591.6
13	51	20	52.46	54.17	11100	119,257	506	0.93	2,540	2,559.7	2,742.4	90,333.7
14	51	14	52.62	54.17	11100	107,930	458	0.91	147	148.1	162.8	5,502.8
15	51	8	52.62	54.33	11100	119,472	507	0.91	211	212.6	233.4	7,875.6
16	51	2	52.66	54.66	11100	140,199	595	0.93	6	6.0	6.5	216.7
											Total Estimate	541,196
											SE	86,050,

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 2012.

	Date	Newborn	Thin white	Fat white	Ragged	Beater	Total
S. Gulf	24 February	0	36	0	0	0	36
	26 February	103	124	0	0	0	227
	28 February	613	844	103	0	0	1,560
	29 February	167	974	225	0	0	1,366
	02 March	112	721	961	0	0	1,794
	03 March	38	27	8	0	0	73
	05 March	8	88	438	0	0	534
	06 March	2	8	393	1	0	404
	10 March	1	3	58	1	0	63
	12 March	0	0	561	13	0	574
	13 March	0	0	56	4	11	71
	16 March	0	0	34	34	23	91
	17 March	0	2	186	368	215	771
	21 March	0	0	140	315	351	806
Front	06 March	550	624	1	0	0	1,175
	07 March	470	1,658	14	0	0	2,142
	10 March	78	757	1,602	0	1	2,438
	12 March	42	429	1,525	2	1	1,999
	15 March	4	67	1,393	2	0	1,466
	18 March	0	0	1,064	10	0	1,074
	21 March	0	0	1,083	175	6	1,264
Strait	06 March	10	128	4	0	0	142
	10 March	8	683	352	0	0	1,043
	13 March	3	131	1,025	9	0	1,168
	15 March	1	54	1,727	7	0	1,789
	19 March	0	0	1,074	260	29	1,363
	23 March	0	0	278	565	150	993

Table 13. Estimated proportions of Northwest Atlantic harp seal pups on the ice at the time of the surveys.

Area	Survey Type	Date	Estimate	Std Err	Correction Applied
S. Gulf	Visual	27 Feb	0.656	0.1579	Yes
		1 Mar	0.882	0.1142	Yes
		2 Mar	0.925	0.0884	Yes
	Photographic	2 Mar	0.925	0.0884	Yes
		4 Mar	0.975	0.0426	Yes
Front	Photographic	14 Mar	0.940	0.0355	Yes
		16 Mar	0.980	0.0163	Yes
Strait	Photographic	10 Mar	0.9986	0.0012	No
		15 Mar	0.9999	<0.00001	No

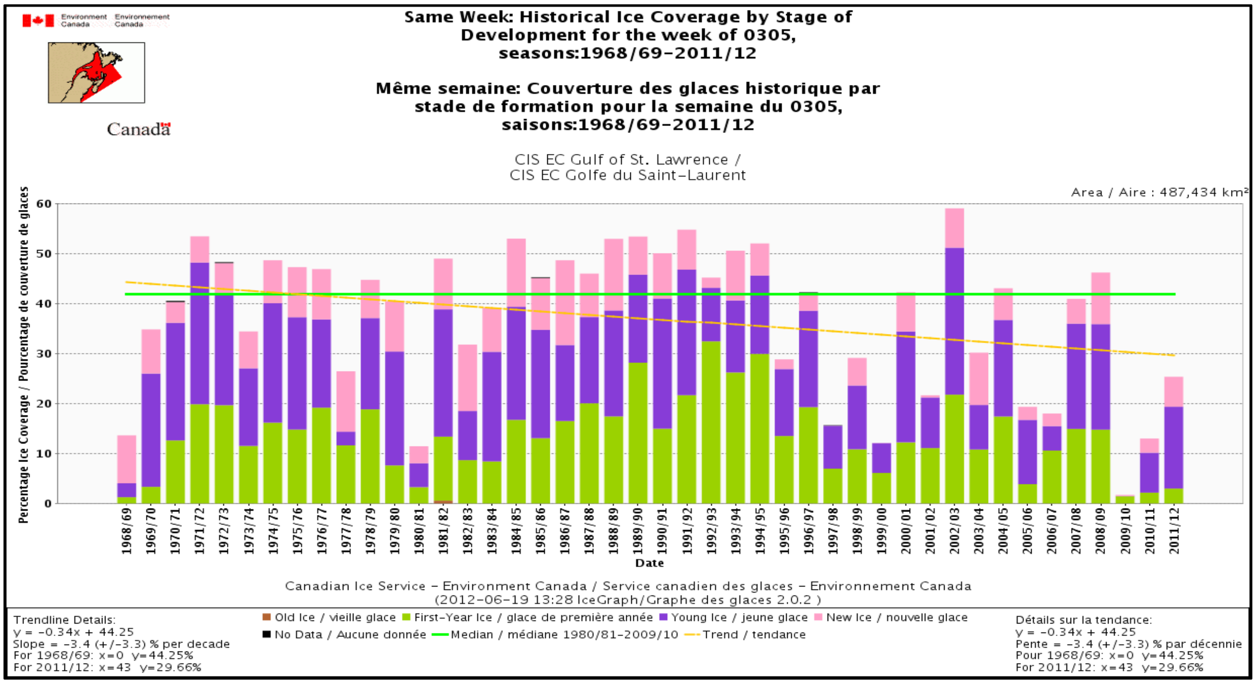
Table 14. Estimated pup production and standard errors of northwest Atlantic harp seals during March 2012. With the exception of the 10 and 15 March Straits surveys, the estimates are corrected for pups that may have been born after the survey date. The 4 March photographic survey of the Southern Gulf was not included because it was considered to be incomplete (shaded area).

Area	Date	Method	Estimate	Std Err	CV
S. Gulf	27 Feb	Visual	117,639	31,835	0.271
	1 March	Visual	137,281	48,398	0.353
	2 March	Visual	112,522	44,552	0.396
	2 March	Photo	111,533	20,046	0.180
	4 March	Photo	71,313	9,038	0.127
	Averaged		**115,508**	**15,066**	**0.130**
Strait	10 March	Photo	74,048	15,280	0.206
	15 March	Photo	13,217	2,221	0.168
		Photo	60,537	21,103	0.349
		Count	521	-	-
		Combined	74,276	21,220	0.286
	Averaged		**74,126**	**12,400**	**0.167**
Front	14 March	Photo	667,704	102,515	0.154
	16 March	Photo	552,241	88,286	0.160
	Averaged		**601,409**	**66,897**	**0.111**
Total			**791,043**	**69,685**	**0.088**

Table 15. Northwest Atlantic harp seal pup production estimates from aerial surveys completed since 1990 (with SE) and the proportion of pupping in each component. Northern Gulf component in 2012 was part of the 'Strait' concentration.

