Northwest Atlantic Fisheries Organization

Serial No. N2523

NAFO SCR Doc. 95/16

SCIENTIFIC COUNCIL MEETING - JUNE 1995

JOINT ICES/NAFO WORKING GROUP ON HARP AND HOODED SEALS, 5-9 JUNE 1995
(SEA-69)

Pup Production of Hooded Seals (*Cystophora cristata*) in the Northwest Atlantic

by

G. B. Stenson[1], R. A. Myers[1], I-H. Ni[2] and W. G. Warren[1]

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

[2] Dept. of Biology, Hong Kong University of Science and Technology
Clearwater Bay, Kowloon, Hong Kong

Abstract

Pup production of hooded seals (*Cystophora cristata*) in two whelping concentrations along the northeast coast of Newfoundland (the 'Front') during March 1990 was estimated using systematic visual surveys. In addition, independent estimates of production in one of the concentrations and number of pups born outside the whelping concentrations were obtained from photographic surveys. Photographic estimates were corrected for incorrectly identified pups by comparing black and white photographs with ultra-violet imagery. Estimates were also corrected for pups absent from the ice at the time of the survey using distinct age-related developmental stages. Approximately 91% of the pups born in the first whelping concentration, and 92% born in the second, were present during the surveys. Based on viusal surveys, the corrected pup production in these patches was estimated to be 48,684 (SE=2,747). Photographic surveys resulted in an estimate of 33,498 (SE=12,450) pups born outside of the whelping patches, although this estimate could not be corrected for the abscence of pups due to the temporal distribution of births. Thus, total pup production was estimated to be 82,182 (SE=12,636). Comparison with estimates made in the mid 1980's suggest that pup production may have increased although they are not statistically different due to the imprecise nature of the estimates.

Introduction

The hooded seal (*Cystophora cristata*) is one of the most abundant, pelagic phocids in the North Atlantic. Although some give birth (whelp) on the pack ice north of Iceland, near Jan Mayen Island in the eastern Atlantic, the majority are found in the Western Atlantic where they undergo annual migrations between whelping areas along the coast of Canada and in Davis Strait, and moulting and summer areas off southeast and west Greenland. In the northwest Atlantic, whelping occurs in the Davis Strait, off Newfoundland and in Gulf of St. Lawrence. Of these, the largest whelping concentration occurs off the coast of southern Labrador or northern Newfoundland (the 'Front'). Using catch data, pup production at the Front was estimated to be approximately 30,000 in the late 1960's (Øritsland and Benjaninsen 1975, Sergeant 1976, Lett 1977, Winters and Bergflødt 1978). In 1984, pup production at the Front was estimated to be 62,000 (95% CI 43,700-89,400; Bowen et al. 1987), based on aerial surveys. Although not directly comparable to earlier studies, this estimate was substantially higher, suggesting that either previous estimates were negatively biased or that the population was increasing.

Commercial hunting of hooded seals at the Front has been reported since the 19th century, but likely occurred earlier. Between 1974 (when quotas were first implemented) and 1982, the average annual catch was 12,500 animals, the majority being pups taken by large vessels at the whelping patch (Anonymous 1994). Following the demise of this hunt in 1983, catches declined to an average of 650 seals per year between 1983 and 1990. This decline in hunt-related mortality may have resulted in an increased population since the 1984 survey.

In addition to understanding hooded seal population dynamics, estimates of abundance are necessary in order to determine the potential impact of this species on fish stocks in the northwest Atlantic. Hooded seals inhabit the Newfoundland continental shelf for much of the winter and spring (Stenson and Kavanagh 1992; Stenson unpubl. data) where they feed on a variety of commerically important fish such as Greenland halibut, *Reinhardtius hippoglossoides*, redfish, *Sebastes* spp., and Atlantic cod *Gadus morhua*, (Stenson et al. 1991; Ross 1992; Lawson et al. 1993), which have been declining in abundance (Sinclair 1993; Bishop et al. 1994; Bowering et al. 1994; Morgan et al. 1994; An accurate estimate of abundance is one of the requirements necessary to quantify the level of consumption of these species by hooded seals.

The objective of this study was to estimate pup production of hooded seals at the Front during 1990 using a combination of visual and photographic surveys and, by comparison to earlier estimates, determine if pup production had changed since the demise of the commercial hunt for young hooded seals.

Methods

Reconnaissance surveys

Reconnaissance surveys designed to locate pupping concentrations were conducted between 5 - 25 March using two Piper Navajo aircraft, equipped with a LORAN C navigation system. Based on maps of historical whelping distributions, and the distribution of suitable ice (¿30cm thick, 6/10 coverage) the area between Cape Harrison (54° 56'N 57° 54'W) to just north of the Funk Islands (49° 45'N 53° 11'W) was surveyed. Systematic east-west transects, spaced 18.5 km apart, were flown at an altitude of 230 m from the coastal margin of the ice pack to the outer edge (Fig. 1). Two observers, one per side, examined all ice considered heavy enough to support seals. This design was expected to have a high probability of locating whelping patches which are generally >9 km in width (Bowen et al. 1987). To account for ice drift and the asynchronous pupping period of hooded seals, some areas were surveyed more than once. When a whelping patch was located satellite and VHF radio transmitters were deployed to facilitate relocation and monitor movements.

