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Pup Production of Northwest Atlantic Harp Seals, *Pagophilus groenlandicus*, in 2022

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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

In March 2022 photographic aerial surveys were conducted in the northern and southern Gulf of St. Lawrence (Gulf) and off the southeast coast of Labrador/northeast coast of Newfoundland (the Front) to estimate the total pup production of Northwest Atlantic (NWA) harp seals. After extensive reconnaissance, four whelping patches were identified: southern Gulf, northern Gulf, northern Front, and southern Front. In the southern Gulf, two independent photographic surveys, each covering the entire whelping patch, were flown on March 5 and 9. Averaging the two survey estimates resulted in an estimated pup production of 63,392 (SE=28,556; CV=45%) for the southern Gulf. In the northern Gulf, photographic surveys of two aggregations were flown March 11 and 12, respectively, with a combined estimated pup production of 46,207 (SE=8,628, CV=19%). On the Front photographic surveys were flown for the northern Front on March 16 and the southern Front on March 25 with a combined estimated pup production of 504,009 (SE=62,818; CV=13%). Combining the estimates from the southern Gulf, northern Gulf and Front areas resulted in an estimate of total NWA harp seal pup production for 2022 of 614,100 (SE=69,500, CV=11%) (rounded to the nearest hundred). This estimate is lower than the 2017 survey for the same area (746,500, SE=89,800) and is the lowest NWA harp seal pup production estimate since 1994.

INTRODUCTION

Harp seals (*Pagophilus groenlandicus*) are an ice-obligatory, migratory pinniped found over continental shelf regions of the North Atlantic and portions of the Arctic Ocean (Sergeant 1991). They are the most abundant marine mammal in the North Atlantic with three populations distinguished by their whelping (pupping) location: the White Sea/Barents Sea, the Greenland Sea and the Northwest Atlantic (NWA; Stenson et al. 2020a). The NWA population, which whelps on pack ice (primarily first year ice) in Atlantic Canada, is the largest of the three populations (Stenson et al. 2020a).

As an abundant predator with a diverse diet, harp seals play an important role in stabilizing their ecosystem and influencing the population dynamics of their prey (Stenson et al. 2020a). Harp seals are also hunted for commercial or subsistence purposes throughout their range. To understand the ecological role of harp seals and to provide advice for sustainable harvest and Ecosystem Based Fisheries Management (EBFM), it is essential to have accurate estimates of their population abundance and trends.

Throughout much of the year, NWA harp seals are widely distributed throughout Arctic and sub-Arctic waters and, therefore, are not available to be counted. However, each year, NWA harp seals migrate southward to give birth on the pack ice off the southeast coast of Labrador/northeast coast of Newfoundland (an area referred to as “the Front”) and in the northern and southern Gulf of St. Lawrence (Gulf) (Sergeant 1991; Stenson et al. 2020a). Harp seals are social animals and characteristically whelp in high-density concentrations (also referred to as patches) 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). Females haul out in similar locations each year and pupping is generally highly synchronized within an area, with most pupping occurring over approximately 1-2 weeks (Sergeant 1991). Typically, females begin pupping in late February in the southern Gulf, and in early March in the northern Gulf and at the Front (Sergeant 1991, Stenson et al. 2022), although in years of poor ice in the Gulf, pupping may begin earlier at the Front as females which typically pup in the Gulf move to the Front to find suitable ice (Sergeant 1991, Hammill & Stenson 2014, Stenson et al. 2020b, 2022). Pups are nursed for approximately 12 days, after which the female weans her pup, mates and disperses to feed (Sergeant 1991). Following weaning, young harp seals continue to rely on the ice for resting as they undergo a three week post-weaning fast and begin their transition to nutritional independence (Sergeant 1991, Burns et al. 2007, Stenson & Hammill 2014). The relatively brief harp seal whelping period, during which pups remain visible on the ice, provides an opportunity for surveys to be completed to obtain estimates of total pup production. Total population abundance can then be estimated from a population model that incorporates data on pup production, removals, annual reproductive rates, population age structure and environmental conditions (e.g. Tinker et al. 2023, Van de Walle et al. 2025).

Prior to 1990, annual pup production was estimated using a variety of methods including variations on a sequential population analysis approach, mark-recapture tagging, and aerial surveys (Sergeant 1975; Benjaminsen & Øritsland 1975; Winters 1978; Cooke 1985; Lavigne et al. 1982; Bowen & Sergeant 1983). Since 1990, aerial surveys have been flown to determine the pup production of NWA harp seals at four or five year intervals (see Stenson et al. 2022). The aerial survey methodology used since 1990 begins with repeated reconnaissance of all suitable ice to locate the whelping patches and the deployment of satellite linked transmitters to monitor ice movement. Multiple surveys are then 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 strip transect survey methods.

Although a review of different estimates concluded that pup production in 1978 was in the order of 300,000–350,000 (Anon. 1981), Bowen and Sergeant estimated pup production to be 506,000 in 1978, 489,000 in 1979 and 534,000 in 1983 (Bowen and Sergeant 1983, 1985). In 1990 pup production was estimated to be 578,000 (SE=39,000) (Stenson et al. 1993). By 2004 it had increased to 991,400 (SE=58,200) and then jumped to 1.6 million (SE=118,000) in 2008 (Stenson et al, 2011). Since then, pup production has declined to 815,900 (SE=69,500) in 2012 (Stenson et al. 2014, 2022) and 746,500 (SE=89,800) in 2017 (Stenson et al. 2020b, 2022). Here we report on harp seal pup production in the Gulf and at the Front in 2022 using the same survey approach used since 1990.

METHODS

IDENTIFICATION OF WHELPING AREAS

Whelping concentrations (patches) were located using fixed-wing and helicopter reconnaissance flights over suitable ice in areas historically used by harp seals (Figure 1, Figure 3). The majority of the fixed-wing reconnaissance was conducted by aircraft (Beechcraft King Air and De Havilland Canada Dash 8) equipped with a WESCAM MX-15 Electro-Optical and Infrared surveillance and reconnaissance imaging system with an HD low-light step-zoom spotter allowing for detection of seal concentrations at distances in excess of 10 km in all directions. One of the two Bell 429 helicopters used for reconnaissance was also equipped with the similar WESCAM MX-10 from February 26 to March 8.

In the southern Gulf, reconnaissance surveys of areas around the Magdalen Islands were flown from 26 February to March 9. There was relatively little first year ice in the southern Gulf between these dates. The fixed wing and helicopter reconnaissance area in the southern Gulf was of approximately 39,000 km^2 between 46° 10’N to 48° 20’N, and 60° 20’W to 64° 33’W, which, based on maps obtained from the Canadian Ice Service, was mostly composed of young ice (15-30 cm thickness) and small concentrations of thin first year ice (30-70 cm thickness) (Figure 2). This area was searched repeatedly across days to minimize the chance of missing whelping concentrations.

At the Front and in the northern Gulf, fixed-wing reconnaissance flights were conducted almost daily (weather permitting) from March 5–22. Generally, repeated systematic east-west transects, spaced 10-20 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° 20’N and 54° 00'N at the Front and between the Strait of Belle Isle (~51° 50'N) and the southern edge of the ice at approximately 50°40’N in the northern Gulf (Figure 3). In addition, based on ice drift data, a large area investigated on March 16 (Figure 3), would have included areas of ice which would have been as far north as 54° 30'N at the start of the reconnaissance on March 5. Therefore, the March 16 reconnaissance would have identified any whelping that occurred north of the initial reconnaissance area. An area of approximately 156,000 km^2 of the Front and northern Gulf was covered by the reconnaissance effort (Figure 1).

Once located, satellite-linked GPS transmitters were deployed within each whelping patch to monitor their location as the pack ice drifted during the survey period (Figure 4).

ESTIMATES OF ABUNDANCE

Pup production was estimated using the same strip transect survey methodology used since 1990 (Stenson et al. 1993, 2002, 2003, 2005, 2011, 2014, 2020b). The timing of surveys was chosen to maximize the number of pups present (i.e., most pups had been born) while taking into consideration ice conditions and forecasted weather.

Surveys were designed based upon reconnaissance flights and estimated ice drift to maximize the number of transects that could be obtained and to ensure that an entire whelping patch was covered on the same day.

Photographic Surveys

As in the 2017 harp seal survey (Stenson et al. 2020b), the 2022 aerial photographic surveys were flown using fixed-wing aircraft (Piper Navajo) 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 cameras had CCD sensor pixel-size spacing of 7.2 µm per pixel and collected black and white, and colour information in each image. One aircraft was used in the southern and northern Gulf, while two were used simultaneously at the Front.

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. Multiple non-processed images were reviewed 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. Frames were captured using an automated time interval to produce an along transect line coverage of 90%, thus ensuring that images were collected with no overlap along a transect. However, it is possible that due to significant tailwinds/headwinds, airspeed differed from those determined by the survey design, thereby introducing the possibility of along transect image overlap. In these cases, seal pups were to be counted in the overlap area (determined using QGIS) on only one of the two frames to ensure that no pups were counted twice. The spacing between transect lines was determined based on the spatial extent of the area to be surveyed, and the amount of time available to complete the survey. When there was time remaining after the planned transects had been flown, a higher survey resolution was achieved by adding transects (thus reducing the spacing) in areas where pup concentrations were relatively denser. If transect spacing changed within a survey, at least three adjacent lines at equal spacing were flown to allow for estimating the variance (see below). Transect lines were spaced at 0.93 to 18.5 km (0.5–10 nmi) apart depending on the configuration and size of the seal patch.

Transect lines were designed pre-flight, with the number of transects, length of lines and transect spacing modified during the photographic surveys based upon ice conditions and the locations of seals pups. Cameras were turned on before pups were encountered on a transect line and turned off if no pups 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. Generally, for each survey, a “zero pup” transect is flown at each end of the survey area (north and south ends for east-west oriented transects; east and west ends for north-south oriented transects) to ensure proper delimitation of the pup concentration. In cases where the concentrations were bordered by open water/unsuitable ice, these “zero pup” lines were not flown; however, they were assumed in the analysis for statistical purposes.

Weather conditions and the relatively small size of the southern Gulf harp seal patch permitted it to be photographed twice, on March 5 and 9 (Figure 5). Thus, an averaged pup production could be calculated for this patch. Transects in the southern Gulf were oriented in an east-west direction. Photographic surveys of the two aggregations forming the northern Gulf patch were conducted in a north-south direction on March 11 and March 12, respectively (Figure 6). Separate surveys on the two patches at the Front were carried out on March 16 and 25 with transects oriented in an east-west direction (Figure 7). Surveys of patches at the Front were also attempted on March 19 and 24, however these were aborted due to weather constraints in both cases and are not considered further.

Photo Reading and Correction for Reader Errors

The geo-referenced imagery was read within the QGIS geographic information system version 3.26 (QGIS.org, 2022). After an initial training period, images were examined by four readers, one reader read all the images from the two southern Gulf surveys, another read all the images from the two northern Gulf surveys, and the images from the two Front surveys were divided between the remaining two readers (Table 1). Each photograph was scanned visually and detected pups were marked resulting in the creation of a point shapefile for each survey (Figures 5-7). After all photographs were examined, each reader re-read a series of 25 photographs in sequence. This was to determine accuracy and repeatability of the reading, with the objective of being within a threshold of 5% or less difference between first and second readings. If counts differed by more than 5%, the counts from the first reading would replace those from the second reading.

To correct for reader errors, a series of 50 randomly selected images from each survey were examined by all readers. The resulting shapefiles were overlaid within a QGIS workspace for comparison. Pups identified by all readers on an image were considered accurate. Pups identified only by some of the readers were re-examined by a fifth, experienced reader to determine accuracy. Accurate pup identifications were tallied for each frame to determine a 'best estimate' of the number of pups present.

The 'best estimate' was modelled for each reader as:

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

Where n_k is the initial count of the k[th] 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. The photo counts for each survey were then 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:

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

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:

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

Where:

- F_j is $F_j = \sum_{k=1}^{P_j} f_{j,k}$ $f_{j,k}$ is the length of photo (k) in transect j,
- P_j is the total number of photographs on transect j,
- l_j is the length of transect j,
- $W_i = S_i / w_i$, where W_i is a weighting factor for the i_{th} 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

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 have remained the same since the survey was first flown in 1990 with only some slight modifications (Stenson et al. 1993, 2002, 2003, 2005, 2011, 2014, 2020b). The number of pups (N_i) for the i_{th} 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 j_{th} transect.

For photographic surveys where frames did not overlap:

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

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:

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

where:

- J_i = the number of transects in the i_{th} group,
- x_{ij} = the number of pups counted on the j_{th} transect in the i_{th} group,
- 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:

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

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:

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

and its error variance:

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

TEMPORAL DISTRIBUTION OF BIRTHS

The estimated number of pups from the photographic surveys needs to be corrected to account for pups that were not yet born when the surveys took place. Surveys to record pup developmental stages were conducted over whelping patches in the three areas multiple times over the course of the nursing period. Staging surveys were conducted between February 26-March 16 in the southern Gulf (Table 8, Figure 1); March 10-17 in the northern Gulf (Table 9, Figure 1); and March 7-24 at the Front (Table 9, Figure 1, Figure 8). Stages were recorded by a total of seven observers: two in the southern Gulf and five in the northern Gulf and Front.

Random, low altitude (~45 m) helicopter flights were flown across whelping patches with pups classified into one of six developmental stages (newborn/yellow, thin white, fat white, grey, ragged jacket, and beater; see Stewart & Lavigne (1980) for a description of the stages). In the southern Gulf, the observations were recorded as four stages (Table 8) whereby fat white and grey were recorded together (fat white/grey) and ragged jacket and beater were recorded together (ragged jacket/beater). To model the distribution of births, the six stages recorded in the northern Gulf and Front (Table 9) were collapsed to four to match the stages as recorded in the southern Gulf (Table 8).

The temporal distribution of births was estimated using a Bayesian birth distribution model recently developed for grey seals (*Halichoerus grypus*; Mosnier et al. 2023) which was modified for harp seals. Briefly, each developmental stage (stages 1-4) is modelled using a Gamma distribution, with each stage having a different rate parameter. All stages have the same shape parameter to reduce the number of parameters in the model. A prior for the sum of stages 1-3 is also included to constrain the model. A fifth, unobserved stage, is included in the model that accounts for pups that are unable to be counted (i.e. pups that have entered the water or left the survey area). Transitions between the stages are modelled using the sum of the Gamma distributions modelling the temporal distribution of births and the stage durations. The model estimates the proportion of pups in each stage over time based on these transitions and the Dirichlet-Multinomial link is used to fit the model to the staging data. See Mosnier et al. (2023) for further model details.

A separate Bayesian birth distribution model was run for each of the three regions (i.e. southern Gulf, northern Gulf, and Front) to estimate the proportion of pups born by the respective survey dates for each region. The Bayesian model estimates the date of first birth from the staging data with February 20 (southern Gulf) and March 3 (northern Gulf, Front) used as the priors for date of first birth based on observations from reconnaissance flights and initial staging transects. Priors for the duration of each stage were based on published data, with priors of 2.4 d for stage 1 - newborn/yellow, 4.42 d for stage 2 - thin white, 15 d for stage 3 - fat white/grey and 30 d for stage 4 - ragged jacket/beater (Kovacs & Lavigne 1985, Myers & Bowen 1989, Stewart & Lavigne 1980; Table 10). The total duration for stages 1-3 is 21.82 d, greater than the ~12 d nursing period of harp seals. This is because the fat white/grey stage included in the model includes both nursing and independent pups as weaning takes place while pups are in the fat white or grey stage.

