Northwest Atlantic Fisheries Organization

Serial No. N948

NAFO SCR Doc. 85/I/14

SCIENTIFIC COUNCIL MEETING - JANUARY 1985

Estimation of Pup Production of Hooded Seals (*Cystophora cristata*) in the Northwest Atlantic during March 1984

by

K. Hay and R. A. Myers

Fisheries Research Branch, Department of Fisheries and Oceans
P. O. Box 5667, St. John's, Newfoundland, Canada A1C 5X1

and

W. D. Bowen

Marine Fish Division, Department of Fisheries and Oceans
P. O. Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2

Introduction

Hooded seals, Cystophora cristata, are known to whelp on floe ice during March-April in three areas in the North Atlantic: at the "West Ice" near Jan Mayen Island, at the "Front" off northeastern Newfoundland and at a recently rediscovered area in the Davis Strait (Sergeant 1974, 1976). A small number of pups (likely <1000 in most years) are also born in the Gulf of St. Lawrence (Sergeant 1966, pers. comm.). After breeding, hooded seals migrate to moult on the pack ice east of Greenland in the Denmark Strait between 66° and 68°N (Rasmussen 1960) and between 72° and 76°N (Sergeant 1974, 1976) during June/July. It is believed, though based on scant evidence, that the entire North Atlantic population moults in these areas. After moulting, the seals disperse widely to feed. During this period their distribution is poorly known.

The relationship and degree of genetic exchange between the Jan Mayen, Davis Strait and Newfoundland populations are not fully understood. Rasmussen (1960) noted that short-term fluctuations in the catch and catch per unit effort of hooded seals at Newfoundland are greater than those of harp seals. He believed that during warm periods the ice was unsuitable at Newfoundland and the animals retreated north. Further, Sergeant (1974) felt that if the Newfoundland population was isolated, it would long ago have been exterminated by the intensive hunting which included an adult kill of 60% females between 1964 and 1973. Seals tagged off Newfoundland or in the Gulf of St. Lawrence have been recaptured off east and west Greenland (Sergeant 1974, 1978, pers. comm.); several seals tagged at Denmark Strait have been captured at west Greenland and Newfoundland supporting the notion of intermixing at least during the non-breeding season. However, no tagged Jan Mayen hooded seals have been recovered at Denmark Strait, Davis Strait or Newfoundland (Øritsland, pers. comm.). Furthermore, a recent study by Bergflodt and Øritsland (1983) found no significant difference in the frequency of supernumerary teeth between samples collected at Newfoundland and Denmark Strait, but a highly significant difference between pooled samples from Newfoundland and Denmark Strait compared to those from Jan Mayen. These data are consistent with tagging results which suggest possible genetic isolation of hooded seals in the West Ice from those in the northwest Atlantic. But an analysis of morphological relationships between these same populations found no multivariate separation of the stocks and concluded that there are few genetic differences between them (Wiig and Lie 1984).

Not only is the genetic relationship between these populations uncertain, but abundance estimates for these areas are imprecise also. This has generated concern about the impact of hunting on trends in the population size of hooded seals. Commercial hunting of hooded seals began in Newfoundland in the late eighteenth century in association with the harp seal, Phoca groenlandica, harvest. Hooded seals were also hunted intensively on moulting grounds in Denmark Strait as early as 1874, but did not become a significant part of the catch at Jan Mayen until the 1920's (Reeves and Ling 1981). Sealing at whelping concentrations in the Davis Strait has not occurred, although these animals have been hunted by Greenlanders along the coasts of West Greenland and probably in Denmark Strait.

Rasmussen (1960) believed that the northern Atlantic represented a single population of hooded seals; this stock having separate breeding grounds at Newfoundland and Jan Mayen and a common moulting area in Denmark Strait. Evidence of a population decline from age composition samples taken in Denmark Strait led Rasmussen (1960) to suggest that summer hunting in Denmark Strait should be prohibited as a conservation measure. Commercial hunting in Denmark Strait ended with the 1960 season. Following this closure, standardized catch per effort increased at Newfoundland (Øritsland 1966, 1973), this being taken as evidence of an increase in population size.

Harvest levels of hooded seals at Newfoundland were unregulated, in practice, prior to 1974 when the first catch quota of 15,000 animals was introduced, although regulations were in place to enforce opening and closing dates of hunting prior to 1974. The reason for the imposition of the quota in 1974 was based upon the need for conservation (Anon. 1973). The quota level of 15,000, although somewhat arbitrary, was based on the belief that the 1966 catch of 16,000 pups was too high and must be limited to less than the 1966 harvest. Sustainable yield calculations were not made until November 1975. These and following calculations depended heavily on an estimate of average pup production for the late 1960's from the survival index method (Øritsland and Benjaminsen 1975, Sergeant 1975, Winters and Bergflodt 1978), and became subject to increasing error as this estimate had to be projected to obtain an estimate of current stock size (Anon. 1982). This uncertainty about stock size was especially important given that in only two years between 1974 and 1982 had the hooded seal quota been taken, leading to concern that the population was being overharvested.

The present program was undertaken to 1) estimate the total pup production of hooded seals in the northwest Atlantic using aerial survey methods and 2) determine through tagging and comparison of age-composition data the relationship between the Davis Strait and Newfoundland populations. Here we report on the first objective only. Previous attempts to estimate pup production in the Davis Strait (Sergeant 1974, 1976, 1977; MacLaren Atlantic Ltd., 1977; MacLaren Marex Inc., 1979), and at the Front (Hay and Wakeham, 1983.a) have suffered from a variety of logistic, design and weather problems with the result that none have yielded reliable estimates of total pup production. The estimation of hooded seal pup production is a difficult statistical problem for several reasons. First, as previously noted, hooded seals are a highly migratory and pelagic species. Pups are born on heavy ice floes approximately 60-130 km and up to 300 km offshore at Newfoundland and in the Davis Strait, respectively. Second, although a substantial fraction of pups are born in areas of concentration, many pups are born in widely scattered areas of low density. Third, although concentrated, it is not a simple matter to locate the pupping areas. Over 50,000 km^2 of suitable ice is present at the Front in most years, an area roughly the size of Ireland and over 4 times this area could be considered suitable habitat in the Davis Strait. Further, having once located concentrations of pups is no guarantee that they will be found again, as ice drift can be considerable (i.e. 30 to 50 km/24 hr). Finally, pups begin to leave the ice after a lactation period of only four days (Bowen et al., submitted) and hence any one survey will be incomplete to the extent that some pups have already left while others are yet to be born. The present study attempts to address each of these difficulties to provide a reliable estimate of total pup production in the northwest Atlantic.

Materials and Methods

Study Area and Design

The survey was designed to include three major strata: 1) concentrations, i.e. whelping patches, 2) scattered pups in areas historically known to have high densities and 3) scattered pups in areas historically known to have low densities. Historically, pup concentrations are known to occur in patches greater than 5 n mi (9.3 km) in their minor dimension (Hay and Wakeham, unpubl. data). The surveys were designed to have a high probability of detecting patches in potential high density areas within the constraints of time and weather. Areas of pup concentrations were determined by plotting historical records (Fig. 1 and 2).

Areas of historically low and high pup density were searched with an interval between transects of 10 and 5 n mi (18.5 and 9.3 km), respectively, at the Front (Fig. 3). However, in Davis Strait historical records were not as extensive and a 15 n mi (28 km) interval was used between transects. This higher interval was largely a consequence of the very long transit time from the survey base (Søndre Strømfjord) to the Davis Strait study area (Fig. 2).

Duration of Pup Stages

Hooded seal pups were classified into four readily identifiable developmental stages based on observations of pups in March 1983:

Newborn
- skin in loose folds along flanks, fur saturated to wet, entire pelage with yellowish hue, awkward body movements. Mother present.

Thin blueback
- ventrum white, neck well defined, trunk conical in shape. Mother present.

Fat blueback
- ventrum white, neck not clearly distinguishable, trunk fusiform in shape. Mother present.

Solitary blueback
- as in fat blueback but mother not present.

To determine the duration of each stage, we followed the development of known-aged individuals from birth to weaning and beyond. Pups were marked with Dalton Rototags to which were attached vinyl-cloth streamers (3 cm x 20 cm) to enable rapid identification from the air. Dye of various colours (Day Glo series Z) was also applied to both pups and adjacent ice to facilitate relocation. Known-age individuals were located daily or more frequently as time and weather permitted and classified into one of the above four stages.

Fixed-Wing Surveys

Aircraft and camera specifications:

For surveys at both the Front and in Davis Strait, a Piper Navajo PA-31 aircraft was used. The Navajo is a low-wing, twin-engine aircraft with a flight endurance of about 7 hours. Altitude was maintained by means of a radar altimeter and accurate navigation along flight lines was made possible by a VLF-Omega navigation system. Vertical photographs (23 cm x 23 cm) were taken using a Wild RC-8 camera equipped with a Universal lens (calibrated focal length = 151.997 mm (Front) or 152.287 mm (Davis Strait) and a minus blue filter (Front) or filter number 2861, 500 NM AV1.4X (Davis Strait)). Kodak Double-X aerographic black and white film (type 2405) was used and an intervalometer provided with the camera was used to obtain about 15-20% overlap between successive photographs.

Survey Design - Assessment of "Scattered" Seals:

To locate the whelping concentrations of hooded seals and to determine the distribution and abundance of the scattered hooded seal pups (those born outside the main concentrations), the fixed-wing aircraft flew the transect patterns shown in Figure 3 (Front) and Figures 8-10 (Davis Strait). In Davis Strait, these survey lines extended from the ice edge to well inside the heavy pack ice to the west (Fig. 8 and 13), while at the Front, the survey lines extended from the heavy coastal ice to the seaward edge of the heavy pack ice zone (Fig. 3 and 7). At the Front, spot-photographs were taken along each transect at an interval of about 3.5 km, for the purpose of evaluating the density of the scattered pups. No spot-photographs were taken along the search transects flown initially in Davis Strait during 16-19 March (Fig. 8). However, spot-photographs at an interval of about 6.4 km were taken along search transects flown in Davis Strait on 26 and 27 March 1984 (Fig. 9 and 10). Surveys were carried out at flight altitudes of 305 m (Front) and 152-305 m (Davis Strait) and at a velocity of about 220 km/hr.

Survey Design - Assessment of Concentrations:

Only one main concentration of whelping hooded seals was identified in each region (Front and Davis Strait). It was necessary to first delineate the approximate position of the patch boundaries so that the desired number of continuous parallel photo-transects could be flown systematically through the entire patch, given the constraints of remaining flight time and the weather. Photo surveys were carried out at an altitude of 305-335 m and at a speed of about 185 km/hr. The first transect was positioned along one edge of the patch; to facilitate navigation, subsequent transects were spaced uniformly at a distance which was determined so as to allow the survey to be completed in the time available (Fig. 4-5, Front and Fig. 11, Davis Strait). The photo-survey was terminated when the last transect did not detect any seals. The transects began and ended a short distance outside the patch, but the photographic sequence was initiated only when seals were detected (visually) along the transect and was terminated when seals were no longer present. The position of the aircraft was recorded at the beginning and end of the photographic sequence, so that the length of each photo-transect could be calculated.

To identify and re-locate whelping concentrations, radio transmitters were deployed on the ice within each concentration at the Front and in Davis Strait. We used configuration 6AS and 6ASP (parachute-deployment) radio transmitters supplied by Telonics Ltd., Mesa, Arizona. Ten-channel SPDF-1 receivers and an antenna system were installed in the fixed-wing aircraft and helicopter in each area. Use of this system allowed the fixed-wing aircraft and helicopter to reliably locate concentrations of seals.

Examination of Aerial Photographs:

Black and white prints (23 cm x 23 cm) of the vertical imagery were examined by three individuals who recorded the number of "families" (mother, pup, and male), mother-pup pairs, solitary pups, and other groupings (adult associations) for each photograph (excluding the area of overlap between successive frames). These three "readers" had participated in the aerial survey of 1984 and all had considerable experience in research on hooded seals. To calibrate readers, 13 photographs were read twice by each of the observers. This preliminary experiment enabled the readers to come to a consensus on identification of images of hooded seals on the photographs. After discussion and comparison of results of the first reading, the three readers produced very similar counts (±10%) of hooded seals for these same photographs on the second reading. Prints were examined with a binocular microscope under low power or with an illuminated hand-lens of magnification 7-8X. An acetate grid with a width slightly less than that of the examined field aided the observers in their examination of the photographs.

Helicopter Surveys

Aircraft Specifications:

A Hughes 500 D helicopter was stationed on the M/V POLAR CIRCLE in the Davis Strait, while another, equipped with Loran-C navigation, was stationed on the research vessel C.S.S. BAFFIN at the Front. The Davis Strait helicopter was not equipped with an electronic navigation system as Loran-C is not available at high latitudes. Both helicopters had barometric altimeters.

Survey Design - Assessment of Concentrations:

During helicopter sighting surveys, each observer (one port rear, one starboard rear) scanned a strip of 100 m width (total strip width was therefore 200 m). This was accomplished by means of upper and lower reference marks on each window which delimited a sighting strip of 100 m width. The observer placed these marks on his/her window by reference to a series of dye marks on the ice spaced at 100 m intervals. Altitude for the helicopter sighting surveys was maintained at 30.5 m. Helicopter ground speed was about 150 km/hr for Davis Strait and 110-170 km/hr for the Front survey.

Helicopter sighting surveys were carried out in the following manner. The first transect was positioned along one edge of the patch and subsequent parallel transects were spaced systematically at an interval of 1.85 km (Fig. 6, Front and Fig. 12, Davis Strait). Transects were terminated when no seals were seen over a distance of several km. The survey ended when no seals were seen along the last transect line. At the Front, beginning and ending positions of each line were recorded from the Loran-C navigation unit. In Davis Strait, the surveys were done by dead-reckoning, using compass bearings and elapsed time and speed to determine distance travelled. The helicopter pilot in Davis Strait took extreme care to adjust indicated (air) speed and heading for wind direction and speed, in order to give a true (ground) speed of about 150 km/hr and to ensure that all transects were oriented north-south and therefore approximately parallel.

Each rear observer transmitted (by intercom) to a recorder the pelage type of each hooded seal pup seen within his/her 100 m-wide strip. These pelage types are described in a previous section.

Statistical Methods

Preliminary Analysis:

Estimation of scattered seals was made by multiplying the area surveyed by the average density of seals in the area as determined by the spot-phototransects previously described. Confidence limits for the density estimates were obtained by a bootstrap estimator, i.e. a histogram was produced of the mean density of 1000 random draws of the observed data with replacement (Effron 1979). The area used for this calculation represents the surface area of the high density stratum, that which was sampled by the spot-photo transects spaced at

5. n. mi (9.3 km) intervals (Fig. 3). This area is that portion of the study area between 51° and 53°N (Fig. 3). Although there is a substantial gap in coverage, we feel that extrapolation of the estimated density to the entire area of the high density stratum is justified, given the homogeneity of the ice conditions (Fig. 7).

Total numbers and standard confidence limits of the number of pups present by day were estimated using Jolly's strip survey sampling method for unequal-sized sampling units (Caughley 1977). Patch area was determined by connecting transect end-points and a strip 0.5 n mi (0.93 km) wide was added to the patch beyond the beginning and ending transects. The width of a sampling unit (transect) was calculated from the flight altitude, negative size and calibrated focal length of the camera lens.

Estimation of Total Pup Production in Patches:

We assume that the number of pups born in a year can be adequately approximated by a continuous function of time, b(t). The pups pass through a series of identifiable stages, which are initially assumed not to change with time and are the same for all individuals. The duration of stage j is denoted by d_j. The number of individuals at time t in stage j is denoted by $n_j(t)$. The number of individuals in the jth stage at time t will thus be

$$n_j(t) = \int_{t-\sum_{k=1}^{j} d_k}^{t-\sum_{k=1}^{j-1} d_k} b(\tau)d\tau \qquad (1)$$

Suppose that at each time t_i a number of animals are sampled and staged. Let S_{ij} be the number of individuals observed to be of stage j at time t_i.

Let O_ℓ be the estimated total number of individuals at time t_ℓ, C_ℓ be the actual number at time t_ℓ, and P_{ij} be the actual proportions of individuals of stage j at time t_i.

