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Estimating Pup Production of Northwest Atlantic Harp Seals, *Pagophilus groenlandicus,* in 2017

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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 Gulf of St. Lawrence during March 2017 to determine pup production of Northwest Atlantic Harp Seals. After extensive reconnaissance, four whelping areas were identified in the southern Gulf, northern Gulf and at the Front ('Groais Island' and 'Strait'). Surveys were carried out between March 6 and18. Very few pups were born in the southern Gulf and no whelping concentrations were observed prior to March 5 which is approximately a week later than usual. Averaging the results of three surveys (two visual, one photographic) of the area, and correcting for pups that were born after the survey, provided an estimated pup production of 18,300 (SE=1,500, rounded to the nearest hundred). This is far lower than the 2012 survey estimate for the same area of 115,500 (SE=15,100). Pup production in the northern Gulf was also lower than in previous years at 13,600 (SE=3,000). A total of 714,600 (SE=89,700) pups were estimated to have been born at the Front; accounting for 96% of all pupping in 2017. Combining the number of pups found in all four areas resulted in an estimated total pup production of 746,500 (SE=89,900, CV=12%) which is the lowest since 1994. The timing of births in the southern Gulf of St. Lawrence was much later than normal in 2017 while unusually early pupping at the Front suggests that some females from the Gulf herd may have moved to the Front to whelp due to the lack of ice suitable for pupping in the Gulf. Although one large concentration formed as usual, approximately 15% of the pupping at the Front occurred in small, dispersed groups later than seen in previous years. Given the unusual ice conditions, distribution of whelping seals, and timing of pupping, assessing the results of the 2017 surveys relative to other estimates of pup production in the Northwest Atlantic is challenging.

Key words: Harp Seal, *Pagophilus groenlandicus*, pup production, survey, abundance, timing of births, Northwest Atlantic.

INTRODUCTION

Harp Seals are the most abundant marine mammal in the North Atlantic. Three populations are recognized based upon their whelping (pupping) location; the White Sea/Barents Sea population, the Greenland Sea population and the Northwest Atlantic (NWA) population. As a predator with a wide range of prey, Harp Seals have an important role in stabilizing their ecosystem and influencing the population dynamics of their prey. Harp Seals are also hunted throughout their range. In order to understand the ecological role of Harp Seals and to provide management advice for both harvest and Ecosystem Based Fisheries Management (EBFM), it is important to have accurate estimates of abundance and population trends for this species.

Unfortunately, the entire population of Harp Seals is not present at any one place or time. Therefore, direct surveys of the population are not possible. However, 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. Females begin pupping in late February in the Gulf, and in early March in the northern Gulf and at the Front (Sergeant 1991, Stenson et al. 1993, 2002, 2003). During this period, pups remain on the ice and are visible for a period during which they can be surveyed and estimates of pup production obtained. By incorporating these estimates along with information on removals, ice-related mortality and annual age-specific reproductive rates into a population model, the total abundance of NWA Harp Seals can be estimated (e.g., Hammill and Stenson 2011, Hammill et al. 2015). Data on reproductive rates, removals from the population and ice conditions are collected annually, while surveys to estimate pup production are completed every four to five years.

Annual pup production was estimated using a variety of methods prior to 1990, including variations on a sequential population analysis approach, mark-recapture tagging, 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 four to five year intervals. In 1990 pup production was estimated to have risen to 578,000 (SE=39,000) (Stenson et al. 1993). By 1999 it had increased to 997,900 (SE=102,100) (Stenson et al. 2002, 2003). Since then pup production has varied considerably from 1.6 million (SE=110,000) in 2008 to 815,900 (69,500) in 2012. It should be noted that this latter estimate has been revised from the 791,000 (SE=69,700) reported previously due to additional analysis of survey transects that had not been completed at the time of the 2013 assessment (Stenson et al. 2005, 2011, 2014, unpublished data). Much of the variability in pup production observed in the 21st century is due to the extremely high interannual variability observed in the seals' fecundity rates (Stenson et al. 2016).

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. Whelping (pupping) normally occurs on ice pans that are extensive enough to dampen wave action and thick enough to resist destruction from storm activity, while still allowing adults access to water (Bajzak et al. 2011). Harp Seals are social animals and form concentrations (often referred to as 'patches') to pup. The aerial survey methodology used since 1990 begins with reconnaissance of all suitable ice to locate the concentrations and the deployment of beacons to monitor ice movement. Multiple surveys are carried out throughout the nursing period to determine the temporal distribution of births, and to count the number of pups born using photographic and/or visual survey methods.

The last estimate of NWA Harp Seal pup production was based upon surveys carried out in 2012 (Stenson et al. 2014). The objective of this study is to estimate the number of Harp Seal

pups born in the Gulf of St. Lawrence and off the northeast coast of Newfoundland in 2017 using the same survey approach used previously.

METHODS

IDENTIFICATION OF WHELPING AREAS

Whelping concentrations were located using fixed-wing and helicopter reconnaissance flights over suitable ice in areas historically used by Harp Seals (Figure 1). At the Front and in the northern Gulf of St. Lawrence, fixed-wing reconnaissance flights were conducted almost daily (weather permitting) from March 6–18. 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 49˚30’N and 55˚00'N at the Front and between the Strait of Belle Isle (~51˚50'N) and the southern edge of the ice at approximately 49˚45’N in the northern Gulf.

In the southern Gulf, reconnaissance surveys of areas traditionally used by Harp Seals were flown from February 28 to March 10. Because of the small amount of ice present in the traditional areas around the Magdalen Islands, fixed wing flights were carried out throughout the southern Gulf from Cape Breton to the Baie des Chaleur, and northward to the Laurentian Channel and Anticosti Island. Information on the location of whelping seals was also gathered during helicopter reconnaissance flights and fixed-wing overflights conducted by Fisheries and Oceans Canada (DFO) Conservation and Protection Branch.

All areas were searched repeatedly to minimize the chance of missing whelping concentrations. Once located, 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 Bell 429 helicopters at both the Front (2) and in the Gulf of St. Lawrence (1), flying at an altitude of 61 m. Two observers seated in the rear of each of these helicopters counted all pups within a pre-measured 30 m strip on each side of the aircraft (i.e., total strip width=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 dedicated 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 carried out in the Gulf on March 6 and 7, while surveys at the Front took place on March 14 and 18. Additional surveys were carried out on March 10, 13, and 22 but these did not cover all of the seals in the area and so are not considered further.

Photographic Surveys

As in the 2012 Harp Seal survey (Stenson et al. 2014), the 2017 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 hydraulically-actuated motion compensation frames designed to minimize the effects of aircraft pitch, roll, and yaw. The two digital cameras employed in 2017 had slightly different CCD sensor pixel-size spacing; 7.2 µm per pixel versus 9.0 µm per pixel in 2012. 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 in each image.

All surveys were flown at an airspeed of 110 knots and at an altitude of 330 m. At this height, both cameras yielded image footprints on the ice of approximately 215 m along the flight line and 325 m across the flight line. The exact size of the area covered was estimated from each georeferenced image file to ensure accuracy. The digital cameras had a resolution of approximately 2.4 cm for objects on the ground when flown at 330 m. We reviewed multiple non-processed images following each flight day to ascertain how well the imagery system was working throughout the day and to adjust camera settings as needed on subsequent surveys.

Sequential frames were shot along transect lines. The surveys were designed to collect imagery with no overlap along a transect. However, in the southern Gulf, overlap occurred. If so, seals were only counted in the overlap area on one frame to ensure that no pups were counted twice. Coverage along a line was generally >90%, with the exception of the southern Gulf where overlap occurred and therefore coverage was 100%, and the northern Gulf where coverage along a line varied between 75 and 93% (average 78%). Transect lines were spaced at 1.85 to 7.4 km (1–4 nmi) apart depending on the configuration of the seal patch. 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 designed based upon reconnaissance flights and estimated ice drift. The limits of the survey area were modified during the photographic surveys based upon ice conditions and the locations of seals. Cameras were turned on before seals were encountered on a transect line and turned off if no seals were observed for an extended period (>15 km) along a transect line or open water was encountered. Most transects ended when ice suitable for pupping was no longer available.

The southern 'Gulf' Harp Seal herd was photographed on March 7. Transects were oriented in a north-south direction.

Photographic surveys of the 'Front' concentrations ('Groais Island' and 'Strait') were carried out on March 14 and 18 while the Northern Gulf concentration was surveyed on March 17. Another photographic survey was carried out on March 19 with the intention to obtain a second photographic estimate of the Groais Island concentration, but due to uneven ice drift, part of the concentration was missed and the survey result was not used. All photographic transects were oriented in an east-west direction.

A total of 26,781 photos were taken. However, only 14,926 were used in the analysis, 2,233 from the southern Gulf of St. Lawrence and 12,693 frames from the northern Gulf and Front. The additional frames were taken during the incomplete survey on March 19 or along transects that overlapped with other surveys and therefore were not used to ensure that areas were not counted twice.

Correction for Reader Errors

The imagery was geo-referenced using the qGIS software. 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 readers, one reader read all of the images from the southern Gulf surveys while four were involved in the reading of images from 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 'best estimate' was modelled as:

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

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 a zero intercept. Since readers were restricted to different surveys, the photo counts for each survey were corrected using the appropriate estimate for the individual reader who read that survey.

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

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:

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

Where σ^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:

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

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*,
- $W_i = S_i / w_i$, where W_i is a weighting factor for the ith patch, 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, 2014). The number of pups (N_i) for the ith survey was estimated by:

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

where x_j is the total number of pups on the jth transect.