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)	1,185,000 (112,474)	1,644,500 (117,900)
2012	115,500 (15,100)	74,100 (12,400)	601,400 (66,900)	797,000 (69,700)
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	0.17	0.11	0.72	
2012	0.15	0.09	0.76	
Average	0.20	0.08	0.72	
SD	0.05	0.03	0.07	

FIGURES



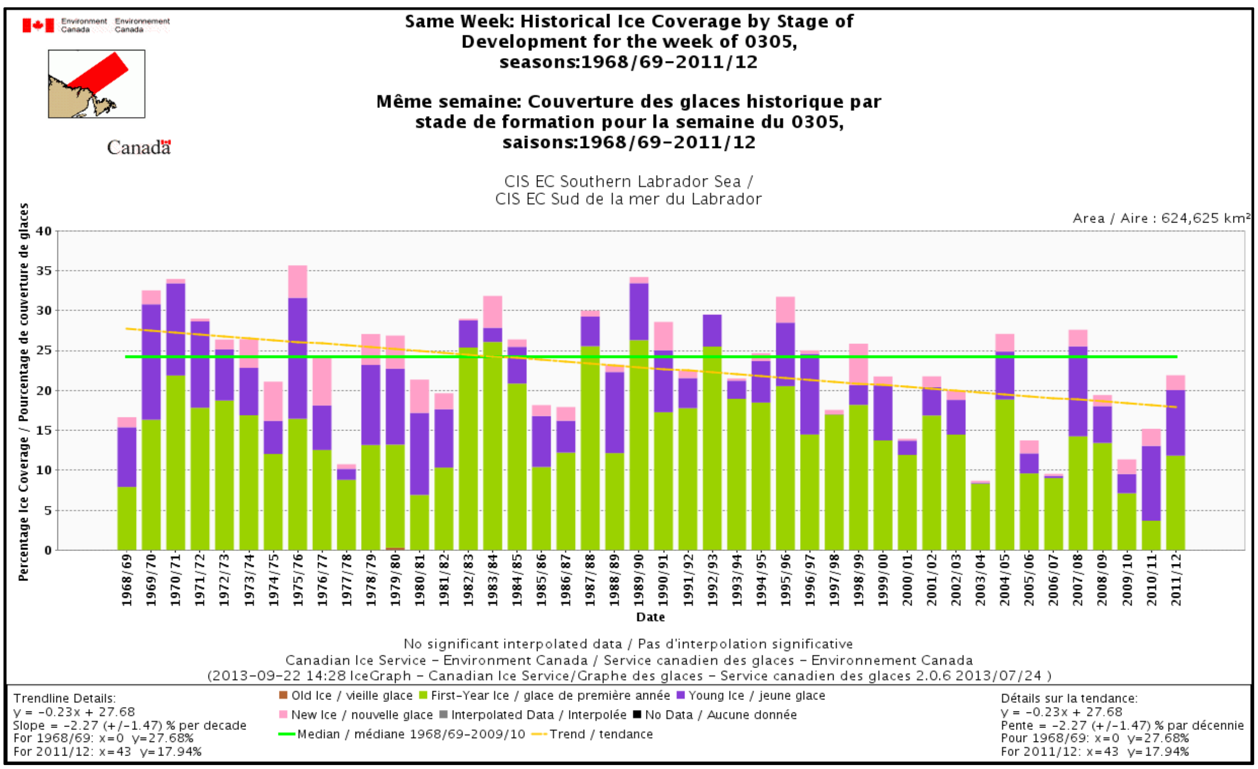


Figure 1. Changes in ice cover during the first week of March between 1969 and 2012 in the Gulf (top) and at the Front (bottom).

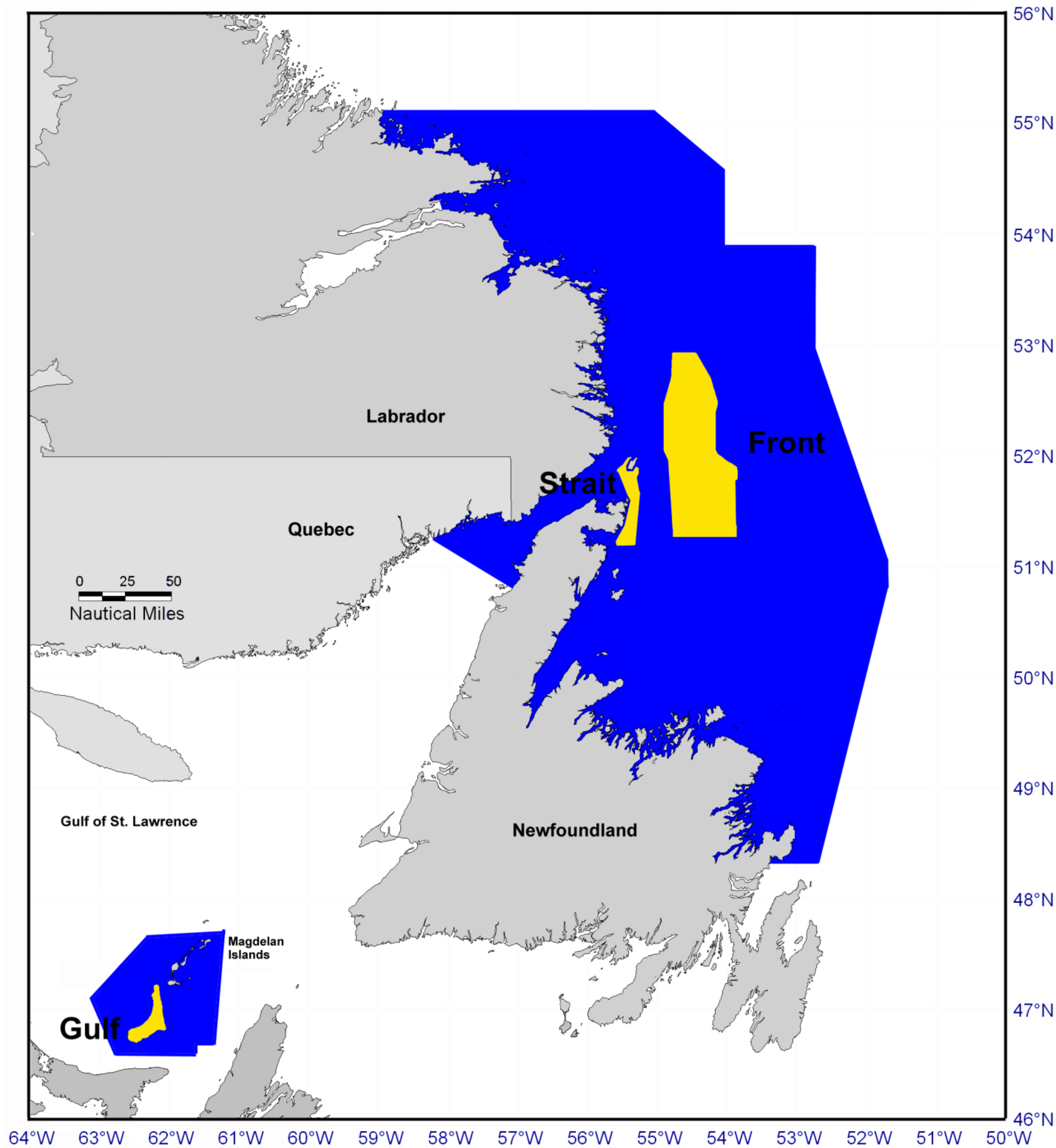


Figure 2. Ice areas examined during fixed wing reconnaissance flights (blue) during the 2012 harp seal survey. Whelping concentrations shown in yellow.

