This paper is not to be cited without prior reference to the authors

International Council of the
Exploration of the Sea

C.M.1976/N:15
Marine Mammals Committee

A STOCHASTIC MODEL FOR THE MANAGEMENT OF THE NORTHWESTERN ATLANTIC HARP SEAL *Pagophilus groenlandicus* POPULATION

Terje Benjaminsen
Institute of Marine Research
Directorate of Fisheries
N-5011 Bergen - Nordnes
Norway

and

Patrick F Lett
Marine Fish Division
Bedford Institute of Oceanography
Dartmouth, Nova Scotia
Canada

Introduction

The exploitation of the northwestern Atlantic harp seal has been well documented, especially in recent years. Nearly 10 million harp seals are known to have been harvested from this population between 1895 and 1946 (Fisher 1955) and another 5.3 million were taken between 1947 and 1964 (Department of Fisheries of Canada 1968; Øritsland 1967). From 1965 to 1974, another 2.3 million seals were slaughtered in the northwestern Atlantic. This gives an average annual kill over the period of 220,000 seals; a figure which has sustained the fishery for 80 years. Recent regulations have set a quota for seals at 150,000 animals between 1972 and 1975, (ICNAF 1972) with a low quota restriction in 1976 only permitting the take of 127,000 seals. These quotas do not included the high Arctic or Greenland catches, which can be considered to be approximately 10,000 animals. However, despite the low quota for 1976, *174,000 seals were killed.

Conflicting views as to the present status of the northwestern Atlantic harp seal have recently generated much controversy. These divergent opinions resulted from the interpretation of incomplete data sets, and poor communication among participating scientists. However, there are methods such as ultra-violet aerial sensing, which it is thought can be used independent of supportive biological information, and do not rely on current scientific opinion. Unfortunately, to date this method produces a "best estimate" of pup production in 1975 which is approximately 15,000 animals less than the catch (Lavigne et al 1975).

Due to large discrepancies in estimation of production and natural mortality, it has been necessary to revise the basic data to incorporate the effects of the diverse fisheries, in addition to use advanced statistical and computer techniques to assess the data; thus producing a reliable assessment of the northwestern Atlantic harp seal stock.

---

* This number is subject to slight alterations.

Amalgamation of Data

The assessment of an animal population requires the estimation of certain vital rates. The estimation of these rates, to a large extent, consists of the analysis of age frequencies which either represent the population or the catch structure. In some populations the catch and population age structures are assumed synonymous, however, this assumption can lead to grave errors in the instance of the northwestern Atlantic harp seal population (Benjaminsen and Øritsland MS 1975).

Initially, the problem consists of producing an age frequency of the total annual catch for one year old and older seals (1+), which amalgamates the catch frequencies from the individual fisheries in their proper proportions. In this fishery the age distribution for the different fisheries is indeed diverse.

Shot samples from Notre Dame Bay, Newfoundland, consist primarily of bedlamers. The La Tabatière, Que., and Labrador net fisheries usually result in a sample with a preponderance of mature animals, while the St.Anthony, Nfld., shot samples seem to be more representative for the population structure. It is assumed that on average each of these fisheries tend to be roughly equivalent to each other in overall catch and can be summed to represent the landsmen catch without producing serious errors. The large ships catch from the moulting lairs, however, is quite different in structure from the overall landsmen's and must be treated separately. One of the primary problems is the fraction of one year old seals in the sample. This age group is usually segregated from the remaining age groups and is only randomly encountered when sampling the moulting lairs (Benjaminsen and Øritsland MS 1975). Furthermore, the closing date also effects the large vessel sample since the earlier the hunt in the moulting lairs is terminated, the less females are represented in the catch (Sergeant 1965, Øritsland 1971). Thus is mature composite age frequencies vary depending on the length of the hunt, and consists mainly of males (Fig. 1).

Samples of the Greenland and the high Arctic hunt, representing 8% of the total catch on average, are excluded from this analysis from 1952 to 1975, since no consistent sampling and catch records are available.

Between 1952 and 1960 jaws were collected on a regular basis from the landsmen's catch and this sector of the hunt can be considered to be well represented (Sergeant 1953, personal communication) and are presented in Table 1. During the years 1952-54 and 1957-58 samples were also collected from the large vessels. However, the 1957-58 samples are sparce and it is unlikely that they accurately represent the catch (Tabel 1). For this reason the years 1955 to 1960 were replaced by an average catch frequency for large vessels. The attendent errors are possibly serious since during this period the large vessel hunt on 1+ animals represented between 87.5-95.5% of the total catch (Tabel 2).

In 1961 sampling began to steadily improve with both the large vessel catch from the moulting lairs and the landsmen catch being well represented (Tabel 1). Annual catch at age samples from 1961 on came from a number of sources (Sergeant 1971, 1972, personal communication; Øritsland 1971 ; Benjaminsen and Øritsland MS 1975). Unfortunately, there was not a good sample taken for either the landsmen or the large vessel catch in 1972, but the available data were included in the ensuing analysis. In 1973 the landsmen sample was again lacking and may not sufficiently represent the fishery. In both 1972 and 1973 there was no basis for using an average sample to represent either fishery, especially since the landsmen and large vessel catches are nearly equivalent to one another. In general, the samples from large vessels seemed to improve from 1967 on, excluding 1972.

The samples from the landsmen hunt and large vessel hunt were first summed for each year, then reduced to their respective percentage compositions. These compositions were then weighted in accordance with the numbers of animals killed in the landsmen and large vessel hunt (summed across ages) and subsequently divided by the sum of weighting factors. In this way then, the age composition data gave the best possible representation of the catch distribution as the hunt has shifted from large vessels to landsmen (Fig. 2). Using this catch distribution the total catch was broken out into catch at age (Table 3).

Calculation of Natural Mortality

The instantaneous rate of natural mortality is possibly the most elusive parameter in population dynamics to estimate. Furthermore, for the harp seal population it is the most important due to the rather low exploitation rate experienced by 1+ animals.

The only representative sample of the population age distribution comes from males of age two and older in the moulting lairs (Benjaminsen and Øritsland MS 1975). Furthermore, it is assumed that there is no difference between natural mortalities rates of male and female harp seals. This is a valid assumption since male and female harp seals seem to experience similar growth rates and achieve equivalent maximum weights (Sergeant 1973a). The metabolic rate and body size of seals is well correlated (Lavigne et al 1976); and since the mortality and metabolic rates of animals are related (Simms et al 1959) it is unlikely that male or female harp seals experience divergent natural mortalities.

Male age samples of moulting seals were taken from Benjaminsen and Øritsland (MS 1975) for 1969, 1970, 1971, 1973 and 1974. In 1968, 1970 and 1973 there were also combined (male and female) samples which were corrected, (Fig. 1), for the fraction of males. These corrected samples were added to the appropriate sexed male sample to produce a total male sample. The age frequencies were then reduced to percentage age compositions so the total instantaneous mortality rates (Z) could be calculated.

Total instantaneous mortality rates, weighted for varying cohort abundance, were calculated by using the equation:

$$(1)\ Z_{(t,t+1)} = \log_e \left[\sum_{i=2}^{i=24} P_t \Big/ \sum_{i=3}^{i=25} P_{t+1} \right]$$

where P is the percentage in year (t) for age (i). One year old animals were not included because of the erratic nature in which they occurred in the sample.

Since there was not a representative male sample in 1972 the total mortality was calculated from 1971 to 1973 and the result value divided by two.

The weighted annual instantaneous mortality rates were as follows:

Year	Total mortality (z)	
1968-1969	0.0667	
1969-1970	0.2247	z = 0.160
1970-1971	0.1882	
1971-1973	0.0892 (Avg.)	
1973-1974	0.1836	z = 0.137

The following two simultaneous equations could then be constructed and solved.

$$\bar{F}_{68-71} + M = 0.160$$

$$\bar{F}_{71-74} + M = 0.137$$

where F is the average instantaneous rate of hunting mortality. Following the implementation of the quota regulations in 1971, hunting effort exerted on 1+ seals was essentially halved such that $\bar{F}_{68-71} = 2\bar{F}_{71-74}$. Hunting effort was calculated by multiplying the number of men by the length of time they hunted 1+ seals and the mean horse power of the vessels. This value was then divided by the mean tonnage of the vessels the number of days was calculated according to the closing dates of the hunt and the other values are taken from ICNAF statiscal yearbooks. Ice condition is not considered in the calculation because of the lack of data, however, its inclusion would presumably greatly improved the calculation of effective effort. The hunting effort, which varies little from year to year was 120,000 man, day, hp, ton^{-1} between 1961 and 1970, and 56,000 between 1972 and 1975. In both cases the standard deviation was only 8900 man, hp, ton^{-1}. Thus the change in effort is 2.07 and the assumption of a halving of effort between the two periods seems quite valid. The two equations then give the following values:

$$M = 0.114 \text{ and } \bar{F}_{68-71} = 0.046 \text{ and } \bar{F}_{71-74} = 0.023.$$

By subtracting the appropriate F value from the z values a standard deviation of 0.0677 and standard error of 0.0302 were calculated. From this limited sample set the variance was indeed great and it is assumed that the standard error more closely reflects the real biological deviation in natural mortality. Other calculations of mortality are somewhat lower, near 8% per year (Ricker 1971, Ulltang 1971).