For photographic surveys where frames did not overlap:

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

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:

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

where:

- J_i = the number of transects in the ith group,
- X_{ij} = the number of pups counted on the jth transect in the ith group,
- 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):

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

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

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

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 averaged (inversely weighted by their variance) using:

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

and its error variance:

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

Temporal Distribution of Births

The temporal distribution of births during the pupping season was estimated in order 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, 2011, 2014). 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 days, SD=0.49 days, *n*=106), Thin Whitecoats (μ=4.42 days, SD =0.70 days, *n*=26), Fat Whitecoats (μ=11.39 days, SD=1.22 days, *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:

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

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):

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

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, was extremely low in the southern Gulf of St. Lawrence during February and March 2017 (Figure 2). Ice cover in 2017 was one of the lowest since records began in 1969. Although reconnaissance flights began on February 28, only occasional single seals were seen before March 5 when a concentration was located north of Prince Edward Island (Figure 1). During the nursing period, the ice drifted eastward towards Cape Breton Island and then northward and out the Cabot Strait. The initial drift was to the south and west (Figure 3).

Total ice at the Front was also below the long-term average (Figure 2). It was similar to that observed during the 2012 survey but below that seen during the period in-between. A concentration of nursing females was first observed on March 6 off northeast Newfoundland near the Groais Islands at approximately 51˚00'N 55˚00'W (Figure 1). Over the next week, this concentration grew into a large concentration of Harp Seals that spread outward to the east as the ice drifted and opened. A number of smaller concentrations (collectively referred to as the 'Strait') were also identified to the north of the large, Groais Island patch, originally to the east of the Strait of Belle Isle. Each of these patches were small and separated by the occasional scattered seal. Movement of each of the concentrations was monitored through the use of satellite linked GPS transmitters (Figure 3).

Reconnaissance to the north of these concentrations continued until March 18. No additional pupping concentrations were found.

A small concentration of seals was located in the northern Gulf of St. Lawrence on March 6 off the coast of Daniel's Harbour at approximately 50˚20'N 58˚15'W (Figure 3). Strong southerly winds forced the ice the seals were on northward and then it drifted southward ending up very close to where it started three weeks earlier. However, this ice broke up and became quite dispersed.

PUP PRODUCTION SURVEYS

Reader Corrections

Correction factors for photographic surveys were developed for all readers. The regressions of the 'best counts' on the individual reader counts were significant and all regressions passed through zero. The fit to the regressions was quite good with corrections ranged from approximately 1–8%. (Table 1). There was very little difference between the counts of the five readers for all of the images examined.

Survey Estimates

Southern Gulf

In the southern Gulf, the herd was delimited and visual surveys were flown on March 6 and 7. A total of 915 pups were counted on the 20 east-west transects flown on 6 March (Table 2, Figure 4), resulting in an estimated total number of pups present on the ice of 17,216 (SE=3,685; CV=21%). A second survey, consisting of 13 east-west transects, was flown on March 7 (Table 3, Figure 4). A total of 1,215 seals were recorded and total pup production was estimated to be 19,292 (SE=2,201; CV=11%).

A photographic survey was also flown on March 7. There was overlap among the photos therefore images were trimmed so that duplicate seals were not counted. A total of 27 north-south transects were completed, with 3,187 pups detected on 2,233 images, resulting in an estimated pup production of 16,768 (SE=2,322, CV=14%) (Table 4, Figure 4).

Averaging all three estimates, without correcting for the temporal distribution of births, resulted in an estimated pup production in the southern Gulf of St. Lawrence of 17,958 (SE=1,466; CV=8.2%).

Northern Gulf

The whelping concentration that was identified in the northern Gulf of St. Lawrence was surveyed photographically on March 17 (Figure 5). The survey consisted of 12 east–west transects spaced at 3.7 km apart (Table 5). The southern transects covered areas of open

water. A total of 768 pups were identified on 2,305 photographs, resulting in an estimated pup production of 13,597 (SE=2,953, CV=22%). Due to high winds and shifting ice, it was not possible to survey this patch a second time, neither visually nor photographically.

Groais Islands

Both visual and photographic surveys of the largest concentration off the northeast coast of Newfoundland were carried out on March 14 (Figure 5). The visual survey consisted of 17 east-west transects carried out by two helicopters and separated into two sections with transect spacing of 5.56 km and one section with lines spaced 2.77 km in between (Table 6). A total of 10,224 pups were counted with an estimate of total pup production of 554,505 (SE=95,219; CV=17%). The photographic survey on the March 14 was split into two segments. The first covered the area that had been surveyed visually. This survey was comprised of eight east-west transects spaced 7.4 km apart with a total of 25,713 pups counted on 4,083 photos (Table 7). The pups were clustered throughout the area and total pup production was estimated to be 586,170 (SE=193,252; CV=33%). Averaging the two surveys resulted in an estimate of pup production on the day of the survey of 560,691 (SE=85,414; CV=15%).

A small section of ice containing Harp Seal pups was surveyed photographically only. This section was east of a large body of open water and could not be reached by the helicopters. Pup production in this group was estimated to be 50,373 (SE=22,477, CV=45%) based upon three transects spaced 7.4 km apart (Table 8). Adding this amount to the average of the two surveys of the rest of the concentration results in an estimated pup production for the entire concentration of 611,064 (SE=88,322; CV=14%).

Strait

A number of small, scattered patches formed up north of the large concentration. While visual surveys of individual patches were carried out, not all were covered and the estimates could not be combined for a visual estimate of the full area. However, a large-scale photographic survey carried out on March 18 covered the area. This survey consisted of 19 transects with spacing of either 7.4 or 3.7 km (Table 9). A total of 6,898 pups were counted on 6,405 photos resulting in an estimated pup production of 101,484 (SE=15,630; CV=15%) Harp Seals. This photographic survey missed one of the small patches that was surveyed visually on the same day. This survey consisted of 13 east-west transects spaced 926 m apart during which 133 pups were counted (Table 10), resulting in an estimated pup production of 2,053 (SE=253; CV=12%). Combining the photographic and visual estimates resulted in a total estimated pup production in the ‘Strait’ area of 103,536 (SE=15,632; CV=15%).

MODELLING THE TEMPORAL DISTRIBUTION OF BIRTHS

Estimates of the proportion of pups in each of the developmental stages were obtained from all four whelping areas (Table 11). Staging surveys were carried out over the entire pupping and nursing period.

Pupping in the southern Gulf of St. Lawrence began later than in 2012 (Figure 6). In contrast, it began earlier in the Groais Island patch than in 2012, and at the same time as the southern Gulf but continued later than the Gulf, ending at the same time as in the 2012 survey. Pupping in the northern Gulf in 2017 was similar in timing to that seen at the Front and Belle Isle in 2012. In 2017, the Strait concentration appeared to form later than the other areas.

The estimated proportion of pups that were born at the time of the March 6 survey in the southern Gulf was 0.9632 (SE=0.0147) (Table 12). This increased to 0.9846 (SE=0.0071) by the next day when the photographic and second visual surveys were carried out. Although it is

small, we did apply a correction for the estimate of pups born after the survey date to all three of these surveys.

The estimated proportion of pups born on the day of the survey was ≥0.999 for all three surveys off Newfoundland (Table 12). Therefore, no correction for the temporal distribution of births was applied.

ESTIMATING TOTAL 2017 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 17,873 (SE=3,835) and 19,593 (SE=2,240) pups and a photographic estimate of 17,029 (SE=2,362) pups (Table 13). Averaging these three surveys results in an estimate of pup production in the southern Gulf of St. Lawrence of 18,302 (SE=1,496; CV=8.2%).

No corrections for pups born after the survey were applied to the northern Gulf, Strait or Groais Island concentrations. Therefore, combining the average estimate from the southern Gulf with those of the northern Gulf (13,597; SE=2,953, CV=22%), Strait (103,536; SE=15,632; CV=15%), and Groais areas (611,064; SE=88,322; CV=14%) resulted in an estimate of total pup production (rounded to the nearest hundred) in 2017 of 746,500 (SE=89,800, CV=12%) (Table 13).

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, 2014) and so the results of the various surveys should be directly comparable. Usually, Harp Seals pup in relatively high-density ‘concentrations’ within a larger area of suitable ice (Sergeant 1991). Stenson and Hammill (2014) observed that pupping appears to occur in traditional areas even if ice conditions are poor and ice related mortality may result. The only time pupping has been observed outside of these usual locations occurred when ice was completely absent when the whelping concentration was forming up. Since missing whelping concentrations is the largest single source of error in a survey, extensive reconnaissance is carried out to detect all of the patches. Once located, we deploy satellite-linked GPS beacons to ensure that we can monitor ice movements so that all of the concentrations identified are surveyed and any duplicates are identified. This, for example, allowed us to determine that some of the smaller groups we surveyed visually on March 18 were also photographed while one group was not. Because of the wide distribution of pupping and extensive ice drift that occurred in 2017, we used a total of eighteen beacons to track the ice. Once located, we carried out ‘staging’ surveys to determine the temporal distribution of births so that the estimates of pup production can be corrected for the proportion of pups present on the ice at the time. The timing of the pup production surveys is designed to maximize the numbers of seal pups present on the ice although it must also take into account the weather, as well as the likelihood that the ice may not persist or that it will spread too extensively to be completely surveyed in a single day. As in the past, the reader’s counts of seals on the photographic images 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.

In 2017, pup production in the southern Gulf was greatly reduced relative to previous surveys. Three surveys of the area resulted in an estimated of only 18,300 (SE=1,500) pups. This is in contrast to 2012 when 115,500 (SE=15,100) pups were born, and 2008 when pup production was estimated to be 287,000 (SE=27,600) (Table 14). The proportion of total Northwest Atlantic pup production that occurred in the southern Gulf has declined since 2004, but in 2017 it went

from an average of approximately 20% of the total to 2%. The timing of births was also considerably later than observed previously.