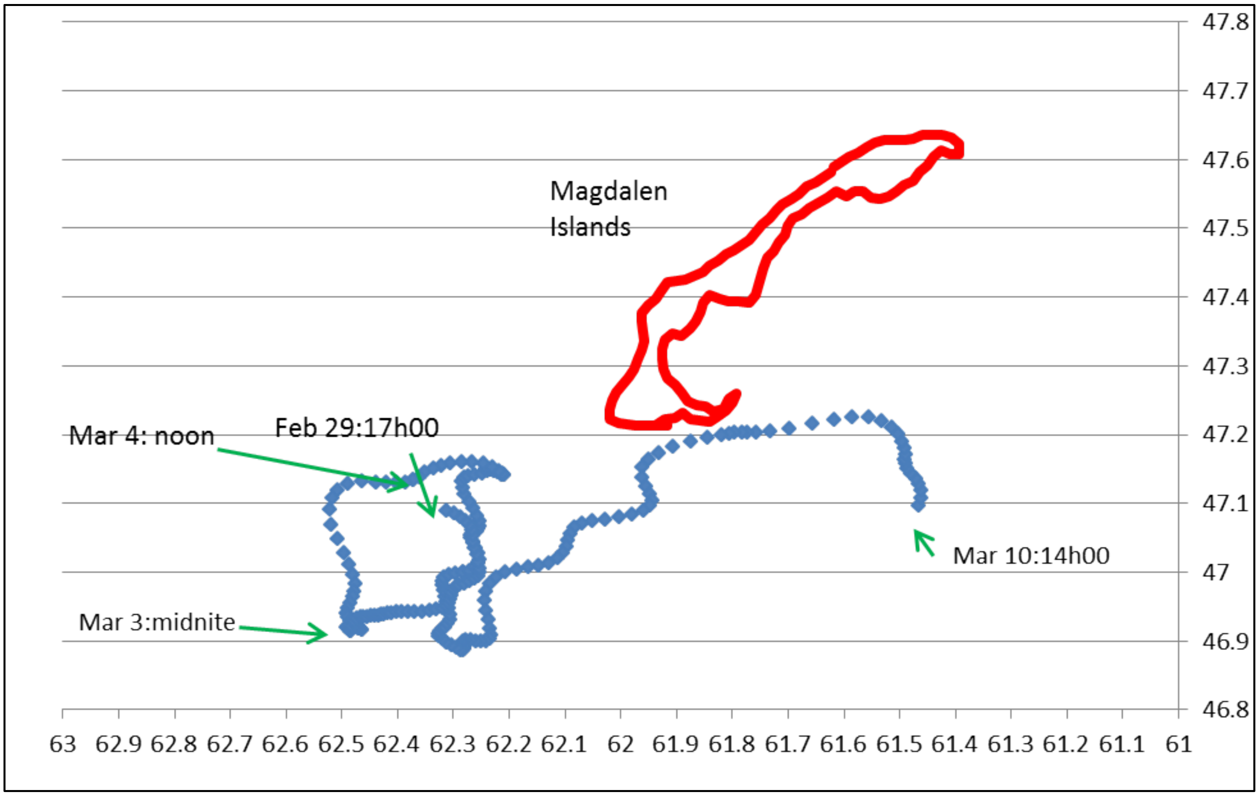


Figure 3. Hourly drift of satellite linked beacon deployed on ice at 17h00 29 February and retrieved on 10 March at 14h00. Each point represents an hourly position.

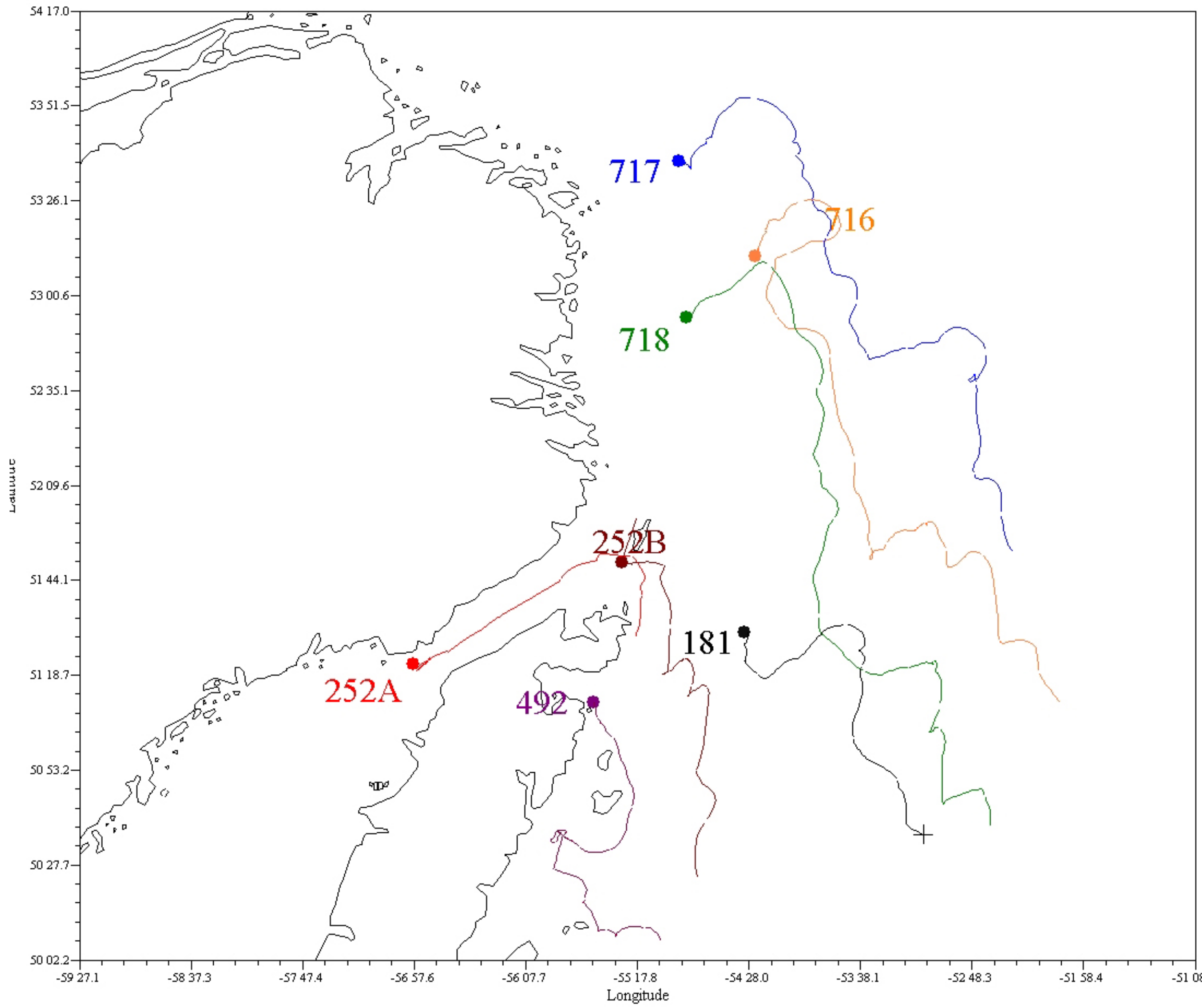


Figure 4. Movement of satellite linked GPS transmitters to monitor ice movement at the Front during the 2012 harp seal survey. Transmitters 252 (A&B) and 492 were placed in the Straits patch while the others were located in the Front patch.