Visual surveys

Visual surveys of the whelping concentrations were conducted on 21, 23, 25, and 27 March, 1990 using a MMB105 helicopter equipped with a Loran C Navigation System and radar altimeter. Surveys conducted on 21 and 25 March were used to estimate abundance while data from all four surveys were used to determine the proportion of pups in various age-specific developmental stages (see below). Observers recorded information on the developmental stage composition and number of pups present within known strips on each side of the aircraft on laptop computers. Survey strips were delineated by placing reference marks on the windows using a known distance marked on the ice. Accessory marks placed at the level of the horizon and in line with the edge of the helicopter floats were used to maintain a constant observer head position. A third observer seated beside the pilot directed the survey to ensure that transect lines were flown correctly. Ground speed varied dependent upon wind conditions but was maintained at the minimum possible ($\leq$ 80 km) to maximize the viewing time and ensure complete counts.

For each survey, the first transect was flown along the first whole minute of latitude closest to one edge of the patch. Each transect began before any seals were encountered and was terminated when no seals were seen over a distance of approximately 5 km. The survey ended when no seals were seen along a transect and could not be observed outside of the survey area.

The first whelping concentration was surveyed on 21 March. The flying altitude was 92 m and the total strip width was 400 m (200 m per observer). Transect spacing was 1.85 km for the first 17 transects but was increased to 3.7 km for the final 7 transects to ensure that the entire patch was surveyed in a single day. The second concentration was surveyed on 25 March at an altitude of 30.5 m to allow for the classification of pup developmental stages (see below). The survey strip width was 200 m (100 m per observer) and transects spaced at intervals of 3.7 km.

All surveys were based on a systematic sampling design with a single random start. The sampling unit was a transect of variable length. The estimate of the number of pups for each survey region was the sum of pups on all transects corrected for the transect spacing. The data were analyzed using the methods outlined in Hammill et al. (1992) and Stenson et al. (1993). The estimated number of pups for the i^{th} survey is given by

$$\hat{N}_i = k_i \sum_{j=1}^{J_i} x_j$$

where x_j is the number of pups on the j^{th} transect, J_i is the number of transects in the i^{th} survey, and k_i is a weighting factor equal to the transect spacing divided by the strip width for the i^{th} group. The estimates of error variance were based on serial difference between transects (Cochran 1977 p. 225; Kingsley et al. 1985) calculated as

$$V_i = \frac{k_i(k_i-1)J_i}{2(J_i-1)} \sum_{j=1}^{J_i-1}(x_j - x_{j+1})^2$$

If transect spacing changed within the survey area, each area of homogeneous transect spacing was treated as a separate survey. The total population was estimated as $\hat{N} = \sum_{i=1}^{I} N_i$ and its error variance $\hat{V} = \sum_{i=1}^{I} V_i$ where I is the number of surveys.

/subsub*Photographic surveys

Fixed-wing aerial photographic surveys were flown in a Piper Navajo photographic airplane using a 23 x 23 cm format *metric mapping* camera (Zeiss RMK/A) equipped with a 150 mm Sonnar lens and Kodak Double-X (2405) aerographic black and white film. All surveys were flown at an altitude of 305 m providing coverage of a 455.5 X 455.5 m area per photo. Correct altitude and transect spacing was maintained using a radar altimeter and Loran C. There was no overlap between consecutive frames.

Images were also obtained using a Vinten 70 mm aerial reconnaissance camera fitted with a 76.2 mm quartz lens, a Wratten 18A ultra-violet filter and Kodak Tri-X (2403) black and white aerographic film. This system recorded images in ultra-violet wavelengths (300-400 nm). Each photograph covered an area of ice 228.6 X 228.6 m.

The survey area consisted of two strata: 1) whelping concentrations, and 2) scattered pups outside of the whelping patches. A systematic aerial photographic survey, consisting of east-west transects spaced 7.4 km apart, was carried out on the second whelping patch on 25 March 1990. The number of pups born outside of the main concentrations was estimated from photographs taken during a series of systematic reconnaissance surveys spaced 37 km apart flown between 54° N and 50° 20' N between 13 - 28 March.

Analysis of the photographic surveys was similar to that used for the visual surveys with a correction for the area between successive, non-overlapping photographs (Stenson et al. 1993). This assumes that the distribution and density of pups on the unobserved portions were similar to those in the observed. The additional component of error that arises from this assumption was judged to be small and, to some extent, is included in the between-transect variability.

A monotonic trend in abundance was observed among the transects flown on 13 March. Therefore, the procedure for estimating the variance of the estimator for a systematic sample with a linear trend (Cochran 1977, Kingsley and Smith 1981) was employed;

$$V_i = \frac{k_i(k_i-1)J_i}{6(J_i-2)} \sum_{j=1}^{J_i-1} (x_j - 2(x_{j+1}) + x_{j+2})^2$$

Positive prints were examined by a single reader with previous experience identifying seals on photographs obtained from both camera types. Each frame was examined twice using a luminated hand-lens (7-8X magnification) and the positions and number of all seals were recorded on a clear acetate sheet laid over each print.

Film counts were corrected by comparing identical areas on a sample of matched black-and-white (Zeiss) and ultra-violet (Vinten) images (Stenson et al. 1993). Seals were identified independently on both films and compared to determine a corrected count. The corrected counts (x) were regressed on the original counts (y), $x = a + by$, to develop a correction factor for pups missed during photograph readings. Separate regressions were derived for transects flown over the whelping concentration and for surveys of the low density strata flown on 20 March (Table 1). Because of the low numbers of pups present on photographs taken on 13 March, a regression line based on all data was used to correct the counts. The regressions were not constrained to pass through the origin. Bootstrap estimates (Efron 1981) of the measurement error associated with variation about the regression were calculated. Two hundred bootstrap samples were generated for each transect. The measurement-error variances of the transects were added to estimate the total measurement-error for the survey and added to the sampling variance.