The following assumptions are made:

1) The random variables S_{ij} and O_ℓ are independent.
2) $O_\ell = C_\ell + \varepsilon_\ell$
where the ε_ℓ's are independent normally distributed random variables with mean 0 and variance σ_ℓ^2.

3) The S_{ij} are obtained by taking a simple random sample of the population and determining the stage class of each individual. Initially, it is assumed that there are no errors in stage determination.

Given the above stochastic assumptions it follows that the likelihood function for the parameters P_{ij}, C_ℓ and σ_ℓ is equal to a constant times

$$\prod_{ij} P_{ij}^{S_{ij}} \prod_{\ell} \frac{1}{\sqrt{2\pi}\sigma} \exp - \frac{1}{2} \left(\frac{O_\ell - C_\ell}{\sigma_\ell}\right)^2 . \qquad (2)$$

Taking the natural logarithm of (2) and ignoring the constant terms, one obtains the log-likelihood function

$$\sum_{ij} S_{ij} \log P_{ij} - \sum_{\ell} \frac{1}{2} \left(\frac{O_\ell - C_\ell}{\sigma_\ell}\right)^2 - \sum_{\ell} \log \sigma_\ell . \qquad (3)$$

Here, we shall use estimates of σ_ℓ obtained from the survey; they shall not be estimated in the likelihood function.

Note that for each i, j the constraints

$$\sum_j P_{ij} = 1, \; P_{ij} > 0 \qquad (4)$$

hold.

The proportions P_{ij} are calculated from b(t), the μ_j's and the d_j's.

That is

$$P_{ij} = \frac{n_j(t_i)}{\sum_j n_j(t_i)} , \qquad (5)$$

where the $n_j(t_i)$'s are given by (1). Note that the constraints in (4) are automatically satisfied for this problem if any of the n_{ij}'s are greater than zero. The C_ℓ's are determined similarly, i.e.

$$C_\ell = \sum_j n_j(t_\ell) \qquad (6)$$

Initially the birthing distribution was assumed to be normal. That is,

$$b(t) = \frac{N}{\sqrt{2\pi}\ \sigma_b} \exp\ [-\ (t - \mu_b)^2/2\ \sigma_b{}^2], \qquad (7)$$

where N is the total number of pups born.

A gamma distribution was also investigated as a suitable form for b(t). That is,

$$b(t) = \frac{N(t-\eta)^{\kappa-1}\exp[-(t-\eta)/\theta]}{\theta^\kappa\Gamma(\kappa)}, \qquad (8)$$

where $\Gamma(\kappa)$ is the gamma function. The parameters η and θ are location-scale parameters and κ is a shape parameter. Note that one more parameter must be estimated for (7) than (8).

Usually the sample taken to determine stage classes is not a simple random sample. For example, if the stages are determined from several cluster samples of a non-homogeneous population, then the assumption of a simple random sample would give too much weight to the multinomial portion of (3), i.e. the sample size will be overestimated. We wish to correct correct for each of the S_{ij}. If equal samples of size B were taken from each cluster, then

$$S_{ij}' = C\ S_{ij} \qquad \text{where } C = \frac{1}{1 + \rho\ (B-1)} \qquad (9)$$

where ρ is intra-class correlation and B is the subsample size (Kish 1965). In the case where subsample size is not equal, then B is usually adequately approximated by the mean size of the cluster samples (Kish 1965).

The natural variability in stage duration can be included in the model if independent estimates of the variability of stage duration are available.

The adequacy of the model fit can be assessed by estimating covariance matrix of the estimates. Let Θ be the vector of parameters to be estimated, and V_Θ be the covariance matrix. As the number of samples increases, the sampling distribution asymtotically approaches the normal form, with means equal to the true parameter values, such that

$$\underline{V}_{\underline{\Theta}} \approx -\ (\partial^2 \text{ Log } L\ /\ \partial\underline{\Theta}\ \partial\underline{\Theta})^{-1}{}_{\underline{\Theta}} = \underline{\Theta}^*, \qquad (10)$$

where Θ^* is the maximum likelihood estimate and L is the likelihood function (Bard 1974). The standard deviations of the estimates are approximated by the square roots of the diagonals in (10). The derivatives can be calculated via finite difference approximations. V_Θ is a rough estimate and must be interpreted with caution (Bard 1974).

High values for the off diagonal elements of V_Θ indicates that the two parameters are confounded, i.e. there is not enough information to obtain good estimates for all the model parameters. In such cases, it is advisable to obtain independent estimates of one of the confounded parameters.

The log-likelihood function was maximized via the Needer-Mead simplex algorithm (Dixon 1972). The program, written in the language APL, is available from R. A. Myers.

Results

Duration of Pup Stages

On 18 and 19 March at the Front, 62 newborn pups were individually marked. The relationship between developmental stage and age is given in Table 1. A total of 128 resightings were made on 49 of the known-age seals. From these data, we estimate that the average duration of the thin blueback stage is 1.50 days and that 11% of pups are fat bluebacks for 3.5 days, whereas 66% and 23% of pups are fat bluebacks for 2.5 and 1.5 days, respectively. All pups classified as newborn initially were classified as thin bluebacks at one day of age. However, observations of newborn harp and grey seals, Halichoerus grypus, indicated that hooded seal pups would be judged as newborns for only about 3 hr on average. Weaning occurred at 3 days postpartum in 4 of 27 seals (15%) and 4 day postpartum in 11 of 15 seals (73%). All pups were weaned at day 5 and older (Bowen et al., submitted). The duration of the solitary stage could not be estimated from the information in Table 1 alone.

Front

Assessment of "Scattered" Seals:

Figure 3 shows the fixed-wing spot-photo search transects flown at the Front, while Table 2 provides counts of hooded seals on the spot-photos. These data were used to provide an estimate of production for "scattered" hooded seals, as outlined in a later section.

Assessment of Concentrations:

Photo-surveys of the hooded seal patch at the Front were carried out on 20 March (Fig. 4 and Table 3), 21 March (Table 4), and 25 March (Fig. 5 and Table 5). Only two lines were flown on 21 March and it has not been possible to reconstruct the patch based on these data. None of the photo-surveys at the Front covered the entire patch. Photographic estimates of pup abundance are shown for 20 March and 25 March in Table 8. The estimates are given both for the patch as defined by the transect lines and for the estimated total patch as determined by the fixed-wing aircraft (see Fig. 4 and 5 and Table 8).

The fixed-wing photographic survey of 20 March produced pup abundance estimates of 11,370 (for the patch as defined by the transect lines) and 19,750 (for the estimated total patch), with a mean density of 19 pups/km^2. The fixed-wing survey of 25 March gave corresponding estimates of 17,950 and 42,860 with a mean density of 50 pups/km^2.

Results for the complete helicopter surveys of 21 March and 25 March are shown in Tables 6 and 7, respectively. The transects flown during these surveys are plotted in Figure 6. Estimates of pup abundance and 95% confidence intervals are shown in Table 8. The peak abundance of hooded seal pups in the Front patch was 35,260 (95% confidence interval of 24,940 to 45,590) on 21 March, with a mean density of 56 pups/km^2. By 25 March the number of pups in the patch had declined to 24,020 (95% confidence interval of 18,860 to 29,170) with a mean density of 47 pups/km^2.

Davis Strait

Assessment of "Scattered" Seals:

On the spot-photographs taken in Davis Strait, no pups were seen which could unambiguously be attributed to production outside of the whelping patch, i.e. pups further than about 18.5 km from the patch (Fig. 9 and 10). Therefore, it is not possible to estimate the abundance of "scattered" pups in this region.

Assessment of Concentrations:

Photo-surveys of the hooded seal patch in Davis Strait were carried out on 20 March (Table 9), 23 March (Table 10), and 25 March (Table 11). Figure 11 shows the positions of the photo-transects flown on each of these three days. The first two photo-surveys were incomplete while the third (25 March) was complete. It was not possible to reconstruct the entire patch based on the photo-surveys of 20 and 23 March. Table 14 presents estimates of pup abundance (plus 95% confidence intervals) for these three photo-surveys. The estimate of pup abundance for 25 March was 9820 pups present (95% confidence interval of 2630 to 17,020) with a mean density of 8.5 pups/km^2.

Results of the helicopter surveys of 21 March and 24 March are presented in Tables 12 and 13, respectively, with pup abundance estimates (and 95% confidence intervals) presented in Table 14. The helicopter survey of 21 March was incomplete. The complete survey of 24 March produced an estimate of 18,590 pups present, with a 95% confidence interval of 13,750 to 23,440 and mean density of 21.8 pups/km^2.

Estimation of Pup Production

"Scattered" Pups at the Front:

Twelve hooded seal pups were seen on the 472 spot photos in the area known to have historically high densities of pups (Fig. 1 and 3), which yielded an estimate of 0.12 pups/km^2 over 61,138 km^2 or a total estimate of scattered pups of 7,400. Confidence limits were placed on the estimate by resampling (with replacement) of the data from the photos 1000 times to obtain bootstrap estimates of the distributions (Fig. 15). The 95% confidence limits for the scattered pups was 2700-14,400.

The Front Patch:

The initial estimates were made assuming the birthing distribution was normal. Eq. 9 was used to adjust the numbers observed in each stage class (Table 15) to correspond to the sample size that corresponded to a simple random sample. Because of the positive intra-class correlation coefficient, the estimates of the effective sample size was much lower than the number actually observed. The resulting estimate of total pup production (Table 16), N = 54 700 indicated that a significant correction was needed to account for the pups that had already left the ice and were yet to be born on the day when the maximum number of pups were observed (21 March). The estimate of peak pupping, March 17.3, is consistent with the qualitative estimates made by a researcher on a research ship at the site.

Taking the square roots of the diagonals of the above estimated covariance matrix calculated as in Eq. 10 yields rough estimates of the standard deviations of the estimates. The resulting estimated 95% confidence limits (Table 16) are large, but consistent with the limited data available for the analysis. The correlation matrix corresponding to this covariance matrix of the estimates was calculated to determine if all the model parameters could be determined from the available data. The resulting correlation matrix is

	N	μ_b	σ_b	d_4
N	1	-.68	.47	-.71
μ_b	-.68	1	-.54	.34
σ_b	.47	-.54	1	-.09
d_4	-.71	.34	-.09	1.

The resulting correlations are acceptable, although they do make the confidence region larger than it would be if they were zero. Two-dimensional slices of the 95% confidence region (calculated from the covariance matrix calculated as in Eq. 10) provide a better indication of the n of precisio the estimates than confidence intervals (Fig. 16).

The largest residual from the model fit is that the number of stage 1's and 2's are underestimated on 21 March (Fig. 17a). This discrepency is probably due to model error, i.e. the birthing distribution may not be continuous and a pulse of births may have occurred between the surveys of 21 March and 25 March.

The likelihood function was maximized again to demonstrate the importance of the correction to the non-random distribution of pups in different stages. That is, the correction factor C in Eq. 9 was set equal to one. The resulting "estimates" for pup production were not reasonable because too little weight was given to the two-point estimates of total abundance (Trial 2, Table 16).

The sensitivity of the estimates to the assumed functional form of b(t) was investigated by using Eq. 11, i.e. the birthing distribution followed by a gamma distribution (Table 16; Fig. 17b). The large confidence limites indicate this model is not identified; only a symmetric birthing function could lead to an identified model. The need to include the extra parameter required by the gamma distribution can be checked by calculating the ratio of the likelihood functions at their respective maxima, λ. The resulting value of $-2 \log\lambda$ using a χ^2 distribution with one degree of freedom is not close to a significant level ($P = .05$). Thus there is no statistical justification for using the more complex model.

The Davis Strait Patch:

The ice conditions at the time of the survey in the Davis Strait were such that few seals, pups or their mothers, could leave the ice before 24 March because the ice was tightly packed with few openings. A storm on 24-25 March broke up the ice and was likely responsible for the reduction in the estimates from 24-25 March (Table 14). It was thus not possible to correct for the pups that left the ice before 24 March or were born after that date. We therefore use the survey of 24 March as our estimate of the pup production in the Davis Strait (Table 14).

Discussion

Reliability of Results

Comparison of Photographic and Sightings Surveys:

Although the fixed-wing photographic survey of 20 March at the Front (Fig. 4) was not complete, it produced a much lower estimate of mean pup density (19 pups/km^2) than the complete helicopter survey (Fig. 6) of the following day (56 pups/km^2). This difference may be explained to some extent by additional births between 20 and 21 March, but probably more importantly by the fact that the fixed-wing survey did not cover the densest concentration of pups in the western part of the whelping patch (compare Fig. 4 with Fig. 6). On the other hand, the photographic survey (Fig. 5) and helicopter survey (Fig. 6) of 25 March at the Front produced very similar estimates of mean density (50 and 47 pups/km^2, respectively; see Table 8).

The incomplete fixed-wing photo-surveys of 20 and 23 March in Davis Strait produced estimates of mean pup density of 10.5 and 9.0 pups/km^2, respectively, very similar to that derived from the incomplete helicopter sighting survey of 21 March (12.6 pups/km^2; see Table 14). The complete helicopter survey of 24 March produced an estimate of 18,590 pups present (mean density of 21.8 pups/km^2), while the complete fixed-wing photo-survey of the next day (25 March) produced much lower estimates (9820 pups with 8.5 pups/km^2). These changes may be explained, at least in part, by the rather sudden break-up of the ice in the whelping patch around mid-day of 24 March. Prior to this time the pack ice consisted of very large unbroken sheets (some to 2 km diameter), which consisted of small consolidated ice floes. Seal families and pups often occurred in the middle of these sheets, far from leads or cracks. Prior to 24 March, there would have been little opportunity for weaned (solitary) pups to begin their migration from the area. With the ice break-up beginning on this date, however, the pups had access to the water and could begin their dispersal. Break-up also resulted in overall enlargement of the whelping patch (Table 14) and this, coupled with dispersal of solitary pups, likely contributed to the reduction in pup numbers and density between 24 and 25 March.

The helicopter sighting survey of 24 March in Davis Strait produced an estimate of 18,590 pups present. This estimate is the basis of the final estimate of pup production of the Davis Strait whelping population (see above). However, as this survey was carried out by dead-reckoning without electronic navigation (eg. LORAN-C), the reliability of the results of this survey must be addressed. Although dead-reckoning will not give results as accurate as those provided by LORAN-C (used by the Front helicopter), we feel that, because of the experience and abilities of our pilot and his conscientiousness in applying corrections for the wind, the actual transect pattern for the survey of 24 March closely approximates the calculated (dead-reckoned) pattern shown in Fig. 12 and that therefore, the results for this survey will be reasonably accurate. In addition, the patch size estimated for the helicopter survey of 24 March is 852 km^2, slightly less than that estimated for the fixed-wing photo-survey (positioned by Omega-VLF navigation) of 25 March (1153 km^2; see Table 14). The patch area is likely to be somewhat greater on 25 March than 24 March because of ice break-up and dispersal starting on 24 March. This observation further suggests that the results of the 24 March helicopter survey are reasonably accurate.

Population Estimates:

There were two surprising results from the survey. First, because of the short lactation period, the correction for the birthing ogive is large and cannot be neglected if accurate population estimates are to be made. Second, there are substantial numbers of scattered pups outside the main concentrations whose presence was not suspected.

Our population estimates are probably as reliable as possible given the constraints of time and weather. However, they are generally probably underestimates of total abundance for three reasons. First, substantial patches of pups could have been missed during our transect search pattern. For example, in 1983 a patch of approximately 3000 pups occurred 50 km south of the 1984 patch area. Second, the area that contains ice suitable for pupping is much larger than the area surveyed. There could have been substantial numbers of widely scattered seals in these regions that are impossible to survey without additional aircraft. Third, no correction for the scattered pups was made for the pups that had left the ice or had not been born on the days the surveys were flown. We felt it was not justified to extrapolate the birthing ogive from the patch to the scattered pups and there was not enough pups seen to make an accurate correction based on the data from the scattered pups.

Pup Production and Trends in Abundance

Our survey results indicate that hooded seal pup production in the northwest Atlantic, particularly at the Front, is considerably greater than previously thought.