To correct for the pups not yet born at the time of the photo surveys, the number of pups estimated from the photographs are corrected by:

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

Where:

- N_i is the corrected estimate
- N_{uncor} is the uncorrected estimate
- Q_i is the proportion of births estimated to have occurred prior to the survey.

As Q_i and N_{uncor} are independent estimates, the error variance is calculated as in Mood et al. (1974):

$$V_i = (N_{uncor}^2 \; x \; V_p/Q_i^4) + V_n/Q_i^2 \; (13)$$

Where:

- V_i is the variance of the corrected estimate
- V_n is the variance of the uncorrected estimate
- V_p is the variance of the proportion of births estimated to have occurred prior to the survey.

For the 2017 pup production survey a modified version of the transition model developed by Myers and Bowen (Bowen et al. 1987; Myers and Bowen 1989, Stenson et al. 2020b) was used to estimate the proportion of pups born on the survey dates. For comparison we also fit this modified version of the Myers birth distribution model to the 2022 staging transect data (see Appendix).

RESULTS

IDENTIFICATION OF WHELPING AREAS

Helicopter based reconnaissance flights began on February 26, during which a patch consisting of a dense concentration of pups between the Gaspé Peninsula and the Magdalen Islands at approximately 47° 53' N, 63° 10' W, and a second, smaller concentration 35 km to the south at approximately 47° 35'N, 63° 8'W was located (Figure 4). During the nursing period, the ice drifted towards the Magdalen Islands. At the time of the first survey on March 5, the patch was located approximately 100 km southeast of where it was first detected (Figure 4).

In the northern Gulf, a relatively dense whelping patch was located on March 10 at the junction of the northern Gulf of St. Lawrence and the Strait of Belle Isle, south of Blanc-Sablon, QC at approximately 51° 15'N, 57° 03'W. On the same day, a smaller grouping of several hundred pups was found 25 km off the coast of St- Barbe, NL at approximately 51° 10'N, 57° 12'W (Figure 4).

At the Front, a patch of nursing females was first observed on March 5 at approximately 53° 27'N, 54° 45'W, 65 km east of Black Tickle, southern Labrador (northern Front, Figure 1). On the same day, a second patch was located approximately 90 km south of the first one, and 85 km east of Williams Harbour (52° 39'N, 54° 28'W). On March 10, two smaller patches were located approximately 85 km east and 100 km north of St. Anthony and Fogo Island, respectively. A severe winter storm occurred overnight on March 12 into much of March 13, after which sea-ice conditions deteriorated rapidly, with larger ice pans being broken into smaller pieces. By March 25th the Williams Harbour, St. Anthony, and Fogo Island patches had merged to become one large patch (southern Front, Figure 8) Movements of each of the patches were monitored through the use of satellite-linked GPS transmitters deployed near the margins of pup aggregations (Figure 4). Reconnaissance to the north of these patches continued until March 16. No additional pupping aggregations were found.

PUP PRODUCTION SURVEYS

Reader Corrections

Correction factors for photographic surveys were developed for all surveys. 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 ranging from only approximately 1–5%. (Table 1). There was very little difference between the counts of the four readers for all of the images examined.

Survey Estimates

Southern Gulf

In the southern Gulf, photographic surveys were flown on March 5 and 9. A total of 16 east-west transects were completed on March 5, with 5,457 pups detected on 2,233 images, resulting in an estimated pup production of 65,973 (SE=36,411, CV=55%) (Table 2, Figure 5).On March 9,14 east-west transects were photographed, with 4,702 pups counted on 2,626 photos, for an estimate of 60,565 pups (SE=46,030, CV=76%) (Table 4, Figure 5). For both southern Gulf surveys a spacing of 3.7 km (2 nmi) between transects was used. On March 5, the aircraft was unable to fly a “zero pup” transect at the northern end of the pup concentration due to unfavorable weather. Although the observer aboard the aircraft visually detected pups north of the photographed area, based on GPS transmitter locations on both days, and the extent of the patch on March 9 (Figure 4), it is reasonable to assume that a line flown 3.7 km north of the northernmost line flown would have detected few, if any, pups and therefore any potential negative bias in the result would be small.

Northern Gulf

The largest of the two whelping patches that were identified in the northern Gulf was surveyed photographically on March 11 (Figure 6). This survey consisted of 24 north-south oriented transects spaced at 1.9 km (1 nmi) apart (Table 4). The survey area was bordered by open water and unsuitable ice, and ‘zero pup’ transects were not flown on either of the east or west ends, therefore ‘zero pup’ transects were assumed for each end in the analysis. A total of 7,102 pups were identified on 1,528 photographs, resulting in an estimated pup production of 45,747 (SE=8,623, CV=19%) (Table 4). The smaller of the two northern Gulf patches was surveyed on 12 March (Figure 6). Spacing for this survey was 0.93 km (0.5 nmi), and only 5 transects were required to cover the patch. Only one pup was detected on the westernmost line which had been determined to be the last possible line in the patch in this direction due to deteriorating ice conditions; a ‘zero’ pup line was assumed on the west end. Only 148 pups were counted on 266 photos, for an estimated pup production of 460 (SE=315, CV=69%) (Table 5). Due to high winds and shifting ice resulting from a storm late that day, it was not possible to survey these patches a second time, either visually or photographically.

Northern Front

The photographic survey on March 16 was split into two blocks which were separated by a thin band of open water (Figure 7). The north end was comprised of six east-west transects spaced 5.6 km (3 nmi) apart; the south end consisted of six transects spaced 11.1 km (6 nmi) apart. In addition to the open water between the northern and southern blocks, there was also open water to the south of the southern block. A GPS transmitter deployed to mark the southeast corner of the southern block (Figure 7, I) would have been near the next planned transect line, however, due to logistical issues that line was not flown. Although it is possible there would have been pups on the planned line (11.1 km to the south of those shown in Figure 7), due to the presence of open water, 'zero pup' transects were assumed at each end of the southern block. A total of 5,425 pups were counted on 3,524 photos (Table 6). Only 7 pups were detected in the northern block. Total pup production was estimated to be 186,969 (SE=40,761; CV=22%) (Table 6).

Southern Front

Due to increasing ice drift as a consequence of ice deterioration and increasing amounts of open water, the patches first found off Williams Harbour, St. Anthony, and Fogo Island had merged into one large low density aggregation by the time it was surveyed photographically on March 25 (Figure 8). This survey consisted of four blocks of transects with varying spacing (Figure 7). From north to south, they were composed of four transects spaced 18.5 km (10 nmi) apart; four transects spaced 9.3 km (5 nmi) apart; four transects spaced 18.5 km (10 nmi) apart; and eight transects spaced 7.4 km (4 nmi) apart (Table 7). Due to the presence of open water, 'zero pup" transects were not flown but rather assumed at the north and south ends of the patch. Over the total 22 transects, 7,020 pups were counted on 6,907 photos resulting in an estimated pup production of 317,039 (SE=47,798; CV=15%) (Table 7).

MODELLING THE TEMPORAL DISTRIBUTION OF BIRTHS

The Bayesian model fit well to the staging data for all three areas (Figures 10-12). The estimated durations of stages 1-3 from the Bayesian model were roughly similar for the three areas (Table 10). For all three areas, the duration of stage 2 was longer than the prior while the stage 3 duration was shorter than the prior for the northern Gulf and the Front (Table 10, Figures 10-12).

In all cases the estimated dates of first birth were revised to an earlier date compared to the priors (Figures 10-12). For the southern Gulf, the estimated date of first birth from the model was February 16 (95% CI: February 12-19). The presence of fat white/grey pups (~12-15 days of age) in the March 3 staging survey (Table 8) is consistent with this date of first birth. Pupping was estimated to have begun at the same time in the northern Gulf (March 1; 95% CI: February 25 - March 4) and at the Front (March 1, 95% CI: February 26 - March 3) (Figures 10-12). The presence of fat white pups in the March 10 staging survey in the northern Gulf and fat white/greys in the March 11-12 staging surveys at the Front (St. Anthony, Fogo Island; Table 9) are consistent with the March 1 estimate for date of first birth.

In the southern Gulf, 99.7% (95% CI: 98.2%-100%) and 100% (95% CI: 99.6%-100%) of pups were estimated to have been born by the March 5 and March 9 surveys, respectively (Table 11). In the northern Gulf 100% (95% CI: 99.0%-100%) of pups were estimated to have been born by the March 11 survey and 100% (95% CI: 100%-100%) of pups were estimated to have been born by the March 16 and March 25 surveys at the Front (Table 11).

Consistent with the results of the Bayesian model, the preferred Myers birth distribution models had an estimated proportion of 1.0 for the pups born at the time of the surveys for the S. Gulf, N. Gulf and the Front (see Appendix).

ESTIMATING TOTAL 2022 PUP PRODUCTION

Based on the results of the Bayesian models for the temporal distribution of births, no corrections for pups born after the survey were applied. Averaging the two estimates of the southern Gulf patch resulted in an estimated pup production of 63,392 (SE=28,556; CV=45%). For the northern Gulf, the combined estimate for the March 11 and 12 surveys is 46,207 (SE=8,628, CV=19%). Combining the photographic estimates of the northern and southern patches resulted in a total estimated pup production in the Front area of 504,009 (SE=62,818; CV=13%).

Combining the average estimate from the southern Gulf with the combined estimates of the northern Gulf and Front areas resulted in an estimate of total NWA harp seal pup production (rounded to the nearest hundred) in 2022 of 614,100 (SE=69,500, CV=11%) (Table 12).

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, 2020b) and, therefore, the results of the various surveys should be comparable. Harp seals are social animals and characteristically whelp in relatively high-density concentrations (patches) in similar locations each year (Sergeant 1991). Stenson and Hammill (2014) observed that NWA harp seals whelp in traditional areas even if ice conditions are poor and ice related mortality may result. The only time pupping has been observed outside of the traditional areas in the Gulf and at the Front has been when the southern extent of suitable ice (ice thicker than 30 cm with a spatial coverage of at least six-tenths) did not extend into the traditional areas at the time the whelping patches were forming (Sergeant 1991; Hammill and Stenson 2014). Since missing whelping patches represents the largest single source of error in this type of survey (Myers and Bowen 1989), extensive reconnaissance of all suitable ice in the Gulf and at the Front was carried out to detect patches with all areas searched repeatedly to ensure no whelping patches were missed (Figure 3). Based on the extensive reconnaissance conducted, no whelping concentrations were located outside of the traditional areas in 2022. Once patches were located, satellite-linked GPS transmitters were deployed to monitor ice movements (Figure 4) and ensure that all of the identified patches were surveyed and that any overlap between surveys was identified (Figures 4-6).

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. Ideally, the photographic surveys are timed to occur after peak pupping, but before pups begin to leave the ice. To account for births which occur after the photographic surveys have been flown, it is necessary to estimate the temporal distribution of births to determine the proportion of pups born on the survey dates. This is done by fitting a transition model to the proportion of pups observed in each developmental stage obtained from a series of staging surveys completed throughout the breeding season (Tables 8 and 9). For the 2017 survey a modified version of the transition model developed by Myers and Bowen (Bowen et al. 1987; Myers and Bowen 1989, Stenson et al 2020b) was used to estimate the birth distribution. This model assumes the date of first birth is known and that uncertainty in the stage duration is known without error. For the 2022 survey we fit a recently developed Bayesian birth distribution model that allows the estimates of first birth date and stage duration to be updated by information from the staging surveys (Mosnier et al. 2023). For all three areas (southern Gulf, northern Gulf and Front) the models fit well to the staging data (Figures 10-12) and updates to the priors for date of first births were consistent with the pup developmental stages observed in the staging surveys for each area. Similar to what was observed for grey seals (Mosnier et al. 2023), the model outputs showed a strong update to the stage durations for stage 2 suggesting a longer duration compared to the priors (Figure 9-11), with the largest updates occurring for the southern Gulf and Front models. Although further work is needed to assess the model's behaviour (Mosnier et al. 2023), given that harp seal pupping may occur in pulses within an area and that all staging data were combined within each area, the longer durations estimated for stage 2 may simply reflect the longer presence of stage 2 individuals across the total area surveyed rather than the stage 2 duration for an individual pup. The estimated proportion of pups born at the time of the surveys was greater than 0.997 for all survey dates (Table 11), therefore, no corrections for the temporal distribution of births were applied. For comparison, we fit the modified Myers birth distribution model to the same staging data. Consistent with the results of the Bayesian model, the Myers model estimated the proportion of pups born at the time of the surveys as 1.0 for all survey dates (see Appendix).

Pup counts from the imagery must also be corrected for the proportion of pups that are photographed but not detected by the readers. As in the past, the reader's counts of seals on the photographic images were standardised 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 (Table 1).

The estimated pup production in the southern Gulf in 2022 (63,900 SE=28,500) was more than three times the estimate for the same area in 2017 (18,300 SE=1,500; Table 13). However, the 2022 estimate was still only approximately one third (33.5%) of the average over the six surveys carried out between 1990 and 2012. Reconnaissance flights covered the traditional whelping areas between the Gaspé Peninsula and the Magdalen Islands from February 26 until March 4 to delineate the whelping patch (Figure 1). Helicopter reconnaissance flights also examined all suitable ice along Prince Edward Island, and along the northwest coast of Cape Breton Island. Areas north of the Gaspé Peninsula consisted of open water or grey ice unsuitable for pupping, therefore, reconnaissance flights were not flown in this area. There was no indication of any pupping occurring outside of the patch identified and surveyed in the southern Gulf (Figure 1). Although the proportion of total NWA harp seal pup production occurring in the southern Gulf was higher in 2022 (10%) than in 2017 (2%), 2022 was still below the proportion observed for any of the 1990-2012 surveys and was less than half of the average for those six surveys (20%). That a greater proportion of pups were born in the southern Gulf in 2022 compared to the previous survey likely reflects the slightly better ice conditions observed in 2022 compared to 2017. In late February, which is the traditional time for pupping to begin in the southern Gulf, total ice coverage in the Gulf was similar for 2017 and 2022 (Figure 9). However, in 2017 this area was characterized by the presence of grey ice and open water (Stenson et al. 2020b, 2022) while the ice in 2022 consisted of later ice development stages which are thick enough to support pupping harp seals (Figure 2). In 2022, the overall ice extent and thickness in the Gulf was low (Figure 9), continuing a trend that has been ongoing since the mid 1990s (Friedlaender et al. 2010; Bajzak et al. 2011, Stenson & Hammill 2014, Van de Walle WP#3). This would account for the low proportion of total pupping that occurs in the southern Gulf relative to historical estimates.

The southern Gulf whelping patch was surveyed photographically on March 5 and 9 (Figure 5). The satellite-linked GPS transmitters, which were deployed to delineate the patch and track movements of the ice indicated that, in general, the concentration of pups moved very little between the two survey dates. However, the ice did expand from east to west and contract north to south. Due to oncoming inclement weather, the flight for the first of these surveys on March 5 was stopped before a 'zero pup' transect could be flown to the north (Figure 5). The observer onboard the aircraft noted that that there were pups to the north of the last line flown. However, based on the locations of transmitter A (Figure 4) on both days, and the spatial extent of counted pups, it is likely that there would have been few, if any, pups at the next planned transect 3.7 km to the north of the last line flown. Considering the similarity in the pup production estimate between the two surveys (i.e. 65,973 (SE=36,411) on March 5 versus 60,565 (SE=46,030) on March 9) (Table 2, Table 3), the number of pups potentially missed is assumed to have been negligible, and is subsumed within the CV.