There was very little ice, both in terms of extent and thickness, in the Gulf during 2017. This continues a trend that has been ongoing since the mid 1990s (Friedlander et al. 2010; Bajzak et al. 2011, Stenson and Hammill 2014). In 2017, only a small amount of ice was thick enough to support pupping Harp Seals. In late February, which is the traditional time for pupping to begin in the southern Gulf, a small amount of grey-white ice was present north of PEI and towards Cape Breton, while some heavier ice was present Northumberland Strait (Figure 7). Reconnaissance flights covered this entire area on February 28 and again over the following days with no indication of pupping until March 5 (cf late February previously). To determine if pupping was occurring in areas outside of the traditional southern Gulf pupping area, fixed wing reconnaissance flights examined all possible ice from the New Brunswick coast, into Baie des Chaleurs, and along the Gaspe Peninsula across to Anticosti Island. Reconnaissance flights out of Newfoundland covered the area in the northern Gulf. There was no indication of pupping outside of the small group that was surveyed.

It is possible that some females gave birth on very thin ice that broke up prior to the reconnaissance flights although where this may have occurred is not apparent. Also, some females may have moved northward towards better ice as seen at the Front in 2010 (Stenson and Hammill 2014). However, they did not pup in the northern Gulf as the number of pups born in that area was also low (13,600, SE=3,000). Also, the temporal distribution of births in the northern Gulf was similar to that seen in 2012 in both the northern Gulf and at the Front.

The presence of fat whitecoats (~1-2 weeks old) at the Front on March 7 strongly suggests that some Gulf females moved to the Front. Traditionally pupping occurs later at the Front with very little pupping prior to March 5 or 6. In 2017, however, pupping appeared to have begun approximately four or more days earlier in the Groais Island patch although it was more protracted and ended near the same date as in 2012. It appears that some early pupping, likely by southern Gulf females, created the nucleus of the whelping concentration that was joined later by Front females that pupped at their usual time, creating a second pulse of pupping. The number of pups born at the Front was higher in 2017 than in 2012 (714,800 versus 626,200) but what proportion of the southern Gulf females may have moved to the Front is unknown, particularly given the apparent higher fecundity rates observed in 2017 (Stenson et al., in prep[1]).

Sergeant (1991) reports a similar situation in 1969. That year ice in the southern Gulf was restricted to Northumberland Strait and shore ice along the north coast of PEI. Approximately 40,000 pups were born in the area compared to the 100,000 who were thought to have pupped there the previous year. However, subsequent sampling did not show any reduction in the 1969 year class in the Gulf and, although there was no way to determine, it was speculated that females had moved north to the Front to pup. The staging data from 2017 provides some evidence that this may occur.

The Strait ‘patch’ surveyed on March 18 consisted of a number of small pupping concentrations spread over a large area. None of these groups formed up into the typical large concentrations seen in previous year. The proportion of pups in the various developmental stages indicated that the timing of pupping was similar in most of these groups and so could be combined, but the overall timing of pupping among these groups was later than in other concentrations observed in either 2017 or 2012. This indicates that, for some reason, pupping occurred later

[1] Stenson, G.B., Buren, A.D., and G.L. Sheppard. In prep. Updated estimates of Reproductive Rates in Northwest Atlantic Harp Seals and the influence of body condition. DFO Can. Sci. Advis. Sec. Res. Doc.

than normal among these smaller groups and raises the possibility that some pupping may have occurred later as well. The area covered during the March 18 survey was quite large and while it is possible that we may have not found some small groups that were not found outside of this area, these are unlikely to have been very large.

All suitable ice up to Grosewater Bay was examined both early in March and again later (March 18). Harp Seal pups were found off southern Labrador during the early flights and drifted southward where they were included in the surveys. No whelping Harp Seals were observed north of the Strait group during the reconnaissance conducted on March 18. If there had been any pupping north of the traditional area, this ice would have drifted south and been examined during flights in late March. This indicates that there was no pupping north of the traditional area in 2017.

With an estimate of 746,500 (SE=89,800), pup production of Northwest Atlantic Harp Seals is lower than it has been since 1994 (Table 14). The 2012 estimate of 815,900 (SE=69,500) 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). However, the decline in 2012 and the large increase between the 2004 and 2008 surveys appears to be primarily due to much lower pregnancy rates associated with density-dependent effects and poor food availability (Stenson et al. 2016). The pregnancy rate of females eight years of age and older in 2017 is estimated to be approximately 58% which is close to the average pregnancy rate over the past decade (Stenson et al. 2020).

This lower 2017 pup production occurred in a year when the ice conditions were very poor, especially in the southern Gulf of St. Lawrence where only a very small number of pups were estimated to have been born. If pupping did occur in late February on the limited ice that was present in their traditional area, they would have to have been lost prior to the reconnaissance on February 28 or missed on these flights and lost before the next flights that did not occur until March 3 due to poor weather. It appears that some of the Gulf females moved to the Front but whether this can account for the >100,000 seals that had regularly pupped in the southern Gulf, even in years of very poor ice and high pup mortality, is not clear. Pupping at the Front was also unusual in 2017. In addition to some very early pupping, there was also some late pupping in the more northerly areas. Given the timing of the surveys at the Front, it is possible that some of the ‘early’ pups may have been weaned and left the ice prior to the survey, but given that relatively few seals had reached the ‘grey’ stage at which weaning often occurs, it is unlikely to have accounted for a significant underestimate. Also, a significant amount of the whelping was spread broadly out in a number of small groups which are difficult to survey and it is always possible that some small groups were missed. Therefore, while the above unusual conditions in 2017 add to the uncertainty in survey results, available ice condition information and the efforts to address potential biases provide an estimate of pup production of Harp Seals in the northwest Atlantic that is comparable with previous surveys.

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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. The total number of photographs read, intercept, slope and adjusted r^2 are presented.

Area	Patch	Reader	Photos Read	Slope (SE)	r^2	Random Error
Front	Groais Is.	BS	3,844	1.009 (0.002)	0.9999	0.366
Front	Strait	KM	6,405	1.086 (0.007)	0.9981	0.740
Front	N. Gulf	RC	2,305	1.028 (0.011)	0.9943	0.314
Font	Groais Is.	VH	139	1.016 (0.004)	0.9991	2.465
Gulf	S. Gulf	PR	2,233	1.041 (0.005)	0.999	0.764

Table 2. Number of pups counted on east-west transects and estimated pup production obtained from a visual survey of the southern Gulf of St. Lawrence on March 6, 2017.

Transect	Latitude	Start Longitude	End Longitude	Transect spacing (m)	Pups counted	Estimated Pups
1	46°34'	62°31.5'	62°58'	1,852	0	0
2	46°35'	62°58.5'	62°31.5'	1,852	6	185
3	46°36'	62°31'	62°59'	1,852	9	278
4	46°37'	62°56'	62°31'	1,852	14	432
5	46°38'	62°33'	62°57'	1,852	51	787
5	46°38'	62°33'	62°57'	926	51	394
6	46°38.5'	62°54.5'	62°33.5'	926	127	1,960
7	46°39'	62°32.5'	62°55'	926	204	2,148
8	46°39.5'	62°53.5'	62°33.5'	926	80	1,235
9	46°40'	62°34'	62°54.5'	926	104	1,605
10	46°40.5'	62°53.5'	62°27.5'	926	1	15
11	46°41'	62°41'	62°53'	926	165	2,547
12	46°40.5'	62°51'	62°27.5'	926	10	154
13	46°42'	62°27.5'	62°53.5'	926	4	31
13	46°42'	62°27.5'	62°53.5'	1,852	4	62
14	46°43'	62°50'	62°28'	1,852	12	370
15	46°44'	62°28'	62°51.4'	1,852	23	710
16	46°45'	62°50.5'	62°28'	1,852	75	2,315
17	46°46'	62°30.5'	62°50.5'	1,852	16	494
18	46°47'	62°49.5'	62°33'	1,852	8	247
19	46°48'	62°33.5'	62°50'	1,852	6	185
20	46°49'	62°52'	62°33.5'	1,852	2	62
-	-	-	-	-	**Total estimated**	**17,216**
-	-	-	-	-	**SE**	**3.685**

Table 3. Number of pups counted on east-west transects and estimated pup production obtained from a visual survey of the southern Gulf of St. Lawrence on March 7, 2017.

Transect	Latitude	Start Longitude	End Longitude	Transect spacing (m)	Pups counted	Estimated Pups
1	46°33'	62°13'	62°59.5'	1,852	4	123
2	46°34'	62°58.5'	62°8.5'	1,852	17	525
3	46°35'	62°58.5'	62°16'	1,852	28	432
3	46°35'	62°58.5'	62°16'	926	28	216
4	46°35.5'	62°9'	62°57'	926	175	2,701
5	46°36'	62°16'	63°2'	926	205	3,164
6	46°36.5'	62°57'	62°12.5'	926	219	3,380
7	46°37'	63°2'	62°16.5'	926	186	2,871
8	46°37.5'	62°12.5'	63°0.5'	926	88	1,358
9	46°38'	62°17'	63°2.5'	926	88	1,358
10	46°38.5'	63°0.5'	62°13.5'	926	108	1,667
11	46°39'	62°19.5'	62°47'	926	93	1,435
12	46°39.5'	62°53'	62°13.5'	926	2	31
13	46°40'	63°1.5'	62°19.5'	926	2	31
-	-	-	-	-	**Total estimated**	**19,292**
-	-	-	-	-	**SE**	**2,201**

Table 4. Number of pups counted on north-south transects and estimated pup production obtained from a photographic survey of the southern Gulf of St. Lawrence on March 7, 2017.