The first estimate of pup production in Davis Strait was given by Sergeant (1974). On 25 March, Sergeant located three patches of hooded seals and guessed total numbers at "perhaps 50,000 ... (which) might imply 20 or 30,000 young". Sergeant noted that photographic surveys would be required to estimate numbers more accurately. The first photographic survey was incomplete, yielding a total estimate of about 4300 adults and 3300 adult females (Sergeant 1976). No estimate of the number of pups was calculated. Visual guesses by observers were higher ranging from 5000 to 10,000 adults. In 1977, two photographic surveys were conducted in Davis Strait (Sergeant 1977, MacLaren Atlantic Ltd. 1977). Sergeant located two patches, only one of which was photographed and suggested on the basis of both photographs and visual observation that "at least 10,000 adult seals, and perhaps twice as many" whelped in the Davis Strait in 1977. MacLaren Atlantic Ltd. (1977) also conducted a photographic survey in 1977 as part of a general inventory of marine birds and mammals of southern Davis Strait and eastern Hudson Strait. Hooded seals were located on 31 March, at which time the majority of adults had left the ice leaving mainly solitary pups. Analysis of the photographs suggested that production was about 13,000 to 25,000 pups. In 1978, MacLaren Marex Inc. (1979) again conducted a photographic survey of hooded seals in Davis Strait and estimated that approximately 11,000 pups were in two patches. Reanalysis of these data (J. Parsons, pers. comm.) resulted in somewhat lower estimates of about 13,700 ± 6000 pups and 8800 ± 3300 pups in 1977 and 1978, respectively.

It is difficult to compare our Davis Strait results with those of the other workers referred to above, given that previous surveys made no attempt to: 1) estimate the abundance of pups outside patches and 2) account for the flux of pups within whelping concentrations. The difference between our estimate of 18,600 (95% confidence interval of 13,800 to 23,400) and previous estimates of around 10,000 might easily be accounted for by differences in experimental design. Thus it is not possible to determine recent trends in pup production at Davis Strait from available data.

Our estimate of 62,100 pups (95% confidence interval of 39,900 to 86,600) at the Front is the only reliable recent estimate of total production for this area. An aerial photographic survey, conducted in March 1983 (Hay and Wakeham 1983a), was incomplete, having photographed only two of three patches. The estimate for these two patches (uncorrected for the birthing ogive) was a total of about 5000 pups with unacceptably wide confidence intervals because of low sampling intensity. Hay and Wakeham (1983b) also calculated Front pup production using a Leslie analysis of pup catches. However, the authors considered their estimates of about 8,000 to 16,000, between 1977 and 1982, to be negatively biased to an unknown extent and therefore of marginal value.

Previous estimates of hooded seal pup production in the northwest Atlantic (Davis Strait and Front) have all been based on the survival index method (Sergeant 1971, Benjaminsen and Øritsland 1975). Øritsland and Benjaminsen (1975) estimated average pup production of 31,400 animals for the year-classes 1966-70. Sergeant (1976) and Winters and Bergflødt (1978) estimated an average production of 27,000 pups for the 1966 to 1971 year-classes. The agreement of these estimates is not surprising given that they are all based essentially on the same data. Further, all of these estimates depend heavily on the 1966 data point.

If we accept that production in the mid 1960's was in the neighbourhood of 30,000, then it would appear that the hooded seal population has increased in recent years. We arrive at the same conclusion whether or not we believe the value of 30,000 represented total northwest Atlantic production or Front production alone. This ambiguity arises from the fact that the degree of intermixing of hooded seal between the Davis Strait and Newfoundland is unknown.

How can we account for a probable population increase, given that sealers have repeatedly in recent years failed to reach their catch quota for hooded seals? Annual kills in Denmark Strait averaged nearly 16,000 hooded seals in the decade prior to its closure in 1960. This, coupled with the low catches in the northwest Atlantic during the late 1950's and early 1960's, undoubtedly increased the survival rate of hooded seals during the early 1960's. In 1977, regulations were imposed limiting the kill of adult females to 10% of the daily catch. In 1978, the catch limit for adult females was reduced to 7.5% and from 1979 to the present, the limit has been 5% of the total catch. These limits reduced the percentage of adult females in the 1+ catches from 50-60% to 25-30% and have likely contributed to an increase in pup production.

If the population has increased, why has this not been reflected by increased catches at Newfoundland? Two reasons may be advanced. First, our results indicate that considerable numbers of pups are born outside of patches and therefore would not be available to commercial hunting. If, as suggested by the March 1983 survey, there is between year variation in the fraction of pups born in patches, then production (in patches) will appear to vary from year to year or there may be longer term trends in this fraction leading to increased or reduced availability of seals to hunters. Second, as suggested by Sergeant (1974) and Rasmussen (1960) there may be a varying proportion of the northwest Atlantic population which migrate to

Newfoundland to whelp; and trends in this migration would affect availability of seals to hunters at the Front. We note that in 1984 a tagging study was initiated which will provide information bearing on this hypothesis in several years. In Davis Strait 1465 hooded seal pups were tagged, while at Newfoundland 808 pups were tagged; 414 at the Front and 394 in the Gulf of St. Lawrence.

The results of our work suggest that using aerial survey methods, suitably corrected to account for the flux of pups in whelping patches, it is quite feasible to estimate hooded seal pup production. However, we feel that further work could be done on the shape of the birthing curve and on the estimation of pups born outside of patches.

Acknowledgements

Many individuals contributed their talents, assistance, and enthusiastic cooperation to this project. We are especially grateful to the following people:

FRONT
Helicopter - Paul Brodie, Brian Beck, Gary Wilton, Howard Sheppard, Edward Neary, and pilot Scotty Aldie.
Fixed-wing - Vicki Mercer, John Parsons, pilot K. Keeling, and camera operator/navigator Buz Sawyer.

DAVIS STRAIT
Helicopter - Wayne Penney, Leon King, Shirley Leach, and pilot Dale Caldwell.
Fixed-wing - Erik Born, pilots Brian Berrigan and Gordon Carter, and camera operator/navigator/engineer Kevin Piekarskie.

We thank Dennis Wakeham, John Parsons, and Vicki Mercer who contributed to the task of counting seals on the aerial photographs. We are especially grateful to Dennis Wakeham who was largely responsible for the task of preparing all the survey data for final analysis.

In addition, we thank the following individuals for their support, suggestions, ideas, and varied assistance: G. H. Winters, D. McKinnon, W. G. Doubleday, D. E. Sergeant, S. Gavaris, H. Edel, J. Heyland, M. Willis, F. O. Kapel, M. C. Mercer, D. McKone and T. Curran Sr. The Greenland Home Rule Government kindly provided permission for us to carry out this research in Greenland.

We also thank Captain James Fahey and the crew of the M/V POLAR CIRCLE and Captain John Mein and the crew of C.S.S. BAFFIN, for their constant support and assistance.

References

Anon. 1973. Report of Meeting of Scientific Advisors to Panel A. In Proc. Special Commission Meeting January 1973 and the 23rd Annual Meeting June 1973. ICNAF Serial No. 3112.

1982. Report on the meeting of an ad hoc working group on assessment of harp and hooded seals in the northwest Atlantic. ICES Cooperative Research Report No. 121. ICES Headquarters, Copenhagen.

Benjaminsen, T. and T. Øritsland. 1975. Adjusted estimates of year-class survival and production with estimates of mortality for northwest Atlantic harp seals. ICNAF Res. Doc. 75/XI/3.

Bergflødt, B. and T. Øritsland. 1983. Frequencies of supernumerary teeth in the lower jaws of North Atlantic hooded and harp seals. Doc. HSW-83/13, submitted at Workshop on Hooded Seals, Bergen, November 1983.

Caughley, G. 1977. Analysis of Vertebrate Populations. John Wiley & Sons, London.

Effron, B. 1979. Computing and theory of statistics: thinking the unthinkable. SIAM (Soc. Ind. Appl. Math) Review. 21: 460-480.

Hay, K. and D. Wakeham. 1983a. Estimation of pup production of hooded seals (Cystophora cristata) at Newfoundland during March 1983 using vertical aerial photography. Presented at International Workshop on the Biology and Population Dynamics of Hooded Seals, Bergen, Norway.

1983b. Use of catch and effort data to estimate the pup production of hooded seals (Cystophora cristata) at Newfoundland. NAFO SCR Doc. 83/51. Ser. No. N709. 12 p.

MacLaren Atlantic Ltd. 1977. Report on the Davis Strait Aerial Survey 77-1. Arctic Petroleum Operators Association, Project No. 134.

MacLaren Marex, Inc. 1979. Report on aerial surveys of marine mammals and birds in southern Davis Strait and eastern Hudson Strait in March, 1978. Arctic Petroleum Operators Association, Project No. 146.

McLaren, P. L., and R. A. Davis. 1983. Distribution of wintering marine mammals off West Greenland and in southern Baffin Bay and northern Davis Strait, March 1982. Unpub. rep. prepared for Arctic Pilot Proj., Calgary, by L.G.L. Ltd., Toronto.

Ord, J. K. 1972. Families of frequency distributions. Griffin, London.

Øritsland, T. 1966. Norwegian catch and effort statistics for harp and hooded seals in the Front area and Gulf area, 1937-66. ICNAF contribution no. 8 to panel A, Ser. No. 1760.

Øritsland, T., and T. Benjaminsen. 1973. Sex and age composition and mortality of hooded seals at Newfoundland. ICNAF Res. Doc. 73/120.

1975. Additional data on the sex ratio, age composition and mortality of Newfoundland hooded seals, with an estimate of pup production and sustainable yield. ICNAF Res. Doc. 75/122.

1975. Sex ratio, age composition and mortality of hooded seals at Newfoundland. ICNAF Res. Bull. 11: 135-143.

Rasmussen, B. 1960. On the stock of hood seals in the northern Atlantic. Fisken og Havet 1: 23 p. (Fisheries Research Board of Canada, Transl. Ser., No. 387. 29 p. typescript).

Reeves, R. R., and J. K. Ling. 1981. Hooded seal, Cystophora cristata Erxleben, 1777, p. 171-194. In S. H. Ridgway and R. J. Harrison [ed.] Handbook of Marine Mammals, Vol. 2 - seals. Academic Press, London.

Sergeant, D. E. 1966. Canadian research report on harp and hood seals of the northwest Atlantic. ICNAF Res. Doc. 66-61.

1971. Calculation of production of harp seals in the western North Atlantic. ICNAF Redbook 1971, Part 3, p. 157-184.

1974. A rediscovered whelping population of hooded seals Cystophora cristata Erxleben and its possible relationship to other populations. Polarforschung 44: 1-7.

1975. Comments on new estimates of production and sustainable yield of harp and hooded seals. ICNAF Res. Doc. 75/147, Ser. No. 3720.

1976. Research on hooded seals Cystophora cristata Erxleben in 1976. ICNAF Res. Doc. 76/126, Ser. No. 4012.

1977. Research on hooded seals in the western North Atlantic in 1977. ICNAF Res. Doc. 77/57, Ser. No. 5132.

1978. Results of tagging and branding of hooded seals, 1972-78. ICNAF Res. Doc. 78/86, Ser. No. 5302.

Wiig, Ø. and R. W. Lie. 1984. An analysis of the morphological relationships between the hooded seals (Cystophora cristata) of Newfoundland, the Denmark Strait, and Jan Mayen. J. Zool. 203: 227-240.

Winters, G. H. and B. Bergfløt. 1978. Mortality and productivity of the Newfoundland hooded seal stock. ICNAF Res. Doc. 78//91, Ser. No. 5307. 5 p. (revised).

Table 1. Developmental stage of 49 hooded seal pups at the Front in relation to age (days).

Days postpartum	Developmental stage				Total
	Newborn	Thin blueback	Fat blueback	Solitary	
1	0	34	4	0	38
2	0	4	36	0	40
3	0	1	19	6	26
4	0	0	4	10	14
5	0	0	0	4	4
6+	0	0	0	6	6
Total	0	39	63	26	128

Table 2. Summary of results of spot-photo surveys of hooded seals carried out at the Front during March 1984 (interval between photos = 3.5 km; survey altitude = 305 m; single photo area = 0.2101 km^2).

Transect number	Length (km)	Number photos taken	Number of hooded seal pups counted			Frequency of photos with number of pups equal to						
			With mother	Solitary	Total	0	1	2	3	4	11	23
19-1	234.3	68	0	0	0	68						
19-2	215.8	55	0	0	0	55						
19-3	213.7	64	0	0	0	64						
19-4	216.3	67	0	0	0	67						
19-5	142.2	45	0	0	0	45						
19-6	141.8	43	0	0	0	43						
19-7	139.9	44	0	0	0	44						
20-1	259.6	78	0	0	0	78						
20-2	262.0	79	0	0	0	79						
20-3	254.1	75	6	1	7	71	3			1		
20-4	253.6	77	0	0	0	77						
20-5	147.2	43	30	12	42	37	2		2		1	1
25-x	218.5	62	1	0	1	61	1					
26-5	197.2	52	1	0	1	51	1					
26-6	134.0	34	1	1	2	32	2					
26-7	113.0	24	0	0	0	24						
TOTALS	3143.2	910	39	14	53	896	9	0	2	1	1	1

Table 3. Summary of photo-transect results from a fixed-wing aerial survey of hooded seals carried out at the Front on 20 March 1984. (Patch area = 590 km^2; maximum number of transects = 44; survey altitude = 305 m; strip width = 0.458 km; sampling intensity = 10.0%).

Transect no.	No. hooded seal pups counted					Transect length (km)	Area (km^2)	Density of pups (no./km^2)
	Families[a]	Female-pup	Female-2 pups	Single pup	Total pups			
20-6	47	52	1	22	123	28.7	13.16	9.3
20-7	56	117	3	77	256	25.2	11.55	22.2
20-8	102	103	8	142	363	28.7	13.16	27.6
20-9	40	49	7	119	222	28.3	12.97	17.1
20-10	29	40	1	96	167	17.2	7.88	21.2
TOTALS	274	361	20	456	1131	128.1	58.72	

[a] dog/mother/pup

Note: These photographic data were also extrapolated to the estimated total patch (area = 1025 km^2; maximum number of transects = 101; sampling intensity = 5.7%). See text for details.

Table 4. Summary of photo-transect results from a fixed-wing aerial survey of hooded seals carried out at the Front on 21 March 1984. (survey altitude = 305 m; strip width = 0.458 km).

Transect no.	No. hooded seal pups counted					Transect length (km)	Area (km^2)	Density of pups (no./km^2)
	Families[a]	Female-pup	Female-2 pups	Single pup	Total pups			
21-1	6	12		18	36	31.0	14.20	2.5
21-2	1	3		73	77	16.2	7.42	10.4
TOTALS	7	15		91	113	47.2	21.62	

[a] dog/mother/pup

Table 5. Summary of photo-transect results from a fixed-wing aerial survey of hooded seals carried out at the Front on 25 March 1984. (Patch area = 360 km^2; maximum number of transects = 30; survey altitude = 305 m; strip width = 0.458 km; sampling intensity = 11.5%).

Transect no.	No. hooded seal pups counted					Transect length (km)	Area (km^2)	Density of pups (no./km^2)
	Families[a]	Female-pup	Female-2 pups	Single pup	Total pups			
25-1	19	46		217	282	36.7	16.81	16.8
25-2[b]	44	59	2	945	1052	44.8	20.52	51.3
25-3[b]	79	168	7	1224	1485	36.3	16.63	89.3
25-4	37	112		366	515	13.1	6.00	85.8
TOTALS	179	385	9	2752	3334	130.9	59.96	

[a] dog/mother/pup

[b] Since transects 25-2 and 25-3 are virtually the same line (Fig. 5), an average of these two lines was used in the analyses to estimate pup density and abundance. The mean length of these two lines was 40.6 km with a mean of 1269 pups, a mean sampling area of 18.61 km^2, and mean density of 68.2 pups/km^2. Thus only three lines were used in these analyses.

Note: These photographic data were also extrapolated to the estimated total patch (area = 860 km^2; maximum number of transects = 67; sampling intensity = 4.8%). See text for details.

Table 6. Summary of sighting results from a helicopter survey of hooded seals carried out at the Front on 21 March 1984. (Patch area = 636 km^2; maximum number of transects = 120; survey altitude = 30.5 m; strip width = 0.2 km; sampling intensity = 10.7%).