Lavigne et al (1976) present an age specific natural mortality schedue which declines from 0.2 for 0-group seals to 0.095 for 5 to 6 years olds. Following this, mortality rises to 0.109 for adults and remains constant. This schedule, although assumed, makes good biological sense since mortality and growth are usually coupled (Simms et al 1959, Bourliere 1959). For harp seals the growth rate begins to become constant at the onset of maturity. According to an analysis of Lavigne's et al (1976) data the instantaneous growth rate of mature seals is 0.12, not far from our estimated mortality of 0.114. However, at some point the mortality rate must exceed growth rate or the biomass of seals would continue to increase forever. Senescent death in harp seals may begin at approximately age 18, if one speculates as to the reason about inflection in the survivorship curve at this time. Thus the critical age for a cohort of seals probably is near 18 years of age.

In our analysis we could find no evidence of an age dependent natural mortality rate, which is not surprising considering the crudity of catch data and the delicate changes in the parameter as suggested by Lavigne et al 1976. However, the analysis was on 2^+ seal and a different mortality rate may be experienced by the younger animals.

Sequential Population Analysis

Sequential population methods (Fry 1949; Murphy 1964; Jones 1964; Gulland 1965; Pope 1972; Doubleday 1975) were developed to estimate fish population sizes and fishing mortalities from catch-at-age data when effort data are not available. Although there are no example of this method being used to assess mammalian populations, no assumptions are violated by its use. For this reason it may be instructional to outline the method.

The sequential population analysis developed by Pope (1972) called cohort analysis was utilized in this study since it assumes that natural nad hunting mortality occur somewhat seasonally, which is true to a great extent in the seal fishery. The method is based on the formula:

$$(2)\ N_i = C_i \text{EXP } M/2 + N_{i+1} \text{EXP } M$$

where N_i is the population of a year-class at the i^{th} birthday, C_i is the catch of a cohort at age i, and M is the instantaneous coefficient of natural mortality. This formula is applied sequentially, the population size is each year depending on the population the year after.

However, some starting values are required. Thus, by expanding equation (2):

$$(3)\ N_i = (C_i EXP(M/2) + C_{i+1} EXP(3M/2) + C_{i+2} EXP(5M/2)$$

$$+ \ldots\ldots\ldots\ldots\ldots + N_t EXP((t-i)M)$$

and assuming that hunting does not completely extirpate a particular cohort, the last term for the final year's population is:

$$(4)\ N_i = \frac{C_i(F_{i+1}+M)}{F_i(1-Exp(-F_{i+1}-M))}$$

Equation 4 then, is used to calculate the population size in the initial year. Thus one of the primary problems is to estimate starting hunting mortality values.

The average hunting mortality calculated for 1972-74 was 0.023 and it was assumed that this value also applied in 1975. The analysis was not started using the 1976 data since all samples are not yet completely analysed. When possible considerable care should be given in estimating the initial hunting mortality since hunting mortalities are low for harp seals and the analysis is therefore more sensitive to initial F for a longer period. However, when the data series is long, poor starting values of F are considerably improved as the analysis continues. After running the analysis and averaging hunting mortalities for ages 10 to 20 it was determined that on average a hunting mortality of 0.02 was adequate for animals of age 25. The age specific hunting mortalities calculated by the formula

$$(5)\ F = Log_e(N_i/N_{i+1}) - M$$

are presented in Table 4.

The resultant population estimates (Table 5) indicate that there was a quite dramatic decline, such that in 1968 the herd was only 45% as large as its size in 1952.

Pup productions estimated by cohort analysis are somewhat erratic, indeed more than would be expected for a mammalian population. This inconsistency can perhaps be attributed to a natural mortality rate among pups which responds in some way to the exploitation rate. Furthermore interspecific competition may be a factor in determining resultant natural mortality rates.

Density Dependent Pregnancy and Whelping Age

It has been proposed by Sergeant (1966, 1973b) that the mean age of whelping for harp seals is a density dependent function relying on population size. This phenomenon is well noted in some other marine mammals (Gambell 1973). Indeed, some sort of mechanism is necessary to equilibrate the population with the carrying capacity of its environment (McLaren 1967). Sergeant (MS 1976) has presented further evidence that the mean age of whelping has shifted to an extremely low level of 4.8 years in 1976, a figure well below the 6.5 years calculated in 1953. However, the reason for this most recent shift from 1968-1976 is not clear since the population has stabilized and seems to be slightly increasing. Furthermore, it will not become lucid until some information on the growth rate of individuals within cohorts becomes available. Sergeant (personal communication) has suggested that the maturity schedule of seals is determined by their growth rate as juveniles since growth approaches an asymptote at about age 5 (Sergeant 1973a). Lavigne et al's(1976) data would also suggest an age of 5. In both examples, the data are extremely variable. The harp seal population did reach it's minimum level between 1966 and 1973 of 1.07 million 1+ seals (Table 5). Assuming that the growth rate of juvenile seals is stock dependent,this would suggest that Sergeant's hypothesis is possibly correct. Until more conclusive evidence concerning the reproductive biology of harp seals is presented, we assume that the maturity schedule of harp seals is dependent on the coincident population size of 1+ animals. There is little evidence to suggest that the Front and Gulf herds experience a different maturity schedule, although this point may be argued by Sergeant (1973b), thus the data utilized from these two areas was not weighted in relation to population size.

The ogive were plotted on "probit" paper and lines were fitted by eye, giving more weight to points closer to the 50% maturity level. Values were then interpolated for each age from these lines, under the assumption that they represented the best fit of the data. The interpolated values were used to determine the following equation (Fig. 4):

$$(6) \quad \text{ARC sine } {}_iE_t = 15.522A - 2.245 \times 10^{-5} N_t - 16.017$$

where ${}_iE_t$ is the fraction of the population whelping, assuming 100% pregnancy for a particular age i, N_t is the population number of 1+ seals in the year t, and A is the age in years.

The shift in maturity in response to population size is assumed to be linear since the best fit of the mean age of whelping over the data series was linear, although again the data are not conclusive. Capstick and Ronald (1976) fit an exponential relationship to two data points, where there seems to be some confusion concerning the independent and dependent variables (see Fig. 4 Capstick and Ronald 1976). In fact, the curve has doubtful biological meaning since according to their hypothesis the mean age of maturity approaches zero at population sizes less than 1 million, a result which they previously speculate as being impossible. In addition, maturity reaches an asymptote at larger herd sizes, such that the population can increase ad infinitum. Surely the opposite effect is expected if it is indeed non-linear, since the biological basis for a shifting maturity ogive would be to constrain the population within the environmental carrying capacity.

Density dependent, age specific maturity would be enough to limit the population, but this is only one of a multitude of factors. Others responding to population size could be natural mortality and fertility rate. Although we have no evidence for density dependent mortality, there does seem to be some data supporting a varying fertility rate (Fig. 5). Fertility rates were determined from a number of sources (Fisher 1952; Sergeant 1966, 1969, 1970, MS 1976; Øritsland 1971). The response seems to be a linearly decreasing function of population size, however, the data are variable and the structure of the relationship is not clear. The data were plotted against the 2+ population size since the younger animals remain segregated from the herd and would not compete. A fluctuating fertility rate is a well noted phenomenon and has been observed in at least three populations of whales (Gambell 1973). In addition, the unexploited population of Antarctic crabeater seals (Lobodon carcinophagus) which like harp seals, also enjoy an unlimited ice substrate on which to whelp, has a low pregnancy rate of 0.76 (Øritsland 1970). Markgren (1969) found that the ovulation rate in moose (Alces alces) was related to a number of factors such as age, body size, nutrition, climate and population density.

Effects of Changing Sex Ratio on Population Projection

The pup production estimates resulting from sequential population analysis are quite erratic (Fig. 3), possibly as a result of unaccountable fluctuations in natural mortality. In addition, the prepondenrance of males in the kill from the moulting seals would result in a sex ratio favouring females. This could increase the estimates of pup production by 15,000 or 20,000 animals.

It is unlikely that there are serious errors in the catch distributions for seals 1 to 6 (Tables 3), since 8% of the variation of this data is unexplained when compared with the actual catch of bedlamers (see Table 2 Øritsland and Benjaminsen MS 1975). This comparison is made by plotting the addition of the catch of 1 to 6 year olds (Table 3) against the catch of bedlamers from 1952 to 1975 as calculated by Øritsland and Benjaminsen (MS 1975). The functional regression (Ricker 1973) through these points has a slope not significantly different from unity and a position not significantly different from the origin.

As previously noted, the best estimates from cohort analysis are between 1961 and 1975 since during this period the catch data are more consistent. Because the estimates of population improve as the analysis proceeds (Pope 1972), 1961 should then give the most reliable abundance level. With this in mind, a projection starting in 1961, subtracting the age specific catch of the various fisheries should give the most reliable pup production, following the application of a maturity ogive. These pup productions, resulting from determining the breeding population, are probably more reliable than those predicted from sequential analysis. However, the number of animals in age groups older than one should be equivalent to the sequential analysis estimates. Recruitments to the 2+ populations were the cohort analysis abundance estimates for one year olds.

The sex ratio of the catch was distributed over ages in accordance with the asymptotic function appearing in Figure 1. The value of the asymptote is represented by the fraction of males in the catch (Table 6). For two-year-olds, the percent of females remained 52.8% females, however, the asymptotic ratio varied in relation to the closing dates of the seal hunt.