Line	Axial (Lon.)		Start Lat. (deg.)	End Lat. (deg.)	Spacing (m)	Length (m)	Pups	Weighted Seals
	Deg. (°)	Min.						
1	62	51.5	46.73	46.51	1,852	23,792	0	0.0
2	62	50.0	46.70	46.51	1,852	21,672	7	36.7
3	62	48.6	46.53	46.69	1,852	17,903	77	408.8
4	62	47.2	46.52	46.68	1,852	17,902	0	0.0
5	62	45.7	46.69	46.51	1,852	20,023	105	551.1
6	62	44.2	46.69	46.50	1,852	20,730	38	199.5
7	62	42.8	46.52	46.69	1,852	20,023	242	1,284.1
8	62	41.4	46.52	46.68	1,852	17,902	347	1,821.8
9	62	39.9	46.69	46.51	1,852	20,586	618	3,263.8
10	62	38.4	46.69	46.51	1,852	19,446	539	2,829.2
11	62	37.0	46.50	46.70	1,852	21,724	439	2,311.4
12	62	35.6	46.52	46.69	1,852	19,552	435	2,282.4
13	62	34.1	46.69	46.51	1,852	20,259	15	79.0
14	62	32.6	46.69	46.50	1,852	20,785	9	47.0
15	62	31.3	46.51	46.69	1,852	20,347	12	63.1
16	62	29.7	46.67	46.50	1,852	18,905	15	79.6
17	62	28.4	46.50	46.70	1,852	23,321	24	126.2
18	62	26.9	46.51	46.68	1,852	19,552	29	151.5
19	62	25.4	46.70	46.51	1,852	21,125	77	402.8
20	62	23.9	46.69	46.51	1,852	21,076	60	314.0
21	62	22.6	46.51	46.67	1,852	17,903	0	0.0
22	62	21.1	46.51	46.68	1,852	7,276	0	0.0
22	62	21.1	46.51	46.68	1,852	8,716	0	-
23	62	19.6	46.65	46.51	1,852	16,765	6	31.5
24	62	18.1	46.65	46.51	1,852	16,494	35	182.6
25	62	16.8	46.52	46.66	1,852	15,547	53	275.6
26	62	15.3	46.52	46.68	1,852	18,376	5	26.0
27	62	13.8	46.65	46.52	1,852	15,076	0	0.0
-	-	-	-	-	-	-	**Total Estimate**	**16,768**
-	-	-	-	-	-	-	**SE**	**2,322**

Table 5. Number of pups counted on east-west transects obtained during photographic surveys of the northern Gulf of St. Lawrence flown March 17, 2017.

Line	Axial (Lat.)		Start Long. (deg.)	End Long. (deg.)	Spacing (m)	Length (m)	Photos	Cover (%)	Pups	Pups on Line	Weighted Seals
	Deg. (°)	Min.									
1	51	15.4	57.05	57.40	3,704	24,539	99	84	0	0.0	0.0
2	51	13.3	57.95	57.02	3,704	65,459	264	85	9	10.9	126.9
3	51	11.4	57.07	57.91	3,704	59,259	240	76	149	202.3	2,647.7
4	51	9.3	57.92	57.20	3,704	50,567	206	76	83	112.6	1,477.7
5	51	7.5	57.18	58.00	3,704	57,523	232	75	106	145.0	1,900.7
6	51	5.2	58.11	57.15	3,704	67,692	273	76	186	252.4	3,281.5
7	51	3.5	57.16	57.98	3,704	44,395	181	76	75	101.1	1,473.0
7	51	3.5	57.16	57.98	3,704	12,883	52	76	9	12.2	-
8	51	1.3	57.89	57.09	3,704	56,283	227	75	93	127.2	1,664.2
9	50	59.5	57.22	57.81	3,704	41,404	168	76	27	36.7	479.6
10	50	57.4	57.80	57.26	3,704	38,047	154	76	12	16.2	211.3
11	50	55.4	57.47	57.85	3,704	10,403	42	76	11	14.9	229.3
11	50	55.4	57.47	57.85	3,704	7,922	32	76	2	2.7	-
12	50	53.4	57.86	57.14	3,704	1,828	9	93	0	0.0	105.1
12	50	53.4	57.86	57.14	3,704	2,503	10	76	0	0.0	-
12	50	53.4	57.86	57.14	3,704	28,756	116	76	6	8.1	-
-	-	-	-	-	-	-	-	-	-	**Total Estimate**	**13,597**
-	-	-	-	-	-	-	-	-	-	**SE**	**2,953**

Table 6. Number of pups counted on east-west transects obtained during a visual survey of the northern Groais Island concentration flown March 14, 2017.

Transect	Lat.		Start Long.		End Long.		Heading	Transet (m)	Pups counted	Weighted seals
	Deg. (°)	Min.	Deg. (°)	Min.	Deg. (°)	Min.				
1	50	26	54	48.8	53	59.5	E	5,550	114	10,545
2	50	23	54	51.8	53	56.9	W	5,550	31	2,868
3	50	20	54	50.3	53	7.4	E	5,550	235	21,751
4	50	17	54	47.3	53	4.3	W	5,550	518	47,869
4	50	17	54	47.3	53	4.3	W	2,775	518	23,934
5	50	15.5	54	49.7	53	4.4	E	2,775	1,220	57,128
6	50	14	54	47.0	53	1.7	E	2,775	520	24,500
7	50	12.5	54	40.4	52	59.7	W	2,775	953	44,076
8	50	11	54	20.5	53	5.6	W	2,775	2,048	96,493
9	50	9.5	54	32.0	53	2.3	W	2,775	1,008	46,877
10	50	8	54	25.9	53	0.6	E	2,775	1,272	58,839
11	50	6.5	54	30.3	53	0.1	E	2,775	782	36,306
12	50	5.	54	26.8	53	0.8	W	2,775	211	9,736
12	50	5	54	26.8	53	0.8	W	5,550	211	19,471
13	50	2	54	26.8	54	1.0	E	5,550	307	28,398
14	49	59	54	35.9	54	24.9	E	5,550	18	1,665
15	49	56	54	36.2	54	26.3	W	5,550	248	22,940
16	49	53	54	45.3	54	31.9	E	5,550	12	1,110
-	-	-	-	-	-	-	-	-	**Total Estimate**	**554,505**
-	-	-	-	-	-	-	-	-	**SE**	**5,219**

Table 7. Number of pups counted on east-west transects obtained during a photographic survey of the northern Groais Island concentration flown March 14, 2017.

Line	Axial (Lat.)		Start Long. (deg.)	End Long. (deg.)	Spacing (m)	Length (m)	Photos	Cover (%)	Pups	Cor. Pups	Pups on Line	Weighted Seals
	Deg. (°)	Min.										
1	50	25	54.95	52.95	7,408	66,676	270	89	839	845.3	944.9	21,500.8
1	50	25	54.95	52.95	7,408	11,660	48	89	0	0.0	0.0	-
1	50	25	54.95	52.95	7,408	34,247	139	92	31	31.5	34.2	-
2	50	21	52.71	54.66	7,408	138,911	560	93	280	282.1	303.1	6,421.8
3	50	17	54.66	52.46	7,408	157,517	635	93	8,944	9,010.6	9,714.1	206,628.9
4	50	13	52.46	54.48	7,408	144,628	583	94	3,731	3,758.8	3,983.0	83,211.4
5	50	9	54.46	52.46	7,408	143,143	577	94	6,134	6,179.7	6,601.6	138,974.1
6	50	5	52.46	54.46	7,408	7,677	31	70	0	0.0	0.0	92,119.8
6	50	5	52.46	54.46	7,408	3,959	16	70	0	0.0	0.0	-
6	50	5	52.46	54.46	7,408	55,326	223	94	1,546	1,557.5	1,659.6	-
6	50	5	52.46	54.46	7,408	53,811	217	94	1,159	1,167.6	1,244.9	-
6	50	5	52.46	54.46	7,408	18,588	75	94	1,299	1,308.7	1,385.1	-
7	50	1	54.62	53.63	7,408	12,131	49	96	3	3.0	3.1	27,729.9
7	50	1	54.62	53.63	7,408	18,836	76	97	629	633.7	655.3	-
7	50	1	54.62	53.63	7,408	23,791	96	97	673	678.0	701.6	-
7	50	1	54.62	53.63	7,408	8,172	33	98	0	0.0	0.0	-
8	49	57	52.83	53.03	7,408	9,170	37	96	18	18.1	18.9	9,583.8
8	49	57	52.83	53.03	7,408	3,959	16	96	427	430.2	446.1	-
-	-	-	-	-	-	-	-	-	-	-	**Total Estimate**	**586,170**
-	-	-	-	-	-	-	-	-	-	-	**SE**	**193,252**

Table 8. Number of pups counted on east-west transects obtained during a photographic survey of the eastern Groais Island concentration flown March 14, 2017.