Transect no.	No. hooded seal pups counted					Transect length (km)	Area (km^2)	Density of pups (no./km^2)
	Newborn	Thin blueback	Fat blueback	Solitary	Total			
1	1	14	326	331	672	28.2	5.64	119.1
2		15	252	346	613	31.9	6.38	96.1
3	1	9	160	179	349	33.1	6.62	52.7
4		7	91	170	268	29.8	5.96	45.0
5		1	63	142	206	23.1	4.62	44.6
6		1	14	60	75	12.9	2.58	29.1
7		6	215	177	398	34.5	6.90	57.7
8		21	180	71	272	34.5	6.90	39.4
9		3	60	90	153	27.6	5.52	27.7
10		9	91	64	164	25.8	5.16	31.8
11		13	105	53	171	25.2	5.04	33.9
12	3	17	151	63	234	17.3	3.46	67.6
13	2	17	127	38	184	14.9	2.98	61.7
Totals	7	133	1835	1784	3759	338.8	67.76	

Table 7. Summary of sighting results from a helicopter survey of hooded seals carried out at the Front on 25 March 1984. (Patch area = 509 km^2; maximum no. of transects = 222; survey altitude = 30.5 m; strip width = 0.2 km; sampling intensity = 10.8%).

Transect No.	No. hooded seal pups counted					Transect length (km)	Area (km^2)	Density of pups (No./km^2)
	Newborn	Thin blueback	Fat blueback	Solitary	Total			
1			11	3	14	8.3	1.66	8.4
2			13	13	26	9.7	1.94	13.4
3		1	42	32	75	10.2	2.04	36.8
4	2	5	73	45	125	10.0	2.00	62.5
5		7	56	44	107	10.0	2.00	53.5
6		2	23	55	80	10.5	2.10	38.1
7		14	97	32	143	11.2	2.24	63.8
8		4	49	46	99	10.2	2.04	48.5
9		7	86	53	146	10.5	2.10	69.5
10		7	77	31	115	13.8	2.76	41.7
11		2	55	52	109	13.8	2.76	39.5
12		5	26	52	83	13.8	2.76	30.1
13		1	6	63	70	13.0	2.60	26.9
14			11	163	174	10.7	2.14	81.3
15		1	24	134	159	14.3	2.86	55.6
16		1	37	101	139	14.8	2.96	47.0
17		2	12	85	99	11.6	2.32	42.7
18			5	174	179	9.2	1.84	97.3
19		2	9	186	197	10.0	2.00	98.5
20	1	1	8	239	249	12.5	2.50	99.6
21		1	3	55	59	9.4	1.88	31.4
22			2	39	41	9.4	1.88	21.8
23		1		63	64	17.0	3.40	18.8
24				46	46	11.2	2.24	20.5
TOTALS	3	64	725	1806	2598	275.1	55.02	

Table 8. Summary of results of hooded seal surveys carried out at the Front during March 1984.

Date	Survey type[a]	No. lines flown	Patch area (km^2)	Strip width (km)	Percent sampled	Total pups on-transect	Percent of pups solitary	Mean density ($pups/km^2$)	Est. number	95% confidence interval	Remarks
March											
20	F	5	590	0.458	10.0	1131	42.1	19.3	11370		partial coverage
20	F	5	1025	0.458	5.7	1131	42.1	19.3	19750	8940-30550	b
21	H	13	636	0.200	10.7	3759	47.5	55.5	35260	24940-45590	
21	F	2	-	0.458	-	113	80.5	5.2	-	-	
25	H	24	509	0.200	10.8	2598	69.5	47.2	24020	18860-29170	
25	F	3	360	0.458	11.5	2066	82.8	49.9	17950		partial coverage
25	F	3	860	0.458	4.8	2066	82.8	49.9	42860	2070-121900	b

a F - fixed-wing photo-survey of patch; H - helicopter sighting survey of patch; S - spot-photo survey of searched areas.

b Extrapolated to the estimated total patch; see text for discussion and Figures 4 and 5.

Table 9. Summary of photo-transect results from a fixed-wing aerial survey of hooded seals carried out in Davis Strait on 20 March 1984. (Patch area = 447 km^2; maximum number of transects = 46; survey altitude = 335 m; strip width = 0.503 km; sampling intensity = 16.7%).

Transect no.	No. hooded seal pups counted					Transect length (km)	Area (km^2)	Density of pups (no./km^2)
	Families[a]	Female-pup	Female-2 pups	Single pup	Total pups			
1		1		2	3	11.1	5.59	0.5
2		10	1	12	24	13.9	7.00	3.4
3	2	11		4	17	18.9	9.51	1.8
4	47	77	2	94	222	23.2	11.68	19.0
5	35	57	1	65	159	17.8	8.96	17.7
6	4	28		20	52	20.8	10.47	5.0
7	9	60	1	17	88	20.9	10.52	8.4
8	37	133		46	216	21.3	10.72	20.1
TOTALS	134	377	5	260	781	147.9	74.44	

[a] dog/mother/pup

Table 10. Summary of photo-transect results from a fixed-wing aerial survey of hooded seals carried out in Davis Strait on 23 March 1984. (Patch area = 384 km^2; maximum number of transects = 45; survey altitude = 305 m; strip width = 0.458 km; sampling intensity = 14.3%).

Transect no.	No. hooded seal pups counted					Transect length (km)	Area (km^2)	Density of pups (no./km^2)
	Families[a]	Female-pup	Female-2 pups	Single pup	Total pups			
1		2		4	6	22.9	10.48	0.6
2		1		3	4	5.7	2.61	1.5
3		22	1	54	78	18.1	8.28	9.4
4	3	39		81	123	11.6	5.31	23.2
5	1	30	1	56	89	22.1	10.11	8.8
6	1	41	2	148	194	39.4	18.03	10.8
TOTALS	5	135	4	346	494	119.8	54.81	

[a] dog/mother/pup

Table 11. Summary of photo-transect results from a fixed-wing aerial survey of hooded seals carried out in Davis Strait on 25 March 1984. (Patch area = 1153 km^2; maximum number of transects = 75; survey altitude = 335 m; strip width = 0.503 km; sampling intensity = 7.8%).

Transect no.	No. hooded seal pups counted					Transect length (km)	Area (km^2)	Density of pups (no./km^2)
	Families[a]	Female-pup	Female-2 pups	Single pup	Total pups			
1	1			19	20	22.7	11.42	1.8
2	3	5		100	108	30.3	15.25	7.1
3	5	18	2	176	203	30.2	15.20	13.4
4	14	116	2	169	303	34.5	17.36	17.5
5	8	24		60	92	31.0	15.60	5.9
6		7		33	40	30.0	15.10	2.6
TOTALS	31	170	4	557	766	178.7	89.94	

[a] dog/mother/pup

Table 12. Summary of sighting results from a helicopter survey of hooded seals carried out in the Davis Strait on 21 March 1984. (Patch area = 268 km^2; maximum number of transects = 107; survey altitude = 30.5 m; strip width = 0.2 km; sampling intensity = 10.1%).

Transect no.	No. hooded seal pups counted				Transect length (km)	Area (km^2)	Density of pups (no./km^2)
	Thin blueback	Fat blueback	Solitary	Total[a]			
1	1	20	5	26	5.0	0.99	26.3
2	5	29	3	37	9.9	1.97	18.7
3	2	11	5	22	12.4	2.47	8.9
4		8	4	16	9.9	1.97	8.1
5	4	61	26	101	12.4	2.47	40.9
6		24	13	39	14.8	2.96	13.2
7	2	22	24	50	17.3	3.46	14.5
8	2	23	6	32	17.3	3.46	9.3
9		4	6	12	12.4	2.47	4.9
10		1	3	4	12.4	2.47	1.6
11			4	4	12.4	2.47	1.6
TOTALS	16	203	99	343	135.8	27.16	

[a] Total pups is not always the same as the sum of pups classified as to thin, fat or solitary; the difference is due to pups that could not be classified.

Table 13. Summary of sighting results from a helicopter survey of hooded seals carried out in the Davis Strait on 24 March 1984. (Patch area = 852 km^2; maximum number of transects = 193; survey altitude = 30.5 m; strip width = 0.2 km; sampling intensity = 10.4%).

Transect no.	No. hooded seal pups counted: Thin blueback	Fat blueback	Solitary	Total[a]	Transect length (km)	Area (km^2)	Density of pups (no./km^2)
1		5	43	50	27.2	5.43	9.2
2		19	77	96	29.6	5.93	16.2
3	1	82	146	239	37.0	7.41	32.3
4		70	183	256	30.8	6.16	41.6
5	2	70	133	209	25.5	5.10	41.0
6	4	65	99	169	18.2	3.64	46.5
7		50	27	79	12.4	2.49	31.8
8		37	51	88	17.3	3.46	25.5
9		55	119	175	31.5	6.30	27.8
10		27	94	123	35.8	7.16	17.2
11		8	34	46	22.9	4.58	10.0
12	1	9	64	74	24.5	4.90	15.1
13			61	61	20.4	4.07	15.0
14		1	77	78	17.0	3.39	23.0
15		11	80	92	22.7	4.53	20.3
16		2	40	42	19.8	3.97	10.6
17		22	21	43	20.4	4.07	10.6
18		4	7	11	11.3	2.26	4.9
19		2	4	6	12.6	2.51	2.4
20		1		1	7.4	1.48	0.7
TOTALS	8	540	1360	1938	444.2	88.84	

[a] Total pups is not always the same as the sum of pups classified as to thin, fat, or solitary; the difference is due to pups that could not be classified.

Table 14. Summary of results of hooded seal surveys carried out in the Davis Strait during March 1984.

Date	Survey type[a]	No. lines flown	Patch area (km^2)	Strip width (km)	Percent sampled	Total pups on-transect	Percent of pups solitary	Mean density (pups/km^2)	Est. number	95% confidence interval	Remarks
March											
20	F	8	447	0.503	16.7	781	33.9	10.5	4690		partial coverage
21	H	11	268	0.200	10.1	343	28.9	12.6	3390		partial coverage
23	F	6	384	0.458	14.3	494	70.9	9.0	3460		partial coverage
24	H	20	852	0.200	10.4	1938	70.2	21.8	18590	13750-23440	
25	F	6	1153	0.503	7.8	766	73.2	8.5	9820	2630-17020	

[a] F - fixed-wing photo-survey of patch; H - helicopter sighting survey of patch; S - spot photo survey of searched areas.

Table 15. Observations used in the likelihood function. Only partial data are available for 20 March.

Date	S_{i1}	S_{i2}	S_{i3}	S_{i4}	O_ℓ	σ_ℓ	ρ	C
20 March	(	655	)	476	-	-	.057	.071
21 March	7	133	1,835	1,784	35,264	4,735	.13	.027
25 March	3	64	725	1,806	24,017	2,490	.29	.03

Table 16. Parameter estimates and 95% confidence limits calculated from Eq. 10.

Trial	Birthing distribution assumed	N	Birthing distribution estimates	d_4	Maximum log-likelihood	Comments
1	Normal	54,700 ±17,500	μ = 17.3 b ± .74 σ = 3.0 b ± .65	3.28 ± .9	207	
2	Normal	225,000 ± 88,500	μ = 13.1 b ± .74 σ = 2.88 b ± .17	1.20 ± .94	5 824	Simple random sample assumed, C=1
3	Gamma	48,200 ±13,930	κ = 8.89 ±31.4 Θ = 1.0 ± 1.74 η = 8.78 ±17.	3.57 ±1.0	206	

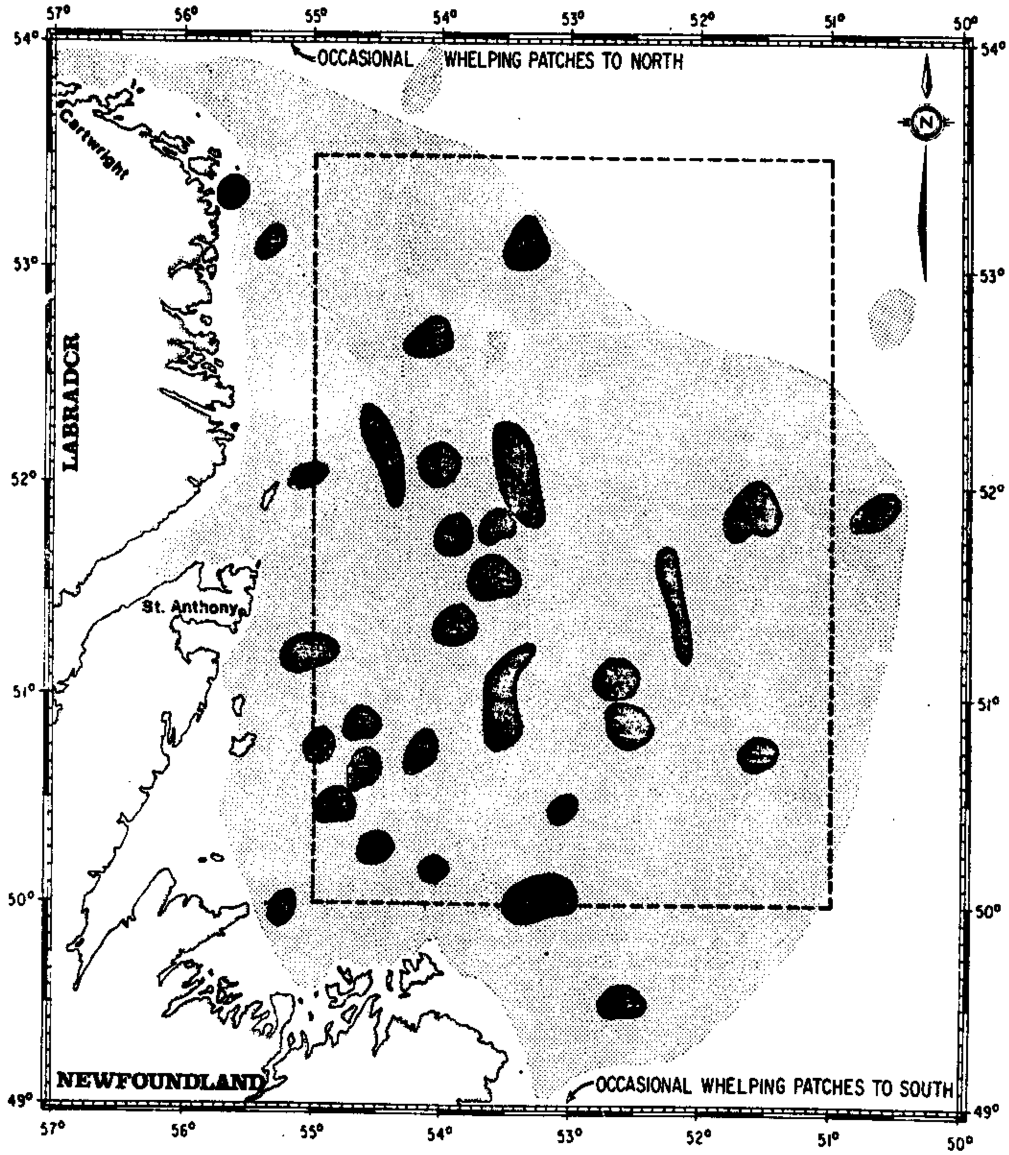


Fig. 1. Cumulative distribution of whelping hooded seals at the Front during the years 1964-83 inclusive. Whelping patches are shown as solid black surfaces, while the stippled region represents the overall distribution of the "scattered" hooded seal families. The dashed box represents the total study area of the 1984 survey. These data were derived from a variety of historical sources, especially Canadian Fisheries Officers reports and diaries, Norwegian progress reports on sealing and seal investigations, the diaries and reports of Mr. T. Curran, Sr., and some recent Canadian research surveys.