In 1961 the sex ratio was assumed to be 50:50 in the population; changing thereafter in response to the sex ratio of the hunt on the moulting lairs and the contribution of this hunt to the total catch of 1+ seals (Table 5). This assumption is reasonable since the number of adult females taken by large vessels in the breeding lairs during the postwar period was small because the value of whitecoat pelts was 2 to 6 times that of an adult pelt. Annual prices for the Norwegian fishery are given by Fiskeridirektøren (1951-1965). Prior to this time Coleman (1938) suggests that few adult females were taken in the steamboat fishery since the cost of powder and shot was in excess of the value of the pelt. During the period from 1895 to 1923 adult seals only comprised 2.7% of the total steamboat catch(Chafe et al 1923).Even less of this would be females. From 1953 to 1960 white-coats were worth from 1.3 to 2 times as much as the adults, however, this declined to 0.7 by 1964.

Furthermore, due to the labour associated with skinning and transporting the adult pelts it is unreasonable to assume that there was excessive killing of breeding females when white-coats were available.

To protect the mature females a closing date of May 5 was established in the Gulf and on the Front in 1961. At this time we assume the sex ratio in the large vessel catch was 55% adult males since the sex ratio in the population would probably be altered in favour of females. Since the proportion of moulting females on the ice would be less than males, the fraction of females in the catch would also have been somewhat smaller than the fraction of males. In 1963 the closing date was changed to April 30. The closing date in 1965 in the Gulf was altered to April 25, and this date was also established on the front in 1968. In 1970 the closing date was April 29 and since 1971 it has been April 24. An agreement was made in 1965 that no females could be killed while breeding.

These regulations obviously decreased the percentage of mature females in the catches. The total Norwegian sample of moulting harps taken from 1969 to 1974 (Benjaminsen and Øritsland, MS 1975) showed a marked surplus of males. In age groups one and two the sex ratio is approximately 50:50 and there after increases to 86% males for mature animals (Fig. 1).

The projection is broken out into males and females and each component is handled separately in the simulation (Table 6). The fertility rate was assumed to be about 94% during this period, and 6% of the breeding population was assumed to be over the age of 25 (Benjaminsen and Øritsland MS 1975). A constant, conservative maturity ogive, calculated from Sergeant's (1966, 1976) data was applied to the breeding population using the following schedule:

Age	2	3	4	5	6	7	8	9	10
Fraction whelping	0	0.075	0.220	0.450	0.700	0.880	0.970	0.990	1.000

which was considered average for the period.

The sex ratio in the breeding population became as high as 54.9% in favour of females in 1971, and has continually dropped since then to 52.9% in 1976 (Table 6), as a result of a much reduced hunt for moulting animals (Table 2). Age specific sex ratios rise as seals get older due to the accumulated effect of selective hunting. In fact, in more recent years this ratio has exceeded 70% females for animals over 20 years.

The change in the sex ratio provides for more pups than would be calculated by applying a 50:50 ratio. Indeed, it is assumed that pup production calculated in this manner is more reliable than estimated from sequential analysis (Fig. 3). Production reached a minimum in 1972 of 294,071 animals, down from 424,561 produced in1962. Since 1972 the production has slowly increased, primarily due to the entry of the 1968 year-class and the quota regulations, so that currently production would be 311,502. Using Sergeant's (MS 1976) latest maturity estimates, production would now be approximately 330,000.

Direct Survey Methods

Ultraviolet sensing method

Ultraviolet photography has been used for detecting certain white animals against a white background of ice or snow (Lavigne and Øritsland 1974). It is anticipated that this method could significantly improve estimates of harp seal pup production.

Details of this method have been outlined by Lavigne et al (1975), as it was applied to the northwestern Atlantic harp seal. It is stated that using a direct statiscal method i.e. applying a mean density estimate to the total herd area, results in confidence limits much too large to suggest the method is useful. In addition the patchiness of seals on the ice results in a skewed distribution from subplot estimates such that the modal value is indeed much less than the mean.

Lavigne et al (1975) have suggested that a ratio estimate should be used to reduce the confidence limits of the estimate. This methods requires additional information over that needed for a direct estimate. Furthermore,the assumptions concerning these supplement data are critical to the estimate. In order for this method to improve upon the direct estimate the correlation of the number of adults to pups in the subplots must be greater than the ratio of the covariance of adults among the subplots divided by 2 times the covariance of the number of pups among subplots. Lavigne et al (1975) count the number of adults from 1220 m to get an estimate of the total herd size and determined ratio estimates at 305 m.

It is suggested that their sample size of 69 subplots was to small. However, this only required a correlation coefficient, r_{AP}, of 0.232 between pups and adults for the method to be valid. Thus the minimum assumption required for the method to be valid is

$$\frac{\sigma_A^2 \cdot P}{2\sigma_P^2 \cdot A} \simeq 0.232$$

where σ^2 is the variance among subplots of pup abundance, P and adult abundance, A. This of course is a minimum assumption and is subject to change depending on how good the actual agreement between the number of pups and adults. This method although perhaps the most promising of all, requires good ground truthing and a more thorough knowledge of the fraction of males present in the breeding lairs. Until these objectives are achieved it cannot be considered an adequate method useful in the evalution of status of the harp seal stock.

Curran's Survey Method

Currently there is only one method of direct estimation of pup production which a majority of scientists agree upon, as being reliable (Fig. 3). Perhaps it is more because of the man, and his long years of experience with seal management, than with the technique.

The following is a brief description of the method. On March 8th and 9th a grid is flown from northern Labrador to Notre Dame Bay, Newfoundland to locate the herd. At this time, the younger females which have less control of parturation than older seals, haul up on the ice to give birth. The sighting of these younger animals gives the herd's location. Approximately two days later the older females will begin to whelp in a somewhat more southerly location. This usually gives the appearance of two herds. The majority of the front herd have whelped by March 12th (Curran personal communication).

Each of these two herds are surveyed separately. First, the extensivness of a herd is determined by circling it and drawing a parallel grid lines. This grid is followed by aircraft and X's are marked on it where there are no seals so the total area of seal density can be calculated.

The pups in specific subpatches are then sometimes counted by Curran and his crew for at least 20 acres. Each subpatch is about 1 acre in size and randomly distributed. In some areas the seals are scattered and in others dense, such that a mean number/acre and an associated variance can be calculated. This density is now applied to the subherd, for which the total area has been determined to give the population size. This exercise then allows for visual estimates from the aircraft for the remaining herd.

Norwegian and Canadian sealers will hunt off particular areas, and Curran receives daily counts of their take. When the hunters move out he will count the remaining seals and add this to the catch, thus arriving at total figures for different areas. By relating these figures to his own estimates he can get an idea of how accurate his original estimates were. In addition to soon learning what a specific number of pups looks like from the air, he claims his method of estimation is always conservative by at least 10%; this is possibly an overstatement.

There is no doubt the method is crude and could be improved by good aerial photography. However, because of his efforts in ground truthing his direct estimates are perhaps the most accurate available.

It has been proposed that 1/3 of the seal herd whelp in the Gulf and 2/3 whelp on the Front Sergeant (1976). According to Curran's estimates from 1971 to date, the breeding population on the Front is about the same size as that in the Gulf. Although Curran's estimates are conservative, the implications of this fact are quite serious. It means that with the Gulf closed to hunting from large vessels, the Front could become severely over-exploited. Apparently, the juvenile seals intermix between the two areas (Sergeant MS 1976) but adults do not, and therefore there is a possibility the assumption of the two herds may be one (Sergeant 1965) is wrong.

Construction of the Simulation

It is our opinion that some further insights can be gained into the population dynamics of harp seals by the construction of a stochastic simulation. By stochastic it is meant that the distribution and variance of certain parameters and state variables is taken into account. Another assumption is that the Front and Gulf herds are indeed one population since they spend the summer together in the Arctic (Sergeant 1965), and intermix as juveniles (Sergeant 1975). Of the two assumptions possible, more evidence supports the one herd hypothesis.

The simulations written in APL (Fig. 6) are represented by the schematic flow chart (Fig. 7). The program presented in Figure 6 requires specific large vessel catch of 1+ seals and pups to be entered, however, the alternative program is slightly changed so fishing mortality rates rather than large vessel catches are entered.

To initiate the program a starting population of animals aged 1 to 25 is entered, then the number of years the program is to run, and the starting date. A quota can then set by entering in a large vessel catch of 1+ seals and pups. An option is also available whereby the catch of 1+ seals and pups by the Magdellanot can be fixed.

The simulation has two options related to its printout. If the number of runs is deemed as one, it will print out the breeding and total population size, the annual sex ratio of the total and breeding population, the total catch of 1+ seals and pups. However, since the model is stochastic, each run will give different answers since the "seed" in the random number generator is not fixed for each iteration. Thus, when the number of runs is greater than one, matrices of total annual and breeding population, in addition to the catch of 1+ seals and pups is printed out. The right hand two columns in each of the matrices is the mean and standard deviation for that year.

The starting population is now broken up into the male and female fractions present in 1977 (Fig. 6, [34] *). One of the problems with this fishery which does not allow it to be interpreted accurately using conventional fisheries models is that the frequency distribution of the catch bears little relationship to the frequency distribution of the population. Therefore the catch cannot be distributed in a similar structure to the population.

---

* [n] represents the line in the program in (Fig. 6).

The frequency distributions of four district fisheries (Fig.8) are used ; the high Arctic, Greenland, landsmen and large vessel catches. These distributions are averages over a number of randomly chosen years between 1952 and 1975 so that baises due to trends in recruitment and effort are reduced. The interpolated values from the curves of best fit were entered into the simulation as average constant values representing the catch frequencies (Fig. 6 [45] - [52]).