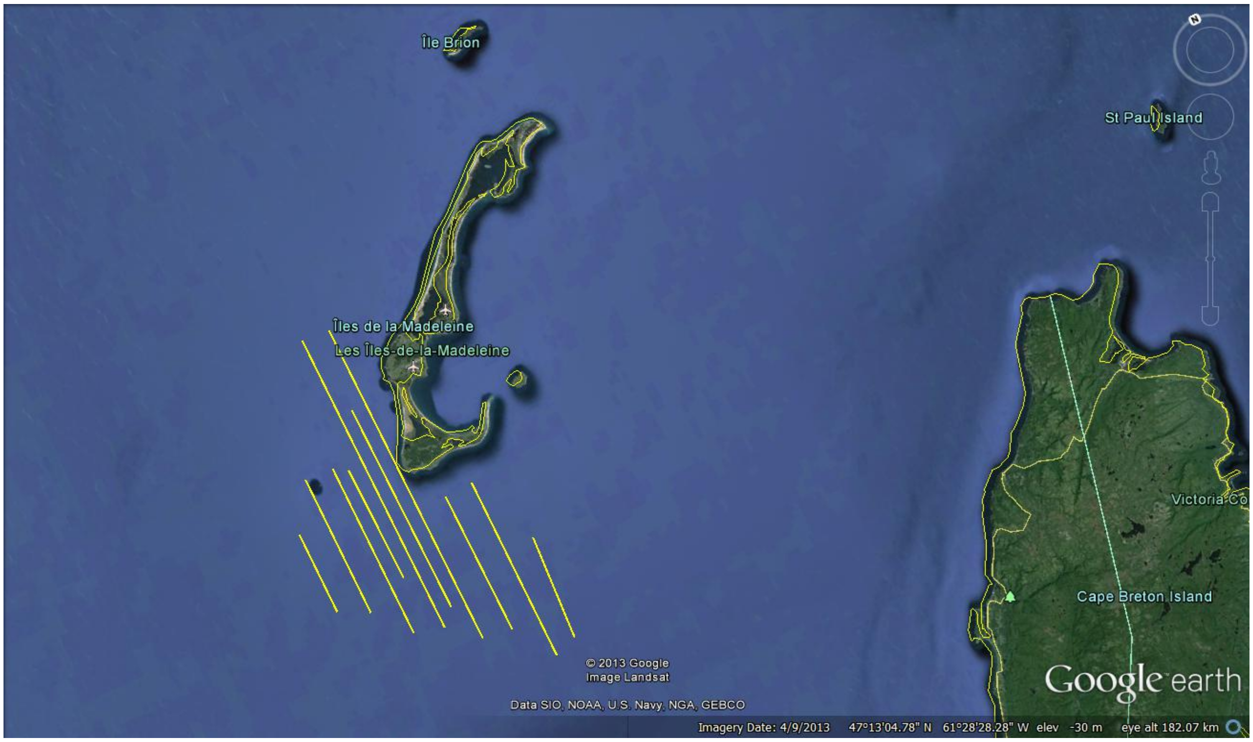


Figure. 5 Location of visual survey transects flown to determine harp seal pup production in the southern Gulf of St. Lawrence 27 February 2012.

Figure 6. Location of visual survey transects flown to determine harp seal pup production in the southern Gulf of St. Lawrence, 1 March 2012.

Figure 7. Location of visual survey transects flown to determine harp seal pup production in the southern Gulf of St. Lawrence, 2 March 2012.

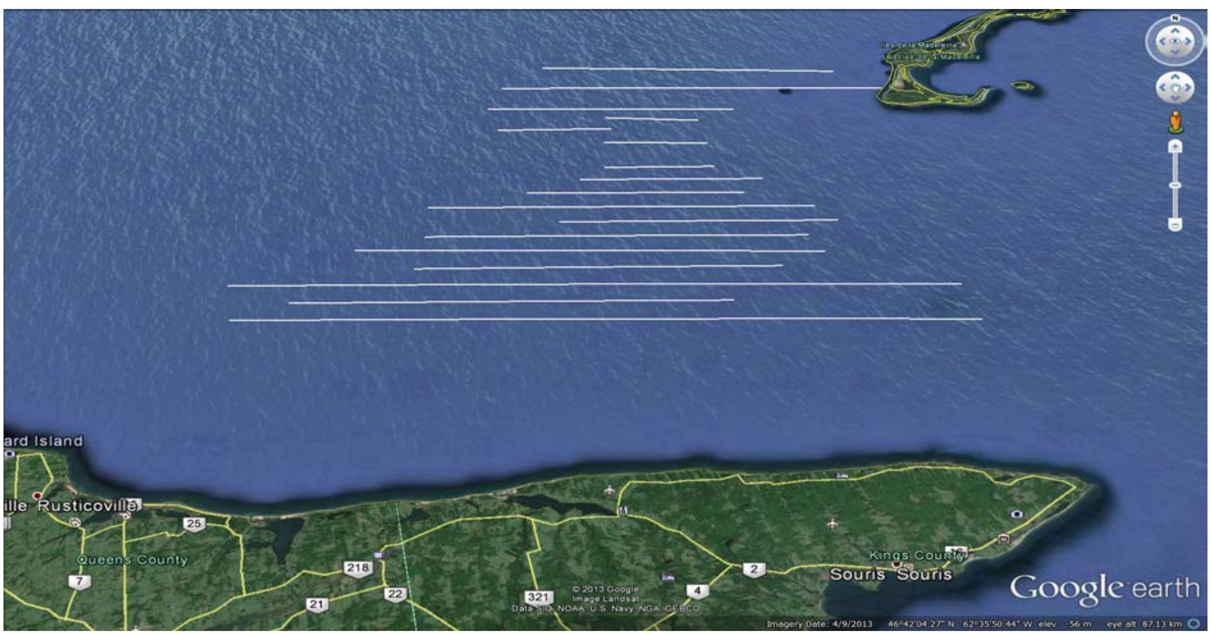


Figure 8. Location of photographic survey transects flown on 2 March 2012 to determine harp seal pup production in the southern Gulf of St. Lawrence.