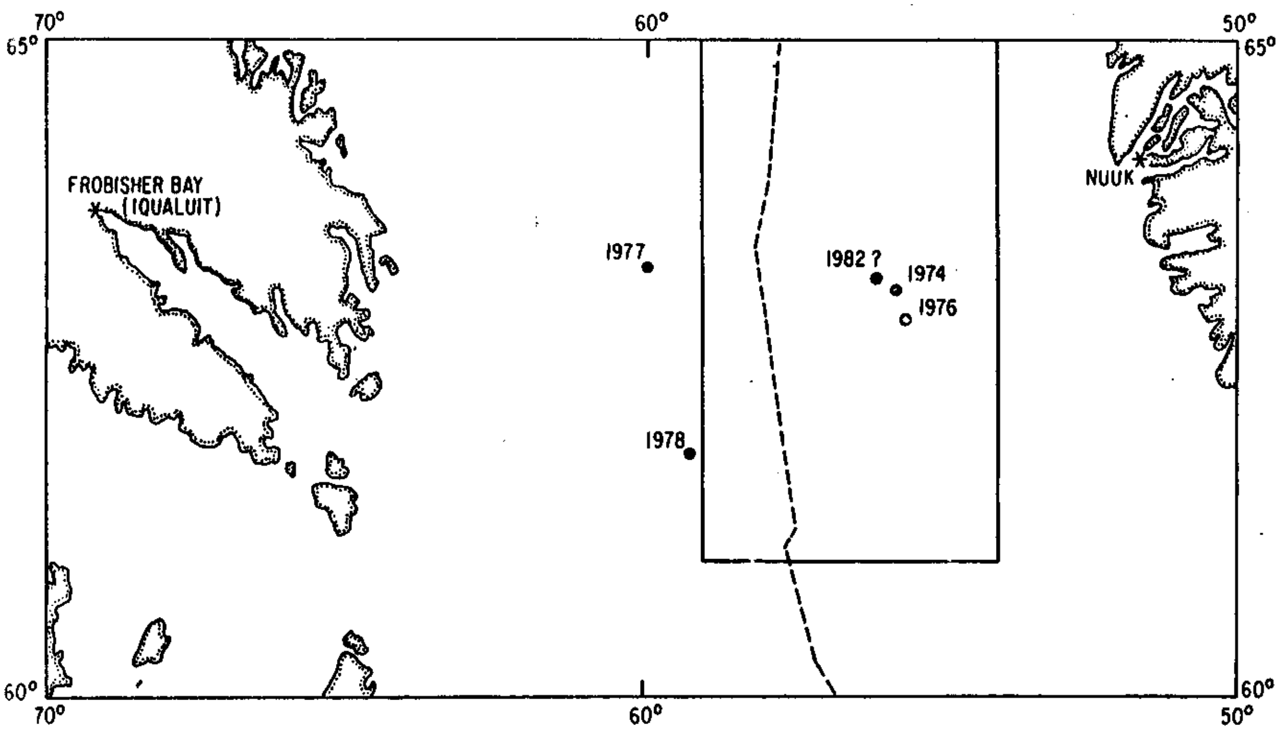


Fig. 2. Distribution of whelping concentrations of hooded seals in Davis Strait for the years 1974, 1976-78 inclusive, and 1982. The solid box represents the 1984 study area and the dashed line represents the fishing zone boundary between Greenland and Canada. Data are taken from the research surveys of Sergeant (1974, 1976, 1977), MacLaren Atlantic Ltd. (1977), and MacLaren Marex Inc. (1979). The 1982 point comes from McLaren and Davis (1983) and comprises a group of 60 hooded seals (including one possible blueback) which may be part of the traditional Davis Strait whelping herd.

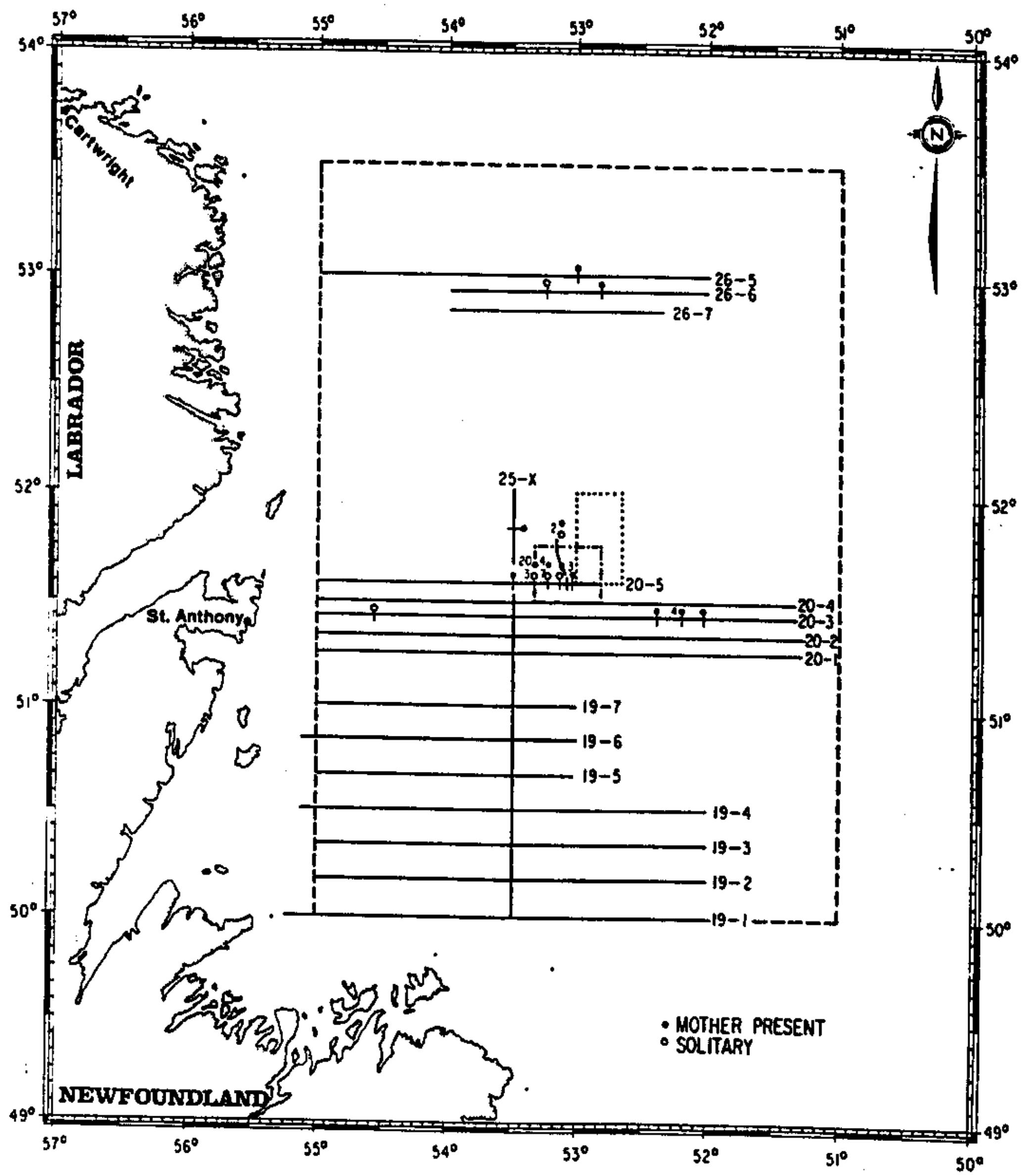


Fig. 3. Transects flown during searches for hooded seals at the Front during March 1984. Spot-photographs were taken at about 3.5 km intervals along these lines. Observations of hooded seal pups (from spot-photos) are indicated along the transects. Transects are identified by date followed by serial number. The dotted rectangle outlines the hooded seal patch of 25 March, while that with alternating dashes and dots outlines the patch of 20-21 March.

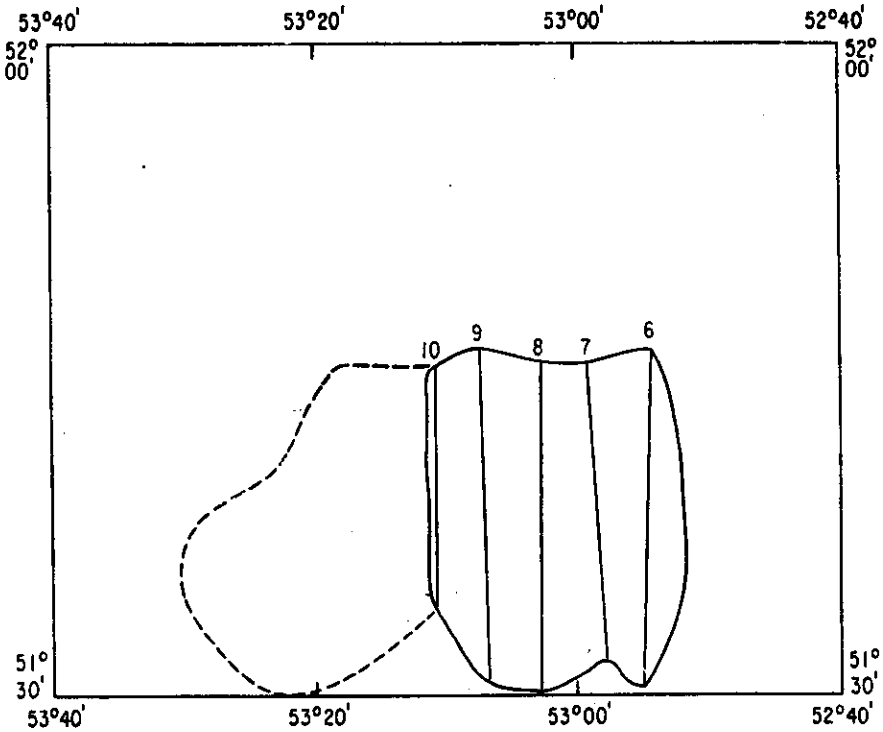


Fig. 4. Transects flown during an incomplete fixed-wing photo-survey of the hooded seal patch at the Front on 20 March 1984. The solid line represents the patch boundary as defined by the photo-transects, while the dashed line represents an approximate extension of the patch from data collected by the fixed-wing aircraft.

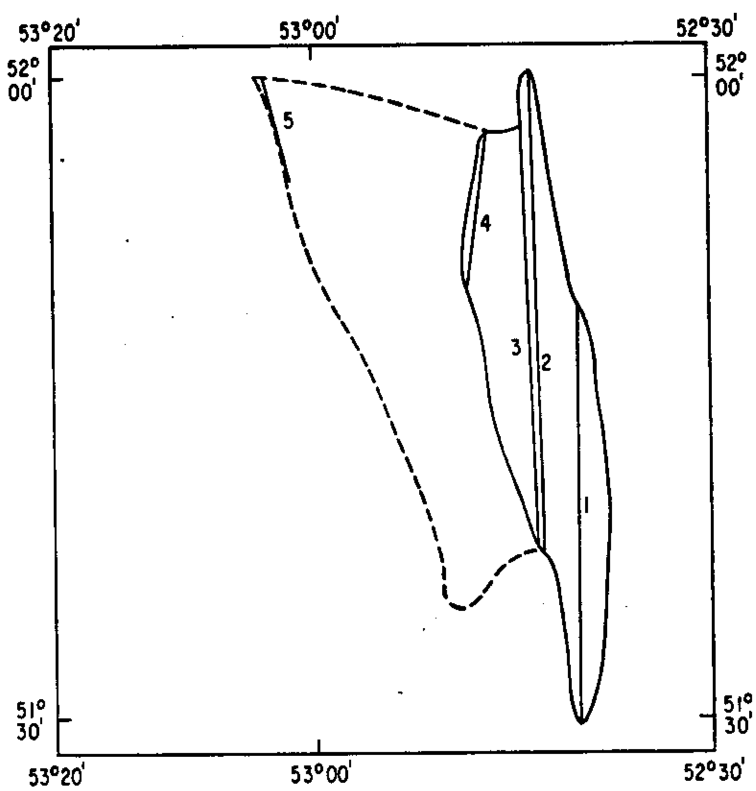


Fig. 5. Transects flown during an incomplete fixed-wing photo-survey of the hooded seal patch at the Front on 25 March 1984. The solid line represents the patch boundary as defined by the photo-transects, while the dashed line represents an approximate extension of the patch from data collected by the fixed-wing aircraft. Transect 5 was a test photo-transect at the edge of the patch and was not used in analyses.

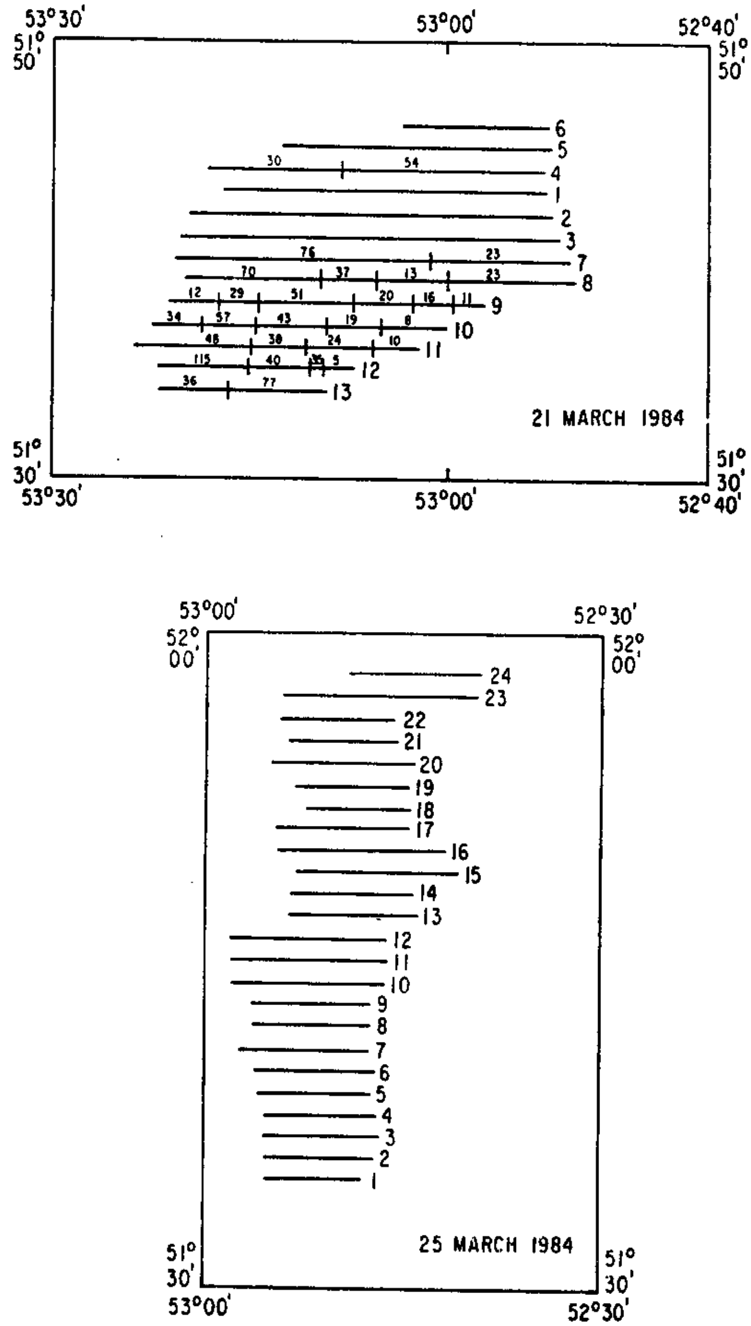


Fig. 6. Transects flown during helicopter sighting surveys of the hooded seal patch at the Front. For the survey of 21 March 1984, the density of pups (no./km^2) is indicated for specific segments of each transect.