Similar to the southern Gulf, estimated pup production in the northern Gulf in 2022 was more than three times higher than in 2017 (46,200 (SE=8,600) versus 13,600 (SE=3,000); Table 13). Although the 2022 estimate is lower than those from 1994 through 2012, it represents a similar proportion of total NWA pup production (9%) as in the five surveys from 1994 to 2012 (average 9%). The estimates of pup production in this area vary greatly among surveys and are often a reflection of the number of seals that may drift through the strait, as well as those that are actually born in situ. The location of this patch within the narrow Strait of Belle Isle, and the presence of open water or grey ice in most of the northern Gulf, allowed for a thorough reconnaissance of this area (Figure 1). Therefore, it is unlikely that any whelping patches were missed. Furthermore, the transect spacing of 1.8 km and 0.93 km for March 11 and March 12, respectively (Figure 6), ensured that this area was well covered.

Estimated pup production at the Front in 2022 (504,000 SE=62,800; Table 13) was the lowest since the 1994 survey (447,700 SE=57,200; Table 13). The proportion of the total NWA harp seal pups born on the Front in 2022 (82%) is second only to the 96% estimated for the 2017 survey. In addition to the near-daily helicopter and fixed-wing reconnaissance conducted at the Front from March 5-22, 14 satellite-linked GPS transmitters were deployed to track whelping patches on the Front. Based on the information collected from these efforts, we are confident that all patches were identified and included in the photographic surveys (Figures 1, 4, 7 and 8). However, there is a possibility that some pups may have been missed during surveys of the individual patches. The patch identified off of Black Tickle on March 6 (Figure 1, Figure 8) was marked by GPS transmitters deployed on March 6 and 7 on its northwest, southwest, and southeast corners. Communication with the transmitter deployed in the northwest corner ended on March 12 during an intense winter storm in the area, suggesting that the ice pan it was on may have broken up. This, along with the deteriorating ice observed in the northern portion of this patch following the storm, suggests pups could have been lost as the ice broke up. A reconnaissance flight was conducted immediately to the north of the northern Front patch, simultaneous to the survey on March 16. This flight covered an area of sea-ice stretching north for approximately 110 km, with no pups detected. It is therefore unlikely that ice pans with pups, from the area of the lost transmitter, would have gone undetected.

In addition, a transmitter located in the southeast corner of the northern Front patch (Figure 7, I) was not covered by the survey on March 16. It was reported that there was a considerable amount of open water in the area where this transmitter was located during the photographic survey. This open water may explain why this transmitter continued to drift east at a relatively high rate, while the other active transmitters in this patch remained in the same area over March 16 and 17, as ice in areas of low total ice cover generally moves more quickly than in areas where ice cover is greater and dampens movement. It is possible that there were pups near this transmitter that were missed by the photographic survey, however, based on the quality of the ice reported in the area during the survey and during subsequent reconnaissance flights, it is unlikely that the number of seals missed would be substantial.

Traditionally, pupping occurs later at the Front than in the Gulf with very little pupping prior to March 5 or 6. However, the presence of grey stage pups (12-15 days old) in the St. Anthony and Fogo Island patches (Figure 8) on March 11 and 12 (Table 9) suggests that, as in 2017, some Gulf females moved to the Front to pup. The model estimated first date of pupping (March 1) for the Front, with a lower CI of February 26 (fit to all available staging data), is consistent with the presence of grey stage pups on March 11 (Figures 10-12). Based on the available staging data (Table 9) it is not possible to determine whether earlier pupping only occurred in the St. Anthony and Fogo Island patches, which would have likely formed up in the area near Belle Isle before drifting south, or whether earlier pupping may have occurred in all areas. Harp seal females are thought to show site fidelity by returning to pup in the same area, presumably the one where they were born, each year (Sergeant 1991). However, it is unknown if females that move to the Front, in years of poor ice in the Gulf, will continue to pup on the Front in subsequent years or return to the Gulf. The presence of suitable ice in the traditional pupping areas in both the southern Gulf and the northern Gulf in 2022 was associated with a higher proportion of total pup production in 2022 (10% and 8%, respectively) compared to 2017 (2% and 2%, respectively). Although the proportion born in the southern Gulf in 2022 was still below the average for surveys conducted from 1990-2012 (Table 13), the higher proportion of pups born in the Gulf in 2022 compared to 2017 suggests that females will return to pup in the Gulf as long as suitable ice forms in the traditional whelping areas.

With an estimate of 614,108 (SE=69,542), pup production of NWA harp seals is the lowest since 1994 (Table 13). Given the timing of the final survey at the Front (March 25), it is possible that some of the pups born early in the whelping period may have left the ice prior to the survey. However, only 4% of pups at the Front (Figures 7 and 8) had reached the beater developmental stage by March 24 suggesting that this is unlikely to have produced a substantial underestimate.

The intense winter storm which occurred on March 12 and 13 resulted in considerable deterioration of ice conditions in all areas and it is possible that pups were lost prior to the March 16 and March 25 surveys on the Front. The extent to which this may have impacted the estimate for pup production for the Front is unknown, but there was no sign of important mortality detected during the reconnaissance and staging flights conducted between the date of the storm and the final survey (Figure 3). A significant amount of the whelping on the Front in 2022 was spread broadly across rapidly drifting pans with large areas of open water making surveying difficult. Although it is always possible that some small groups were missed as a result, the extensive reconnaissance conducted throughout the survey period in all areas means that it is highly unlikely that any significant concentrations were missed.

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TABLES

Table 1: Regression statistics used to correct for missed harp seal 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. SE, standard error.

Survey Date	Area	Reader	Photos Read	Slope (SE)	r^2	Random Error
March 5	S. Gulf	PR	1,687	1.029 (0.003)	0.9996	0.643
March 9	S. Gulf	PR	3,014	1.010 (0.003)	0.9996	1.688
March 11/12	N. Gulf	BS	2,106	1.012 (0.003)	0.9997	0.060
March 16	N. Front	EF	4,485	1.011 (0.006)	0.9984	0.100
March 25	S. Front	MW	4,907	1.026 (0.011)	0.9944	0.097
March 25	S. Front	EF	2,113	1.049 (0.013)	0.9928	0.099

Table 2: The number of harp seal pups counted on east-west transects and the estimated pup production obtained from the March 5, 2022, photographic survey of the southern Gulf of St. Lawrence (S. Gulf) whelping patch. SE, standard error.

Transect	Latitude	Start Longitude	End Longitude	Transect Spacing (m)	Transect Length (m)	Photos	Cover (%)	Pups Counted	Pups on Transect	Estimated Pups
1*	47° 57.0'	-	-	3700	-	-	-	0	0.0	0.0
2	47° 55.0'	-62° 1.1'	-62° 14.5'	3700	16,684	72	97	653	694.6	7756.9
3	47° 53.0'	-62° 7.1'	-61° 48.7'	3700	23,028	99	95	3186	3462.6	38791.4
4	47° 51.0'	-61° 49.0'	-62° 4.1'	3700	18,798	81	96	2	2.1	23.8
5	47° 49.0'	-62° 3.7'	-61° 46.6'	3700	21,384	92	95	1278	1383.5	15403.7
6	47° 47.0'	-61° 45.9'	-62° 2.8'	3700	21,148	91	95	31	33.4	371.0
7	47° 45.0'	-61° 55.5'	-62° 3.4'	3700	9,870	43	97	9	9.6	152.1
7	47° 45.0'	-61° 43.6'	-61° 54.7'	3700	13,864	60	97	4	4.2	-
8	47° 43.0'	-62° 3.8'	-61° 55.5'	3700	10,338	45	97	1	1.1	11.7
9	47° 41.0'	-61° 55.5'	-62° 11.7'	3700	20,210	87	97	29	30.9	340.9
10	47° 39.0'	-62° 10.7'	-61° 55.5'	3700	19,034	82	97	13	13.8	152.7
11	47° 37.0'	-61° 55.5'	-62° 16.5'	3700	26,318	113	95	171	184.7	2039.0
12	47° 35.0'	-62° 16.3'	-61° 55.5'	3700	26,082	112	97	53	56.1	612.0
13	47° 33.0'	-61° 55.5'	-62° 21.9'	3700	33,134	142	96	6	6.4	70.8
14	47° 31.0'	-62° 21.9'	-61° 55.5'	3700	33,134	142	96	3	3.2	35.4
15	47° 29.0'	-61° 55.5'	-62° 21.9'	3700	33,132	142	96	14	15.0	164.9
16	47° 27.0'	-62° 21.9'	-61° 55.6'	3700	33,134	142	96	4	4.3	47.1
17	47° 25.0'	-61° 55.6'	-62° 21.9'	3700	33,134	142	96	0	0.0	0.0
									Total Estimated	**65,973**
									SE	**36,411**

** Assumed zero line, open water.*

Table 3: The number of harp seal pups counted on east-west transects and the estimated pup production obtained from the March 9, 2022, photographic survey of the southern Gulf of St. Lawrence (S. Gulf) whelping patch. SE, standard error.

Transect	Latitude	Start Longitude	End Longitude	Transect Spacing (m)	Transect Length (m)	Photos	Cover (%)	Pups Counted	Pups on Transect	Estimated Pups
1	47° 54.0'	-61° 54.7'	-61° 28.7'	3700	32,398	136	92	0	0.0	0.0
2	47° 52.0'	-61° 28.7'	-62° 22.0'	3700	66,474	278	91	1	1.1	12.6
3	47° 50.0'	-62° 17.8'	-61° 28.7'	3700	61,196	256	91	104	115.8	1301.9
4	47° 48.0'	-61° 51.2'	-62° 27'	3700	44,621	186	89	3868	4388.8	50429.1
4	47° 48.0'	-61° 28.7'	-61° 50.9'	3700	27,596	116	91	38	42.3	0.0
5	47° 46.0'	-62° 29.3'	-61° 28.7'	3700	75,722	310	88	343	391.7	4416.7
6	47° 44.0'	-61° 29'	-62° 18.7.0'	3700	62,158	260	91	102	113.5	1275.5
7	47° 42.0'	-62° 18.5'	-61° 38'	3700	50,638	214	90	8	9.0	103.1
8	47° 40.0'	-61° 38.2'	-62° 13.9.0'	3700	44,636	187	91	34	37.7	423.3
9	47° 38.0'	-62° 13.9'	-61° 48.4'	3700	31,918	134	90	32	35.8	404.9
10	47° 36.0'	-61° 48.4'	-62° 13.7'	3700	31,676	133	90	152	170.5	1938.4
11	47° 34.0'	-62° 16.8.0'	-61° 52.3'	3700	30,718	129	90	6	6.8	77.1
12	47° 32.0'	-61° 52.5'	-62° 12.8.0'	3700	25,438	107	89	1	1.1	12.9
13	47° 30.0'	-62° 12.4'	-61° 50.6'	3700	27,358	115	89	13	14.7	169.1
14	47° 28.0'	-61° 49.4'	-62° 1.7'	3700	15,360	65	88	0	0.0	0.0
								Total Estimated		**60,565**
								SE		**46,030**

Table 4: The number of harp seal pups counted on north-south transects and the estimated pup production obtained from the March 11, 2022, photographic survey of the larger northern Gulf of St. Lawrence (N. Gulf) whelping patch. SE, standard error.

Transect	Longitude	Start Latitude	End Latitude	Transect Spacing (m)	Transect Length (m)	Photos	Cover (%)	Pups Counted	Pups on Transect	Estimated Pups
1*	-57° 27.0'	-	-	1852	-	-	-	0	0.0	0.0
2	-57° 25.0'	51° 8.4'	51° 27.8'	1852	35,999	151	91	78	86.8	488.3
3	-57° 23.0'	51° 28.6'	51° 18.3'	1852	18,959	95	90	32	36.0	205.8
4	-57° 22.0'	51° 18.2'	51° 26.2'	1852	14,879	91	92	97	106.2	593.4
5	-57° 20.0'	51° 26.2'	51° 20.4'	1852	10,799	81	92	167	184.7	1048.0
6	-57° 18.0'	51° 20.3'	51° 26.7'	1852	11,999	112	93	430	467.8	2599.3
7	-57° 17.0'	51° 26.5'	51° 16.8'	1852	17,999	92	91	407	454.1	2574.5
8	-57° 15.0'	51° 11.3'	51° 25.6'	1852	26,399	104	90	236	264.8	1503.6
9	-57° 14.0'	51° 25.7'	51° 11.8'	1852	25,679	49	90	120	134.3	761.6
10	-57° 12.0'	51° 11.5'	51° 23.5'	1852	22,129	52	89	54	61.4	352.8
11	-57° 10.0'	51° 23.9'	51° 11.7'	1852	22,559	63	90	38	42.9	246.0
12	-57° 9.0'	51° 11.4'	51° 23.1'	1852	21,598	63	90	182	205.8	1181.9
13	-57° 7.0'	51° 23.2'	51° 12.9'	1852	19,200	80	90	302	338.7	1928.9
14	-57° 56.0'	51° 9.7'	51° 24.1'	1852	26,638	55	90	354	400.1	2289.5
15	-57° 40.0'	51° 24.2'	51° 12.5'	1852	21,840	65	91	71	79.0	446.6
16	-57° 24.0'	51° 12.3'	51° 25.7'	1852	24,718	34	90	121	136.1	775.8
17	-57° 8.0'	51° 25.5'	51° 19.3'	1852	11,521	42	92	411	450.5	2532.4
18	-56° 59.0'	51° 19.0'	51° 25.6'	1852	12,239	63	92	2007	2209.7	12461.4
19	-56° 58.0'	51° 26.4'	51° 18.4'	1852	14,879	63	91	877	974.2	5521.3
20	-56° 56.0'	51° 16.7'	51° 24.7'	1852	14,880	46	90	414	467.4	2689.9
21	-56° 54.0'	51° 24.8'	51° 17.9'	1852	12,959	51	91	449	500.7	2853.1
22	-56° 53.0'	51° 17.3'	51° 25.6'	1852	15,359	76	90	255	286.2	1639.3
23	-56° 51.0'	51° 25.4'	51° 21.1'	1852	7,919	111	90	147	164.7	955.9
24	-56° 50.0'	51° 20.8'	51° 26.1'	1852	9,839	108	93	15	16.4	91.8
25	-56° 48.0'	51° 27.4'	51° 19.4'	1852	14,878	93	91	1	1.1	6.3
26*	-56° 46.0'	-	-	1852	-	-	-	0	0.0	0.0
								Total Estimated		**45,747**
								SE		**8,623**

** Assumed zero line, open water.*

Table 5: The number of harp seal pups counted on north-south transects and the estimated pup production obtained from the March 12, 2022, photographic survey of the smaller northern Gulf of St. Lawrence (N. Gulf) whelping patch. SE, standard error.