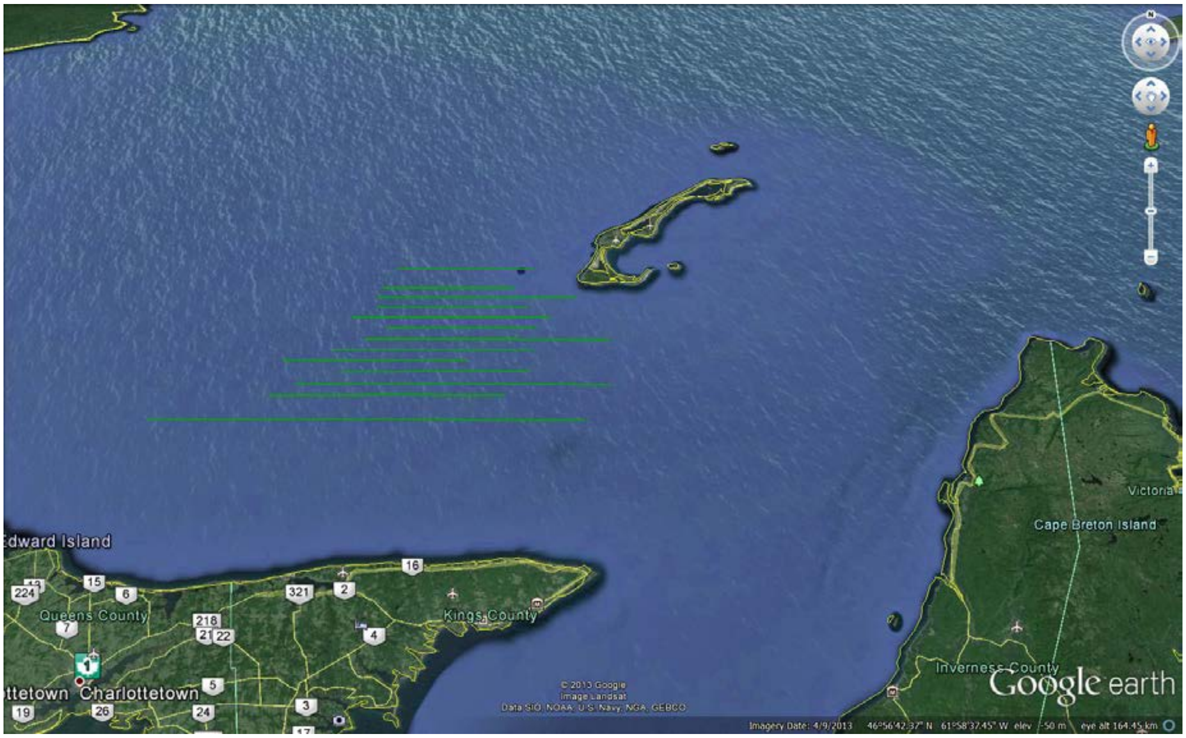


Figure 9. Location of photographic survey transects flown on 4 March 2012 to determine harp seal pup production in the southern Gulf of St. Lawrence.

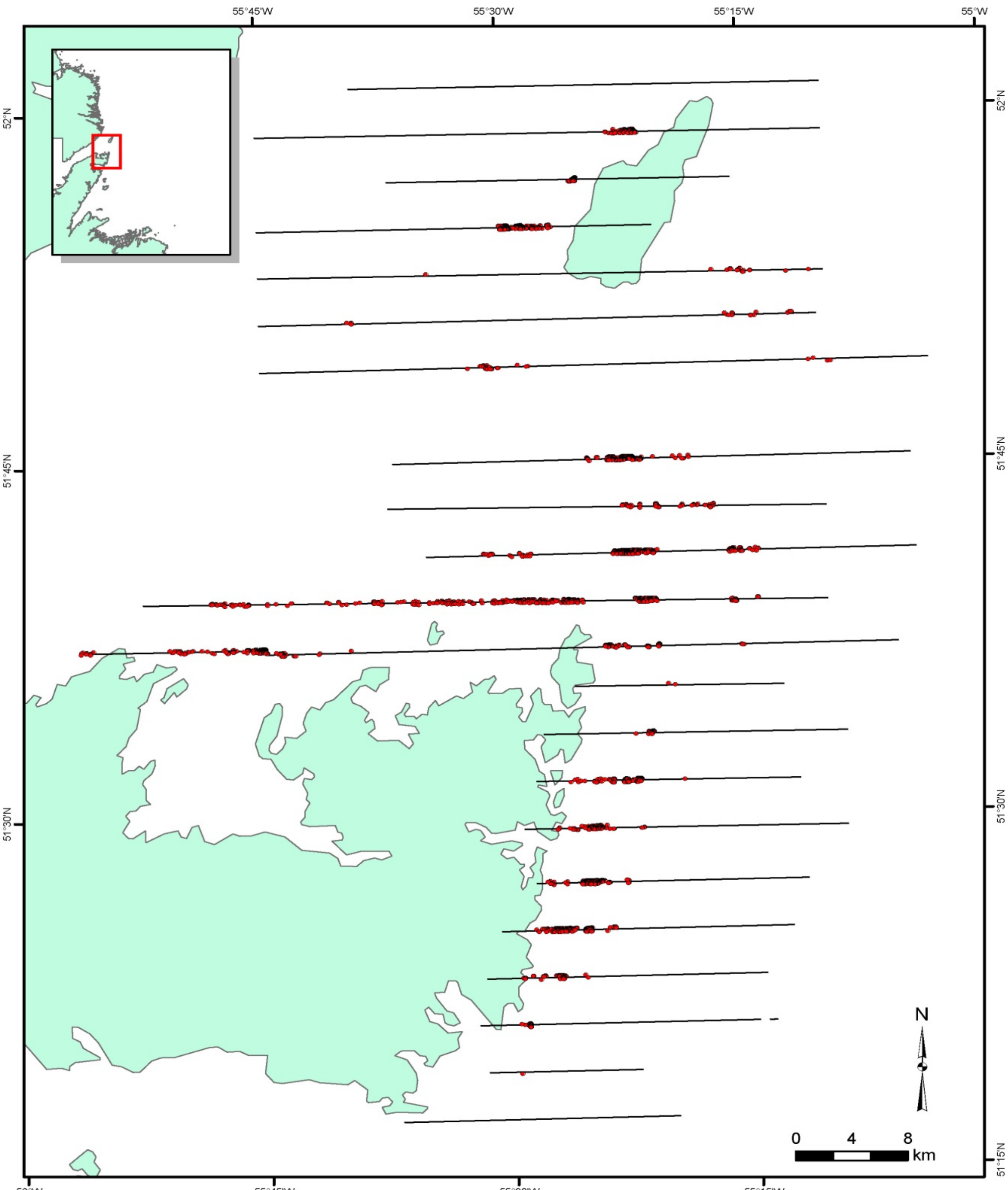


Figure 10. Photographic transect lines, and seals identified, during surveys flown in the 'Straits' patch 10 March, 2012.