Transect	Axial (Lat.)		Start Long. (deg.)	End Long. (deg.)	Spacing (m)	Length (m)	Photos	Cover (%)	Pups	Cor. Pups	Pups on Line	Weighted Seals
	Deg. (°)	Min.										
1	50	25	54.95	52.95	7,408	66,676	270	89	839	845.3	944.9	21,500.8
1	50	25	54.95	52.95	7,408	11,660	48	89	0	0.0	0.0	-
1	50	25	54.95	52.95	7,408	34,247	139	92	31	31.5	34.2	-
2	50	21	52.71	54.66	7,408	138,911	560	93	280	282.1	303.1	6,421.8
3	50	17	54.66	52.46	7,408	157,517	635	93	8,944	9,010.6	9,714.1	206,628.9
4	50	13	52.46	54.48	7,408	144,628	583	94	3,731	3,758.8	3,983.0	83,211.4
5	50	9	54.46	52.46	7,408	143,143	577	94	6,134	6,179.7	6,601.6	138,974.1
6	50	5	52.46	54.46	7,408	7,677	31	70	0	0.0	0.0	92,119.8
6	50	5	52.46	54.46	7,408	3,959	16	70	0	0.0	0.0	-
6	50	5	52.46	54.46	7,408	55,326	223	94	1,546	1,557.5	1,659.6	-
6	50	5	52.46	54.46	7,408	53,811	217	94	1,159	1,167.6	1,244.9	-
6	50	5	52.46	54.46	7,408	18,588	75	94	1,299	1,308.7	1,385.1	-
7	50	1	54.62	53.63	7,408	12,131	49	96	3	3.0	3.1	27,729.9
7	50	1	54.62	53.63	7,408	18,836	76	97	629	633.7	655.3	-
7	50	1	54.62	53.63	7,408	23,791	96	97	673	678.0	701.6	-
7	50	1	54.62	53.63	7,408	8,172	33	98	0	0.0	0.0	-
8	49	57	52.83	53.03	7,408	9,170	37	96	18	18.1	18.9	9,583.8
8	49	57	52.83	53.03	7,408	3,959	16	96	427	430.2	446.1	-
-	-	-	-	-	-	-	-	-	-	-	**Total Estimate**	**586,170**
-	-	-	-	-	-	-	-	-	-	-	**SE**	**193,252**

Table 9. Number of pups counted on E-W transect during photographic survey of the Straits concentrations, March 18, 2017.

Transect	Axial (Lat.)		Start Long. (deg.)	End Long. (deg.)	Spacing (m)	Length (m)	Photos	Cover (%)	Pups	Cor. Pups	Pups on Line	Weighted Seals
	Deg. (°)	Min.										
1	51	11	54.64	55.46	7,408	57,523	232	97	2	2.2	2.2	45.7
2	51	7	55.46	54.66	7,408	56,527	228	97	6	6.5	6.7	135.9
3	51	3	54.64	55.45	7,408	57,021	230	98	87	94.5	96.3	1,946.2
4	51	1	55.44	54.66	7,408	55,534	224	96	106	115.2	119.9	1,236.3
4	51	1	55.44	54.66	3,704	55,534	224	96	106	115	120	618
5	50	59	55.41	54.68	3,704	52,063	210	98	690	750	764	7,715
6	50	57	54.59	55.44	3,704	59,511	240	96	401	436	454	4,677
7	50	55	54.11	55.46	3,704	95,216	384	98	800	869	883	8,858
8	50	53	55.45	54.22	3,704	86,791	350	97	1678	1823	1,881	19,179
9	50	51	55.44	54.18	3,704	89,267	360	98	1131	1229	1,254	12,626
10	50	49	53.94	55.40	3,704	103,150	416	98	90	98	100	1,006
11	50	47	53.94	55.38	3,704	101,911	411	96	108	117	122	626
11	50	47	53.94	55.38	7,408	101,911	411	96	108	117	122	1,253
12	50	43	55.50	53.96	7,408	109,351	438	92	125	136	148	3,145
13	50	39	55.53	54.11	7,408	100,673	407	90	189	205	229	5,044
14	50	35	53.77	54.95	7,408	83,585	344	99	387	420	424	8,584
15	50	31	54.99	53.72	7,408	90,256	363	97	414	450	463	9,363
16	50	27	53.82	54.87	7,408	75,185	306	98	361	392	398	8,043
17	50	23	54.90	53.50	7,408	100,327	404	97	50	54	56	1,130
18	50	19	53.47	53.59	7,408	8,373	35	99	0	0	0	2,123
18	50	19	53.62	54.90	7,408	91,955	375	98	94	102	104	-
19	50	15	54.88	53.33	7,408	110,597	446	96	179	194	202	4,129
-	-	-	-	-	-	-	-	-	-	-	**Total Estimate**	**103,597**
-	-	-	-	-	-	-	-	-	-	-	**SE**	**15,632**

Table 10. Number of pups counted on east-west transects obtained during a visual survey of the western edge of the Straits area flown March 18, 2017.

Transect	Lat.		Start Long		End Long		Heading	Transect (m)	Pups counted	Weighted seals
	Deg. (°)	Min.	Deg. (°)	Min.	Deg. (°)	Min.				
1	50	20.0	55	8.5	55	4.0	E	926	1	15
2	50	20.5	55	4.0	55	12.2	W	926	4	62
3	50	21.0	55	12.1	55	0.9	E	926	7	108
4	50	21.5	55	1.0	55	12.2	W	926	13	201
5	50	22.0	55	12.0	55	2.4	E	926	10	154
6	50	22.5	55	3.2	55	12.1	W	926	11	170
7	50	23.0	55	11.1	55	59.8	E	926	12	185
8	50	23.5	55	0.6	55	12.2	W	926	24	370
9	50	24.0	55	11.6	55	0.8	E	926	28	432
10	50	24.5	55	1.0	55	10.7	W	926	13	201
11	50	25.0	55	10.3	55	1.7	E	926	9	139
12	50	25.5	55	1.8	55	11.5	W	926	1	15
13	50	26.0	55	11.2	55	0.8	E	926	0	0
-	-	-	-	-	-	-	-	-	**Total Estimate**	**103,597**
-	-	-	-	-	-	-	-	-	**SE**	**15,632**

Table 11. Numbers of Harp Seal pups in individual age dependent stages in the Gulf of St. Lawrence and on the Front during March 2017.

Area	Date	Newborn	Thin White	Fat White	Grey	Ragged	Beater	Total
S. Gulf	March 07	242	764	416	-	0	0	1,422
S. Gulf	March 10	29	213	1,779	-	2	0	2,023
S. Gulf	March 12	3	90	1,617	-	24	0	1,734
Groais Is.	March 07	96	482	250	0	0	0	828
Groais Is.	March 10	26	1,628	1,040	118	6	0	2,818
Groais Is.	March 13	9	278	1,031	244	7	0	1,569
Groais Is.	March 16	0	79	1,961	678	18	0	2,736
Groais Is.	March 19	0	0	459	227	199	8	893
Groais Is.	March 24	0	0	195	190	515	260	1,160
Strait	March 08	97	111	0	0	0	0	208
Strait	March 10	0	27	0	0	0	0	27
Strait	March 13	4	144	154	30	1	0	333
Strait	March 16	1	9	89	28	0	0	127
Strait	March 17	13	121	1,204	464	5	0	1,807
Strait	March 18	0	35	162	85	1	0	283
Strait	March 20	0	1	303	239	3	0	546
Strait	March 22	0	2	341	255	3	-	601
Strait	March 24	0	0	199	429	11	0	639
Strait	March 25	0	0	15	32	18	2	67

Area	Date	Newborn	Thin White	Fat White	Grey	Ragged	Beater	Total
Strait	March 26	0	0	60	227	171	62	520
N. Gulf	March 07	44	90	0	0	0	0	134
N. Gulf	March 10	13	158	18	0	0	0	189
N. Gulf	March 18	0	2	95	91	1	0	189
N. Gulf	March 24	0	0	33	50	17	0	100

Table 12. 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	March 6	0.9632	0.0147	Yes
-	Visual + Photo	March 7	0.9846	0.0071	Yes
Groais Is	Visual + Photo	March 14	0.9998	0.0002	No
Strait	Photos	March 18	0.9999	<0.0000	No
N. Gulf	Photographic	March 17	1.0	<0.0000	No

Table 13. Estimated pup production and standard errors of Northwest Atlantic Harp Seals during March 2017. The southern Gulf surveys are corrected for the estimated numbers of pups that may have been born after the survey. Estimates in bold are used in the final total.

Area	Date	Method	Estimate	Std Err	CV
S. Gulf	March 6	Visual	17,873	3,835	0.215
-	March 7	Visual	19,593	2,201	0.114
-	March 7	Photo	17,029	2,362	0.139
-	**-**	**Averaged**	**18,302**	**1,496**	**0.082**
N. Gulf	March 17	Photo	13,597	2,953	0.217
Groais Is. N	14 March	Photo	586,170	193,252	0.330
-	-	Visual	554,505	95,219	0.172
-	**-**	**Averaged**	**560,691**	**85,414**	**0.152**
Groais Is. E	14 March	Photo	50,373	22,477	0.446
-	**-**	**Total**	**611,064**	**88,322**	**0.140**
Strait	18 March	Photo	101,484	15,630	0.154
-	-	Visual	2,053	253	0.123
-	**-**	**Combined**	**103,597**	**15,632**	**0.151**
-	**-**	**Total**	**746,499**	**89,755**	**0.120**

Table 14. Northwest Atlantic Harp Seal pup production estimates from aerial surveys completed since 1990 (with SE), and the proportion of pupping in each component.