Correction for the temporal distribution of births

Hooded seal pups were classified into one of three distinct age-dependent developmental stages (newborn/thin, fat, and solitary) based on morphology and the presence or absence of the female (Bowen et al. 1987). All four observers underwent a training period to ensure accurate classifications of age-dependent developmental stages as described by Stenson and Myers (1988). On 21 March, observers carrying out surveys to estimate abundance noted the presence or absence of an attending female for each pup within the survey area. Specific stage classifications were made during a separate survey flown at an altitude of 15 m or lower. The proportions of pups in the various stages were also determined during surveys flown on 23, 25, and 27 March. These surveys were flown at an altitude of 30.5 m with transect intervals of 3.7 km. All pups present within a 50 m strip on either side of the helicopter were classified according to developmental stage. On 25 March, stage classification were combined with visual abundance surveys; pups present within an inner 50 m strip were classified while pups in the outer 50 m strip were only counted.

Using information on the proportion of pups in each of these developmental stages and the duration of each stage (Bowen et al. 1987; Stenson and Myers 1988; Myers and Bowen 1989; Stenson et al. 1993), the survey results for each whelping concentration were independently corrected for pups which had either left the ice prior to the survey or had not yet been born. The model output provides an estimate of the fraction of the total pups born that were visible to be photographed on any day.

Developmental stages are denoted by the subscript j, and a pup passes from stage j to $j+1$. We specify stage duration in terms of instantaneous transition intensity functions: $\phi_j(\tau) = \lim_{\Delta\tau \to 0}$ (probability an animal passes from stage j to $j+1$ in the interval $[\tau, \tau + \Delta\tau])/\Delta\tau$), where τ is the time spent in stage j. This specifies the force of transition into stage $j+1$ from stage j, given that the animal has spent time τ in stage j. Note that the transition intensities depend only on the current stage and the time spent in that stage to that point. The rate at which pups enter stage j at time t is denoted by $m_j(t)$, and is given by the recurrence relationship

$$m_j(t) = \int_0^\infty m_{j-1}(t-\tau)\phi_{j-1}(\tau)\, d\tau \ .$$

If there is no mortality, the total number of pups in stage j that can be observed at time t, $n_j(t)$, is the integral of the rate pups entered stage j time τ ago times the probability that those pups have not entered stage $j+1$, i.e.

$$n_j(t) = \int_0^\infty m_j(t-\tau)\,(1 - \int_0^\tau \phi_j(s)\, ds)\ d\tau.$$

These two equations adequately describe stages 1 (newborn/thin) and 2 (fat). By stage 3 (solitary) some pups may have entered the water, so the fraction of Stage 3 pups that were not visible was also estimated.

The transition intensity, ϕ_j, of stages 1, 2, and 3 was assumed to follow a gamma density. That is,

$$\phi_j(t) = \rho_j(\rho_j t)^{\kappa_j - 1} e^{-\rho_j t}/\Gamma(\kappa_j)$$

where κ_j is the shape parameter, ρ_j is the scale parameter, and $\Gamma()$ is the gamma function. These parameters were estimated in Bowen et al. (1987).

Our basic assumption was that the starting date of the birthing was estimated from independent data, i.e. from reconnaissance surveys, that stage 3 lasted 3.5 days and that pups remained on the ice and thus were visible to be surveyed. This left two parameters to be estimated from the stage duration data: the location and shape of the probability distribution of births over time, $m_1(t)$. The maximum likelihood method described by Myers and Bowen (1989) was used to estimate these model parameters.

The confidence region for the parameters of the birthing distribution were based upon the likelihood ratio test (Cox and Hinkley 1974, page 343). That is, if p parameters were fit to the model, then the parameters that fell within the $100(1-\alpha)\%$ confidence region were those with log likelihood values that were no less than the maximum log likehood minus $\frac{1}{2}\chi^2_{p,\alpha}$. The confidence limits for the derived parameter, i.e. the proportion visible on the day of the survey, were the minimum and maximum within the confidence region.

In order to test the robustness of the estimates and confidence limits, the model was run using a variety of assumptions. The date of first pupping, the functional form of the birthing distributions, the duration of the last developmental stage, and the proportion of pups in the last stage which are visible were varied.

Results

A single hooded seal pup was first observed among a large whelping concentration of harp seals (54° 04' N 54° 46' W) on 7 March 1990. This pup, a thin blueback, was found during daily helicopter reconnaissance and visual surveys of the harp seal whelping patch (Stenson et al. 1993). At least 5 additional thin bluebacks were seen among whelping harp seals between 12 - 17 March.

Large numbers of scattered hooded seals were observed on 11 March during fixed-wing reconnaissance transects flown between 51° 20'N and 51° 40'N and 51° 55' W and 54° 10'W. A whelping concentration was located north of this area and a satellite transmitter was deployed southwest of this patch at 51° 53'N 53° 22'W on 13 March.

A second whelping concentration was identified on 25 March in an area slightly north of the first patch. To ensure that this concentration was independent of the first, helicopter reconnaissance flights were flown to the south of this second patch. Although we failed to locate the first concentration, fixed-wing reconnaissance flights and photographs of the region indicated that hooded seals were present farther south on 25 March. Also, two small VHF transmitters (range 10-30 km), placed on the ice within the original patch, could not be located during survey and reconnaissance flights over the second concentration from 25 -27 March. To confirm that the two concentrations were independent, maps of the transects flown were overlaid using estimates of drift obtained from the satellite transmitter placed near the first group. No overlap occurred between the two concentrations.