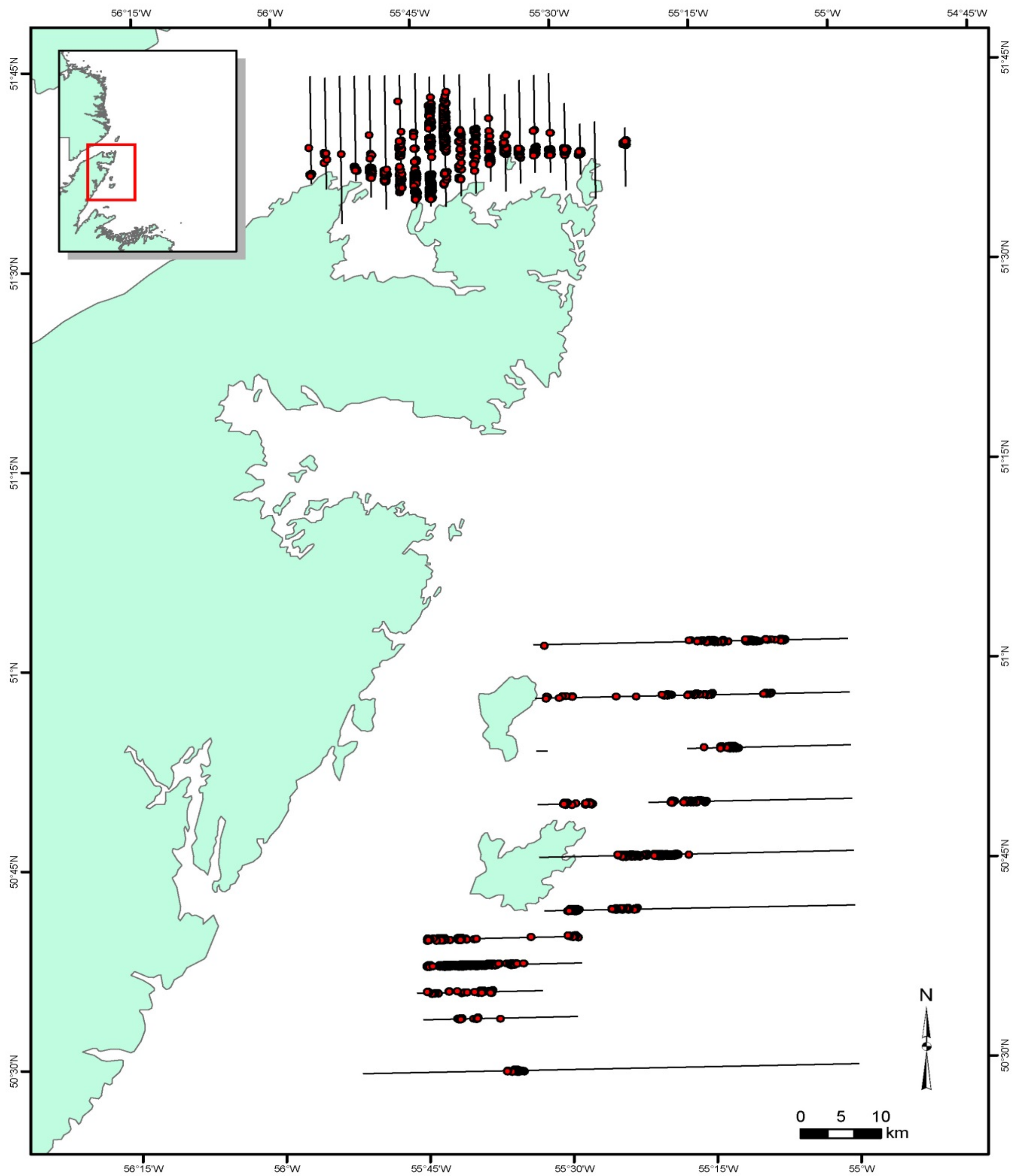


Figure 11. Photographic transect lines, and seals identified, during surveys flown in the Pistolet Bay and Grey Islands areas of the 'Straits' patch 15 March, 2012.

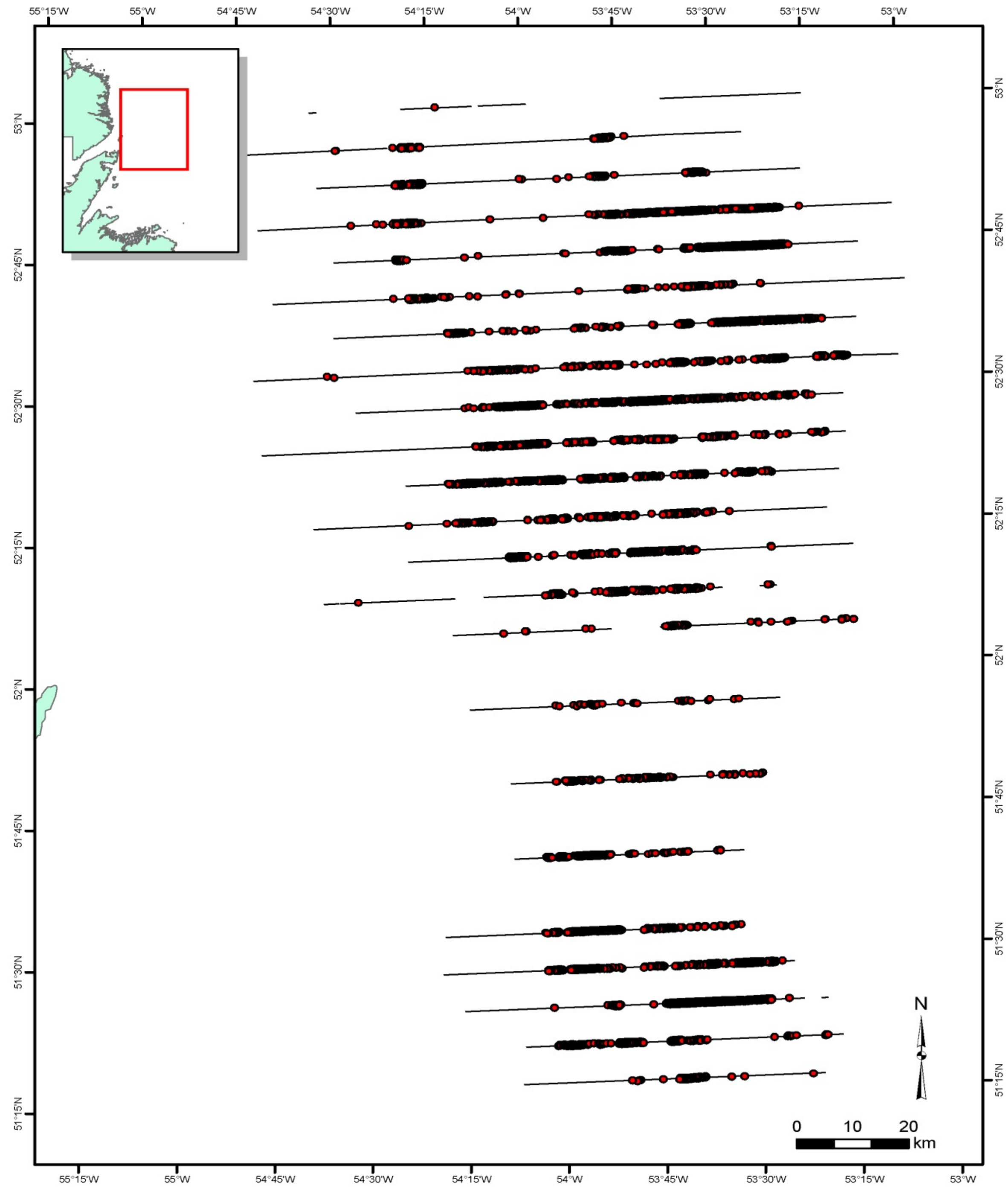


Figure 12. Photographic transect lines, and seals identified, during surveys flown in the 'Front' patch 14 March, 2012.