Year	Southern Gulf	Northern Gulf	Front	Total
1990	106,000 (23,000)	4,400 (1,300)	467,000 (31,000)	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)	626,200 (66,700)	815,900 (69,500)
2017	18,300 (1,500)	13,600 (3,000)	714,600 (89,700)	746,500 (89,800)
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	0.14	0.09	0.72	-
2017	0.02	0.02	0.96	-
Average	**0.18**	**0.07**	**0.75**	**-**
SD	**0.08**	**0.04**	**0.11**	**-**

FIGURES

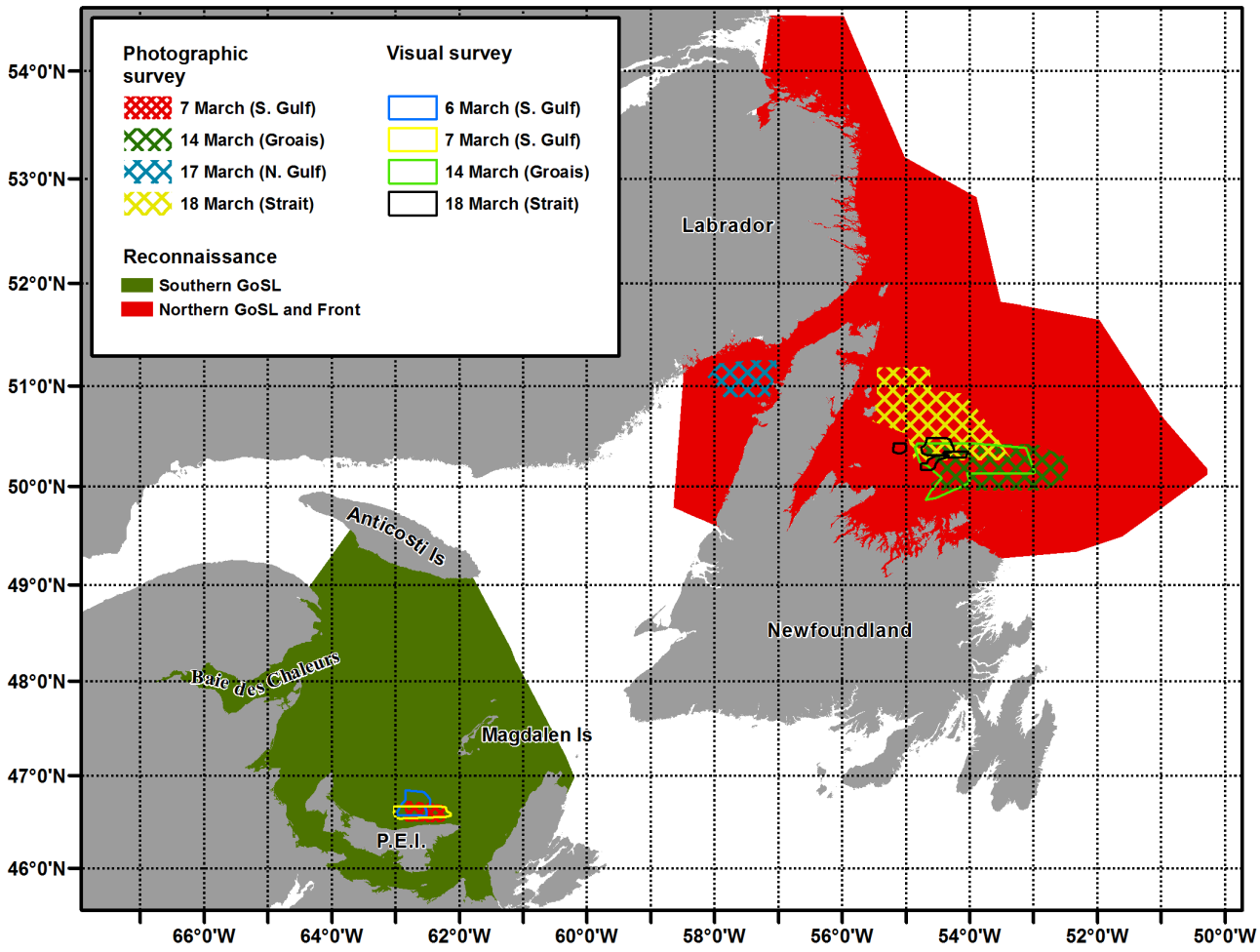
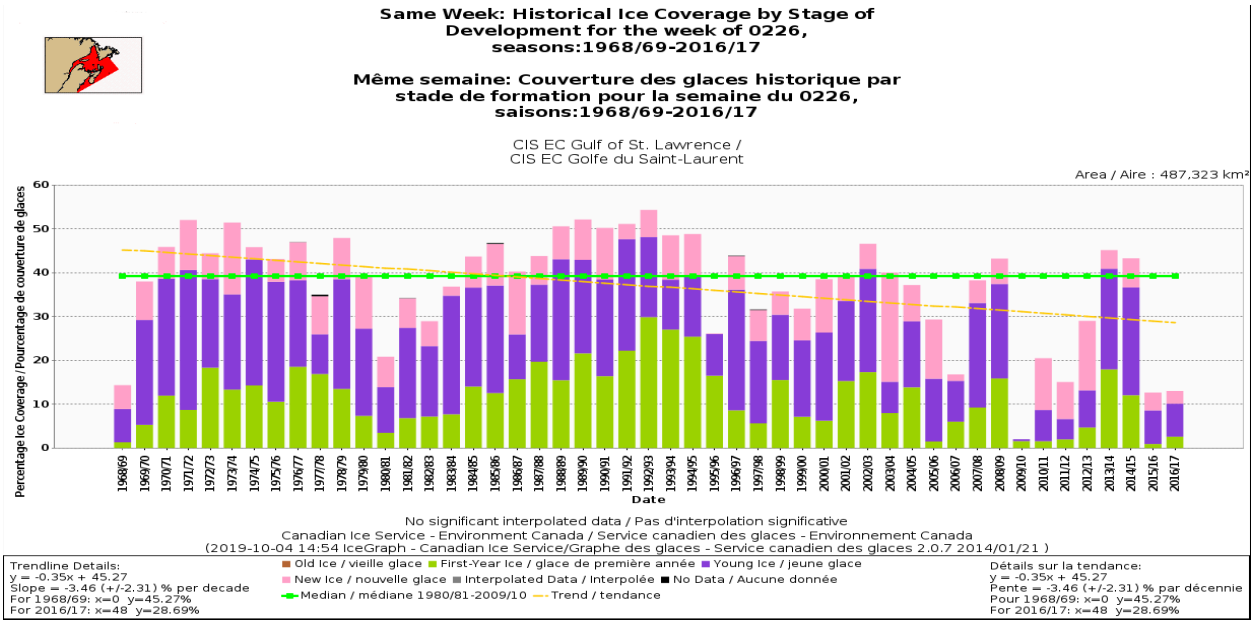


Figure 1. Reconnaissance and locations of whelping concentrations identified during the 2017 Harp Seal survey.



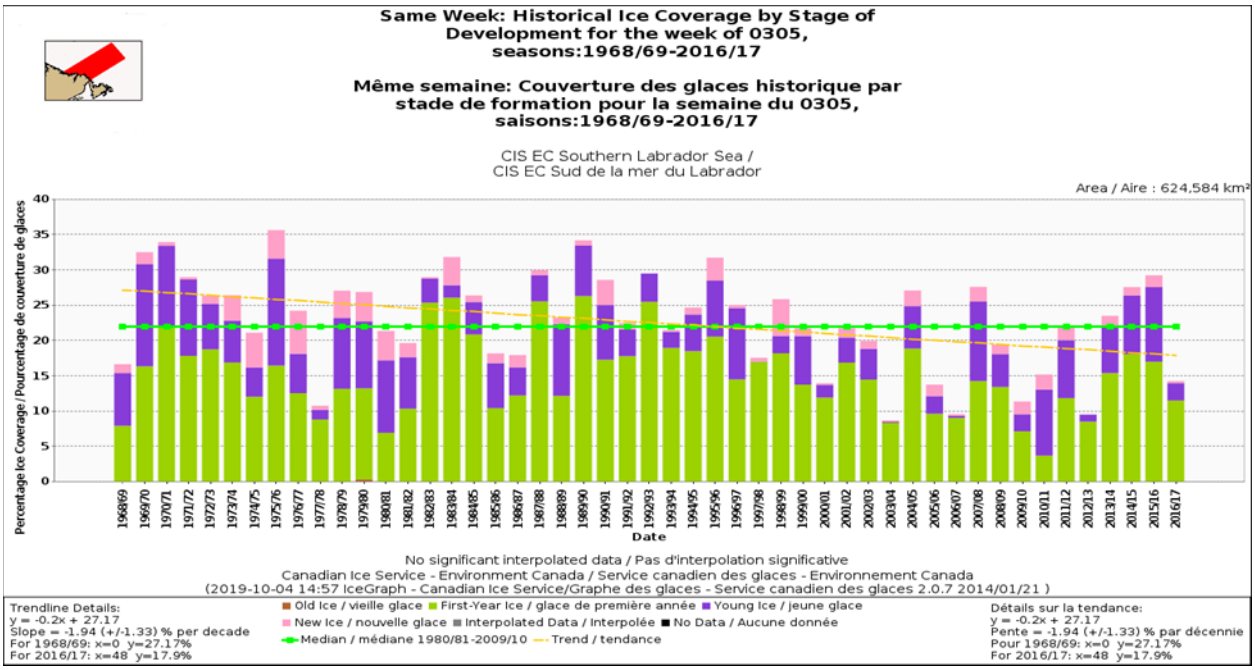


Figure 2. Historic ice cover (1969–2017), by type, in the southern Gulf of St. Lawrence (top, week of February 26), and off southern Labrador (bottom, week of March 3). Harp Seals prefer first year ice.