Transect	Longitude	Start Latitude	End Latitude	Transect Spacing (m)	Transect Length (m)	Photos	Cover (%)	Pups Counted	Pups on Transect	Estimated Pups
1*	-57° 12.6'	-	-	926	0	-	-	0	0.0	0.0
2	-57° 11.8'	51° 6.0'	50° 58.1'	926	14,640	62	91	1	1.1	3.1
3	-57° 11.0'	50° 59.0'	51° 6.0'	926	12,961	55	90	17	19.0	54.4
4	-57° 10.2'	51° 0.2'	51° 6.0'	926	10,800	46	92	125	137.3	386.8
5	-57° 9.4'	51° 6.0'	50° 59.0'	926	12,960	55	92	5	5.5	15.5
6	-57° 8.6'	51° 6.0'	50° 59.9'	926	11,280	48	90	0	0.0	0.0
								Total Estimated		**460**
								SE		**315**

** Assumed zero line, open water.*

Table 6: The number of harp seal pups counted on east-west transects and the estimated pup production obtained from the March 16, 2022, photographic survey of the northern Front (N. Front) whelping patch. SE, standard error.

Transect	Latitude	Start Longitude	End Longitude	Transect Spacing (m)	Transect Length (m)	Photos	Cover (%)	Pups Counted	Pups on Transect	Estimated Pups
1	52° 57.0'	-53° 50.3.0'	-52° 45.2'	5550	32,398	136	92	0	0.0	0.0
2	52° 54.0'	-53° 48.3.0'	-52° 39.4'	5550	66,474	278	91	1	1.1	18.9
3	52° 51.0'	-52° 26.0'	-53° 45.9'	5550	20,876	88	91	0	0.0	0.0
4	52° 48.0'	-52° 31.3.0'	-53° 41.6'	5550	61,196	256	91	2	2.2	37.6
5	52° 45.0'	-53° 39.4.0'	-52° 36.4'	5550	8,400	36	92	4	4.4	74.7
6	52° 42.0'	-53° 37.8.0'	-52° 22.8'	5550	42,716	180	91	0	0.0	0.0
7*	52° 39.0'	-	-	5550	-	-	-	0	0.0	0.0
7*	52° 39.0'	-	-	11100	-	-	-	0	0.0	0.0
8	52° 33.0'	-52° 14.8.0'	-53° 18.1'	11100	71,500	299	91	494	547.9	18711.9
9	52° 27.0'	-51° 37.5.0'	-53° 22.0'	11100	118,308	496	99	1781	1811.6	56570.7
10	52° 21.0'	-53° 17.5.0'	-51° 47.6'	11100	101,974	426	91	1304	1453.3	49413.7
11	52° 15.0'	-51° 44.0'	-53° 11.5'	11100	99,574	416	97	831	865.2	27468.9
12	52° 9.0'	-51° 31.9.0'	-53° 7.4'	11100	108,930	455	93	401	435.2	14485.7
13	52° 3.0'	-53° 3.8.0'	-51° 27.9'	11100	109,648	458	97	607	635.3	20187.2
14*	51° 47.0'	-	-	11100	-	-	-	0	0.0	0.0
								Total Estimated		**186,969**
								SE		**40,761**

* *Assumed zero line, open water.*

Table 7: The number of harp seal pups counted on east-west transects and the estimated pup production obtained from the March 25, 2022, photographic survey of the southern Front (S. Front) whelping patch. SE, standard error.

Transect	Latitude	Start Longitude	End Longitude	Transect Spacing (m)	Transect Length (m)	Photos	Cover (%)	Pups Counted	Pups on Transect	Estimated Pups
1*	51° 34.0'	-	-	18500	-	-	-	0	0.0	0
2	51° 24.0'	-52° 0.0'	-52° 50.1'	18500	58,074	243	94	482	526.7	28699.7
3	51° 14.0'	-51° 29.1'	-52° 49.9'	18500	94,072	393	87	562	660.4	38587.1
4	51° 4.0'	-52° 49.8'	-52° 24.3'	18500	29,758	125	98	112	117.1	17572.4
4	51° 4.0'	-52° 20.6'	-52° 15.7'	18500	5,760	25	99	99	102.2	0
4	51° 4.0'	-52° 8.3'	-51° 59.0'	18500	10,800	46	96	107	114.1	0
5	50° 54.0'	-52° 50.1'	-51° 30.6'	18500	93,196	389	89	218	252.2	7289.6
5	50° 54.0'	-52° 50.1'	-51° 30.6'	9250	93,196	389	0	218	252.2	3644.8
6	50° 49.0'	-51° 33.1'	-52° 49.6'	9250	89,808	379	88	444	517.3	15158.6
7	50° 44.0'	-52° 0.5'	-52° 49.5'	9250	57,592	241	96	205	219.8	12949.6
7	50° 44.0'	-51° 47.0'	-51° 57.7'	9250	12,480	53	94	169	184.1	0
7	50° 44.0'	-51° 31.7'	-51° 40.7'	9250	10,558	45	94	68	74.5	0
7	50° 44.0'	-51° 23.2'	-51° 24.6'	9250	1,680	8	105	3	3.1	0
8	50° 39.0'	-53° 20.1'	-51° 26.9'	9250	133,426	557	92	579	646.6	17959.5
9	50° 34.0'	-51° 26.4'	-53° 20.2'	9250	134,384	560	86	539	643.1	9532.9
9	50° 34.0'	-51° 26.4'	-53° 20.2'	18500	134,384	560	0	539	643.1	19065.7
10	50° 24.0'	-53° 34.3'	-52° 38.0'	18500	66,710	280	98	679	708.2	50625.4
10	50° 24.0'	-52° 33.8'	-52° 21.0'	18500	15,118	64	96	23	24.6	0
10	50° 24.0'	-52° 14.7'	-51° 36.0'	18500	45,834	192	93	193	212.0	0
10	50° 24.0'	-51° 29.4'	-51° 27.7'	18500	1,920	9	103	0	0.0	0
10	50° 24.0'	-51° 23.7'	-51° 20.6'	18500	3,600	16	99	2	2.1	0
11	50° 14.0'	-53° 20.3'	-51° 26.3'	18500	135,586	566	87	331	389.4	22870.8
12	50° 4.0'	-52° 39.2'	-53° 20.1'	18500	48,714	204	96	224	239.3	24818.4
12	50° 4.0'	-52° 26.8'	-52° 36.0'	18500	11,038	47	95	101	108.9	0
12	50° 4.0'	-51° 56.2'	-52° 23.5'	18500	32,638	137	82	72	90.3	0
13	49° 54.0'	-52° 57.0'	-53° 20.2'	18500	27,836	117	90	9	5.2	5724.6
13	49° 54.0'	-52° 51.4'	-52° 52.8'	18500	1,680	8	105	1	0.5	0
13	49° 54.0'	-52° 45.3'	-52° 47.1'	18500	2,160	10	99	2	1.1	0
13	49° 54.0'	-52° 26.5'	-52° 42.9'	18500	19,676	83	89	14	8.1	0

Transect	Latitude	Start Longitude	End Longitude	Transect Spacing (m)	Transect Length (m)	Photos	Cover (%)	Pups Counted	Pups on Transect	Estimated Pups
13	49° 54.0'	-52° 8.8'	-52° 20.7'	18500	14,160	60	89	53	30.7	0
13	49° 54.0'	-51° 57.0'	-52° 6.8'	18500	11,756	50	89	54	31.2	0
13	49° 54.0'	-51° 20.2'	-51° 57.0'	18500	33,840	142	86	33	20.2	0
13	49° 54.0'	-51° 20.2'	-51° 21.4'	18500	1,438	7	101	2	1.1	0
13	49° 54.0'	-52° 57.0'	-53° 20.2'	7400	27,836	117	90	9	5.2	2289.4
13	49° 54.0'	-52° 51.4'	-52° 52.8'	7400	1,680	8	105	1	0.5	0
13	49° 54.0'	-52° 45.3'	-52° 47.1'	7400	2,160	10	99	2	1.1	0
13	49° 54.0'	-52° 26.5'	-52° 42.9'	7400	19,676	83	89	14	8.1	0
13	49° 54.0'	-52° 8.8'	-52° 20.7'	7400	14,160	60	89	53	30.7	0
13	49° 54.0'	-51° 57'	-52° 6.8'	7400	11,756	50	89	54	31.2	0
13	49° 54.0'	-51° 20.2'	-51° 57.0'	7400	33,840	142	86	33	20.2	0
13	49° 54.0'	-51° 20.2'	-51° 21.4'	7400	1,438	7	101	2	1.1	0
14	49° 48.0'	-52° 8.3'	-52° 6.9'	7400	1,698	8	105	8	8.4	3018.9
14	49° 48.0'	-52° 5.0'	-51° 20.0'	7400	53,996	225	90	106	123.9	0
15	49° 44.0'	-51° 24.2'	-52° 5.0'	7400	48,958	205	108	259	271.7	6162.5
15	49° 44.0'	-51° 10.0'	-51° 16.4'	7400	7,680	33	90	1	1.2	0
16	49° 40.0'	-52° 14.1'	-51° 5.1'	7400	83,038	347	91	232	266.8	14435.4
17	49° 36.0'	-52° 5.8'	-51° 8.5'	7400	69,020	287	92	327	373.4	0
18	49° 32.0'	-52° 4.8'	-51° 8.5'	7400	67,920	284	92	137	156.2	3469.4
19	49° 28.0'	-52° 6.2'	-51° 36.8'	7400	35,518	149	89	51	60.2	1376.8
19	49° 28.0'	-51° 28.8'	-51° 8.0'	7400	25,198	106	76	101	139.1	3727.3
20	49° 24.0'	-51° 55.4'	-51° 51.3'	7400	5,040	22	91	4	4.6	1759.6
20	49° 24.0'	-51° 48.5'	-51° 36.4'	7400	14,642	62	92	64	72.9	0
20	49° 24.0'	-51° 24.1'	-51° 3.2'	7400	25,200	106	93	76	85.3	6301
21	49° 20.0'	-51° 34.2'	-51° 29.8'	7400	5,280	23	91	28	32.3	0
21	49° 20.0'	-51° 23.7'	-51° 2.7'	7400	25,440	107	89	133	156.1	0
22*	49° 16.0'	-	-	7400	-	-	-	0	0.0	0
								Total Estimated		**317,039**
								SE		**47,798**

** Assumed zero line, open water.*

Table 8: The number of harp seal pups counted in individual age dependent stages in the southern Gulf of St. Lawrence (S. Gulf) whelping patch between February 26 and March 16, 2022.

Area	Date	Newborn	Thin White	Fat White/Grey	Ragged/Beater	Total
S. Gulf	Feb 26	23	249	0	0	272
S. Gulf	March 3	66	793	476	0	1335
S. Gulf	March 4	5	279	204	0	480
S. Gulf	March 9	3	19	206	0	228
S. Gulf	March 10	2	22	513	0	537
S. Gulf	March 14	0	11	2139	45	2195
S. Gulf	March 16	0	5	1004	39	1048

Table 9: The numbers of harp seal pups counted in individual age dependent stages in the northern Gulf of St. Lawrence (N. Gulf) and Front whelping patches between March 10-24, 2022. See Figure 1 and Figure 7 for locations of the patches.

Area	Patch	Date	Newborn	Thin White	Fat White	Grey	Ragged	Beater	Total
N. Gulf	Blanc Sablon	March 10	28	341	131	0	0	0	500
N. Gulf	Blanc Sablon	March 10	0	53	0	0	0	0	53
N. Gulf	Blanc Sablon	March 14	0	98	400	60	0	0	561
N. Gulf	St. Barbe	March 14	0	46	23	1	0	0	70
N. Gulf	Blanc Sablon	March 17	0	25	502	243	9	1	780
Front	Black Tickle	March 7	174	1179	0	0	0	0	1353
Front	Williams Harbour	March 11	1	593	104	0	0	0	698
Front	St. Anthony	March 11	9	86	36	5	0	0	136
Front	St. Anthony	March 12	0	430	167	13	0	0	610
Front	Fogo Island	March 12	0	120	67	13	0	0	200
Front	Black Tickle	March 15	0	128	1184	97	0	2	1411
Front	Williams Harbour	March 16	0	38	597	114	3	3	755
Front	Williams Harbour	March 17	0	1	11	1	1	0	14
Front	St. Anthony	March 17	0	48	194	123	3	0	368
Front	Fogo Island	March 17	0	7	73	42	1	0	123
Front	Black Tickle	March 19	0	6	611	521	22	0	1160
Front	St. Anthony	March 24	0	0	30	196	180	15	421

Table 10: Information from the Bayesian birth distribution model including the prior shape and rates and the estimated durations, shapes and rates for the four stages for the southern and northern Gulf of St. Lawrence (S. Gulf, N. Gulf), and the Front. sd, standard deviation.

Region	**Stage**	**Shape (prior)**	**Rate (prior)**	**Duration (d; mean ± sd; est)**	**Shape (mean ± sd; est)**	**Rate (mean ± sd; est)**
S. Gulf	1; Newborn/Yellow	18.5	7.5	2.14 ± 0.61	18.49 ± 1.32	8.58 ± 1.42
	2; Thin White	18.5	4	6.81 ± 1.63	18.49 ± 1.32	2.57 ± 0.41
	3; Fat White/Grey	18.5	1.2	16.53 ± 2.76	18.49 ± 1.32	0.90 ± 0.09
	4; Ragged/Beater	18.5	0.6	-	18.49 ± 1.32	0.58 ± 1.19
	Sum (stages 1-3)	-	-	25.49 ± 2.61	-	-
N. Gulf	1; Newborn/Yellow	18.5	7.5	2.50 ± 0.79	18.25 ± 1.25	7.62 ± 1.45
	2; Thin White	18.5	4	6.20 ± 1.73	18.25 ± 1.25	3.12 ± 0.54
	3; Fat White/Grey	18.5	1.2	12.66 ± 3.29	18.25 ± 1.25	1.55 ± 0.38
	4; Ragged/Beater	18.5	0.6		18.25 ± 1.25	0.30 ± 0.87
	Sum (stages 1-3)	-	-	21.37 ± 2.94	-	-
Front	1; Newborn/Yellow	18.5	7.5	2.81 ± 0.95	17.97 ± 1.42	6.72 ± 1.48
	2; Thin White	18.5	4	7.32 ± 177	17.97 ± 1.42	2.52 ± 0.20
	3; Fat White/Grey	18.5	1.2	11.89 ± 2.29	17.97 ± 1.42	1.54 ± 0.14
	4; Ragged/Beater	18.5	0.6	-	17.97 ± 1.42	0.52 ± 0.95
	Sum (stages 1-3)	-	-	22.02 ± 2.55	-	-

Table 11: Estimated proportions of Northwest Atlantic Harp Seal pups on the ice at the time of the surveys.

Area	Survey Type	Date	Estimate	Confidence Interval	Correction Applied
S. Gulf	Photo	March 5	0.997	0.982-1.000	No
S. Gulf	Photo	March 7	1.000	0.996-1.000	No
N. Gulf	Photo	March 11	1.000	0.990-1.000	No
Front	Photo	March 16	1.000	1.000-1.000	No
Front	Photo	March 25	1.000	1.000-1.000	No

Table 12: Estimated 2022 NWA harp seal pup production. Estimates in bold are used in the final total. SE, standard error. CV, coefficient of variation. SE, standard error. CV, coefficient of variation.