Visual surveys of both whelping concentrations were successfully completed. The first concentration, located on 19 March from 51° 15'N to 52° 25'N and between 52° 17'W and 52° 29'W was surveyed on 21 March. A total of 4,816 pups were counted over 24 transects. Mean density was 10.7 pups/km^2 (SE=5.7). The numbers of pups present was estimated to be 26,900 with a standard error of 1,378 (Table 2).

The visual survey of the second concentration was carried out on 25 March and consisted of 18 transects ranging from 11.4 to 79.3 km in length. A total of 950 pups were observed for a mean density of 5.3 pups/km^2. The total numbers of pups present was estimated to be 17,594 with a standard error of 1,375 (Table 2).

Photographic surveys

Only the second whelping concentration was surveyed photographically. On 25 March 1990 photographs were obtained along six east-west transects, spaced 7.4 km apart. After correcting for reader errors, the estimated pup production in this concentration was 24,545 (SE=3,625; Table 2).

To provide an estimate of the number of hooded seals giving birth outside of the whelping concentrations, 23 low density strata photographic transects were flown on six separate days between 13 -28 March. Based on the flight lines and estimates of drift obtained from the satellite-linked location beacon, transects flown on 13, 19 and 20 March were considered to be independent and were combined to give complete coverage of the survey area. Four transects flown on 13 March south of the whelping concentrations included the area where scattered hooded seal females were observed previously. Difficulties with the camera operation resulted in exceptionally low coverage ($\leq 15\%$) on some transects resulting in a large variance estimate. The total estimated number of pups present was 22,005 (SE=10,528, Table 2).

The transects flown on 19,20 March surveyed the area to the north of the whelping patches and resulted in an estimated pup production of 11,493 (SE=6,645, Table 2).

Correction for temporal distribution of births

Stage classification surveys were flown on 21, 23, 25, 27 March. Two estimates of the the proportion of pups in each stage were available for each of the patches (Table 3). To determine if classifications were consistent between observer pairs, two independent estimates of stage composition of the whelping patch were made during the first survey. These results were comparable; 74% of the pups were estimated to be in stages 1-3 from the lower altitude (15 m) transects while 76.7% were estimated in these stages based on data from the higher altitude (92 m) surveys conducted simultaneously.

The best fit (maximum likelihood) to the develomental stage classification data obtained from whelping patch one (Table 3) was obtained from a model assuming that the birthing distribution followed a log-logistic distribution, the date of first pupping was 14 March, the length of the last stage was 3.5 days, and that 100% of the last stage were visible. Based on this model, an estimated 91% of the pups born in the first whelping concentrations visible on the day of the survey. Alternative assumptions resulted in similar estimates ranging from 85% to 95%, indicating that the choice of assumptions does not affect the estimate significantly. The standard error on the correction was approximately 4%.

For whelping patch two, we initially assumed a log-logistic distribution and a start date of 22 March and that 100% of the last stage were still visible. With these assumptions we estimated that 92% of the pups were visible on the day of the survey. The standard error on the correction was again approximately 4%.

The uncorrected estimate of pup production in the two whelping concentrations is 44,494 (SE = 1,947). Assuming the most conservative corrections by using the log-logistic distribution (i.e. 91% of the pups were visible in Patch 1 and 92% in Patch 2) the estimate of pup production in these two areas corrected for pups which were not present on the ice is 48,684 (SE = 2,747). No data were available to allow us to correct for pups not visible during the surveys of pups born outside of the whelping patchs.

Discussion

Although aerial surveys provide a reasonable method of estimating pup production in species such as the hooded seal which are found at relatively low densities over a large, unstable habitat, the accuracy of the estimate obtained is dependent upon the degree to which the possible sources of error are minimized. Myers and Bowen (1989) assessed the relative importance of different sources of bias in estimating abundance from aerial surveys of seals and concluded that the greatest source of bias arose from missing whelping concentrations. We believe that the extensive reconnissance conducted prior to and during the survey period reduced the likelihood of missing major whelping concentrations.

The second most important source of error is the potential of missidentifying pups on the photographs. The use of two camera systems operating simultaneously allowed us to compare two images obtained at different wavelengths (ultra-violet vs visible) in order to correct for errors which may have occurred during the readings of the photographs. Although it is possible that pups could be missed (or misidentified) on both film types, the count based on matched frames used for the reader error corrections provided the best estimate of the actual numbers present. The possibility of false positives on the Zeiss film was not examined during previous studies (Bowen et al. 1987, Hay et al. 1985). However, the corrections we applied subsequently were small. Also, previous surveys were flown at lower altitudes, resulting in larger image sizes, which likely reduce the number of misidentifications.

The use of the low photographic coverage stratum was designed to estimate pup production of pups outside of the whelping concentrations. The large variances associated with this survey reflect the low level of coverage, the limited transects flown on a single day and the clumped distribution of hooded seals. Bowen et al. (1987) used a similar survey design in 1984 to estimate hooded seal pup production at the Front. We found that a greater proportion of the total births occur outside of the whelping patch in this survey than in their study (43% vs 17%) and that the densities of pups observed in the two patches (10.7 and 5.3 pups km^{-2}) were lower than reported in 1984 (56 pups km^{-2}). These differences may be due to the strong winds and extensive ice drifting which occurred in 1990, resulting in more diffuse whelping concentrations.