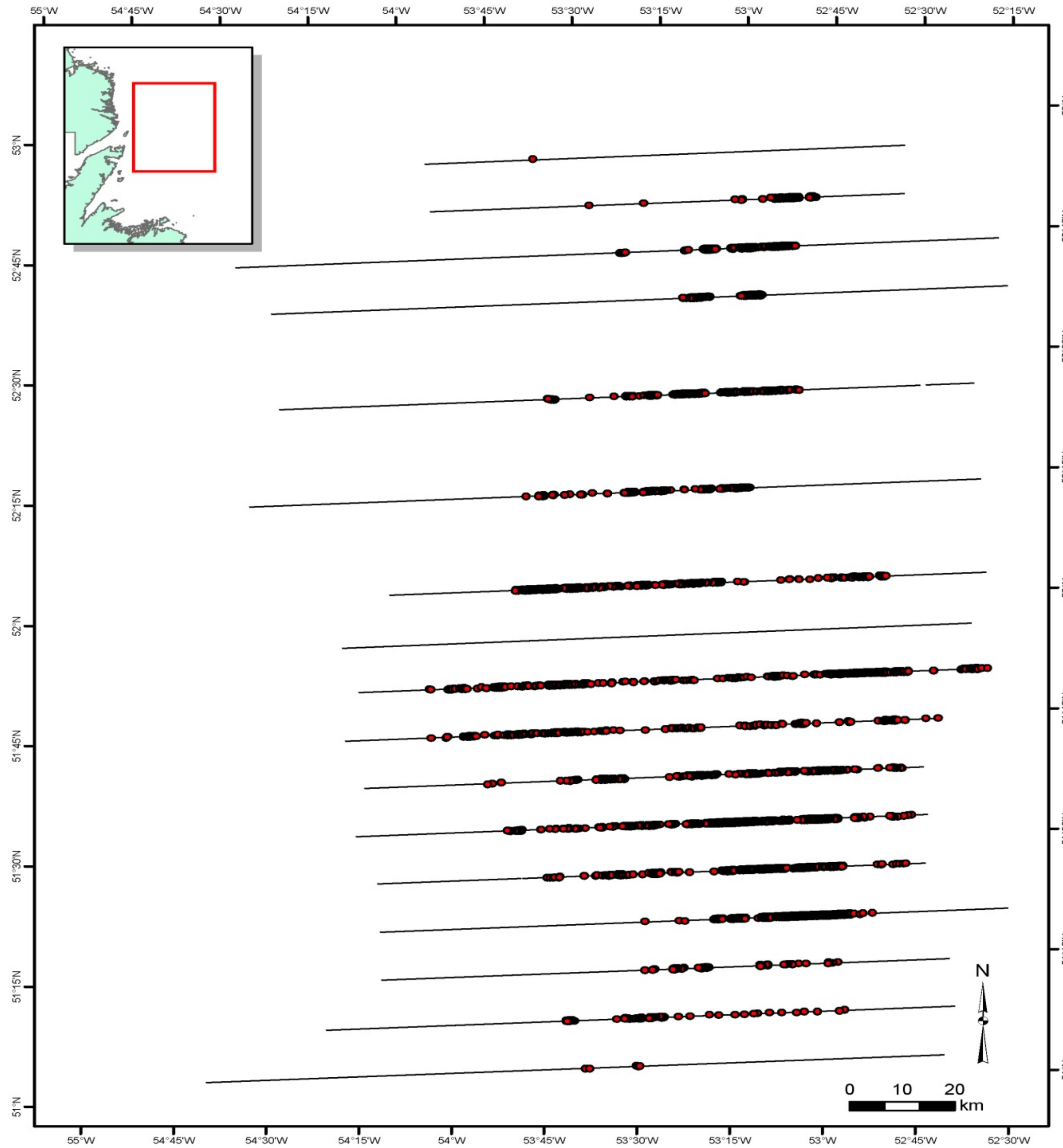


Figure 13. Photographic transect lines, and seals identified, during surveys flown in the 'Front' patch 16 March, 2012.

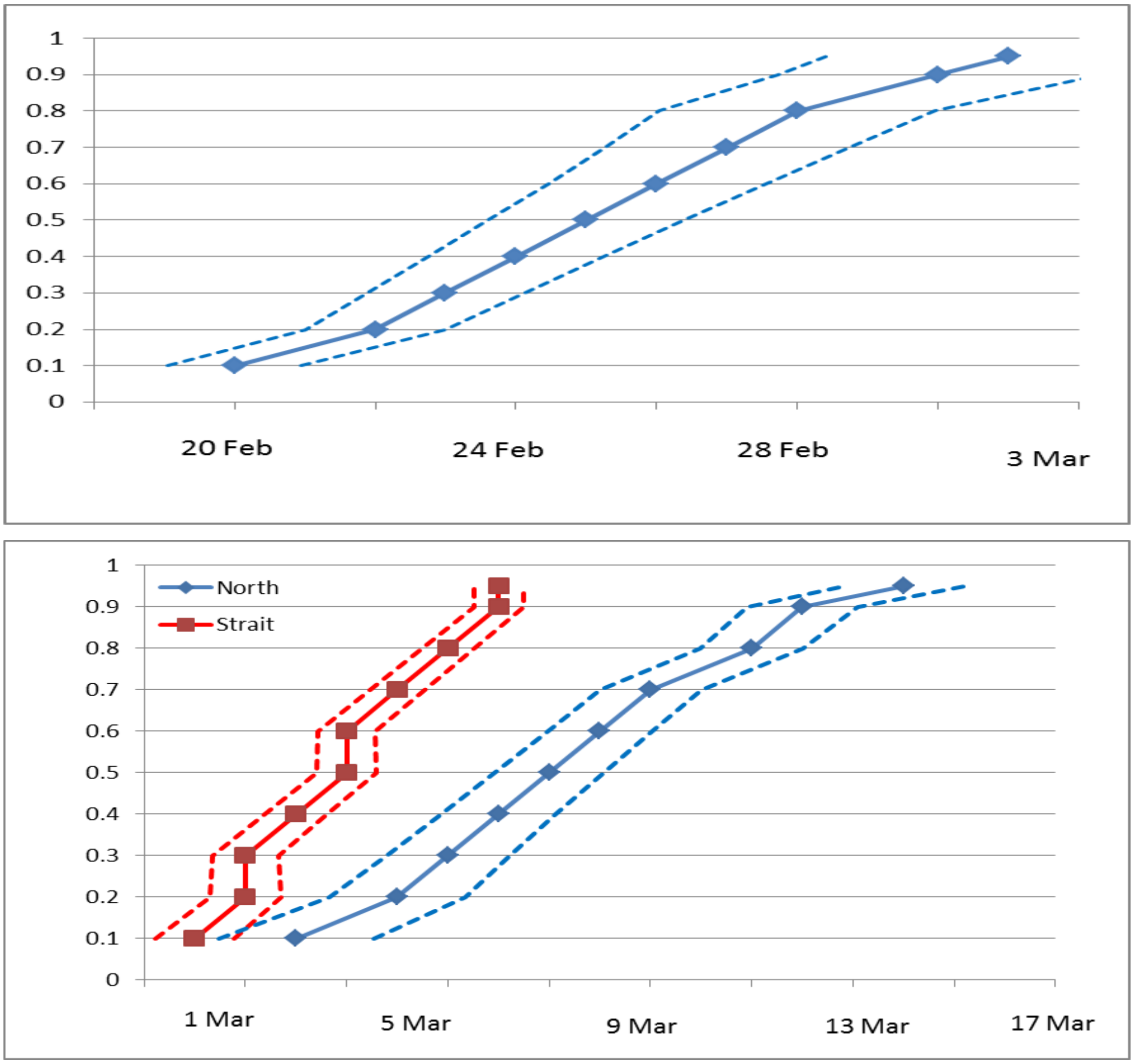


Figure 14. Proportion of pups born (Y-axis) with day (±SE) in the southern Gulf (top), and the at the Front in the North (diamond) and Strait (squares) patches during February-March 2012