All the uncontrolled catches, i.e. those excluding large vessels, had a normally distributed random component. The means and standard deviations for these fisheries were as follows:

Catch of 1+ seals

Landsmen catch	13026 ± 5048	ISD	
Greenland	3784 ± 1040		(Kapel 1975)
High Arctic	1294 ± 729		(Sergeant 1971)

Catch of 0-group seals

Landsmen	36949 ± 14442	ISD
Greenland	3784 ± 1040	

In each case the catch was broken into the frequency distribution through multiplying it by the average catch distribution. It was then fractioned into males and females by (1) assuming that each uncontrolled catch had the same sex ratio as the current population and (2) that the large vessel catch had the same age dependent sex ratio as that in Figure one since the closing dates are to remain fixed.

The next step in the program is to calculate the size of the breeding population ([84]) and for this two functions must be evaluated. First density-dependent age specific whelping ages are calculated using the equation ([73]):

(I) ARC sine $_{i}E_{t}$ = $15.522A-2.245 \times 10^{-5}N_{t}-16.017$

where $_{i}E_{t}$ is the fraction of the population whelping assuming 100% pregnancy for a particular age i and population number of 1+ seals N_t in the year t, and A is the age in years. The ARC sine of $_{i}E_{t}$ is constrained such that it cannot be 90 or 0.

A density-dependent fertility rate is calculated using the following equation ([73]):

(II) $P = 1.048 - 9.746 \times 10^{-8} N_2$

where P is the pregnancy rate and N_2 is the number of harp seals between the ages 2 and 25. These two equations act together to constrain the pup production with the carrying capacity of the environment in addition to augmenting the production at lower population levels. They make the birth rate a power function of population size. The summation of the breeding population vector is multiplied by 1.06 since it was determined that on average 6% of the breeding population is over the age of 25.

Equation I and II represent the feedback within the simulation which changes its nature from linear to non linear, this providing some additional realism.

Following the calculation of pup production the catches of 1+ males and females are subtracted from the total number([86], [87]). Similarly, the pup catch is subtracted from the total catch ([94]).

Natural mortality is also considered a stochastic, normally distributed parameter of 0.114 ± 0.0302 which means that it can vary as widely as from 0.174 to 0.0536, less than 5% of the time. Natural mortality is applied using the following equation ([97 - 99]):

(III) $N_t \leftarrow N_t$ EXP(-M)

Natural mortality is applied to the population after the catch has been subtracted off, since the hunt primarily occurs during the spring and natural mortality and hunting mortality occur quite separately.

The surviving pups after exploitation and natural mortality are assumed to have a 0.50:0.50 sex ratio. The numbers of males and females at age are now updated and the 0 group cohort is catenated into the vector for 1-year-olds and the remaining 25-year-old seals are dropped from the vector (101 , 102). Annual sex ratios of the total and breeding populations are calculated. A test is made to determine if the simulated time period has expired and if more iterations are to occur. If the simulation time has elapsed the remaining portion of the program dealing with the calculation of means and variances and formating executes.

Results and Discussion of the Simulation

Allen (1975) has pointed out that his linear model allows the population to increase ad infinitum which restricts its usefulness for making long term predictions. Thus the initial use of the simulation was to investigate what the implications of different assumption concerning the pregnancy rates and maturity rates had on the population, when there was no fishery other than the uncontrolled landsmen and aboriginal hunt.

Many mammalian populations show a varying fertility rate (Gambell 1973, Markgreen 1969) in response to space and food availability, and indeed there is evidence to indicate that the pregnancy rate for harp seals can also be altered in response to changes in density (Fig. 5). When this relationship was incorporated into the simulation, it limits the population (Fig. 9) to about 6.5 million animals. At this time the fertility rate was approximately 0.4 which brought the population into equilibrium with the uncontrolled landsmen and aboriginal hunt. However, the reproductive potential of the stock was unrealistic, since when MSY (maximum sustainable yield), to be discussed later, was determined, catch levels could be sustained which were in excess of those which have led to a decline in the herd.

It was apparent from this exercise that an additional mechanism was necessary to constrain the reproductive potential of the population. For this reason, a density-dependent maturity ogive was added into the simulation. The effect was to produce a population size which was in equilibrium with the landsmen and aboriginal catch levels at an abundance of 3.7 million seals. The sequential analysis estimate for 1952 (Table 5) was $\sim$ 2.3 million seals, which Sergeant (1975) concluded was near the maximum popuolation size. Evidence from this analysis do not agree with Sergeant's conclusions.

A simulated "recruitment" curve (Fig. 10) was compared with values from the sequential population analysis. The line passed through the axis of the data, but the scatter in the pup production values was too great to suggest if the two techniques confirmed one another. However, one apparent fact was that pup production had to be in excess of the 1952 production level, to sustain the high catches between 1830 and 1923 (Chafe 1923).

The curve (Fig. 10) is a power function of population size. Allen (1975) speculates as to the possible shape of the recruitment curve and concludes that if reproduction is a linear function of stock size, the Beverton and Holt (1957) recruitment curve is indeed the best representation of the recruitment process of seals. In addition, to the linear shift in maturity our model allows for a linear shift in the pregnancy rate which adds more curvature to the relationship. Ricker (1954) recruitment is not realistic for a stock as undynamic as harp seals, since the declining portion of this curve, results from a population being much further out of equilibrium with the carrying capacity of the environment, than it is possible for seals to get. At the point of maximum population size then, the reproductive rate is equivalent to the mortality rate.

It was necessary to determine the MSY population level as a reference point for harp seal management. This could not be determined from the simulation if only catch was controlled, since under these conditions the population could only come into some equilibrium or collapse. Therefore, the alternate program was utilized such that catch would vary in response to population size, by controlling the hunting morality rate. This allows for a Shaefer type curve (Fig. 11) to be generated. Hunting mortality by large vessels was calculated under present conditions to be approximately 0.01 on 1+ seals. Holding this mortality constant, the hunting level on pups was allowed to vary. The predicted value for maximum sustainable yield approximately 200,000 pups and 40,000 1+ seals, with respect to the present pup to 1+ seals kill ratio. The MSY population size is near 1.6 million 1+ seals, or a breeding stock of 375,000 females.

The variance in catch becomes greater on the left hand side of the Shaefer type curve (Fig. 11). This fact has been speculated on by Doubleday (1976), but here the biological basis is apparent. At stock sizes less than 1.2 million the maturity ogive can no longer shift to the left thus the population loses much of its density dependent control to maintain stability. This same result was shown by Lett and Kohler (1976) for an Atlantic herring stock.

Using the 1977 age specific abundance levels (Table 5) the population was projected ahead with fixed large vessel catches of pups and 1+ seals (Fig. 12). When the large vessels removed 10,000 1+ seals and 80,000 pups the mean population size increased, reaching the MSY breeding stock size by 1989, however, there is a 66% chance MSY could be reached by 1983. The total average catch including landsmen, large vessels, Canadian native and Greenland is ~150,000 seals. When the large vessels take 10,000 1+ seals and 100,000 pups the mean population size reaches MSY in 1991, a date which is not much different than that for the projected 1971-1974 management strategy. In all iterations the population increased at this level of exploitation.

When the large vessel catch was 10,000 1+ seals and 120,000 pups for a total average catch of 190,000, the population did not change in size. However, 20% of the time the population declined and 80% of the time it stayed the same or increased. When 10,000 more 1+ seals were removed by large vessels (Fig. 12D) the population declined in all cases.

In conclusion, this study would indicate that the catch should not exceed 170,000 seals to allow the population to increase to MSY, assuming kill ratio of 20% 1+ seals to 80% pups and keeping in mind this includes the high Arctic and Greenland hunt. Furthermore, because of the growing uncertainties of prediction encountered as one moves away from the current population size (Fig. 12) quotas should not be set more than 3-5 years in advance. A complete re-examination of the population dynamics and herd assessment is necessary at least every 5 year.

Sampling of the landsmen and large vessel catch must be continued at an accelerated level in the interim, in addition to samples collected from the moulting lairs for estimates of natural mortality. In addition, samples of ovaries should be collected from the breeding to detect shifts in the maturity ogive. Ultraviolet aerial sensing of the herd, with adequate ground truthing, must be persued until a direct estimate of the population size is available. We believe that the model presented in this paper is quite complete as far as the population dynamics is concerned, and for this reason a logical extension of the simulation could incorporate some community structure, and bioenergetic submodels.

Aknowlegement

R E F E R E N C E S

Allen, R. L. 1975. A life table for harp seals Pagophilus groenlandicus (Erxleben). Symposium on the Biology of the Seal, Guelph, Canada, August 1972. Rapp. P-v Réun. Cons. per. int. Explor. Mer. 169:303-311.

Benjaminsen, T. and T. Øritsland. MS 1975. Adjusted estiamtes of year-class survival and production with estimates of mortality for Northwestern Atlantic harp seals. Int. Comm. Northwest Atl. Fish. Working Pap., 1975(XI/3): 38 p.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fishery Investigations, Ser. II, Vol. 19, 533 p.

Bourlière, F. 1959. Lifespans of mammalian and bird populations in nature. In G.E.W. Wolstenholme and Maeve O'Connor [ed] Colloguia on Ageing. J. and A. Churchill Ltd., London.

Capstick, C.K., and K. Ronald. 1976. Modelling seal populations for herd management. FAO Scientific Consultation on Marine Mammals, Bergen, Norway. ACMRR/MM/SC/77. 19 p.