The correction required for the temporal distribution of births varied between this and the 1984 survey. In the previous study, only 64% of the pups were estimated to have been present during the survey (Bowen et al. 1987). In contrast, over 90% were present on the ice during the 1990 surveys. The use of alternative model assumptions still resulted in estimates of 85% or greater for this survey. The reason for this difference is not clear. One possibility may be the way in which the models were applied. In 1984, one whelping patch was located and a single unimodal curve fit. In 1990, however, two concentrations were identified and separate curves fit to each one. This resulted in two distinct pulses of births. Bowen et al (1987) noted that the large residuals in their model fit to the number of pups in the early stages may have been due to a pulse of births between successive surveys which would have been masked by their assumption of a unimodal distribution but identified in the current survey. Alternatively, the difference may represent a real change in the shape of the pupping distribution between the two years; pupping being spread over a longer time period in 1984 while in 1990, it occurred in two distinct pulses. The temporal distribution of births of harp seals in this area during 1990 also differed from that observed earlier (Stenson et al. 1993). The differences between these two surveys illustrates the variability which can occur between years and emphases the importance of estimating pup production outside of the whelping concentrations and the temporal distribution of births during each survey.

Complete visual surveys were made of the two whelping concentrations located while a photographic estimate was available for the second only. The photographic estimate was higher than the visual although the difference was not significant at the 5% level. The difference may be accounted for by slightly different survey areas and differences in the percentage of area covered by each survey.

Population Trends

Combining the more conservative, visual estimates for the whelping patches (48,684, SE=2,747) with the photographic estimates of pups born outside of the whelping patch on 13 and 20 March (33,498, SE=12,450), results in an estimate for total pup production of hooded seals at the Front in 1990 of 82,182 (SE=12,636). A number of estimates of pup production at the Front over the past three decades are available (Table 4, Fig. 2). However, many of these results were obtained using different methods and are not directly comparable. Using the survival index method, pup production from 1966-77 was estimated to be in the order of 25,000 - 32,000 (Øritsland and Benjaninsen 1975, Sergeant 1976, Lett 1977, Winters and Bergflødt 1978). These estimates are similar since they rely upon similar data and are heavily influenced by a single high catch in 1966 (Bowen et al. 1987). A sequential population analysis (Winters and Bergflødt 1978) resulted in a similar estimate for this period but should not be viewed as independent estimates since it was fit to an esitmate of 1971 pup production obtained from the survival index. Hay and Wakeham (1983) estimated annual pup production between 8,000 to 16,000 for the period 1977 to 1982 using a Leslie analysis, but felt that it was likely an underestimate because it only included whelping patches where hunting occurred. There was no estimate of pup production outside of these whelping patches or of pups which may have left the ice prior to the time of the hunt.

The only estimate of pup production in hooded seals which can be compared directly to the current study is the survey conducted in 1984 (Bowen et al. 1987). After correcting for pups born outside of the whelping concentration and the temporal distribution of births, they estimated total pup production at the Front to be 62,400 (95% C.I. 43,700 - 89,400). An additional 18,600 (95% C.I. 14,000-23,000) pups were estimated to have been born in the Davis Strait. Despite the different estimation methods were used, Bowen et al. (1987) concluded that the hooded seal population at the Front had likely increased between the 1960's and 1984. An aerial photographic survey in 1985 (Hay et al. 1985) produced a similar, but imprecise estimate of (61,400 95% C.I. 16,500 - 119,450) pups at the Front which was not corrected for the temporal distribution of births. The results of the present study (82,182 SE=12,636) suggest that pup production may have increased slowly (5% per annum) since 1984. However, because of the size of the confidence intervals and the possibility of exchange between the Front and Davis Strait populations, we cannot rule out the possibility of a stable or slightly declining level of pup production. Due to the unavoidable low precision of estimates for this species, more time may be required between surveys to detect any changes which may be occurring. Another survey will therefore be necessary before we will be able to determine the actual rate of change in hooded seal pup production.

Acknowledgements

We would like to thank W. Penney, D. Wakeham, D. McKinnon, J. Brattey, J. Drew, V. Mercer, E. Perry, and our helicopter pilots, K. Steele and P. McLelland, without whose help the surveys would not have been completed. We would also like to thank the crew of the the CCGS Sir John Franklin for their invaluable assistance, the aircraft pilots and crew for their dedication, D. Wakeham for reading the photos, and M. Hammill, M. Kingsley, D. Bowen and W. Stobo for assistance in planning the study. E. Perry, J. Lawson, and B. Sjare reviewed earlier versions of this manuscript. Support for this work was provided under the Government of Canada's Atlantic Fisheries Adjustment Program (Northern Cod Science Program).

Literature Cited

Anonymous. 1978. Report of the *Ad Hoc* Working Group on Seals. International Commission for the Northwest *Atlantic* Fisheries Redbook 1978: 17-20.

Anonymous. 1994. Report of the Joint ICES/NAFO Working Group on Harp and Hooded Seals. Int. Coun. Explor. Sea C.M.1994/Assess:5.

Bishop, C. A., J. Anderson, E. Dalley, M.B. Davis, E. F. Murphy, G. A. Rose, D. E. Stansbury, C. Taggart and G. Winters. 1994. An assessment of the cod stock in NAFO Divisions 2J+3KL. North Atlantic Fisheries Organization SCR Doc. 94/40.

Bowen, W. D., R. A. Myers, and K. Hay. 1987. Abundance estimation of a dispersed, dynamic population: Hooded seals (*Cystophora cristata*) in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 44:282-295.