Area	Patch	Date	Estimate	SE	CV
Southern Gulf	-	March 5	65,973	36,411	0.552
	-	March 9	60,565	46,030	0.760
		Averaged	**63,892**	**28,557**	**0.447**
Northern Gulf	Blanc-Sablon	March 11	45,747	8,623	0.188
	St. Barbe	March 12	460	315	0.686
		Combined	**46,207**	**8,628**	**0.187**
Front	Northern	March 16	186,969	40,761	0.218
	Southern	March 25	317,039	47,798	0.151
		Combined	**504,009**	**62,818**	**0.125**
Total			**614,108**	**69,542**	**0.113**

Table 13: Northwest Atlantic Harp Seal pup production estimates (rounded to nearest 100) from aerial surveys completed since 1990 (with Standard Error in parentheses), and the proportion (prop.) of pupping in each component. SD, standard deviation.

Year	Southern Gulf	prop.	Northern Gulf	prop.	Front	prop.	Total
1990	106,000 (23,000)	0.18	4,400 (1,300)	0.01	467,000 (31,000)	0.81	578,000 (39,000)
1994	198,600 (24,200)	0.28	57,600 (13,700)	0.08	446,700 (57,200)	0.64	702,900 (63,600)
1999	176,200 (25,400)	0.18	82,600 (22,500)	0.08	739,100 (96,300)	0.74	997,900 (102,100)
2004	261,000 (25,700)	0.26	89,600 (22,500)	0.09	640,800 (46,900)	0.65	991,400 (58,200)
2008	287,000 (27,600)	0.17	172,600 (22,300)	0.1	1,185,000 (112,500)	0.72	1,644,500 (117,900)
2012	115,500 (15,100)	0.14	74,100 (12,400)	0.09	626,200 (66,700)	0.77	815,900 (69,500)
2017	18,300 (1,500)	0.02	13,600 (3,000)	0.02	714,600 (89,700)	0.96	746,500 (89,800)
2022	63,900 (28,500)	0.10	46,200 (8,600)	0.08	504,000 (62,800)	0.82	614,100 (69,500)
Average	-	0.16	-	0.07	-	0.76	-
SD	-	0.08	-	0.03	-	0.10	-

FIGURES

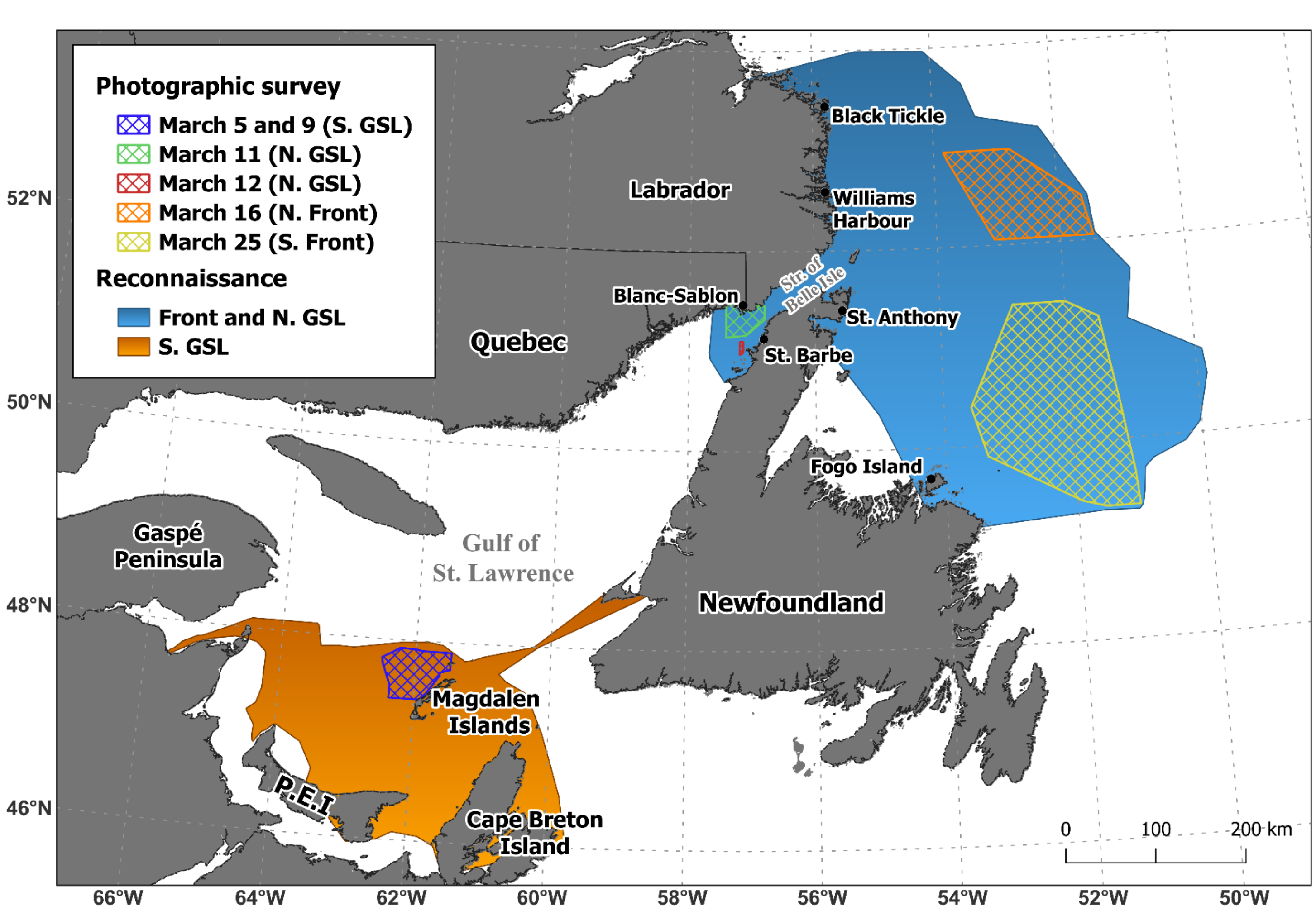


Figure 1: Reconnaissance areas and locations of whelping patches identified during the 2022 Harp Seal survey.

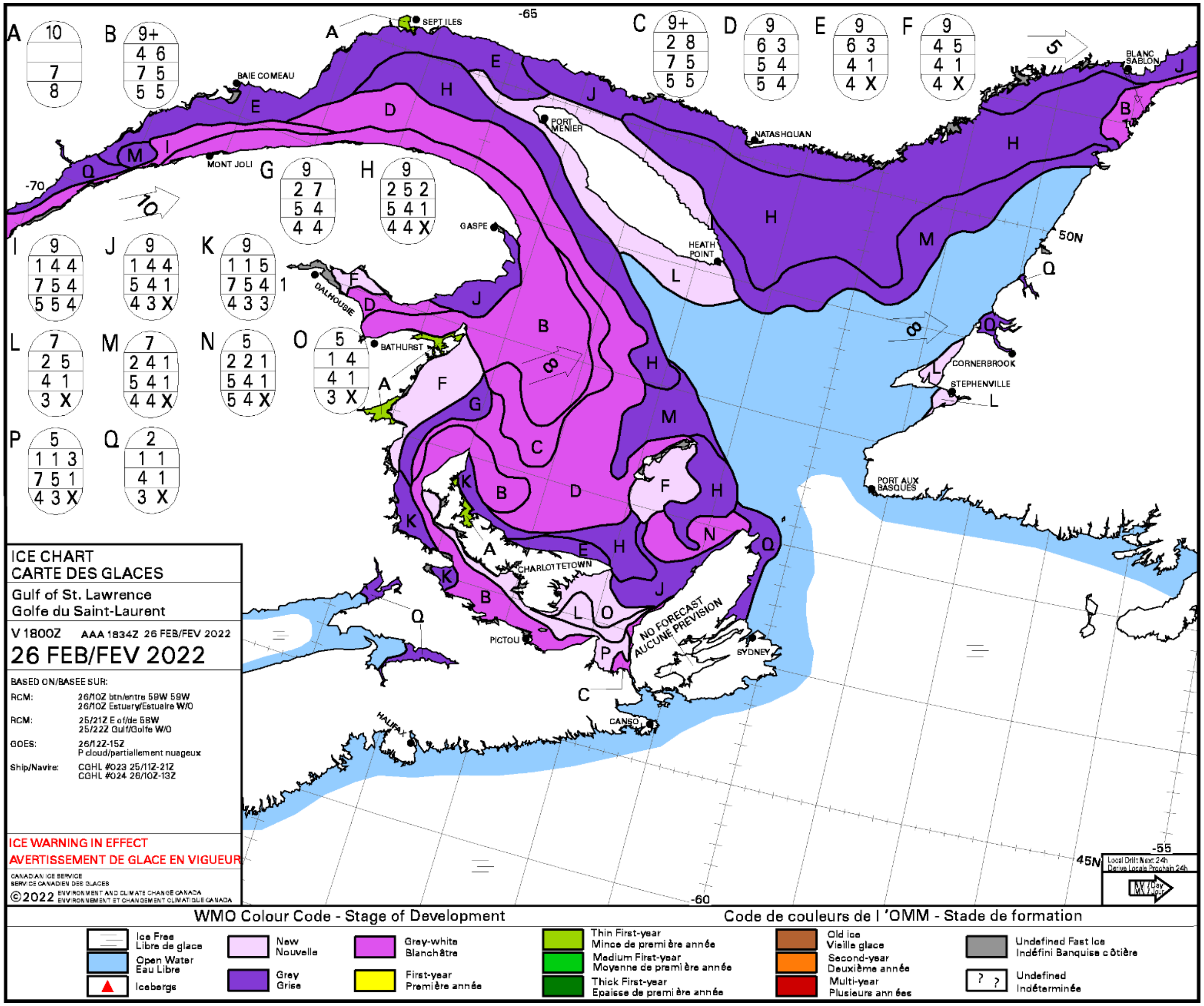


Figure 2: Ice map showing location and type of ice in the Gulf of St. Lawrence on February 26, 2022 (Source: [Canadian Ice Service]()).

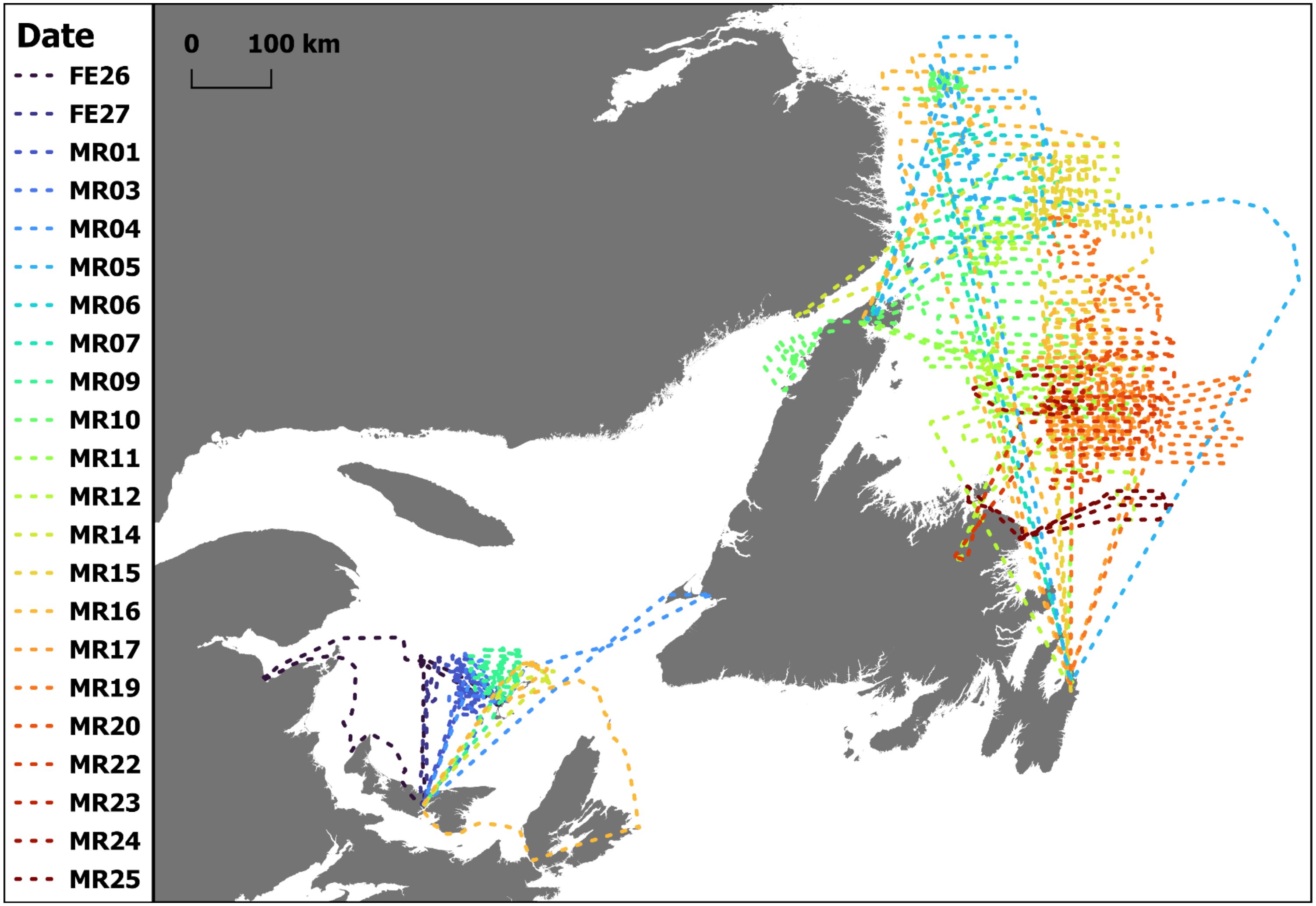


Figure 3: Near-daily reconnaissance effort conducted during the northwest Atlantic harp seal pup production survey, February 26 to March 25, 2022.