Chafe, L.G., W.A. Mann, and H. M. Mosdell. 1923. Chafe's Sealing Book, a history of the Newfoundland sealfishery from the earliest available records down to and including the vouage of 1923. The Trade Printers and Publishers Ltd. 108 p.

Coleman, J. 1938. The Newfoundland seal-fishery and its possible influence on the Greenlanders. Polar Record, 2(16):99-103.

Department of Fisheries of Canada. 1968. Canadian Atlantic coast harp and hood seal catch statistics: an historical series by regions, methods of capture, types of pelts, areas of catch, 1946-1967. Economic Service, Department of Fisheries of Canada, Ottawa.

Doubleday, W. G. 1975. The least squares approach to analysing catch at age data. Int. Comm. Northwest Atl. Fish. Res. Doc. 75/35.

Doubleday, W. G. 1976. Environmental fluctations and fisheries management. Int. Comm. Northwest. Atl. Fish. Sel. Pap. 1.1:141-150.

Fisher, H. D. 1952. Harp seals of the Northwest Atlantic. Fish. Res. Board Can. General Ser. No. 20, 4 p.

Fisher, H. D. 1955. Utilization of Atlantic harp seal populations. Trans. 20 North American Wildlife Conference: 507-518.

Fiskeridirektøren, 1951- 1965. Selfangsten...... Årsbertn. Norg. Fisk. 1946-1964.

Fry, F. E. J. 1949. Statistics of a lake trout fishery. Biometrics 5: 27-67.

Gambell, R. 1973. Some effects of exploitation on reproduction in whales. J. Reprod. Fert., Suppl. 19: 533-553.

Gulland, J. A. 1965. Estimation of mortality rates. Annex to Arctic Fisheries Working Group Report. ICES C.M. 1965 (3).

International Commission for the Northwest Atlantic Fisheries 1972. Int. Comm. Northwest Atl. Fish. Sum. Doc 72/6.

Jones, R., 1964. Estimating population size from commercial statistics when fishing mortality varies with age. Rapp. P.v. Cons.perm. int. explor. Mer, 155,38:210-214.

Kapel, F.O. 1975. Data on the catch of harp and hooded seals 1954-1974, and long-term fluctuations in sealing in Greenland. Int. Comm. Northwest. Atl. Fish. Res Doc 75/XII/9.

Lavigne, D.M., and N.A. Øritsland. 1974. Ultraviolet photography: A new metod for remote sensing of mammals. Can. J. Zool. 52: 939-941.

Lavigne, D. M., S. Innes, K. Kalpakis and K. Ronald. 1975. An aerial sensus of western Atlantic harp seals (Pagophilus groenlandicus) using ultraviolet photography. Int. Comm. Northwest Atl. Fish. Res. Doc. 75/XII/144.

Lavigne, D. M., W. Barchard, S. Innes, and N.A. Øritsland 1976. Pinniped bioenergetics. FAO. Scientific Consultation on Marine Mammals. Bergen, Norway. ACMRR/MM/SC/112.

Lett, P. F. and A. C. Kohler. Recruitment: a problem of multi-species interaction and environmental pertenbations, with special reference to Gulf of St. Lawrence Atlantic herring (Clupea Larengus harengus). J. Fish. Res. Board Can 33: 1353-1371.

Markgren, G. 1969. Reproduction of moose in Sweden. Viltrevy 6 (3):125-299.

McLaren, I. A. 1967. Seals and group selection. Ecology 48(1): 104-110.

Murphy, G. I. 1964. A solution of the catch equation. J.Fish. Res. Board Can. 22: 191-201.

Øritsland, T. 1967. Revised catch and effort statistics for the Norwegian seal hunt in the Front and Gulf areas off Newfoundland, 1937-1967. Int. Comm. Northwest Atl. Fish. Serial No. 1959.

Øritsland, T. 1970. Sealing and seal research in the south-west Atlantic pack ice, Sept.-Oct. 1964, p. 367-376. In Antarctic ecology [ed] M.W. Hollgate Vo 1. Academic Press, London.

Øritsland, T. 1971. Catch and effort statistics for Norwegian sealing in Front area, Newfoundland, 1971. Int. Comm. Northwest Atl. Fish. Res. Doc. 71/132.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Int. Comm. Northwest Atl. Fish. Res. Bull. 9: 65-74.

Ricker, W. E. 1971. Comments on the West Atlantic harp seal herd and proposals for the 1972 harvest. Int. Comm. Northwest. Atl. Fish. Res. Doc 75/IXX/143 (Appendix).

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 19, 382 p.

Sergeant, D. E. 1965. Migration of harp seals Pagophilus groenlandicus in the northwest Atlantic. J. Fish. Res. Board Can. 22:433-464.

Sergeant, D. E. 1966. Reproductive rates of harp seals, Pagophilus groenlandicus (Erxleben). J. Fish. Res. Board Can. 23: 757-766.

Sergeant, D.E. 1971. Calculation of production of harp seals in the western north Atlantic. Int. Comm. Northwest Atl. Fish. Redbook 1971, Part III: 157-184.

Sergeant, D. E. 1972. Canadian studies on harp seals in 1971. Int. Comm. Northwest. Atl. Fish. Res. Doc. 72/59.

Sergeant, D. E. 1973a. Feeding, growth, and productivity of northest Atlantic harp seals (Pagophilus groenlandicus). J.Fish. Res. Bd. Can. 30:17-29.

Sergeant, D. E. 1973b. Environment and reproduction in seals. J. Reprod. Fert., Suppl. 19: 555-561.

Sergeant, D. E. 1975. Results of research on harp seals in 1975 with an estimate of production. Int. Comm. Northwest. Atl. Fish. Res. Doc. 75/XII/142.

Sergeant, D. E. 1976. Studies on harp seals of the western north Atlantic populations in 1976. Int. Comm. Northwest. Atl. Fish Res. Doc. 76/X/124.

Simms, H.S., B.N. Berg, and D. F. Davies. 1959. Onset of disease and the longevity of rat and man. In G. E. W. Wolstenholme and Maeve O'Connor [ed] Colloguia on Ageing. J. and A. Churchill Ltd. London.

Table 1. Catch at age of the northwest Atlantic harp seal from different landsmen and large vessel fisheries. Individual samples are shown from 1961 on. Annual percentage compositions have been weighted in relation to the ratio of landsmen to larger vessel catch.

Age	Large vessel A	Landsmen A	% 1952	Large vessel A	Landsmen A	% 1953	Large vessel A	Landsmen A	% 1954	Large vessel Avg.	Landsmen A	% 1955
1	10	27	4.29	419	15	27.61	233	15	35.76	30.71%	48	29.28
2	24	95	10.57	124	52	8.71	91	26	14.28	13.99	77	14.07
3	15	98	6.96	103	98	7.86	26	23	4.31	7.70	98	8.48
4	11	114	5.49	61	108	5.22	36	57	6.52	6.02	41	6.16
5	13	115	6.30	62	111	5.32	19	45	3.63	4.90	58	5.34
6	25	101	11.03	48	100	4.28	24	33	4.26	4.20	35	4.38
7	17	96	7.75	43	86	3.80	21	40	3.92	3.64	30	3.79
8	17	81	7.61	48	51	3.72	20	23	3.39	3.28	39	3.57
9	12	60	5.40	47	50	3.65	13	16	2.27	2.94	13	2.91
10	14	54	6.15	39	41	3.02	21	10	3.31	2.72	14	2.72
11	12	60	5.40	51	28	3.66	8	8	1.37	2.46	10	2.43
12	3	42	1.60	28	34	2.22	18	7	2.87	2.27	13	2.29
13	3	21	1.41	22	22	1.69	18	5	2.84	2.10	2	1.99
14	5	12	2.13	17	19	1.33	9	4	1.45	1.96	3	1.87
15	9	24	3.86	33	34	2.55	12	4	1.90	1.82	5	1.77
16	3	12	1.32	37	10	2.54	16	0	2.44	1.74	4	1.67
17	5	15	2.16	26	14	1.86	7	2	1.11	1.54	3	1.48
18	4	8	1.69	16	11	1.17	2	5	0.40	1.34	4	1.31
19	2	8	0.88	12	6	0.85	8	2	1.26	1.26	2	1.21
20	11	12	4.56	50	39	3.72	4	8	0.76	1.01	2	0.97
21	3	6	1.26	32	7	2.22	2	3	0.36	0.76	4	0.76
22	0	6	0.05	18	3	1.21	2	2	0.34	0.67	3	0.67
23	1	4	0.44	12	7	0.87	5	1	0.78	0.50		0.47
24	3	2	1.23	9	3	0.62	1	0	0.15	0.42		0.39
25	1	4	0.44	5	1	0.33	2	1	0.32	0.06		0.05

Table 1. (cont'd) Catch at age of the northwest Atlantic harp seal from different landsmen and large vessel fisheries. Individual samples are shown from 1961 on. Annual percentage compositions have been weighted in relation to the ratio of landsmen to larger vessel catch.