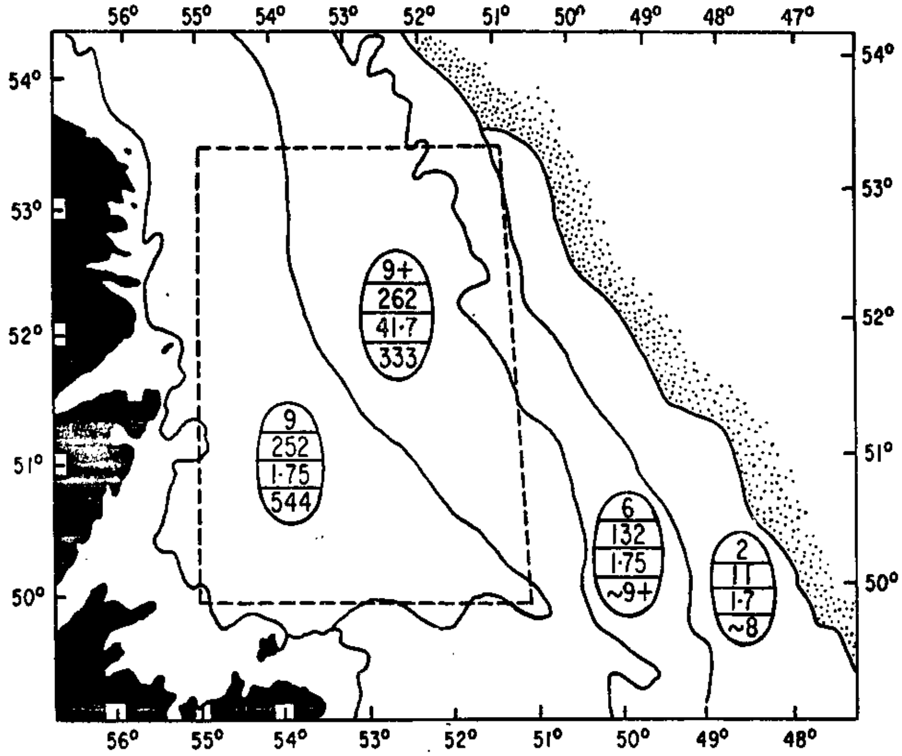


Fig. 7. Ice conditions off northeast Newfoundland and southeast Labrador on 20 March 1984, as prepared by Ice Central, Atmospheric Environment Service, Ottawa. The study area is shown as a dashed box. The codes for ice conditions are given in Appendix I.

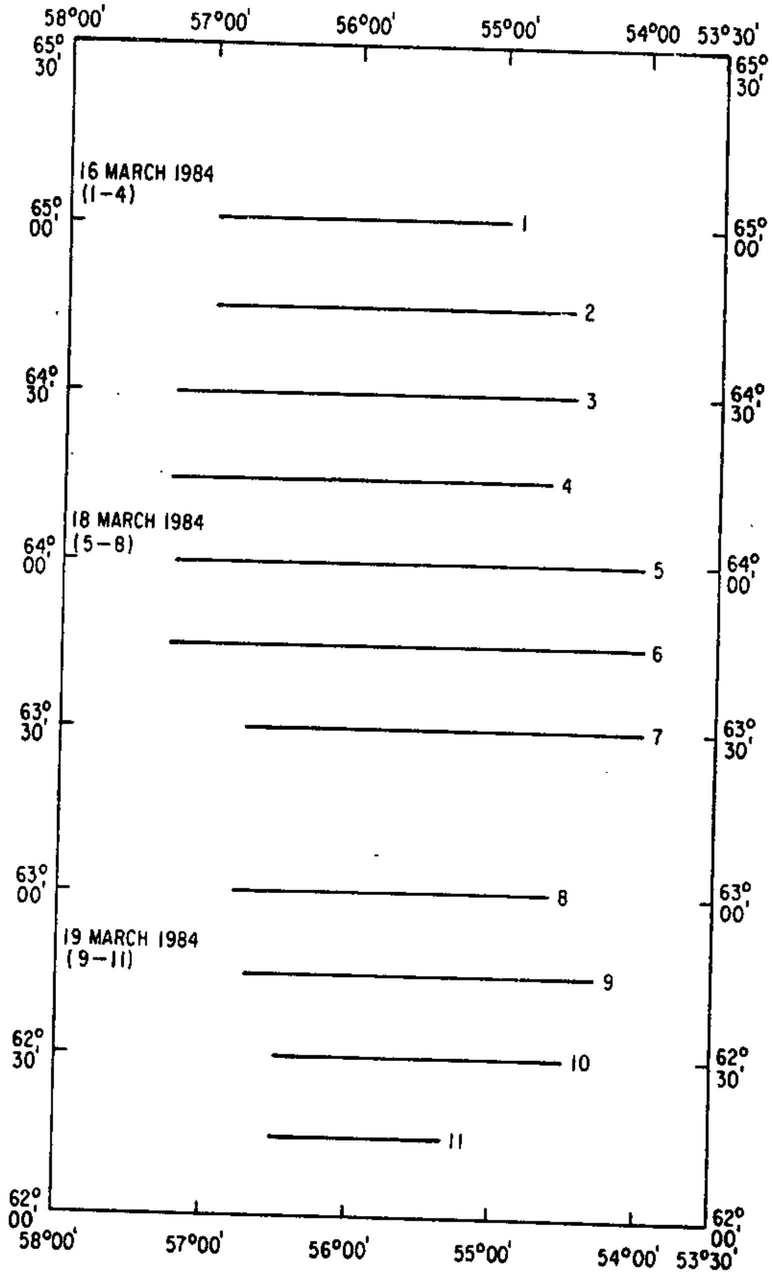


Fig. 8. Transects flown during searches for hooded seals in Davis Strait, 16-19 March 1984.

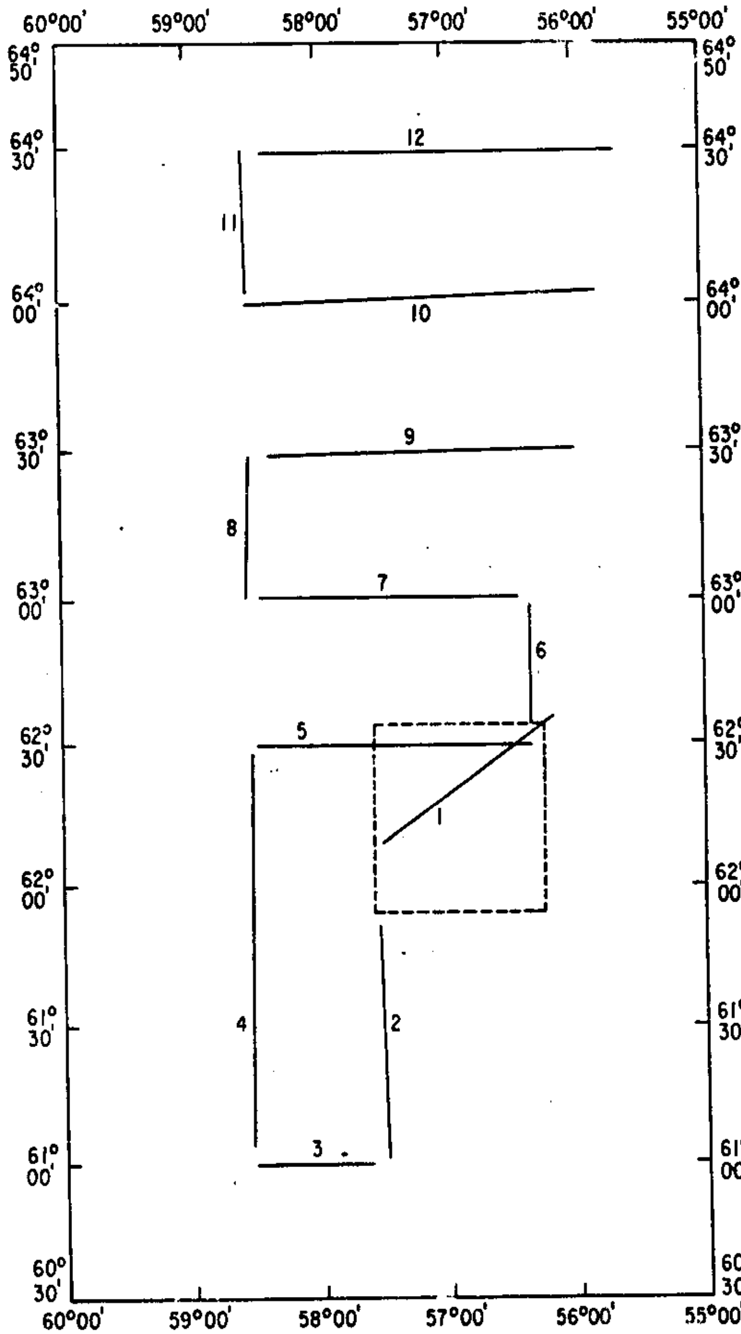


Fig. 9. Transects flown during searches for hooded seals in Davis Strait on 26 March 1984. Aerial photographs were taken at an interval of about 6.4 km along these transects. The dashed box represents the hooded seal patch of 25 March (as defined by the photo-survey on that day) plus a zone of width 18.5 km around the patch.

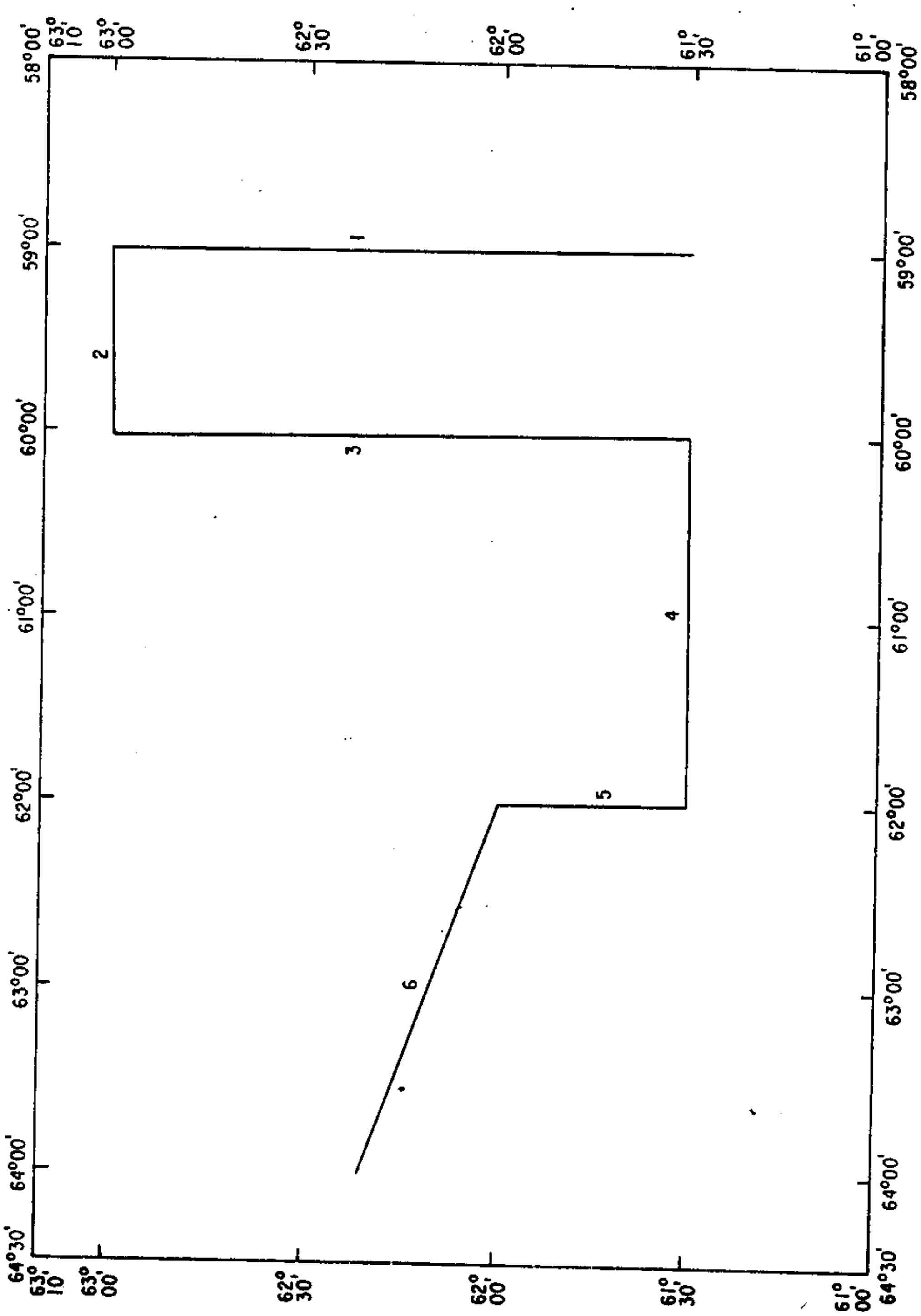


Fig. 10. Transects flown during searches for hooded seals in Davis Strait on 27 March 1984. Spot-photos (6.4 km interval) were taken on transects 1, 2, 3, and 4.

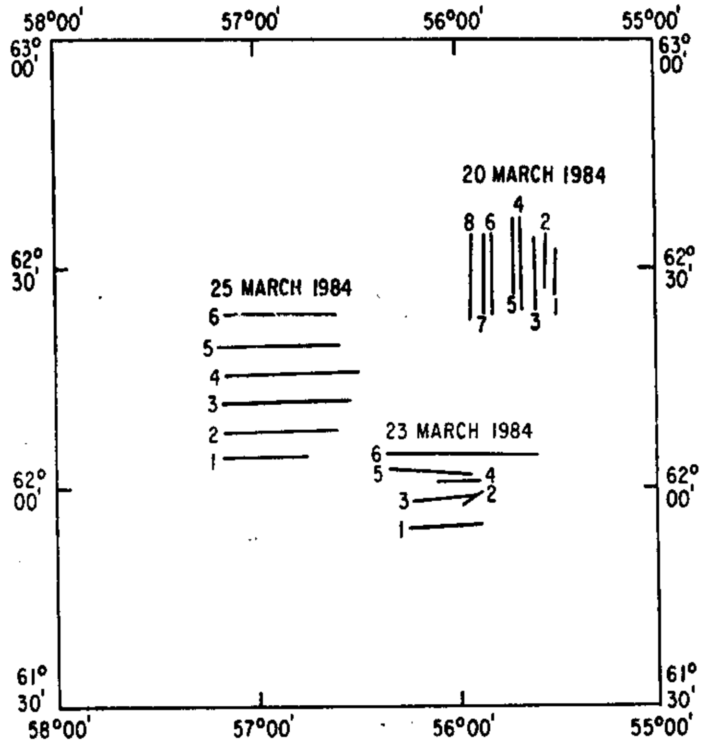


Fig. 11. Transects flown during fixed-wing photo-surveys of the hooded seal patch in Davis Strait on 20, 23 and 25 March 1984.

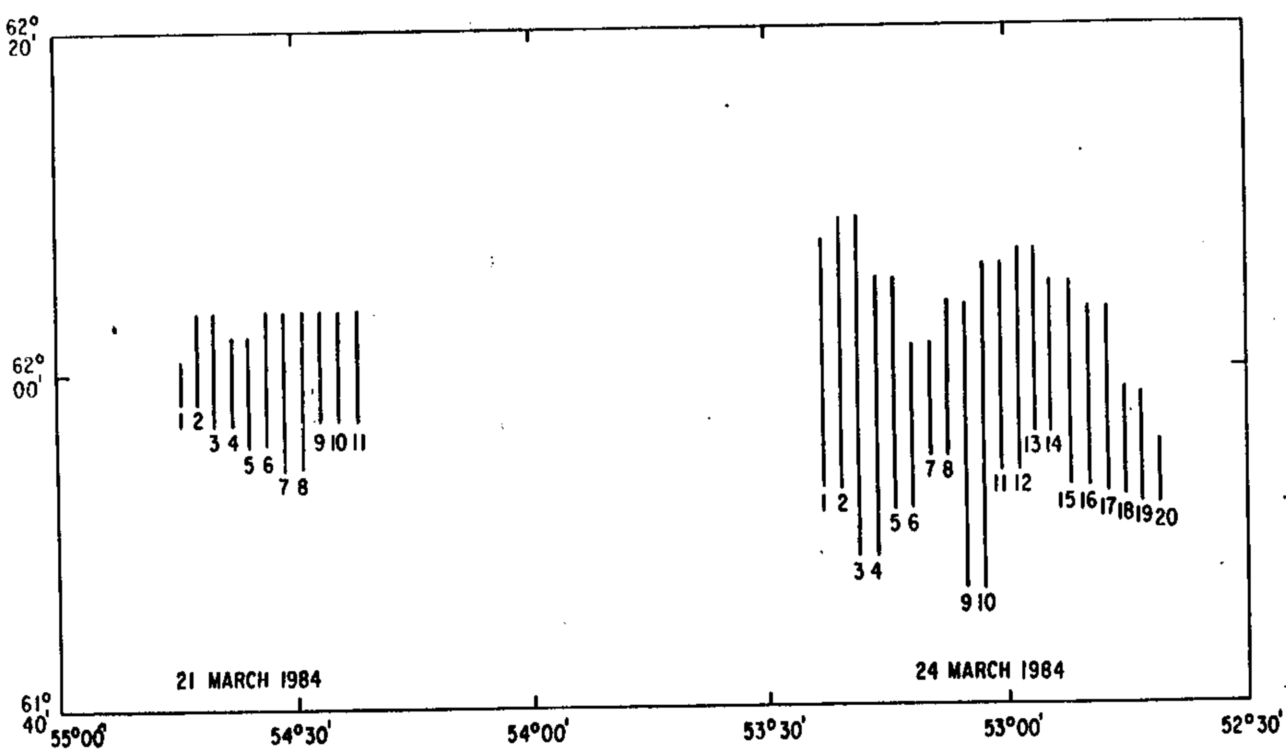


Fig. 12. Transects flown during helicopter sighting surveys of the hooded seal patch in Davis Strait. As these surveys were accomplished using dead-reckoning without an electronic navigation system, the latitude scale is only approximately accurate, while the longitude scale was chosen arbitrarily.