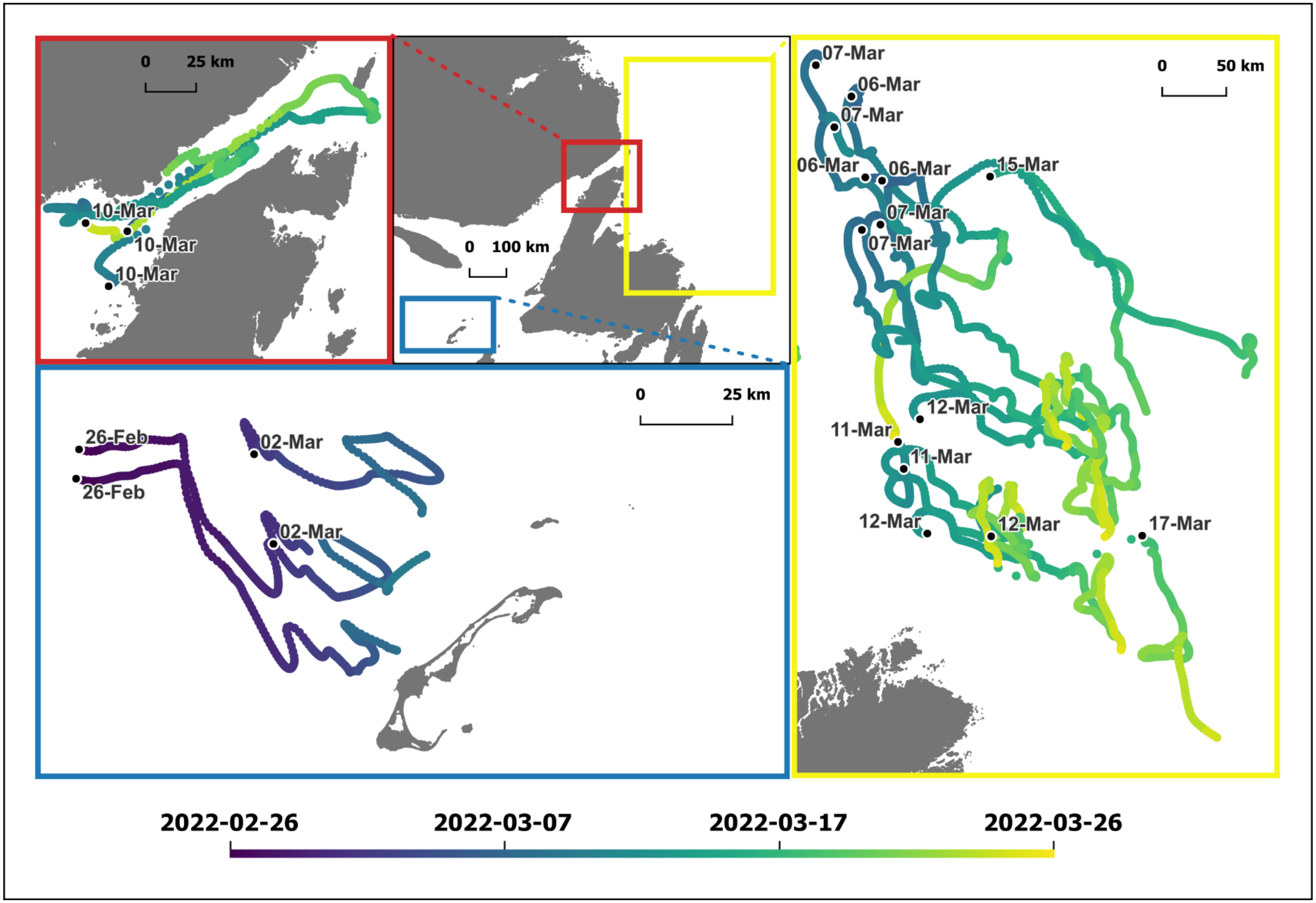


Figure 4: Movement over time of satellite-linked GPS transmitters deployed in whelping patches to monitor ice movement during the March 2022 harp seal survey in the southern Gulf of St. Lawrence (blue box), northern Gulf of St. Lawrence (red box), and at the Front (yellow box). Date and location of transmitter deployments are indicated (black dots). Locations were estimated at a 1-hour interval using a correlated random walk state-space model using the R package aniMotum (Jonsen et al. 2023).

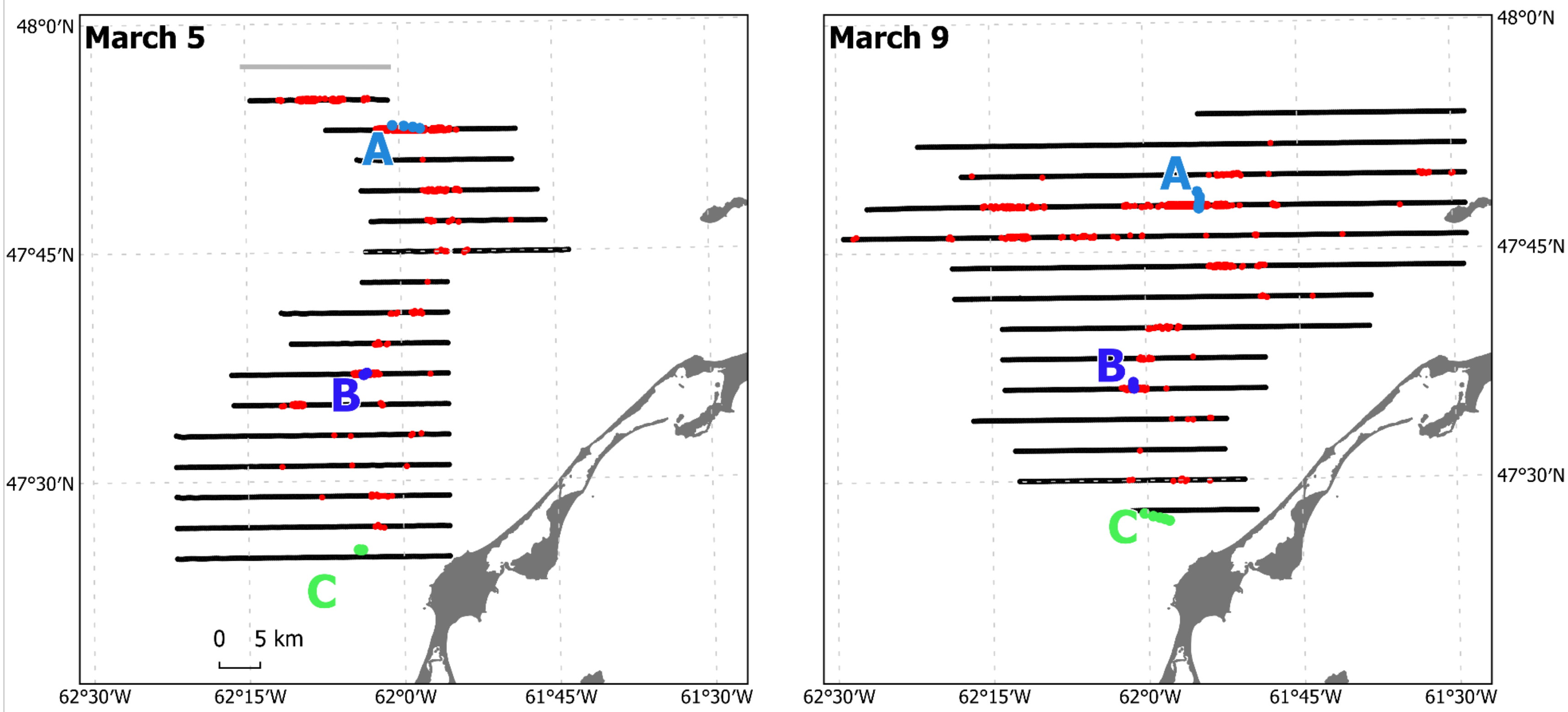


Figure 5: Survey transects (black lines) flown during the March 5 (left) and March 9 (right) photographic surveys of the southern Gulf of St. Lawrence harp seal whelping patch. Red dots indicate the location of seal pups during the surveys. The grey line is an assumed zero pup transect which was not photographed due to absence of suitable sea ice. Locations of three (A to C) satellite-linked GPS transmitters are shown for the time of survey corresponding to each map.

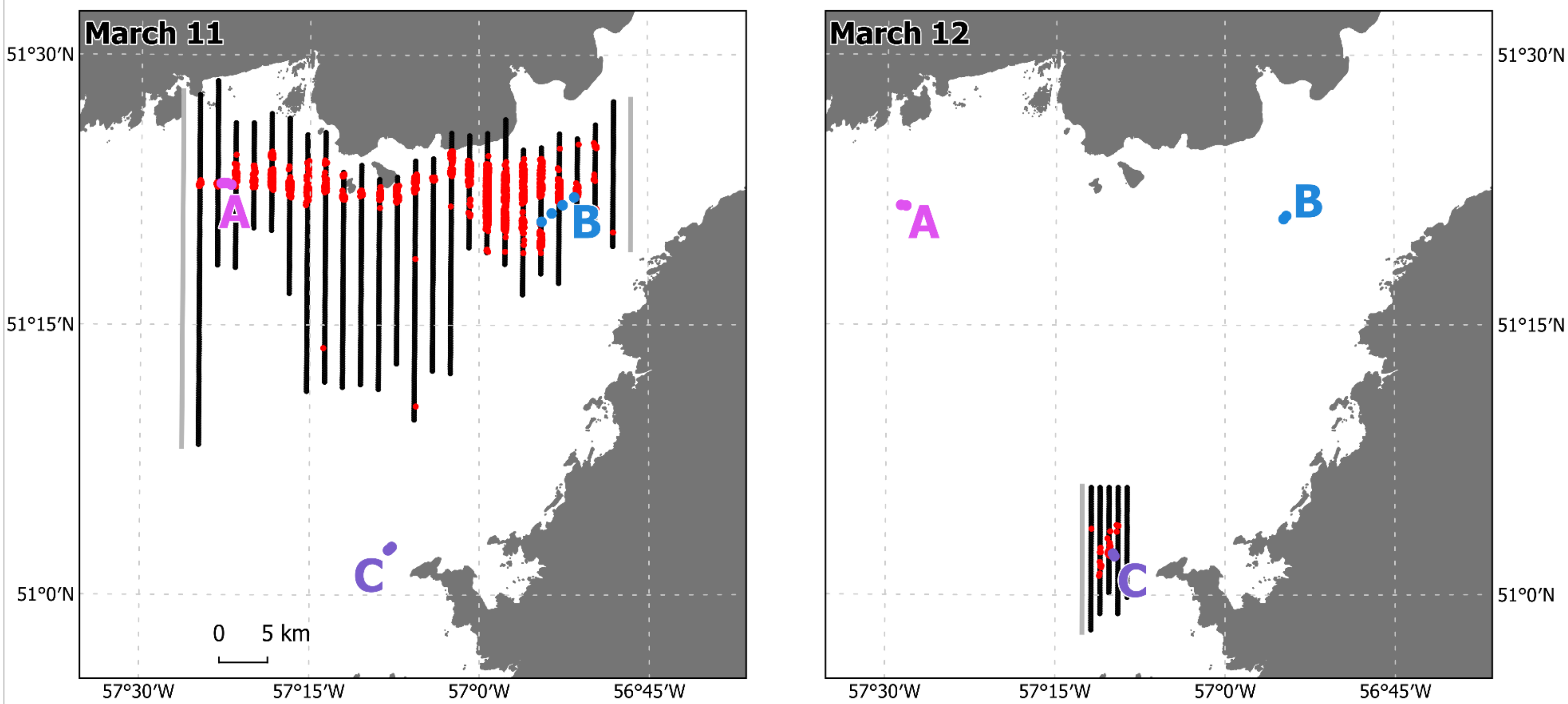


Figure 6: Survey transects (black lines) flown during the March 11 (left) and March 12 (right) photographic surveys of the northern Gulf of St. Lawrence harp seal whelping patches. Red dots indicate the location of seal pups during the surveys. Grey lines are assumed zero pup transects which were not photographed due to absence of suitable sea ice. Locations of three (A to C) satellite-linked GPS transmitters are shown for the time of survey corresponding to each map.

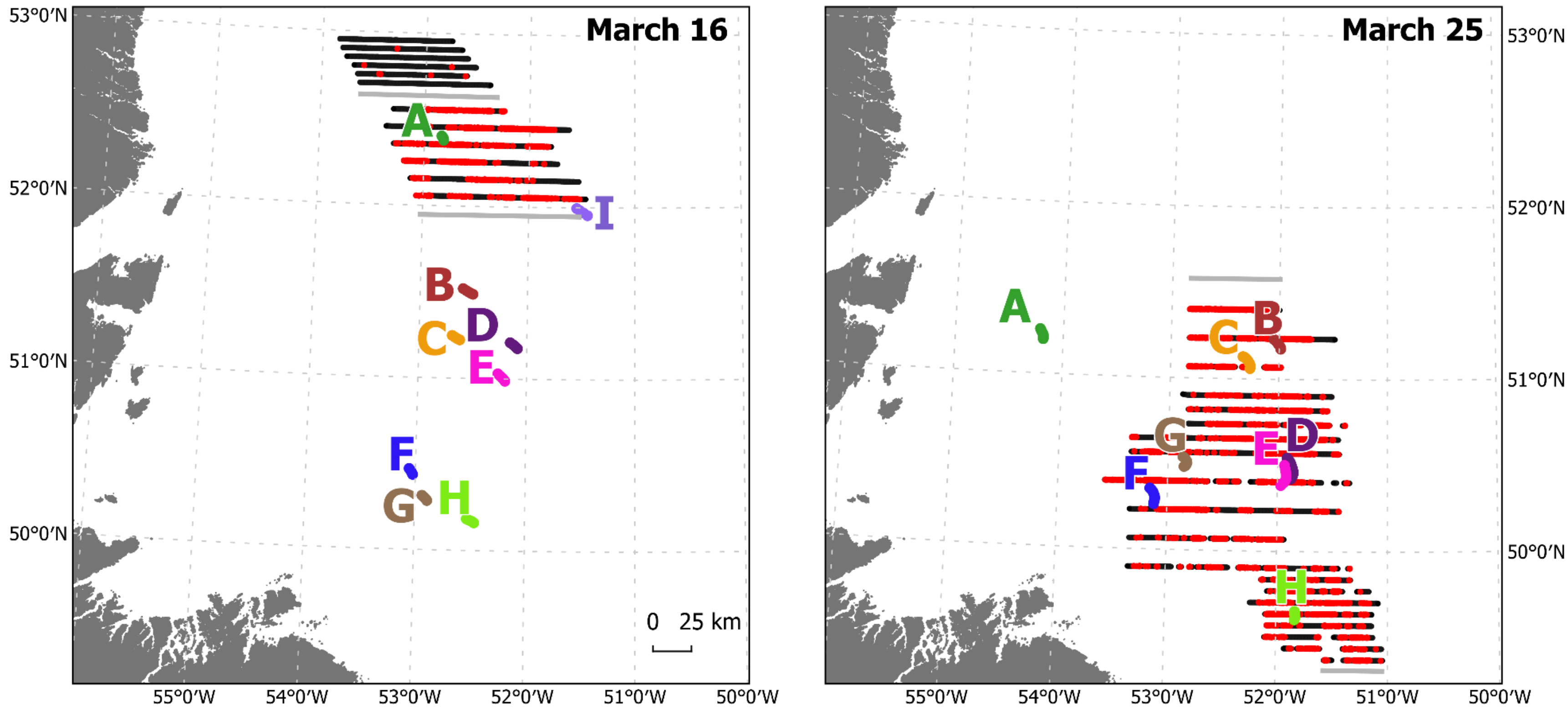


Figure 7: Survey transects (black lines) flown during the photographic surveys of the Front harp seal whelping patches on March 16 (northern Front, left) and March 25 (southern Front, right). Red dots indicate the location of seal pups during the surveys. Grey lines are assumed zero pup transects which were not photographed due to absence of suitable sea ice. Locations of nine (A to I) satellite-linked GPS transmitters are shown for the time of survey corresponding to each map. Transmitter 'I' had ceased transmitting by March 25.