Age	Large vessel A	Landsmen A	% 1956	Large vessel A	Landsmen A	% 1957	Large vessel A	Landsmen A	% 1958	Large vessel A	Landsmen A	% 1959	Large vessel A	Landsmen A	1960
1		11	27.42		11	29.78	40	26	15.43		9	29.37		34	19.49
2		59	13.42		20	13.64	15	25	7.14		23	13.74		107	9.12
3		62	7.88		23	7.67	19	90	4.01		25	7.79		67	5.17
4		55	6.27		26	6.11	22	142	3.19		18	6.06		202	4.02
5		37	4.97		17	4.91	18	110	2.57		23	5.09		47	3.36
6		35	4.32		15	4.21	11	115	2.21		26	4.48		62	2.97
7		42	3.94		21	3.77	11	82	1.97		25	3.93		41	2.60
8		54	3.82		17	3.36	9	81	1.76		22	3.52		19	2.34
9		45	3.37		16	3.03	9	58	1.59		21	3.19		14	2.11
10		33	2.97		21	2.88	17	69	1.51		17	2.90		18	1.92
11		23	2.58		21	2.64	13	63	1.38		10	2.53		13	1.67
12		30	2.52		18	2.42	14	45	1.26		7	2.29		12	1.52
13	AVG	19	2.19	AVG	12	2.18	8	40	1.13	AVG	5	2.09	AVG	6	1.39
14		20	2.07		16	2.09	6	31	1.10		9	2.03		9	1.35
15		11	1.80		14	1.93	16	27	1.01		7	1.86		4	1.23
16		20	1.88		9	1.78	14	14	0.90		4	1.72		5	1.15
17		15	1.62		8	1.58	6	18	0.80		4	1.54		3	1.02
18		25	1.62		8	1.39	1	13	0.72		2	1.32		3	0.87
19		15	1.37		6	1.29	3	5	0.67		3	1.25		0	0.83
20		16	1.17		11	1.11	9	15	0.58		2	0.99		4	*0.66
21		10	0.84		6	0.85	7	3	0.42		0	0.72		0	0.48
22		8	0.73		5	0.71	6	3	0.37		0	0.64		1	0.42
23		9	0.60		0	0.48	2		0.25		1	0.50		0	0.33
24		7	0.49		2	0.43	4		0.22		0	0.40		0	0.27
25		3	0.10		3	0.09	2		0.05		1	0.07		0	0.05

Table 1. (cont'd) Catch at age of the northwest Atlantic harp seal from different landsmen and large vessel fisheries. Individual samples are shown from 1961 on. Annual percentage compositions have been weighted in relation to the ratio of landsmen to larger vessel catch.

Age	Large vessel A	Landsman A	% 1961	Large vessel A	Landsman A	Landsman B	Total Landsman	% 1962	Large vessel A	Landsman A	Landsman B	Total Landsman	% 1963	Large vessel A	Landsman A	Landsman B	Total Landsman	% 1964
1	122	16	26.35	201	20	6	26	23.55	111	18	26	44	7.93	3	10	43	53	3.13
2	34	65	10.39	245	50	15	65	29.17	121	52	83	135	10.28	6	31	42	73	5.53
3	25	100	10.27	61	74	16	90	8.25	106	86	54	140	9.42	8	74	50	124	7.97
4	30	126	12.62	56	95	30	125	8.15	55	90	33	123	5.83	11	64	32	96	9.30
5	11	39	4.27	39	95	21	116	6.07	46	80	26	106	4.93	7	65	32	97	6.72
6	13	52	5.34	17	33	7	40	2.60	61	56	21	77	5.35	12	40	42	82	9.65
7	15	43	5.30	15	46	14	60	2.54	67	32	8	40	5.04	6	27	29	56	5.15
8	9	27	3.24	16	42	16	58	2.63	66	36	10	46	5.09	5	11	35	46	4.28
9	8	28	3.08	17	29	13	42	2.53	63	22	12	34	4.67	5	10	23	33	4.00
10	17	24	4.76	6	18	16	34	1.15	72	25	15	40	5.36	8	6	27	33	5.95
11	10	15	2.84	8	14	10	24	1.24	70	24	14	38	5.20	4	11	18	29	3.25
12	3	20	1.63	13	17	3	20	1.77	51	20	10	30	3.83	4	5	21	26	3.19
13	4	16	1.64	6	11	11	22	0.99	57	11	9	20	4.03	3	6	20	26	2.53
14	6	7	1.61	9	13	8	21	1.32	56	17	14	31	4.17	3	3	21	24	2.48
15	1	12	0.81	12	21	23	44	1.98	42	22	11	33	3.31	5	4	7	11	3.50
16	5	5	1.29	4	7	10	17	0.69	54	15	9	24	3.91	4	2	11	13	2.90
17	4	3	0.98	12	9	4	13	1.56	36	13	11	24	2.76	5	4	12	16	3.62
18	2	2	0.52	5	11	4	15	0.78	24	9	4	13	1.78	8	1	6	7	5.37
19	3	0	0.63	4	1	6	7	0.56	18	4	12	16	1.45	4	0	14	14	2.92
20	2	7	0.77	9	4	12	16	1.26	18	10	10	20	1.53	0	2	6	8	0.18
21	0	0	0.21	1	1	2	3	0.16	17	5	6	11	1.30	4	0	6	6	2.74
22	2	0	0.42	4	6	5	11	0.61	12	5	8	13	1.01	2	2	3	5	1.42
23	1	2	0.31	0	1	3	4	0.17	9	4	10	14	0.84	2	0	5	5	1.42
24	0	1	0.26	1	1	2	3	0.16	8	2	6	8	0.66	3	1	2	3	2.02
25	1	4	0.41	1	2	3	5	0.18	4	1	2	3	0.31	1	0	6	6	0.79

Table 1. (cont'd) Catch at age of the northwest Atlantic harp seal from different landsmen and large vessel fisheries. Individual samples are shown from 1961 on. Annual percentage compositions have been weighted in relation to the ratio of landsmen to larger vessel catch.

Age	Large vessel A	Landsman A	Landsman B	Total Landsman	% 1965	Large vessel A	Landsman A	Landsman B	Total Landsman	% 1966	Large vessel A	Large vessel B	Total large vessel	Landsman A	Landsman B	Landsman C	Total Landsman	% 1967
1	32	4	4	8	13.21	120	10	1	11	15.30	176	55	231	17	12	6	35	18.53
2	13	17	10	27	6.58	100	29	2	31	13.75	61	31	92	14	42	11	67	8.68
3	13	45	24	69	8.72	39	42	3	45	6.86	18	5	23	1	46	17	64	3.34
4	15	72	34	106	11.42	40	44	5	49	7.17	18	6	24	9	37	24	70	3.56
5	23	71	24	95	14.06	45	42	7	49	7.79	29	19	48	11	58	30	99	6.11
6	22	66	18	84	13.09	45	50	5	55	8.06	46	22	68	21	72	25	118	8.11
7	7	39	15	54	5.56	44	33	4	37	7.15	40	19	59	26	64	27	117	7.39
8	2	32	16	48	3.25	31	19	0	19	4.69	30	13	43	21	43	14	78	5.21
9	2	18	4	22	1.92	15	14	4	18	2.67	23	5	28	26	31	10	67	3.79
10	5	9	5	14	2.72	17	8	2	10	2.55	16	8	24	16	27	9	52	3.12
11	1	10	5	15	1.17	23	10	1	11	3.34	34	13	36	21	14	11	46	3.89
12	7	12	6	18	3.72	17	5	0	5	2.32	18	6	24	14	15	5	34	2.67
13	1	16	7	23	1.18	15	7	0	7	2.17	14	5	19	16	10	6	32	2.24
14	5	8	7	15	2.76	17	7	0	7	2.42	19	10	29	15	16	7	38	3.15
15	4	8	10	18	2.52	14	7	0	7	2.05	20	10	30	13	12	7	32	3.08
16	2	6	6	12	1.41	14	7	1	8	2.09	14	6	20	17	4	6	27	2.19
17	1	5	5	10	0.91	10	3	2	5	1.46	18	8	26	12	9	3	24	3.34
18	3	2	4	6	1.51	17	1	0	1	2.14	20	9	29	9	7	4	20	2.71
19	3	6	4	10	1.71	10	1	2	3	1.37	21	9	30	8	4	6	18	2.74
20	1	3	1	4	0.60	11	2	0	2	1.45	15	4	19	11	5	4	20	1.95
21	2	3	2	5	1.06	8	1	0	1	1.03	8	4	12	3	3	4	10	1.16
22	1	1	1	2	0.50	3	1	1	2	0.46	8	1	9	2	4	0	6	0.84
23	0	2	0	2	0.10	7	1	0	1	0.91	8	3	11	3	0	1	4	0.94
24	0	1	2	3	0.15	4	0	0	0	0.49	4	2	6	5	2	2	9	0.68
25	0	1	2	3	0.15	2	0	2	2	0.34	4	2	6	1	3	1	5	0.58

Table 1. (cont'd) Catch at age of the northwest Atlantic harp seal from different landsmen and large vessel fisheries. Individual samples are shown from 1961 on. Annual percentage compositions have been weighted in relation to the ratio of landsmen to larger vessel catch.