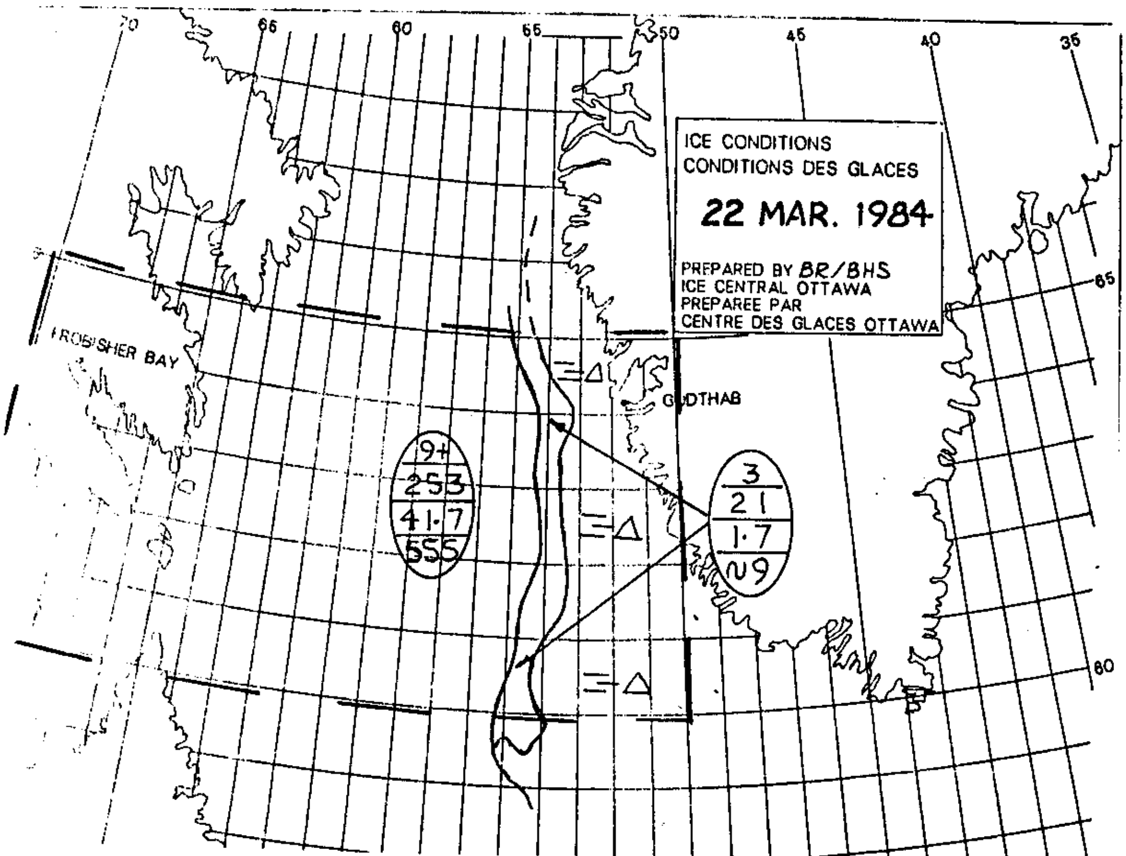


Fig. 13. Ice conditions in Davis Strait on 22 March 1984, as prepared by Ice Central.

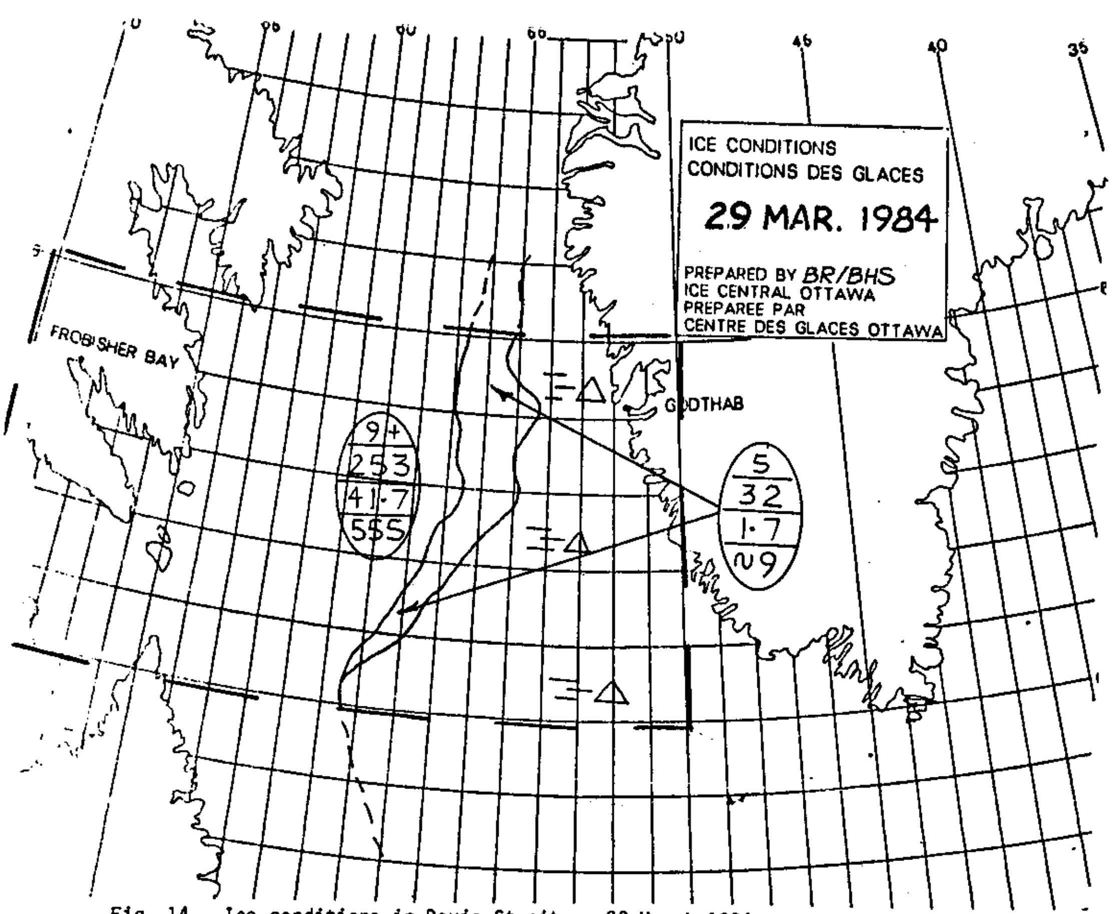


Fig. 14. Ice conditions in Davis Strait on 29 March 1984, as prepared by Ice Central.

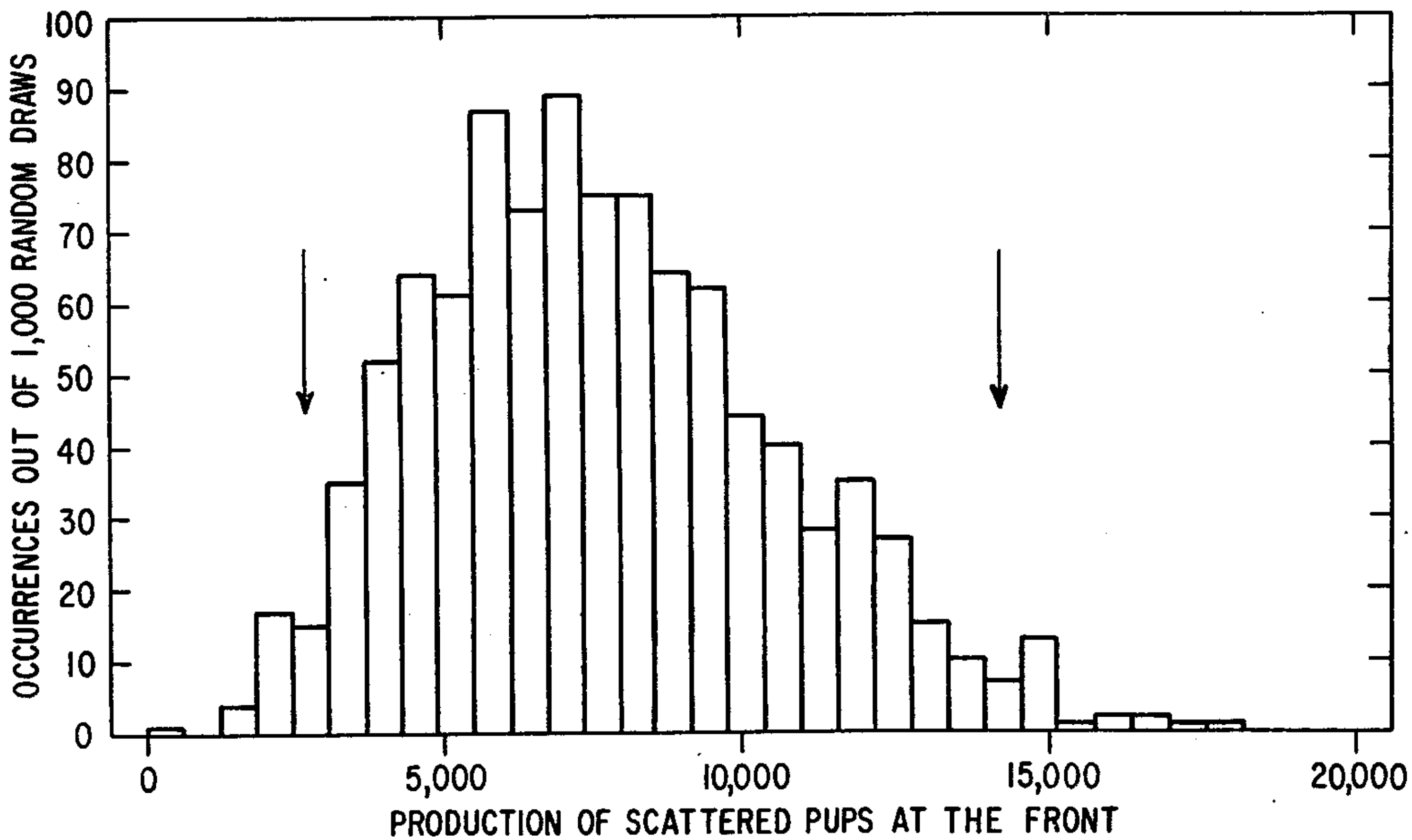


Fig. 15. Histogram of 1000 bootstrap simulations of the data on scattered seals at the Front. The 95 percentile limits are indicated by arrows.

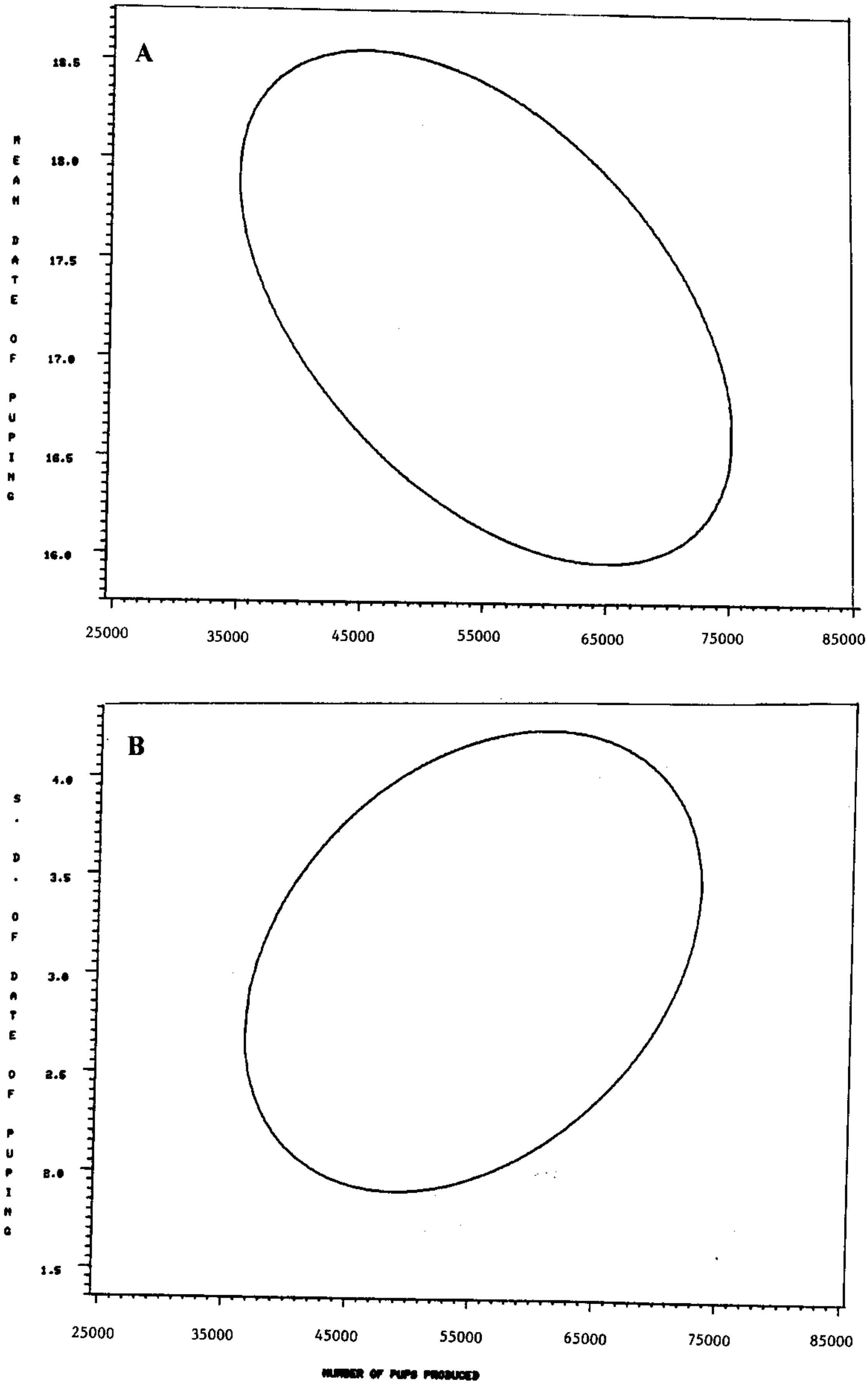
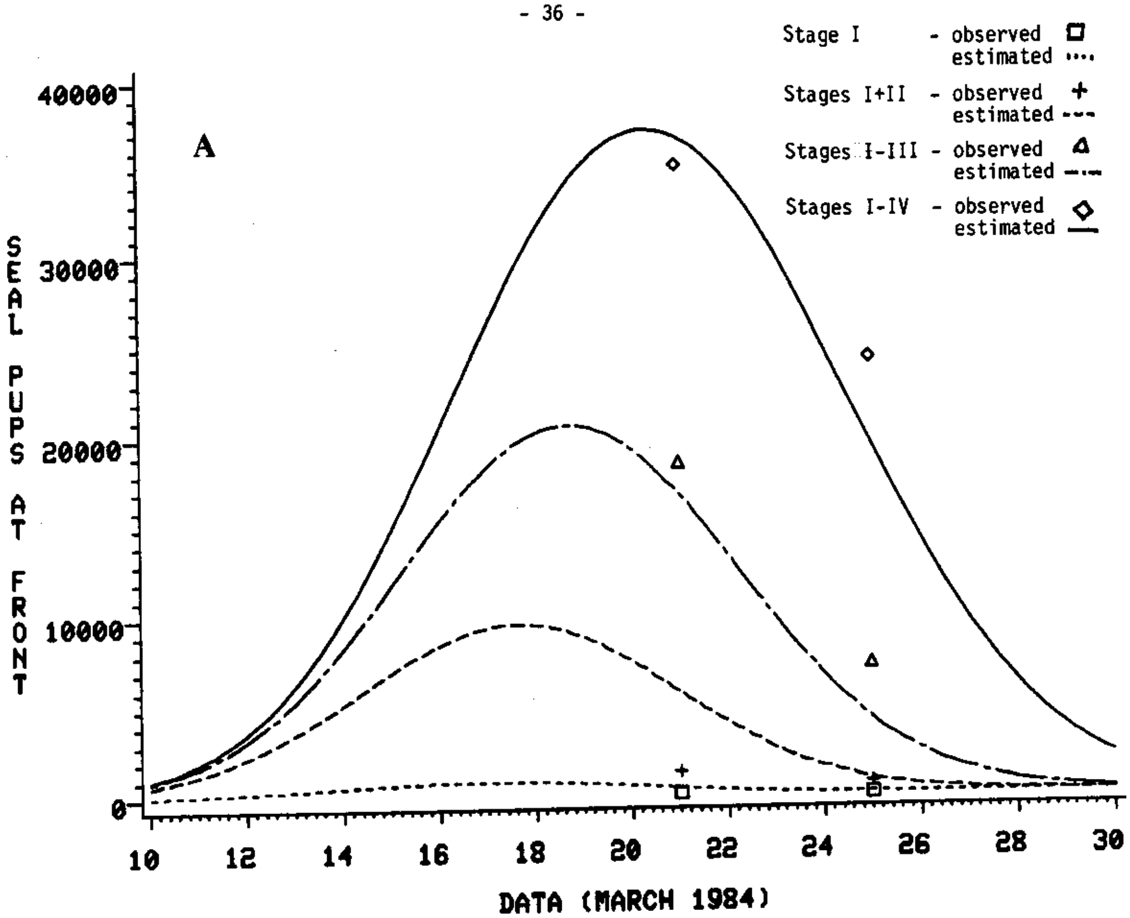