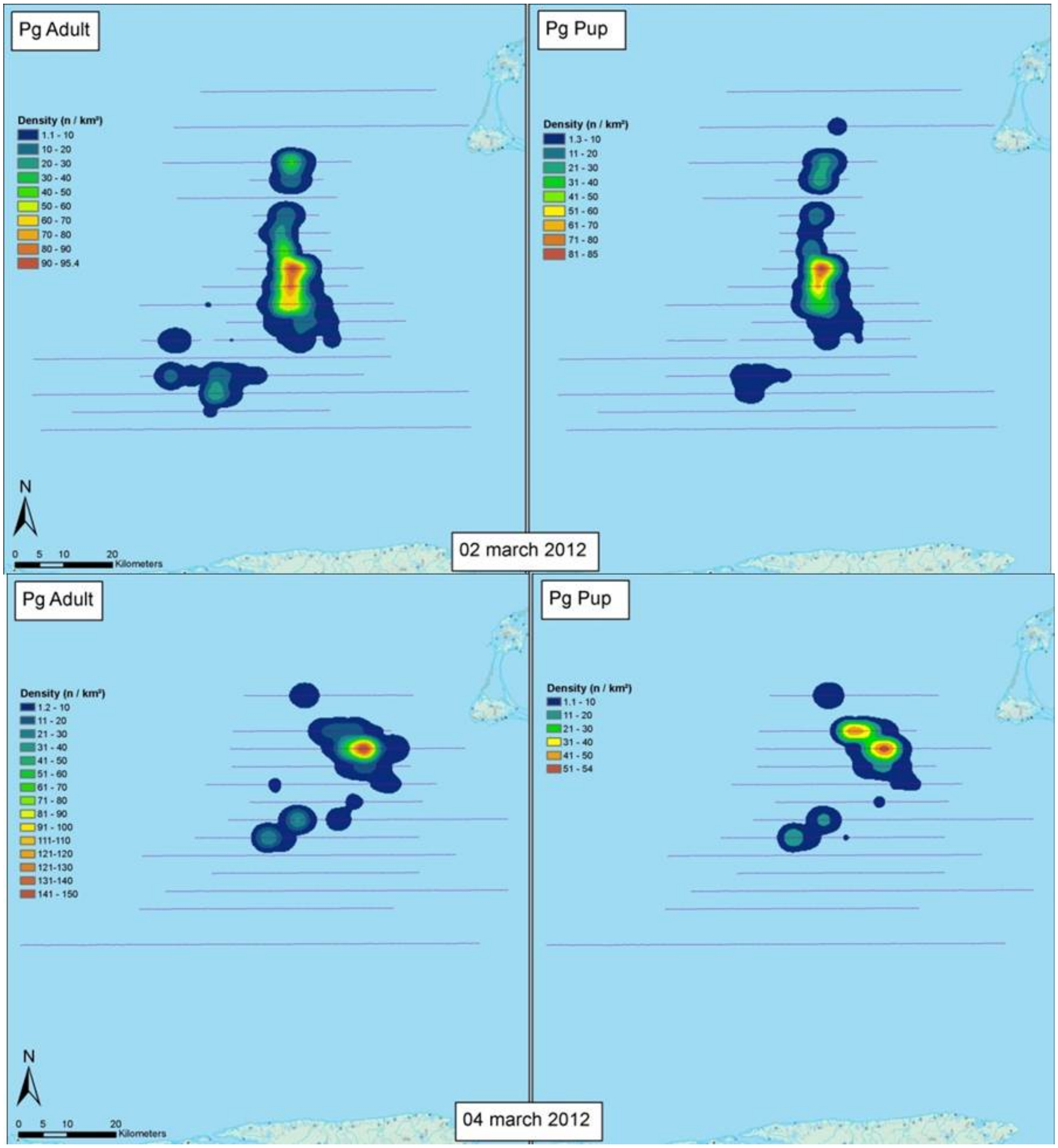


Figure 15. Distribution of seals on photographic surveys flown 2 (top) and 4 March (bottom) 2013.

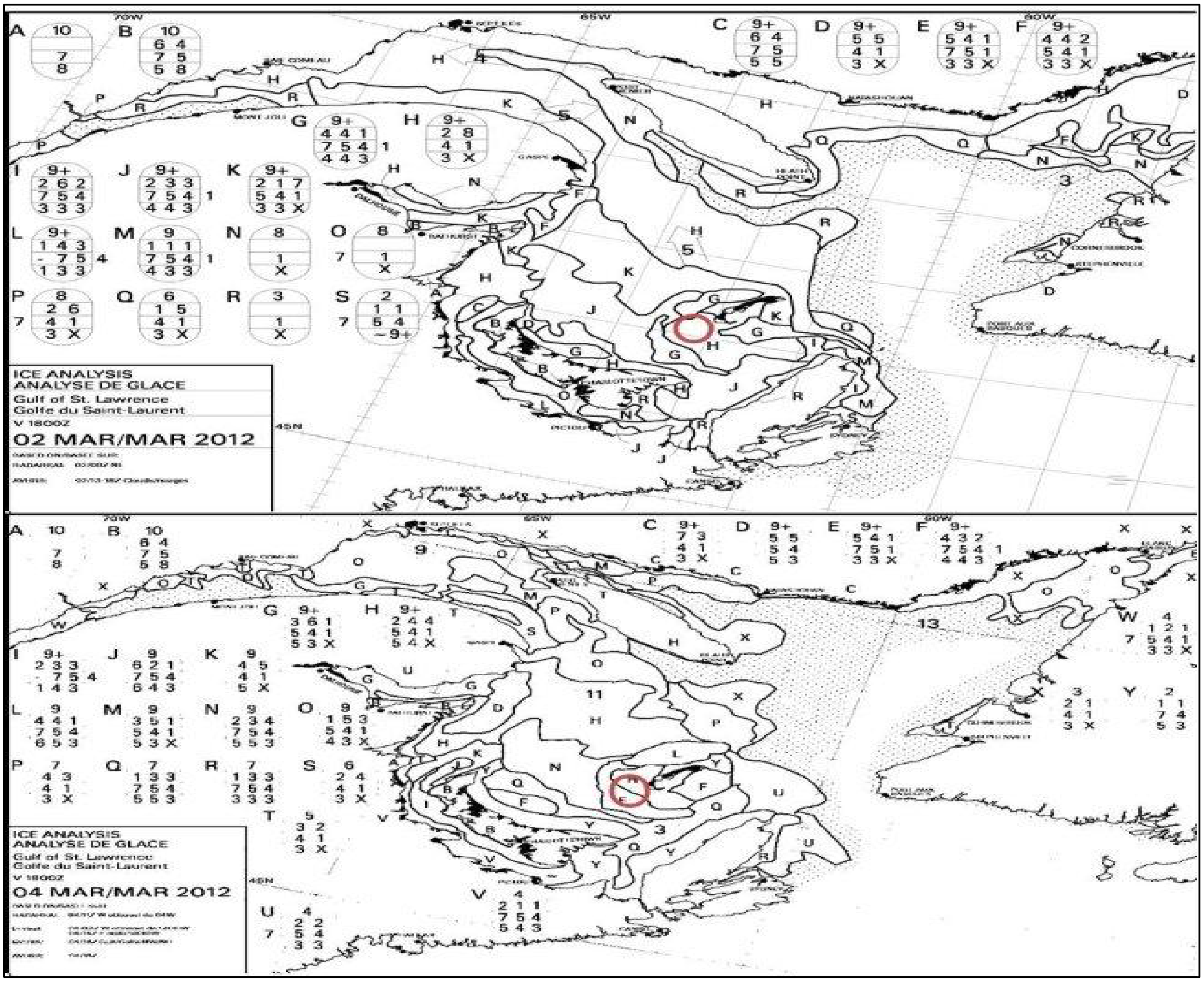


Figure 16. Ice chart for the Gulf of St Lawrence on 2 (top) and 4 (bottom) March. The herd was located to the southwest of the Magdalen Island (circle), primarily in zone H which is thin ice. The egg scale has total ice cover (% x10) in the top row, the % cover of each ice type (x10) in the second row, the type of ice in the third row, and size of ice flow in the bottom row. Ice types 7, 5, 4 and 1 represent thin first-year (30-70 cm thick), grey-white (15-30 cm thick) , grey ice (10-15 cm thick) and new ice (<10 cm thick). For floe size 4,3 and X represent medium floes (100-500 m across), small floes (20-100 m across) and ice of unknown or no form respectively (from [Environment Canada, Weather and Meteorology.)](#)