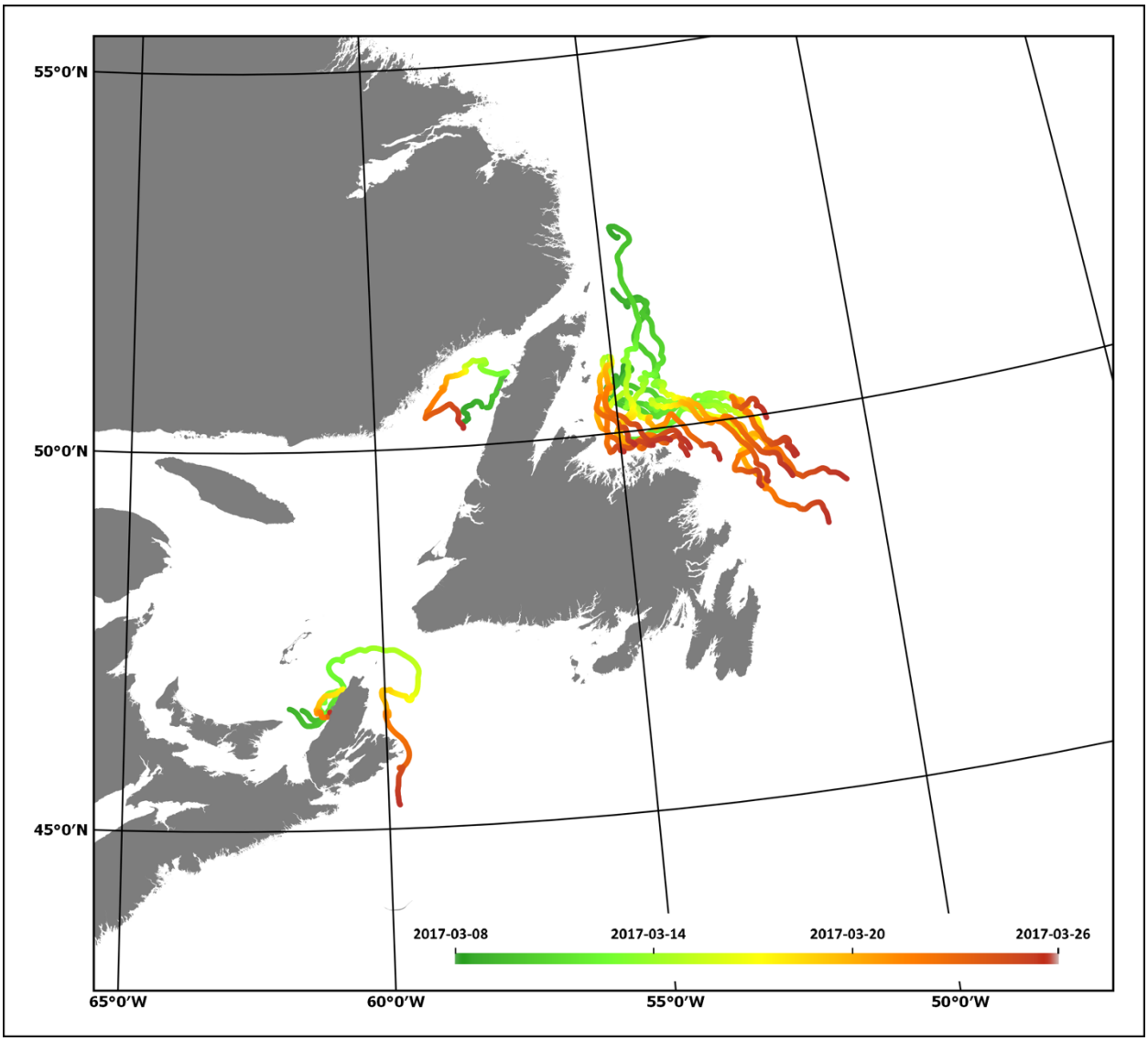


Figure 3. Movement of satellite-linked GPS transmitters deployed in whelping concentrations to monitor ice movement during the March 2017 Harp Seal survey.

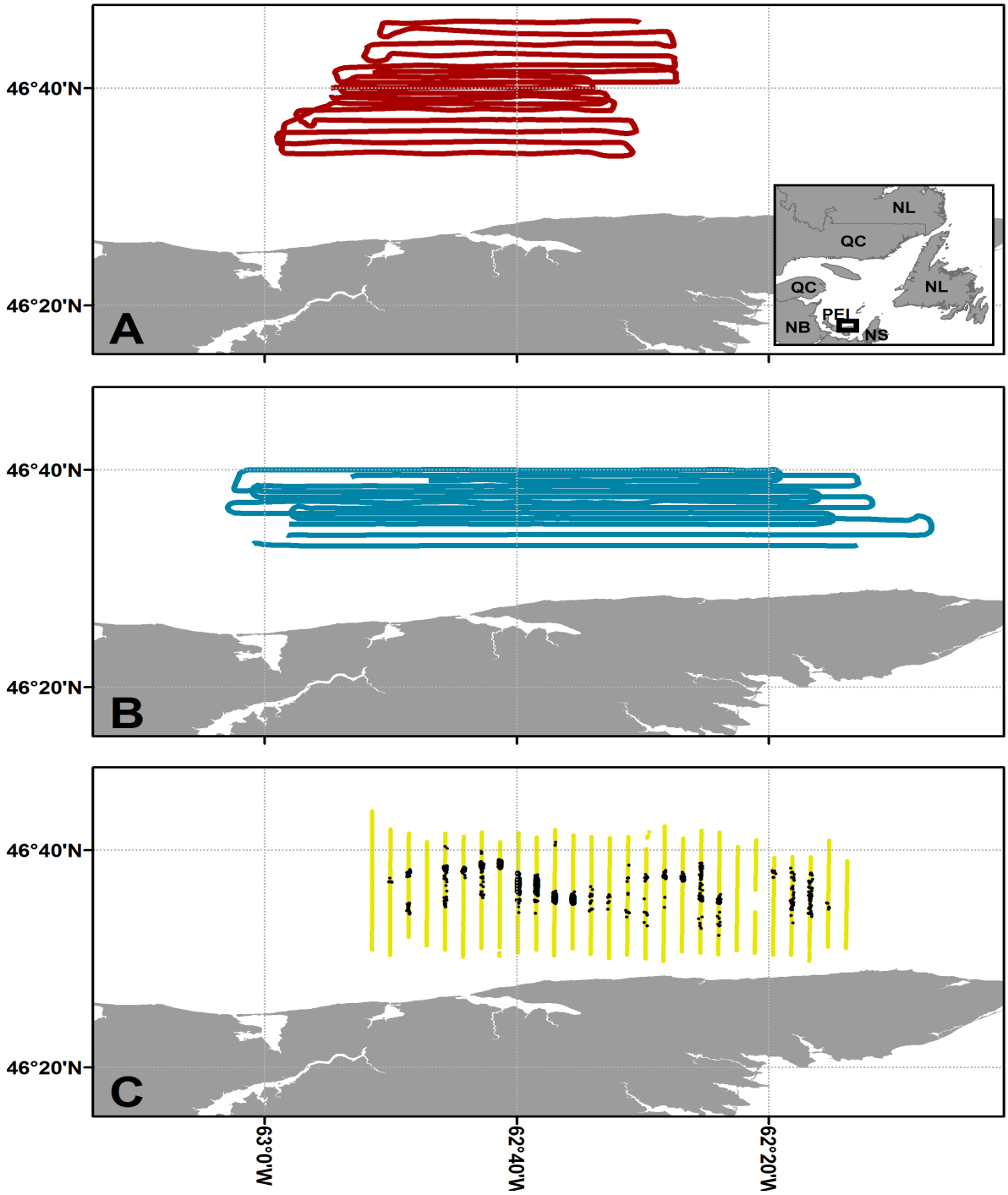


Figure 4. Survey transects during the March 6 (A) and March 7 (B) visual surveys, and March 7 photographic survey (C). Black dots indicate the location of seals during the photographic survey.