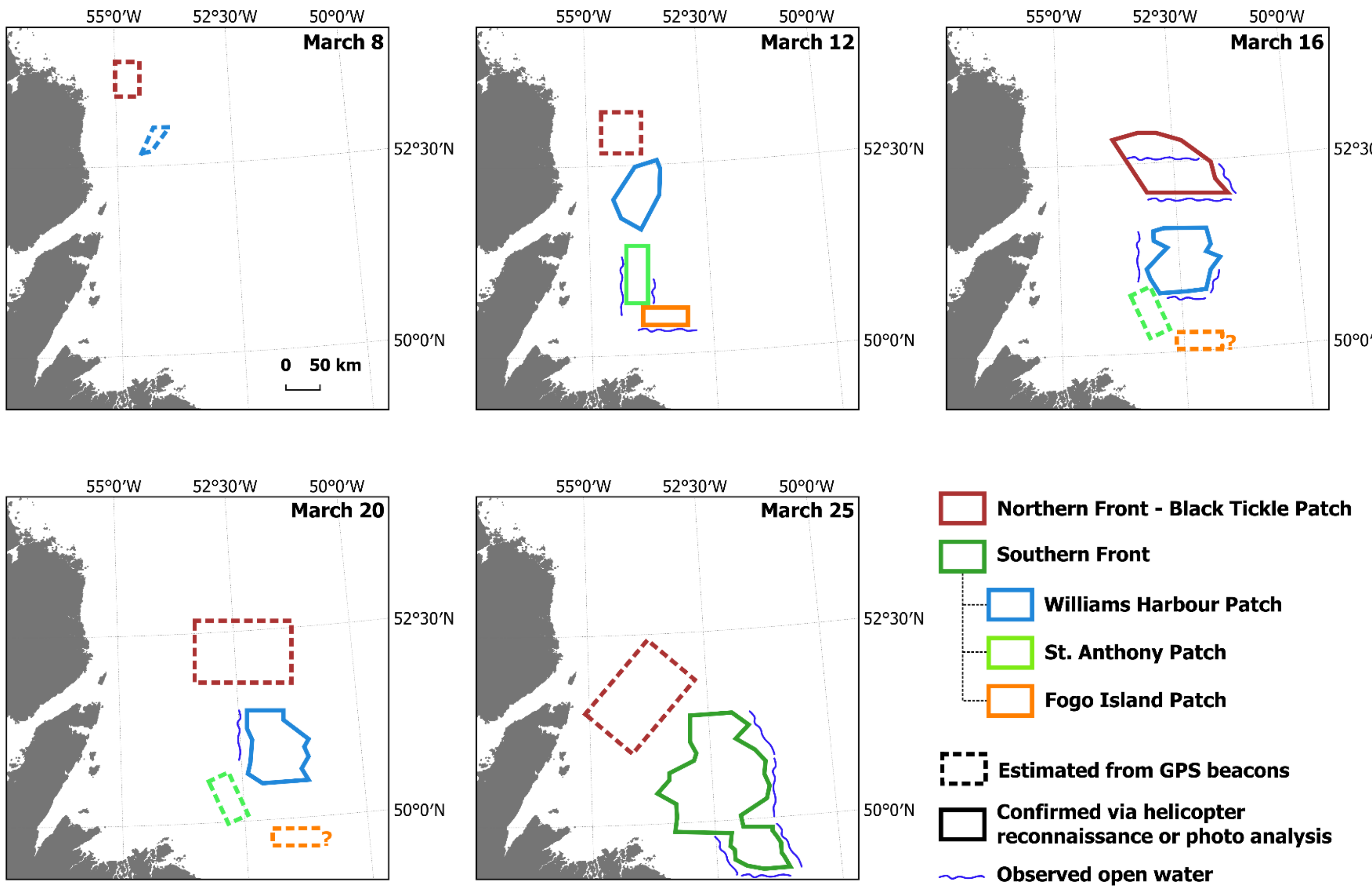
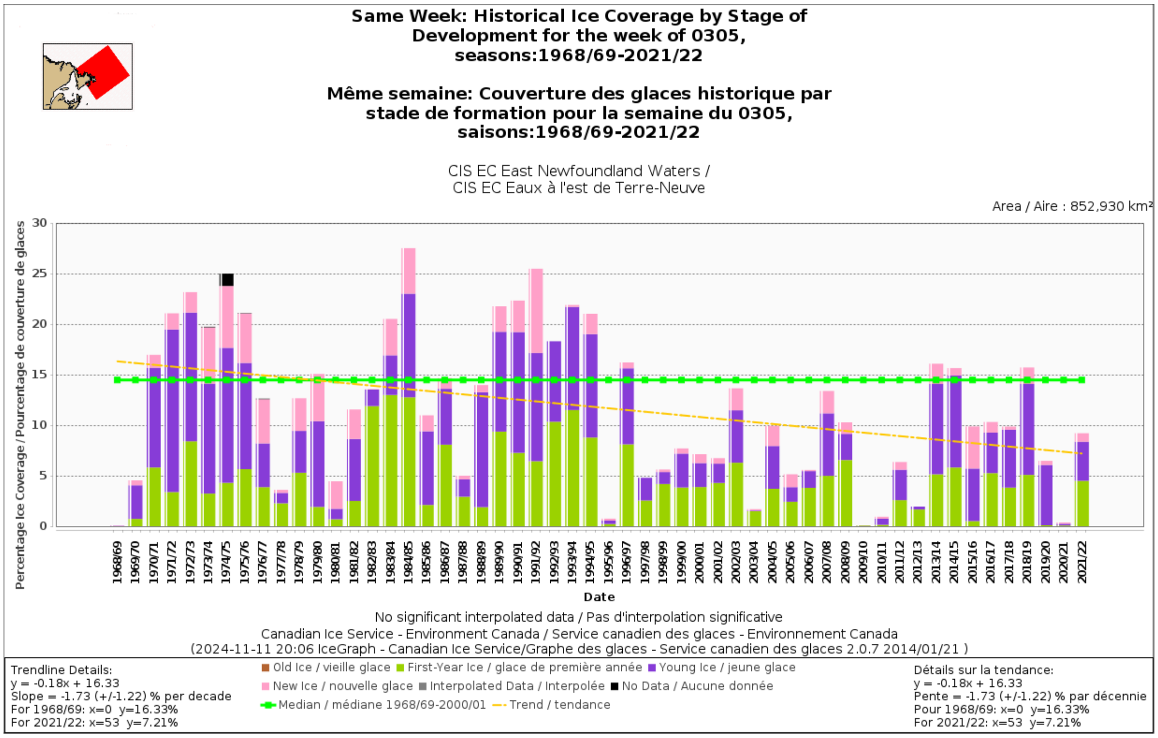


Figure 8: Movement of harp seal whelping patches on drifting sea-ice off the Front over the course of the 2022 pup production survey. Patches were delineated by aircraft reconnaissance and monitored using satellite-linked GPS transmitters deployed on the ice by helicopter. St. Anthony and Fogo Island patches had not yet been delineated on March 10.



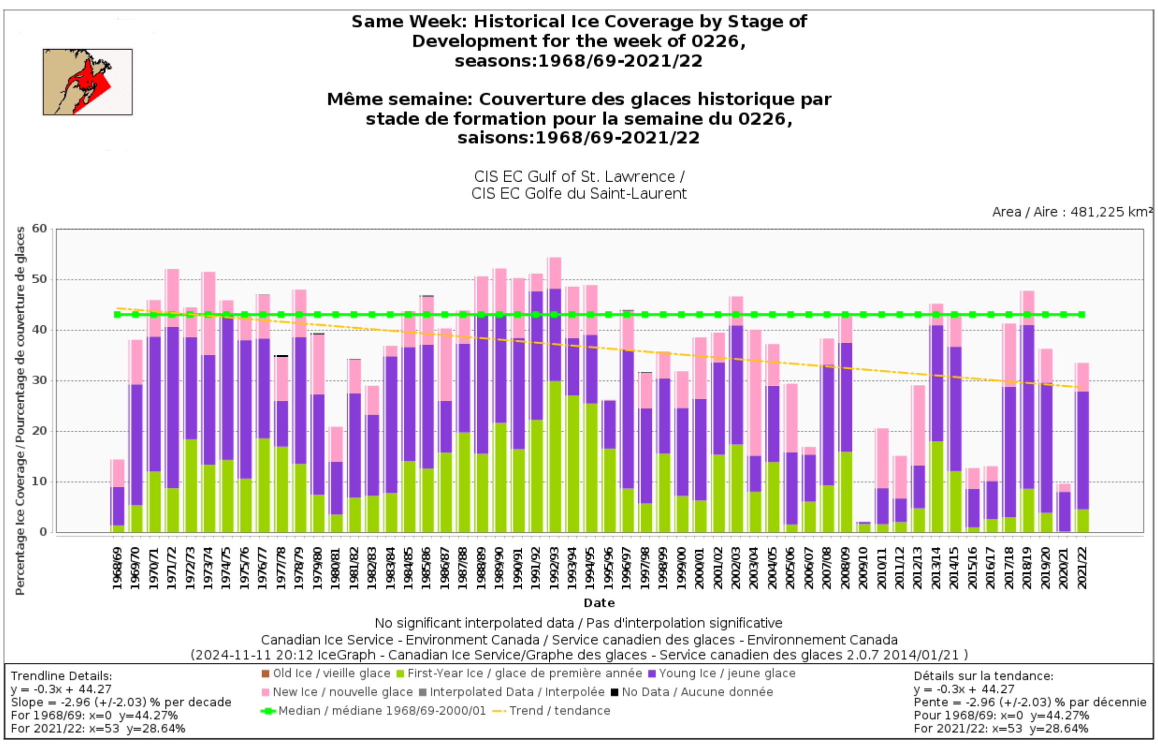


Figure 9: Historic ice cover (1969–2022), by type, off of southern Labrador (top, week of March 3), and in the southern Gulf of St. Lawrence (bottom, week of February 26). Harp Seals prefer first year ice.

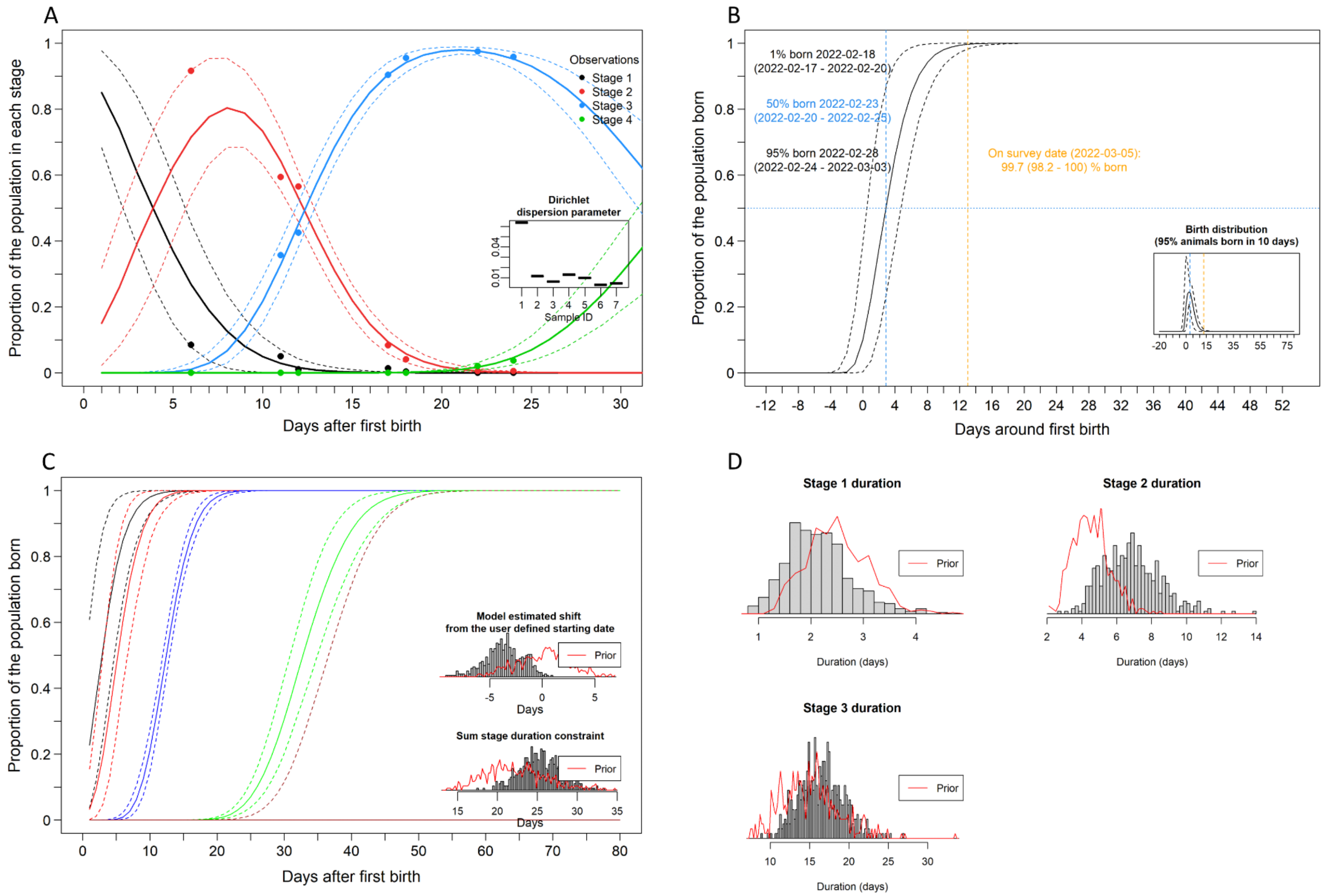


Figure 10: Output from the Bayesian birth distribution model for the southern Gulf of St. Lawrence showing A) estimated proportion (median ± 95% CI) of pups in each stage, the observed proportions (points) from the staging data and the Dirichlet dispersion parameters (inset figure) from the staging data; B) predicted birth curve (median ± 95% CI) showing the proportion born (± 95% CI) on the March 5 survey date and the date at which 1%, 50% and 95% of the pups were born; C) birth and transition curves (median ± 95% CI) for the different stages; and D) barplots showing the posteriors of the distributions and the prior (red line) for the duration of the first three stages.