Age	Large vessel A	Large vessel B	Total large vessel	Landsman A	Landsman B	Total Landsman	% 1968	Large vessel A	Large vessel B	Total large vessel	Landsman A	Landsman B	Landsman C	Landsman D	Total Landsman	% 1969
1	84	142	226	7	11	18	15.04	62	396	458	87	37	9	5	138	35.77
2	77	78	155	8	48	56	11.37	2	56	58	13	14	20	4	51	5.10
3	48	43	91	8	68	76	7.71	6	40	46	13	21	49	29	112	5.26
4	20	27	47	8	56	64	4.58	1	32	33	13	10	69	18	110	4.28
5	17	32	49	5	39	44	4.23	2	43	45	11	11	71	11	104	5.05
6	23	20	43	9	54	63	4.30	4	30	34	10	2	49	6	67	3.62
7	27	48	75	12	41	53	6.13	1	38	39	5	5	60	11	81	4.22
8	39	38	77	15	39	54	6.28	6	45	51	7	4	59	10	80	5.08
9	23	31	54	16	17	33	4.29	2	39	41	1	2	43	11	57	3.96
10	26	30	56	15	18	33	4.42	0	29	29	6	11	40	2	59	3.12
11	19	23	42	10	14	24	3.30	3	24	27	4	6	38	3	51	2.84
12	18	12	30	13	14	27	2.59	1	18	19	4	2	22	6	34	1.97
13	16	16	32	9	7	16	2.46	2	21	23	5	5	20	1	31	2.21
14	24	18	42	7	9	16	3.10	2	24	26	3	2	16	1	22	2.27
15	20	15	35	9	10	19	2.72	2	24	26	3	1	24	0	28	2.37
16	20	14	34	11	6	17	2.61	2	16	18	2	1	18	1	22	1.69
17	11	17	28	10	9	19	2.27	0	24	24	6	5	11	0	22	2.13
18	17	27	44	7	4	11	3.11	0	21	21	2	0	11	1	14	1.77
19	16	22	38	5	5	10	2.70	0	22	22	3	2	5	0	10	1.78
20	11	16	27	3	2	5	1.87	0	20	20	2	0	4	1	7	1.58
21	6	11	17	4	1	5	1.22	1	13	14	2	0	5	1	8	1.16
22	5	19	24	4	3	7	1.72	2	10	12	1	1	2	0	4	0.94
23	4	10	14	2	0	2	0.95	2	9	11	2	0	0	0	2	0.84
24	2	8	10	1	0	1	0.67	1	5	6	0	0	1	0	1	0.45
25	1	4	5	0	1	1	0.35	0	7	7	0	1	0	0	1	0.53

Table 1. (cont'd) Catch at age of the northwest Atlantic harp seal from different landsmen and large vessel fisheries. Individual samples are shown from 1961 on. Annual percentage compositions have been weighted in relation to the ratio of landsmen to larger vessel catch.

Age	Large vessel A	Large vessel B	Total large vessel	Landsman A	Landsman B	Landsman C	Landsman D	Total Landsman	% 1970	Large vessel	Landsman A	Landsman B	Landsman C	Landsman D	Total Landsman	% 1971	Large vessel	Landsman A	Landsman B	Landsman C	Total Landsman	% 1972
1	105	134	239	41	31	5	21	98	18.17	239	3	4	17	39	63	31.59	12	11	1	0	12	6.21
2	98	112	210	41	69	12	60	182	17.46	66	18	15	29	27	89	10.72	9	19	6	3	28	8.10
3	11	34	45	15	89	32	67	203	6.29	53	35	51	45	33	164	11.19	9	17	2	1	20	14.27
4	17	29	46	25	45	55	63	188	6.13	19	34	30	17	14	95	5.02	24	26	3	3	32	9.88
5	18	15	33	23	40	77	68	208	5.53	18	45	32	31	5	113	5.37	9	10	1	6	17	10.07
6	12	18	30	19	16	38	44	117	3.91	11	30	9	9	21	69	3.30	10	15	0	3	18	6.54
7	15	26	41	14	8	35	24	81	4.12	10	16	9	6	18	49	2.61	13	5	0	4	9	5.15
8	8	15	23	43	12	64	22	141	3.79	8	23	4	6	15	48	2.34	9	8	0	3	11	4.72
9	13	22	35	49	8	66	25	148	4.74	17	21	7	3	13	44	3.35	6	5	1	0	6	4.14
10	18	13	31	49	8	82	24	153	4.54	16	30	3	4	31	58	3.61	6	6	0	1	7	5.29
11	13	7	20	24	4	61	13	102	2.97	10	9	2	10	20	41	2.39	4	13	0	2	15	3.72
12	20	6	26	28	4	42	8	82	3.09	12	6	6	2	26	40	2.61	5	7	0	6	13	3.72
13	12	11	23	26	1	37	8	72	2.72	8	8	6	4	22	40	2.11	2	5	0	2	7	3.46
14	6	10	16	19	0	30	5	54	1.95	4	9	3	0	13	25	1.20	2	15	0	0	15	2.23
15	11	13	24	29	2	32	10	73	2.81	6	4	3	0	18	25	1.45	6	6	0	2	8	2.57
16	13	4	17	30	1	27	2	60	2.12	6	3	5	0	11	19	1.28	4	3	1	0	4	1.91
17	7	8	15	20	0	30	9	59	1.96	6	5	3	1	8	17	1.22	3	8	0	0	8	1.66
18	7	10	17	12	1	21	6	40	1.81	9	4	1	0	10	15	1.54	2	7	0	3	10	1.41
19	7	7	14	18	1	17	6	42	1.63	6	3	2	0	7	12	1.08	0	5	0	0	5	0.99
20	6	6	12	22	3	16	6	47	1.56	8	2	0	1	11	14	1.39	5	13	0	1	14	1.58
21	4	4	8	10	1	10	1	22	0.90	5	0	0	2	7	9	0.87	1	7	1	1	9	0.83
22	5	2	7	5	0	9	1	15	0.72	9	0	0	0	4	4	1.23	3	3	0	2	5	0.59
23	3	0	3	7	0	4	3	14	0.43	7	0	0	0	4	4	0.99	1	2	0	2	2	0.41
24	3	1	4	5	0	5	1	11	0.45	4	1	0	0	1	2	0.56	2	3	0	0	3	0.34
25	0	1	1	3	0	6	0	9	0.21	7	1	0	0	2	3	0.96	0	0	0	0	0	0.25

Table 1. (cont'd) Catch at age of the northwest Atlantic harp seal from different landsmen and large vessel fisheries. Individual samples are shown from 1961 on. Annual percentage compositions have been weighted in relation to the ratio of landsmen to larger vessel catch.

Age	Large vessel A	Large vessel B	Total large vessel	Landsman A	% 1973	Large vessel A	Landsman A	Landsman B	Landsman C	Landsman D	Total Landsman	% 1974	Large vessel A	Landsman A	Landsman B	Landsman C	Landsman D	Landsman E	Total Landsman	% 1975
1	171	4	175	6	6.52	360	0	8	46	106	160	26.66	464	20	0	157	146	55	378	28.80
2	232	5	237	14	9.61	227	0	18	33	22	73	15.62	223	55	1	123	30	47	256	17.10
3	188	0	188	16	8.40	86	2	7	11	7	27	5.89	102	56	12	61	13	20	162	9.79
4	173	5	178	9	6.98	65	5	10	10	5	30	4.86	67	19	26	40	1	10	96	5.98
5	293	6	299	11	11.26	67	17	12	5	6	40	5.40	57	8	62	29	4	4	107	6.20
6	81	0	81	11	4.16	88	61	19	7	4	91	8.73	57	4	57	25	2	5	93	5.58
7	67	1	68	16	4.34	21	20	13	3	1	37	2.73	28	5	71	22	1	9	108	5.48
8	79	6	85	15	4.61	21	30	18	3	0	51	3.33	23	4	50	11	0	2	67	3.55
9	42	0	42	21	4.16	36	19	17	1	0	37	3.56	29	3	21	7	0	2	33	2.21
10	37	4	41	17	3.47	21	15	20	0	0	35	2.65	17	0	19	18	0	10	47	2.07
11	45	3	48	24	4.65	16	8	18	0	1	27	2.03	28	0	14	14	0	1	29	2.01
12	30	0	30	27	4.54	24	11	14	2	0	27	2.47	17	2	14	11	0	4	31	1.81
13	36	0	36	22	4.09	23	6	17	1	0	24	2.29	20	0	10	20	1	1	32	1.93
14	24	0	24	21	3.56	19	2	17	1	0	20	1.90	15	0	9	18	0	0	27	1.58
15	36	1	37	18	3.56	30	2	16	0	0	18	1.86	15	0	5	10	0	0	15	1.05
16	32	1	33	15	3.04	16	2	21	0	1	24	1.90	13	0	7	7	0	2	16	1.04
17	25	1	26	11	2.28	16	4	13	1	0	18	1.65	13	0	1	7	0	1	9	0.74
18	23	1	24	10	2.08	14	1	10	0	0	11	1.24	10	0	7	9	0	0	16	0.97
19	29	1	30	6	1.76	12	2	7	0	0	9	1.04	8	0	2	4	0	0	6	0.47
20	33	0	33	6	1.89	10	1	6	0	0	7	0.85	6	0	0	4	0	1	5	0.38
21	18	0	18	3	0.99	8	0	8	0	0	8	0.78	5	0	0	3	0	0	3	0.26
22	18	0	18	13	0.23	9	0	7	0	0	7	0.79	7	0	1	2	0	0	3	0.32
23	20	0	20	0	0.67	7	0	4	0	0	4	0.56	5	0	0	0	0	1	1	0.18
24	15	0	15	0	0.50	11	0	0	0	0	0	0.61	6	0	1	2	0	0	3	0.29
25	17	0	17	0	0.56	9	1	1	0	0	2	0.58	5	0	0	2	0	0	2	0.22

Table 1. (cont'd) Catch at age of the northwest Atlantic harp seal from different landsmen a large vessel fisheries. Ind. idual samples are shown from 1961 on. Annual percentage compositions have been weighted in relation to the ratio of landsmen to larger vessel catch.