Bowering, W. R., W. B. Brodie, and D. Power. 1994. Greenland Halibut in NAFO Subarea 2 and Divisions 3KLM: A rapidly declining resource with a rapidly increasing fishery. North Atlantic Fisheries Organization SCR Doc. 94/57.

Cochran, W. G. 1977. Sampling Techniques. 3rd ed. John Wiley and Sons, London.

Cox, D. R., and D.V. Hinkley. 1974. Theoretical Statistics. Chapman and Hall, London, 210pp.

Efron. B. 1981. Non parametric standard errors and confidence intervals. Can. J. Statistics. 9:139-172.

Hammill, M. O., G. B. Stenson and R. A. Myers. 1992. Hooded seal (*Cystophora cristata*) pup production in the Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 49:2546-2550.

Hay, K., G. B. Stenson, D. Wakeham and R. A. Myers. 1985. Estimation of pup production of hooded seal (*Cystophora cristata*) at Newfoundland during March 1985. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 85/96.

Hay, K. and D. Wakeham. 1983. Use of catch and effort data to estimate the pup production of hooded seals (*Cystophora cristata*) at Newfoundland. North Atlantic Fisheries Organization SCR Doc.83/85 Ser. No. N709, 12 p.

Kingsley, M. C. S. and G. E. J. Smith. 1981 Analysis of data arising from systematic transect surveys. pp. 40-48. *in* F. L. Miller and A. Gunn, eds. Proc. Symp. Census and Inventory Methods for Populations and Habitats, Banff, April 1980. Contribution No. 217, Forest, Wildlife and Range Experiment Station, Univ. of Idaho, Moscow, Idaho.

Kingsley, M.C.S., I. Stirling, and W. Calvert. 1985. The distribution and abundance of seals in the Canadian High Arctic, 1980-1982. Can. J. Fish. Aquat. Sci. 42: 1189-1210.

Lawson, J. W., G. B. Stenson, and D. G. McKinnon. 1993. Diet of harp seals (*Phoca groenlandica*) in 2J3KL during 1991-93. NAFO SCR Doc. 93/36.

Morgan, M. J., W. R. Bowering, and W. B. Brodie. 1994. A comparison of results from Canadian deepwater surveys in 1991 and 1994, with emphasis on Greenland halibut. North Atlantic Fisheries Organization SCR Doc. 94/53.

Lett, P.F. 1977. A model to determine stock size and management options for the Newfoundland hooded seal stock. Can. Atl. Fish. Sci. Adv. Comm. Res. Doc. 77/25.

Myers, R. A. and W. D. Bowen. 1989. Estimating bias in aerial surveys for harp seal pup production. J. Wildl. Manage. 53:361-372.

Øritsland, T., and T. Benjaminsen. 1975. Additional data on the sex ratio, age composition and mortality of Newfoundland hooded seals, with an estimate of pup production and sustainable yield. International Commission for the Northwest Atlantic Fisheries Research Document 75/122.

Power, D. 1994. The status of Divisions 3LN redfish resource. North Atlantic Fisheries Organization SCR Doc. 94/54.

Ross, S.-A. 1992. Food and feeding of the hooded seals *Cystophora cristata* in Newfoundland. M. Sc. Thesis. Memorial University of Newfoundland, St. John's, Newfoundland, Canada. 164 p.

Sergeant, D. E. 1976. Research on hooded seals *Cystophora cristata* Erxleben in 1976. International Commission for the Northwest Atlantic Fisheries Research Document 76/X/126.

Sinclair, A. 1993. Report on the assessments of groundfish stocks in the Canadian Northwest Atlantic, May 4-14, 1993. Can. Tech. Rep. Fish. Aquat. Sci. 1946e:200p.

Stenson, G. B. and D. J. Kavanagh. 1993. Distribution of harp and hooded seals in offshore waters of Newfoundland. North Atlantic Fisheries Organization SCR Doc. 93/45.

Stenson, G. B. and R. A. Myers. 1988. Accuracy of pup classifications and its effect on population estimates in the hooded seals (*Cystophora cristata*). Can. J. Fish. Aquat. Sci. 45:715-719.

Stenson, G. B., R. A. Myers, M. O. Hammill, I-H. Ni, W. G. Warren and M. C. S. Kingsley. 1993. Pup production of harp seals, *Phoca groenlandica*, in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 50:2429-2439.

Stenson, G. B., I-H. Ni, S-A. Ross, and D. McKinnon. 1991. Hooded seal, *Cystophora cristata* feeding and interactions with commercial fisheries in Newfoundland. Can. Atl. Fish. Sci. Adv. Coun. Res. Doc. 91/45.

Winters, G. H. and B. Bergflødt. 1978. Mortality and productivity of the Newfoundland hooded seal stock. International Commission for the Northwest Atlantic Fisheries Res. Doc. 78/xi/91.

Table 1. Regression statisitcs used to correct for misidentified pups on photographs taken during surveys of hooded seals off Newfoundland, 1990. Standard errors are incuded in parentheses.

	No. of Photos	Intercept	Slope	r^2
Concentrations	158	0.035 (0.022)	0.964 (0.032)	.85
Scattered:				
March 13	1111	0.019 (0.008)	0.521 (0.015)	.52
March 19/20	267	0.007 (0.005)	0.591 (0.012)	.90

Table 2. Visual and photographic estimates of hooded seal pup production (,000's) at the Front during March 1990. Surveys included in final estimate are shown in bold. Standard errors are included in parentheses.