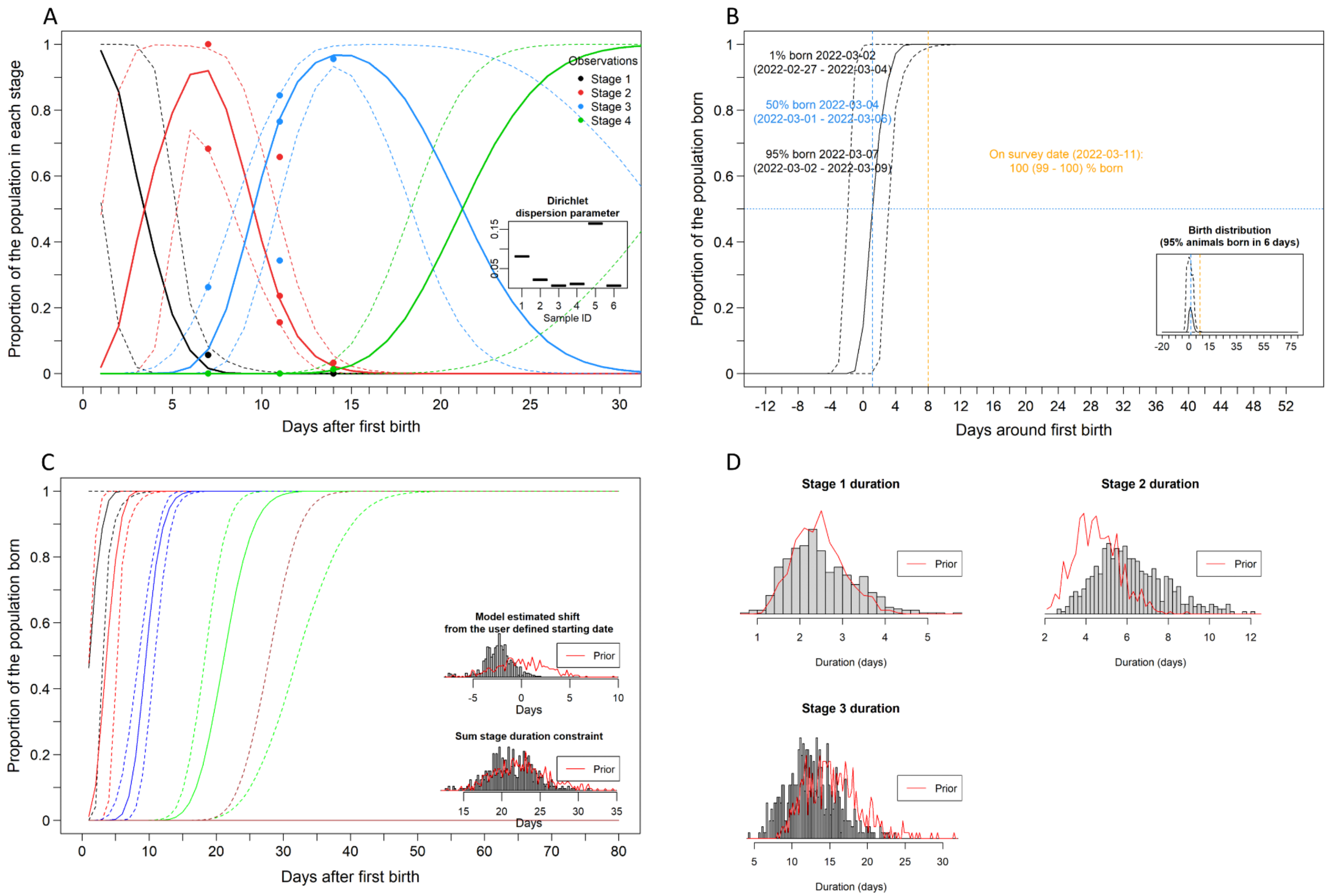


Figure 11: Output from the Bayesian birth distribution model for the northern Gulf of St. Lawrence showing A) estimated proportion (median ± 95% CI) of pups in each stage, the observed proportions (points) from the staging data and the Dirichlet dispersion parameters (inset figure) from the staging data; B) predicted birth curve (median ± 95% CI) showing the proportion born (± 95% CI) on the March 11 survey date and the date at which 1%, 50% and 95% of the pups were born; C) birth and transition curves (median ± 95% CI) for the different stages; and D) barplots showing the posteriors of the distributions and the prior (red line) for the duration of the first three stages.

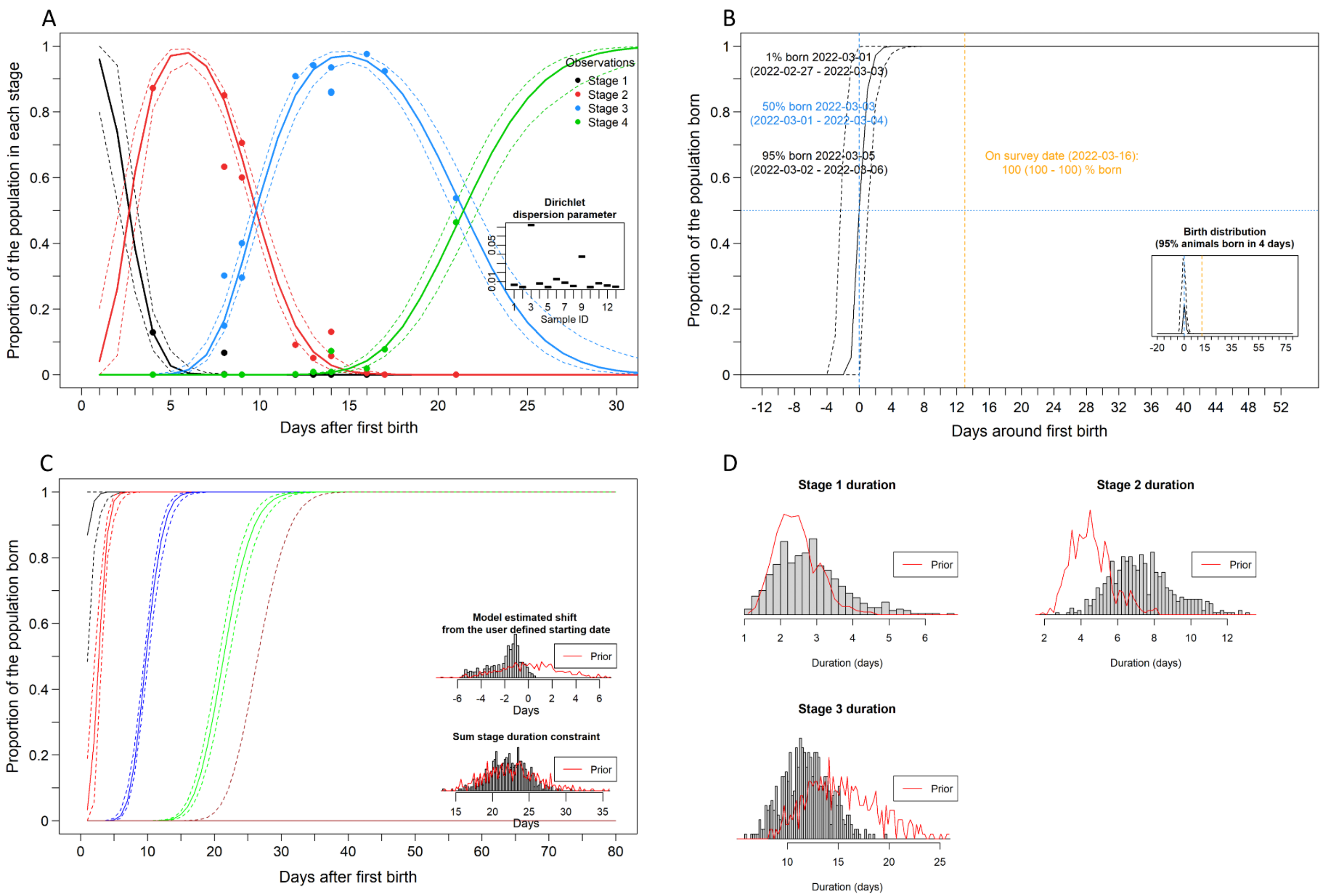


Figure 12: Output from the Bayesian birth distribution model for the Newfoundland Front showing A) estimated proportion (median ± 95% CI) of pups in each stage, the observed proportions (points) from the staging data and the Dirichlet dispersion parameters (inset figure) from the staging data; B) predicted birth curve (median ± 95% CI) showing the proportion born (± 95% CI) on the March 16 survey date and the date at which 1%, 50% and 95% of the pups were born; C) birth and transition curves (median ± 95% CI) for the different stages; and D) barplots showing the posteriors of the distributions and the prior (red line) for the duration of the first three stages.

APPENDIX

For the 2017 pup production survey a modified version of the transition model developed by Myers and Bowen (Bowen et al. 1987; Myers and Bowen 1989, Stenson et al. 2020b) was used to estimate the proportion of pups born on the survey dates. Here we fit the modified version of the Myers birth distribution model to the 2022 staging transect data for the southern Gulf of St. Lawrence (S. Gulf), northern Gulf of St. Lawrence (N. Gulf), and the Front (Table 8, Table 9) to compare results to those obtained for the 2022 survey using a modified version of the Bayesian birth distribution model developed by Mosnier et al. (2023).

A separate model was run for each of the regions to estimate the proportion of pups born by the respective survey dates for each region. We fit the same four pup stages as the Bayesian birth distribution model (Table 10). The shape and rate parameters used for the priors in the Bayesian model fitting (Table 10) were used to fit the Myers model for each region. The distribution of pups born over time was modelled using the gamma probability distribution.

The Myers model assumes the date of first birth is known. Both the fit of the model and the estimated proportion born at the time of the survey can be sensitive to the date used for first birth. Therefore, models were initially fit using:

1. The date of first birth estimated from observations made during reconnaissance flights and the initial staging transects and,
2. The estimated date of first birth obtained from the Bayesian birth distribution models (Table A1).

For the dates of first birth estimated from observations, the models for all regions failed to converge without errors (Table A1).

For the S. Gulf the model which used the date of first birth estimated from the Bayesian birth distribution model (February 16) converged without error (Table A1). Subsequent models were fit with increasing dates of first birth until models failed to converge without error. Based on the AIC (Akaike Information Criterion), the model which used February 16 as the date of first birth was the preferred model with an estimated proportion of 1.0 for pups born at the time of the first survey (March 5; Table A1, Figure A1).

For the N. Gulf and the Front the models using the dates of first birth estimated from the Bayesian birth distribution model (March 1) failed to converge without error (Table A1). Subsequent models were fit using the lower credible interval (CrI) from the estimated date of first birth from the Bayesian birth distribution models (February 25 and 26 for the N. Gulf and Front, respectively). These models converged without error. Subsequent models were fit with increasing dates of first birth until models failed to converge without error. Based on the AIC, the models which used February 26 as the date of first birth were the preferred models for both regions with an estimated proportion of 1.0 for pups born at the time of the survey in the N. Gulf (March 11) and the first survey at the Front (March 16) (Table A1, Figure A1).

These results are consistent with those obtained using the modified version of the Bayesian birth distribution model developed by Mosnier et al. (2023) (Table 11).

Table A1: Comparison of the fit of Myers birth distribution models to staging transect data from the southern Gulf of St. Lawrence (S. Gulf), northern Gulf of St Lawrence (N. Gulf) and the Front. Values are reported only for the models which converged without errors. AIC, Akaike Information Criterion. Values in bold indicate the preferred model.

Region	Estimated Date of First Birth	Model Convergence	Shape	Rate	Survey Date	Proportion Born	AIC
S. Gulf	February 20[a]	Yes, but with errors	-	-	-	-	-
	February 16[b]	Yes	8.18 (2.23)	1.09 (0.26)	March 5[d]	1.0 (0)	**-5064.77**
	February 17	Yes	6.35 (1.78)	0.98 (0.24)	March 5[d]	1.0 (0)	-5053.88
	February 18	Yes, but with errors	-	-	-	-	-
N. Gulf	March 3[a]	Yes, but with errors	-	-	-	-	-
	March 1[b]	Yes, but with errors	-	-	-	-	-
	February 25[c]	Yes	7.50 (0.83)	1.29 (0.13)	March 11	1.0 (0)	-1850.86
	February 26	Yes	5.27 (0.58)	1.10 (0.09)	March 11	1.0 (0)	**-1854.68**
	February 27	Yes, but with errors	-	-	-	-	-
Front	March 3[a]	No	-	-	-	-	-
	March 1[b]	Yes, but with errors	-	-	-	-	-
	February 26[c]	Yes	5.88 (5.69)	1.24 (0.92)	March 16[e]	1.0 (0)	**-6582.66**
	February 27	Yes	3.86 (4.20)	1.03 (0.82)	March 16[e]	1.0 (0)	-6567.94
	February 28	Yes, but with errors	-	-	-	-	-

[a] estimated based on observations from reconnaissance flights and initial staging transects

[b] estimate from the Bayesian birth distribution model

[c] lower credible interval (CrI) of the estimate from Bayesian birth distribution model

[d] first photographic survey date, a second photographic survey occurred on March 7

[e] first photographic survey date, a second photographic survey occurred on March 25

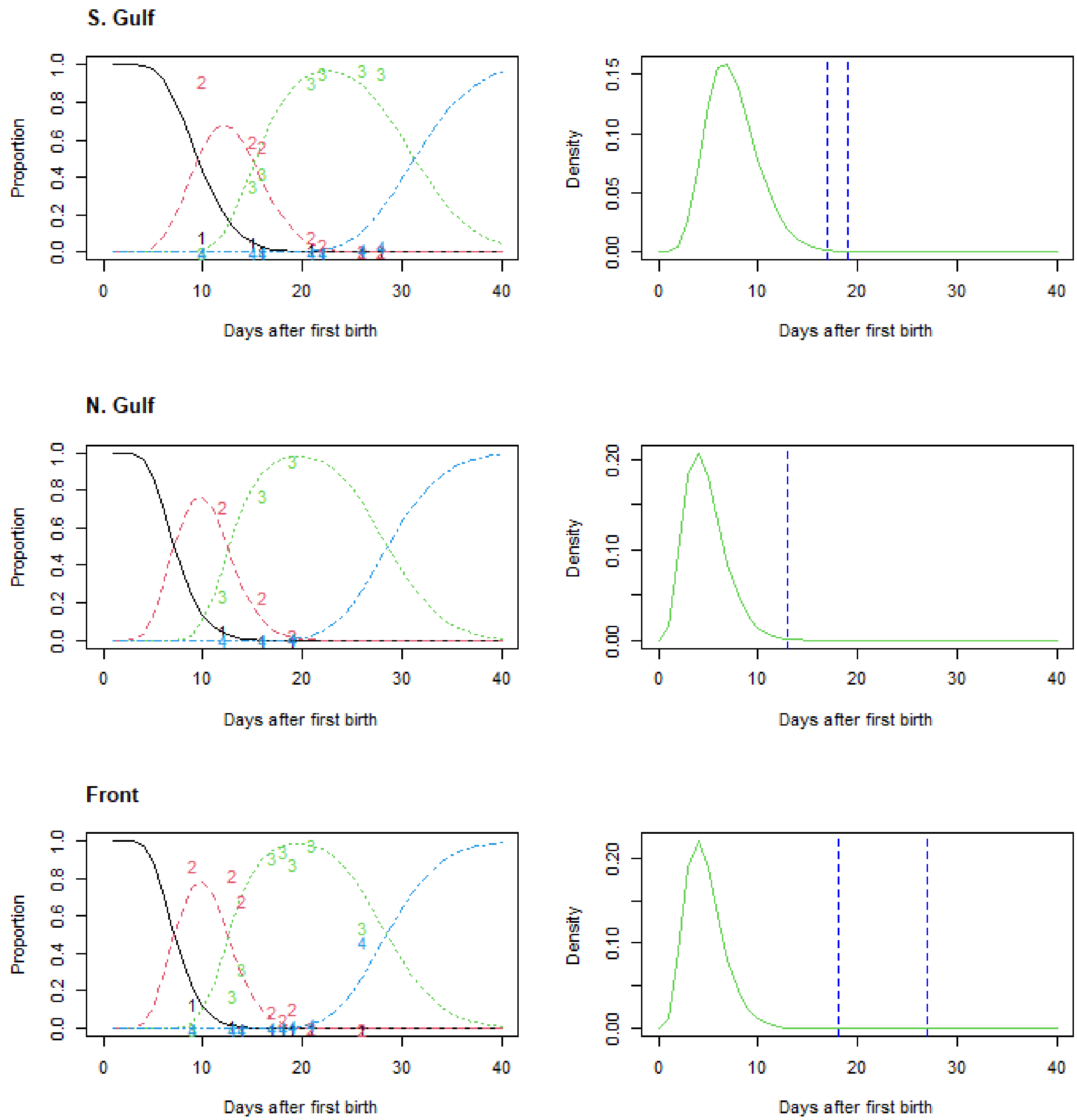


Figure A1: Output from the selected Myers birth distribution models for the southern Gulf of St. Lawrence (S. Gulf), northern Gulf of St Lawrence (N. Gulf) and the Front showing the estimated proportion of pups in each stage (left panels) and the predicted birth curves (right panels). Vertical dotted lines in the right panels indicate the days of the photographic surveys. The dates of first birth used in the model were February 16, 2022 for the S. Gulf and February 26, 2022 for both the N. Gulf and the Front.