Fig. 16. Two-dimensional slices of the 95% joint confidence region for Trial 1 (Table 16) relevant to (A) mean date of puping and (B) standard deviation of date of puping, calculated from the approximation of the covariance matrix of the estimates (Eq. 10).



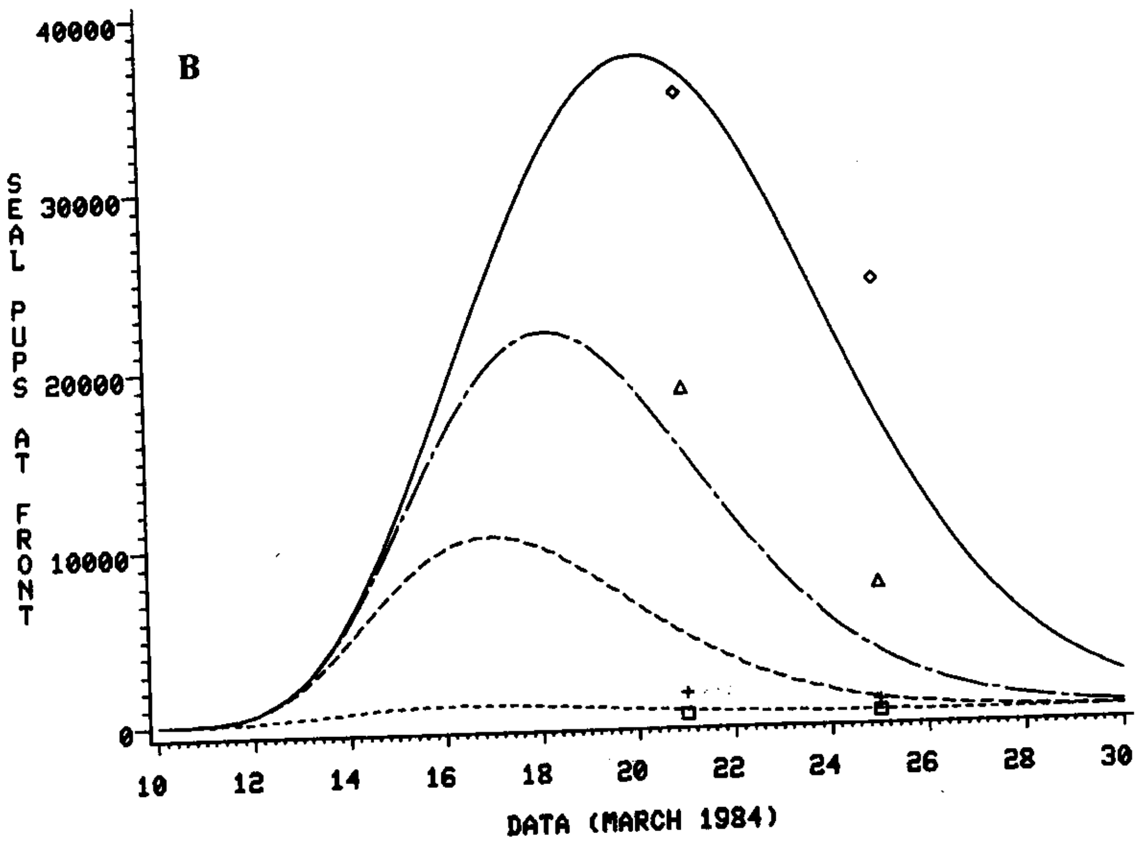


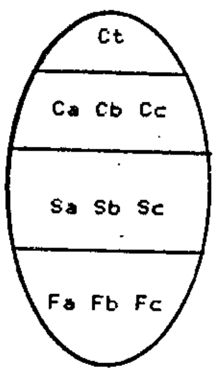
Table 17. Observed and estimated numbers of pups of different stages present on the ice off Labrador in March 1984 (Trial 1, Table 16), using the assumption of (A) a normal birthing distribution and (B) a gamma birthing distribution.

APPENDIX 1. INTERNATIONAL SEA ICE SYMBOLS

1. INTRODUCTION

BECAUSE OF THE USE OF RADIO FACSIMILE BY COMMERCIAL SHIPS, THE WORLD METEOROLOGICAL ORGANIZATION (WMO) APPROVED THE INTERNATIONAL SEA ICE NOMENCLATURE IN 1968 AND HAS NOW APPROVED A SET OF SYMBOLS FOR USE ON ICE CHARTS. THE INTENT OF THE SYMBOLS IS TO PERMIT MOST ICE DATA TO BE SHOWN IN NUMERICAL OR SYMBOLIC FORM, ELIMINATING THE LANGUAGE BARRIER FROM INTERNATIONAL ICE DATA EXCHANGE AND FROM USE ON BROADCAST ICE CHARTS BY SHIPS OF ALL NATIONS.
THE COUNTRIES OF THE NORTHERN HEMISPHERE WHICH OPERATE SIGNICANT ICE INFORMATION PROGRAMS NOW USE THESE INTERNATIONAL SEA ICE SYMBOLS. THE BASIC DATA ON ICE CONCENTRATION, ICE TYPES, AND ICE FLOE SIZE ARE ENCLOSED IN A SIMPLE OVAL AND ARE DESCRIBED HEREIN, TOGETHER WITH THE APPROPRIATE CODE TABLES AND EXAMPLES OF THE CODED ICE DATA.

2. THE MAIN SYMBOLS



Ct - TOTAL CONCENTRATION OF ICE IN THE AREA, REPORTED IN TENTHS.

CaCbCc - PARTIAL CONCENTRATION IN TENTHS OF THICKEST (Ca), SECOND THICKEST (Cb), AND THIRD THICKEST (Cc) ICE TYPES. (See notes 1 and 2 below)

SaSbSc - STAGE OF DEVELOPMENT (AGE) OF ICE CONCENTRATIONS REPORTED BY Ca, Cb, AND Cc. (See note 3 below)

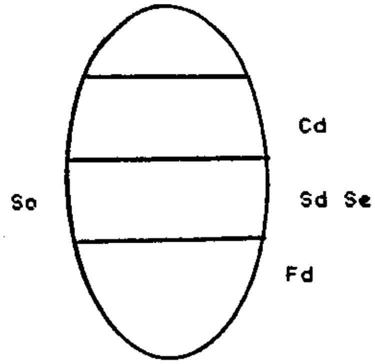
FaFbFc - FORM OF ICE (FLOE SIZE) CORRESPONDING TO Sa, Sb, AND Sc, RESPECTIVELY. (See notes 4 and 5 below)

NOTES

1. PARTIAL CONCENTRATIONS Ca, Cb, AND Cc SHALL BE ONE TENTH OR MORE
2. IF ONLY ONE ICE TYPE IS PRESENT, Ca EQUALS Ct AND THE SECOND LEVEL IS LEFT BLANK.
3. THE DECIMAL (.) WHICH IS AN INTEGRAL PART OF THE CODE FOR MEDIUM FIRST YEAR OR THICKER ICE TYPES, APPEARS ONLY ONCE IN THE SYMBOLIC FORM. ICE THICKNESS RANGES INCREASE FROM RIGHT TO LEFT AND, THEREFORE, ALL ICE TYPES TO THE LEFT OF THE DECIMAL (.) ARE UNDERSTOOD TO HAVE THIS MARK AS PART OF THE SYMBOL AND IT IS NOT REPEATED FOR EACH ONE.
4. THE ABSENCE OF INFORMATION ON FORM (FLOE SIZE) SHALL BE INDICATED BY AN "X" IN THE APPROPRIATE POSITION OF Fa, Fb, OR Fc.
5. WMO ALLOWS REPORTING PREDOMINANT FORM FOR EACH TYPE (Fa Fb Fc) AND ALSO ALLOWS AN ALTERNATIVE WHICH REPORTS PREDOMINANT FORM AND SECONDARY FORM (Fp Fs) OF ALL ICE PRESENT. CANADIAN PRACTICE IS TO USE THE PREDOMINANT FORM FOR EACH ICE TYPE AND THAT IS INDICATED ON ICE CENTRAL PRODUCTS. OBSERVED ICE CHARTS REQUIRE A DASH FOLLOWING Fa AND Fb WHEN ONLY TWO TYPES OF ICE ARE PRESENT.

SUPPLEMENTARY SYMBOLS

NOTE: EXCEPT FOR So AND Sd, THESE SYMBOLS WILL NOT BE USED ON CHARTS PRODUCED BY ICE CENTRAL OTTAWA. OBSERVED ICE CHARTS WILL AT TIMES REPORT ALL SYMBOLS.



Cd - PARTIAL CONCENTRATION OF FOURTH ICE TYPE. (See notes 2,3 below)

So Sd Se - DEVELOPMENT STAGE (AGE) OF REMAINING ICE TYPES. (See notes 1,2,4,6, and 7)

Fd - FORM (FLOE SIZE) OF FOURTH ICE TYPE. (See notes 5, and 7 below)

NOTES

1. Se IS ONLY REPORTED WHEN A THINNER ICE TYPE REMAINS AFTER Sd, AND MAY BE A TRACE OF ICE. PARTIAL CONCENTRATION OF Se IS OBTAINED BY SUBTRACTING PARTIAL CONCENTRATIONS (Ca, Cb, Cc, AND Cd) FROM TOTAL CONCENTRATION (Ct).

2. Cd IS ONLY REPORTED WHEN Se IS REPORTED AND WHEN ONE OR MORE TENTHS OF ICE TYPES THINNER THAN Sa, Sb, AND Sc REMAIN.

3. WHEN NOT INCLUDED, Cd EQUALS Ct -(Ca + Cb + Cc).

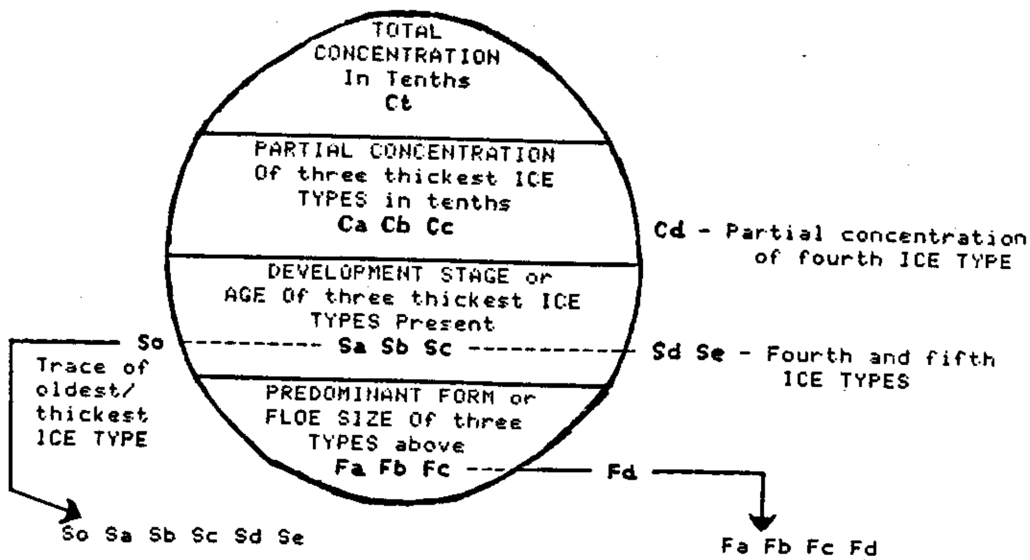
4. WHEN Se IS NOT PRESENT, Sd MAY BE A TRACE OF ICE.

5. Fd IS ALWAYS REPORTED WHEN THE CONCENTRATION OF Sd IS ONE OR MORE TENTHS.

6. IF ONLY ONE TYPE OF ICE INSIDE THE OVAL, THEN CONCENTRATION OF Sd, WHEN REPORTED, IS LESS THAN ONE TENTH.

7. So, WHEN REPORTED, IS A TRACE OF ICE TYPE THICKER/OLDER THAN Sa. NO INFORMATION ON THE FORM OF THE ICE TYPE IS PROVIDED.

THE COMPLETE CODE



DEVELOPMENT STAGE/AGE OF ICE

1 - NEW ICE	
2 - NILAS ICE	Up to 10 cm
3 - YOUNG ICE	10-30 cm
4 - GREY ICE	10-15 cm
5 - GREYWHITE ICE	15-30 cm
6 - FIRST YEAR ICE	Over 30 cm
7 - THIN FIRST YEAR ICE	30-70 cm
8 - THIN FIRST YEAR ICE (FIRST STAGE)	30-50 cm
9 - THIN FIRST YEAR ICE (SECOND STAGE)	50-70 cm
1• - MEDIUM FIRST YEAR ICE	70-120 cm
4• - THICK FIRST YEAR ICE	Over 120 cm
7• - OLD ICE	
8• SECOND YEAR ICE	
9• MULTI YEAR ICE	
▲• ICEBERGS	

PREDOMINANT FORM OR FLOE SIZE

0 - PANCAKE	
1 - BRASH	
2 - ICE CAKE	<20 m
3 - SMALL FLOE	20-100 m
4 - MEDIUM FLOE	100-500 m
5 - BIG FLOE	500 m-2 km
6 - VAST FLOE	2-10 km
7 - GIANT FLOE	>10 km
8 - FAST ICE	
9 - ICEBERGS	
X - UNKNOWN/UNDETERMINED	

NOTE 1. 3 AND 6 ONLY USED WITH RADAR AND SATELLITE ANALYSIS

2. 8 AND 9 USED WHEN MEASURED DETAIL IS AVAILABLE

3. 8• AND 9• USED DURING CERTAIN PERIODS IN THE ARCTIC