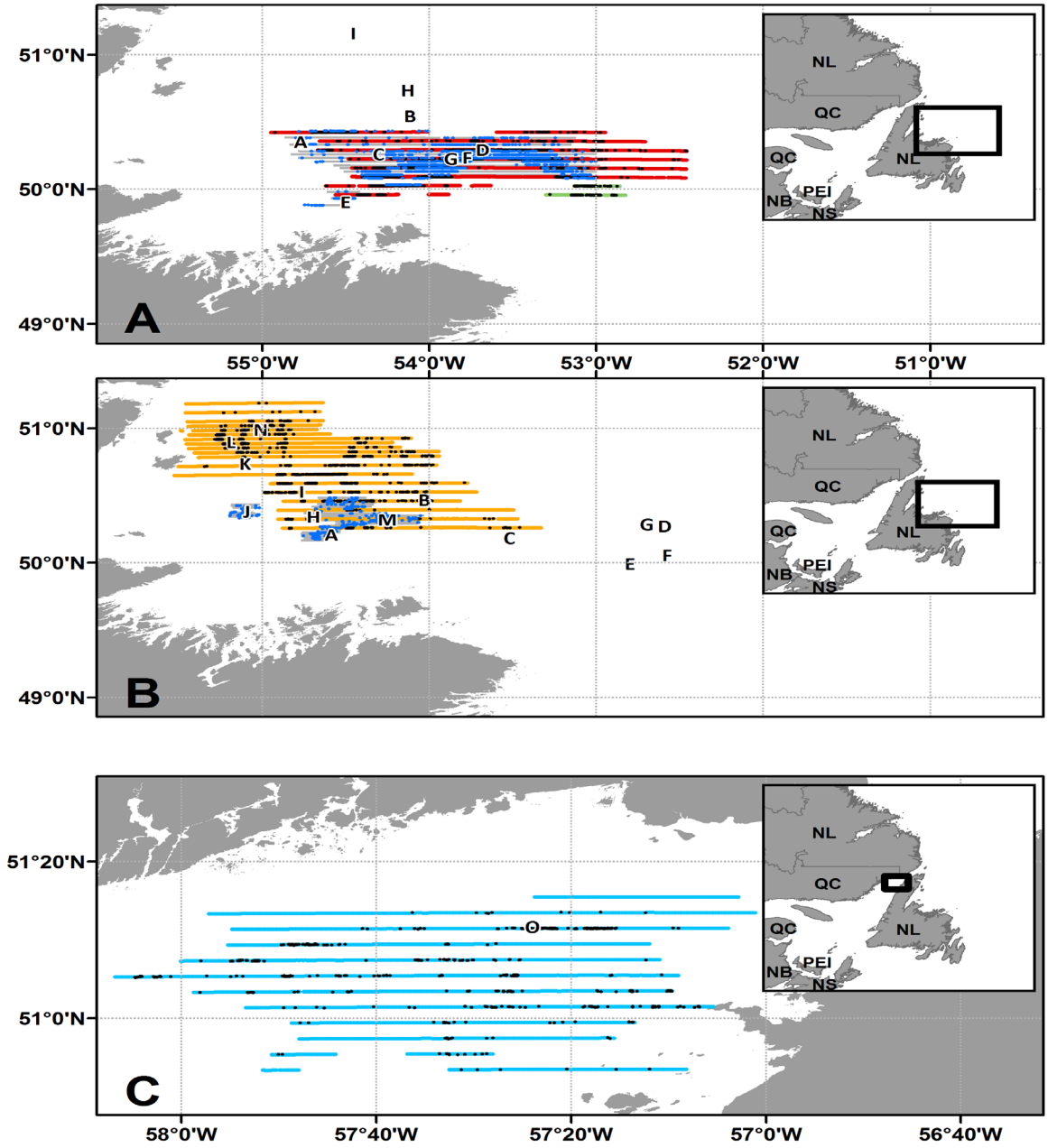


Figure 5. Survey transects of the Groais Island (A, March 14), Strait (B, March 18), and Northern Gulf (C, March 17) whelping concentrations. Visual surveys are indicated by grey line while photographic surveys are in colour. The 'northern' Groais Island survey lines are red while the separate 'eastern' Groais Island transects are in green. Pups identified during visual surveys are shown in blue while pups identified on photographs are black. Letters refer to individual ice beacons to indicate drift.

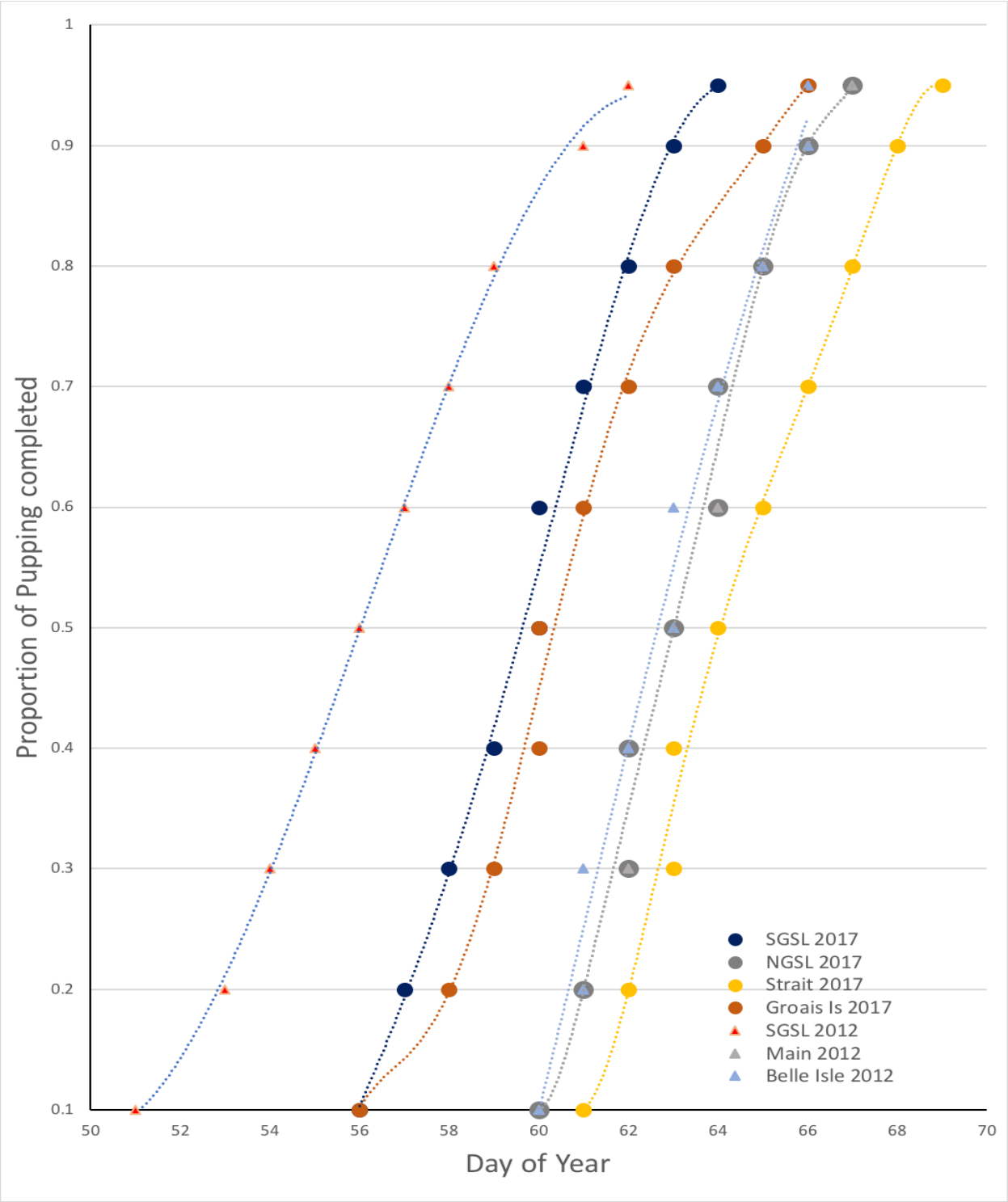


Figure 6. Proportion of pups born versus day of year in the four whelping concentrations in 2017 (circles), and three concentrations in 2012 (triangles).

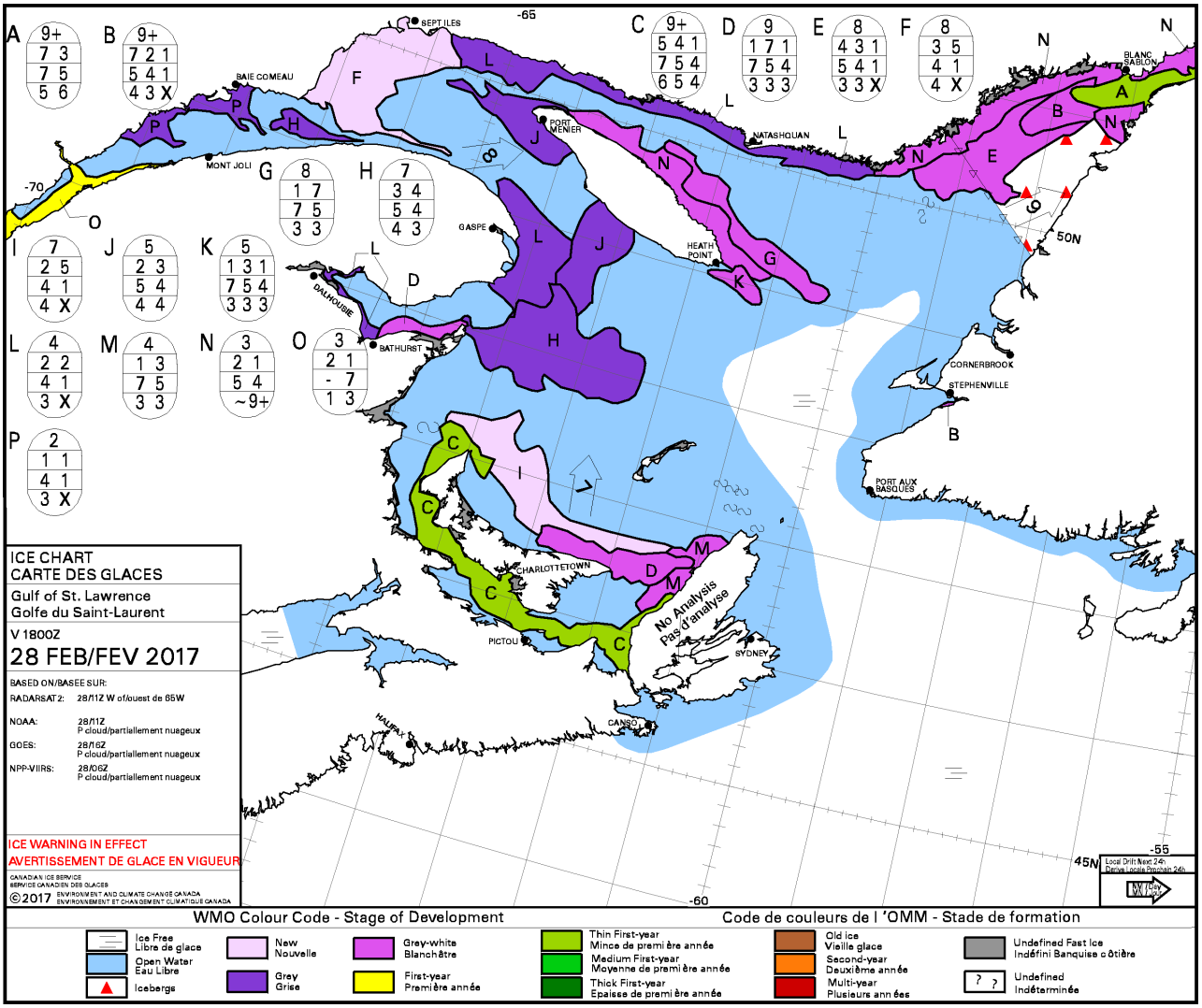


Figure 7. Ice map showing location and type of ice in the Gulf of St. Lawrence February 28, 2017 (Source: Canadian Ice Service).