	Date	Visual[1]	Photographic
Concentration			
1	21	**26.9 (1.4)**	
2	25	**17.6 (1.4)**	24.5 (3.6)
Scattered	13		**22.0 (10.5)**
	19/20		**11.5 (6.6)**

[1] Uncorrected for pups not present on the ice. Corrected estimate for the two concentrations is **48,684 (SE = 2,747)**.

Table 3: Summary of pup developmental stage classifications[1] obtained from visual surveys of the whelping concentrations at the Front, 1990.

Date	No. of Transects	Stage 1[2] N	Stage 1[2] %	Stage 2[3] N	Stage 2[3] %	Stage 3[4] N	Stage 3[4] %	Total Pups
Whelping Concentration 1:								
March 21	10	130	37.0	130	37.0	91	25.9	351
March 23	11	41	5.9	235	33.6	426	60.6	702
Whelping Concentration 2:								
March 25	18	92	19.0	328	67.9	63	13.0	483
March 27	24	23	5.8	220	56.0	150	38.2	393

[1] Stage classifications are described by Bowen et al. (1987).
[2] Stage 1 = Newborn and Thin bluebacks.
[3] Stage 2 = Fat bluebacks.
[4] Stage 3 = Solitary.

Table 4: Published estimates of hooded seal pup production ('000s) in the Front 1963 - 1990.

Year	Estimate	Confidence Interval	Method[1]	Reference
1961-1971	32.8	-	SI	Lett 1977
1963-1978	24 - 30	-	SPA	Winters & Bergflødt 1978[3]
1966-1970	31.4	-	SI	Øritsland & Benjaminsen 1975
1966-1971	27.0	-	SI	Sergeant 1976
	27.1	-	SI	Winters & Bergflødt 1978
1977	11.0	-	Leslie[4]	Hay & Wakeham 1983
1978	13.6	-	"	"
1979	16.2	-	"	"
1980	12.2	-	"	"
1981	9.6[5]	-	"	"
1982	7.7	-	"	"
1984[2]	62.4	43.7 - 89.4	AC/VS	Bowen et al. 1987
1985	61.4	16.5 - 119.5	AC	Hay et al. 1985
1990[2]	82.2	57.0 - 107.4[6]	AC/VS	This study

[1] SI = Survival Indices
SPA = Sequential Population Analysis
AC = Photographic aerial survey
VS = Visual Survey
[2] Corrected for pups not present on the ice at the time of the survey.
[3] Tuned to the SI estimate of 27,000 in 1971, assumed mortality rates of 0.135
[4] Projected mean daily catch rates against cumulative catch. Least squares linear regression used to estimate pup production. Landsmen's catch and catch outside of the whelping patches added.
[5] Catch was 10,736
[6] Approximate 95% C.I. based on standard error of 12,600.

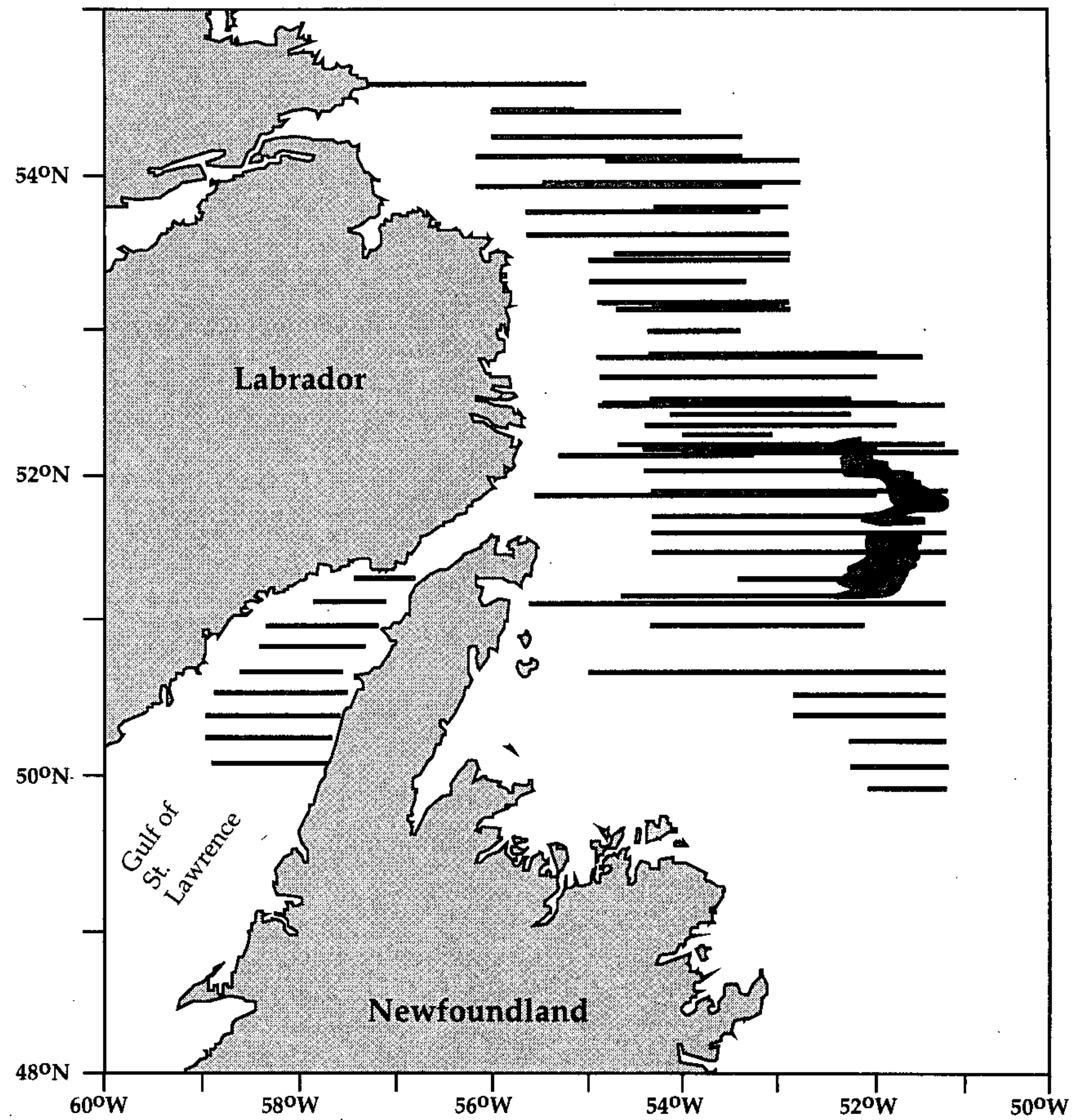

Figure 1. Reconnaissance survey transects flown during March 1990. Hatching indicates location of whelping concnetrations.

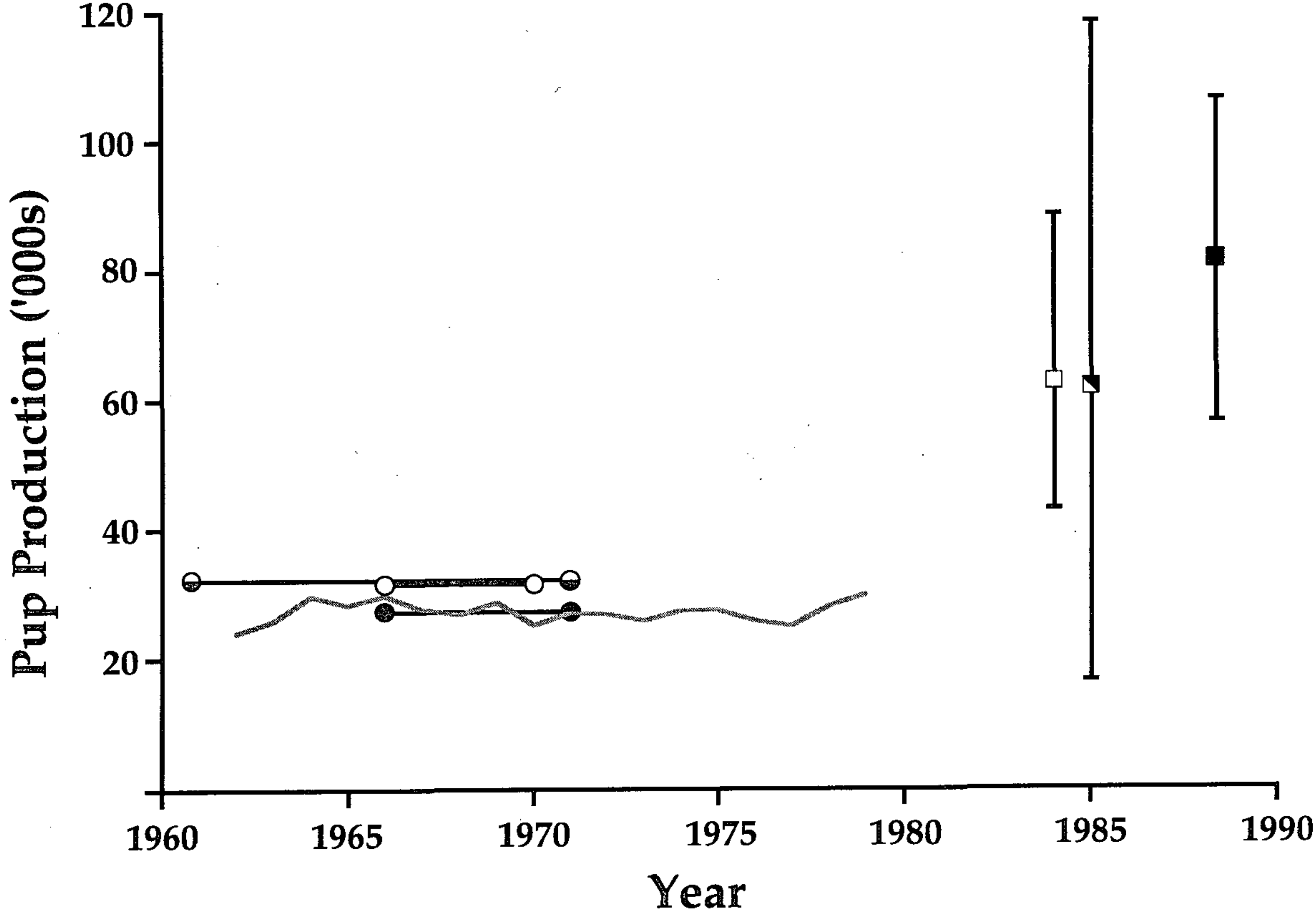

Figure 2. Pup production estimates of hooded seals in the Northwest Atlantic: cohort analysis by Winters and Bergflødt 1978 (——); average production based on the survival index method by Øritsland and Benjaminsen 1975 (○——○), Lett 1977 (○——○), Sergeant 1976 and Winters and Bergflødt 1978 (•——•); and aerial survey by Bowen et al. 1987 (□, with 95% CI), Hay et al. 1985 (□, with 95% CI), and this paper (□, ± 2SE).