Age	Large vessel A	Landsman A	Landsman B	Landsman C	Landsman D	Landsman E	Total Landsman	% 1976
1	292	0	7	88	75	113	283	33.20
2	112	0	18	57	34	58	167	18.96
3	60	1	26	45	20	25	117	12.08
4	35	13	9	37	11	17	87	8.73
5	24	16	4	22	2	2	46	4.76
6	13	15	3	20	1	0	39	3.84
7	18	19	1	10	1	0	31	3.26
8	13	13	0	16	2	0	31	3.12
9	11	9	1	3	0	0	13	1.46
10	6	14	1	9	0	0	24	2.30
11	6	8	0	6	2	0	16	1.59
12	5	4	0	5	2	0	11	1.12
13	8	5	0	3	0	0	8	0.93
14	5	4	0	4	1	0	9	0.94
15	5	3	0	13	0	0	16	1.57
16	5	1	0	4	0	0	5	0.58
17	5	1	0	5	0	0	6	0.67
18	3	0	0	4	0	0	4	0.44
19	2	0	0	4	0	0	4	0.41
20	1	0	0	5	0	0	5	0.47
21	1	0	0	1	0	0	1	0.12
22	2	0	0	1	0	0	1	0.14
23	1	0	0	1	0	0	1	0.16
24	0	0	0	1	0	0	1	0.09
25	0	0	0	1	0	0	1	0.09

Table 2. The total catch of 1+ northwest Atlantic harp seals by landsmen and large vessels from 1952 to 1975.

YEAR	LANDSMEN	LARGE VESSEL	% LANDSMEN	% LARGE VESSEL
1952	10667	98378	9.8	90.2
53	8100	66811	10.8	89.2
54	5443	83939	6.1	93.9
1955	5401	75671	6.7	93.3
56	5428	42585	11.3	88.7
57	3605	76437	4.5	95.5
58	19563	137227	12.5	87.5
59	3998	77304	4.9	95.1
1960	6648	114534	5.5	94.5
61	5877	13170	30.9	69.1
62	13388	99513	11.9	88.1
63	14529	57094	20.3	79.7
64	14933	60348	19.8	80.2
1965	17738	33757	34.4	65.6
66	12647	59364	17.6	82.4
67	15245	41361	26.9	73.1
68	5910	30328	16.3	83.7
69	10532	44940	19.0	81.0
1970	13839	26225	34.5	65.5
71	6044	14343	29.6	70.4
72	11427	1646	87.4	12.6
73	10416	15081	40.9	59.1
74	10982	21828	33.5	66.5
1975	22733	10992	67.4	32.6

Table 3. Catch at age data of the northwest Atlantic harp seals resulting from the weighting of samples and application to the total catch.

Age	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
0	198063	197975	184491	260020	346846	171909	149350	243255	164158	174762	211285	285994
1	4679	20685	35353	26005	14664	25488	44871	25180	37848	6586	27588	6780
2	11529	6527	14119	12499	7175	11796	20701	11778	18220	2597	34154	8785
3	7589	5888	4257	7526	4215	6631	12830	6675	10108	2566	9762	8044
4	5983	3913	6444	5467	3355	5280	11387	5194	9486	3155	9549	4980
5	6875	3988	3590	4738	2660	4248	9163	4360	6478	1067	7108	4215
6	12029	3207	4207	3889	2310	3647	8247	3838	5783	1335	2932	4572
7	8451	2843	3879	3367	2108	3256	6812	3365	4877	1326	2978	4308
8	8302	2790	3351	3171	2045	2908	6268	3021	4200	811	3081	4349
9	5889	2732	2246	2588	1804	2618	5347	2731	3737	771	2963	3993
10	6711	2263	3271	2414	1588	2493	5231	2485	3506	1192	1350	4582
11	5889	2741	1350	2159	1378	2285	4754	2168	3145	712	1462	4440
12	1740	1664	2841	2031	1349	2088	4129	1961	2896	409	2075	3272
13	1532	1267	2806	1763	1169	1877	3792	1792	2627	411	1160	3440
14	2325	996	1430	1659	1112	1809	3419	1741	2488	403	1550	3562
15	4208	1909	1882	1567	964	1670	3141	1595	2264	204	2319	2828
16	1443	1901	2415	1485	1006	1541	2774	1479	2172	325	810	2240
17	2355	1395	1092	1311	867	1367	2566	1319	1912	248	1829	2355
18	1844	879	391	1161	865	1205	2188	1128	1673	130	914	1522
19	962	640	1243	1068	734	1112	1916	1075	1538	157	652	1242
20	4971	2786	746	859	624	964	1741	854	1273	193	1470	1306
21	1383	1630	356	674	450	696	1150	617	923	53	183	1107
22	60	909	338	592	392	615	1028	548	831	105	715	865
23	481	649	773	418	321	417	842	427	616	78	199	717
24	1344	468	151	348	263	371	702	343	513	65	183	566
25	481	254	320	47	54	83	157	62	69	103	215	267

Table 3. (cont'd) Catch at age data of the northwest Atlantic harp seal resulting from the weighting of samples and application to the total catch.

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
0	270952	187284	225250	279858	159971	236532	220520	213349	119658	102744	118036	140629
1	2502	7413	11558	10877	5980	20985	7844	7315	1990	1949	9604	9629
2	4418	3693	10383	5100	4521	2993	7535	2483	1289	2874	5629	5719
3	6364	4898	5183	1959	3069	3088	2714	2591	2272	2511	2123	3275
4	7429	6408	5414	2090	1823	2512	2644	1163	1573	2087	1752	1999
5	5364	7889	5880	3587	1682	2966	2387	1250	1604	3367	1945	2072
6	7702	7349	6086	4760	1711	2125	1687	764	1041	1243	3144	1867
7	4117	3121	5373	4341	2437	2479	1776	606	820	1299	985	1832
8	3419	1826	3543	3059	2498	2983	1637	542	752	1380	1200	1186
9	3189	1081	2018	2227	1705	2325	2045	776	659	1245	1283	740
10	4751	1524	1928	1830	1757	1831	1958	837	842	1038	954	693
11	2597	655	2522	2282	1310	1666	1286	554	592	1392	732	672
12	2544	2088	1756	1570	1031	1153	1332	606	593	1360	891	605
13	2023	660	1639	1316	976	1295	1175	490	552	1224	825	646
14	1988	1553	1825	1852	1233	1333	844	277	355	1064	685	529
15	2799	1415	1548	1810	1082	1393	1211	335	410	1067	674	353
16	2314	794	1580	1289	1037	991	914	297	304	909	686	350
17	2887	512	1104	1964	903	1248	847	284	264	682	594	247
18	4290	846	1619	1592	1237	1039	780	357	224	623	447	323
19	2331	961	1035	1608	1073	1042	703	251	158	526	377	159
20	142	340	1094	1143	742	927	676	322	252	566	306	127
21	2189	593	780	684	485	680	389	203	132	298	282	88
22	1130	282	349	491	684	554	312	286	94	690	287	106
23	1130	58	687	552	379	491	185	229	67	201	201	59
24	1616	87	373	400	267	267	195	129	54	151	219	97
25	628	87	256	342	139	310	91	222	40	171	210	74

Table 4. Hunting mortality levels of the northwest Atlantic harp seal calculated from cohort analysis assuming M = 0.114.

Age	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
0	0.644	0.585	0.634	0.844	0.989	0.499	0.524	0.733	0.557	0.570	0.759	1.101
1	0.024	0.112	0.174	0.151	0.088	0.150	0.210	0.140	0.209	0.034	0.146	0.042
2	0.062	0.039	0.095	0.078	0.052	0.087	0.159	0.072	0.130	0.018	0.218	0.058
3	0.032	0.037	0.029	0.062	0.032	0.057	0.116	0.065	0.074	0.022	0.075	0.067
4	0.032	0.019	0.047	0.044	0.033	0.046	0.119	0.058	0.112	0.027	0.096	0.046
5	0.060	0.024	0.020	0.041	0.025	0.048	0.095	0.056	0.087	0.015	0.071	0.051
6	0.066	0.033	0.030	0.025	0.023	0.039	0.112	0.048	0.089	0.021	0.047	0.055
7	0.084	0.019	0.047	0.027	0.016	0.038	0.086	0.056	0.072	0.024	0.053	0.082
8	0.055	0.033	0.025	0.045	0.019	0.024	0.086	0.046	0.084	0.014	0.066	0.092
9	0.066	0.022	0.031	0.022	0.030	0.028	0.051	0.045	0.067	0.018	0.060	0.103
10	0.049	0.030	0.029	0.038	0.016	0.048	0.065	0.028	0.068	0.025	0.036	0.112
11	0.063	0.023	0.021	0.022	0.025	0.025	0.110	0.032	0.041	0.016	0.035	0.145
12	0.035	0.021	0.028	0.036	0.016	0.044	0.053	0.055	0.049	0.006	0.052	0.091
13	0.014	0.030	0.041	0.020	0.024	0.025	0.096	0.027	0.089	0.008	0.019	0.103
14	0.038	0.010	0.039	0.028	0.014	0.042	0.053	0.054	0.043	0.016	0.033	0.068
15	0.093	0.036	0.022	0.050	0.019	0.024	0.087	0.029	0.083	0.004	0.109	0.070
16	0.058	0.051	0.054	0.019	0.038	0.034	0.047	0.050	0.046	0.014	0.018	0.132
17	0.133	0.066	0.034	0.034	0.013	0.060	0.067	0.026	0.076	0.006	0.088	0.059
18	0.140	0.061	0.022	0.042	0.026	0.020	0.117	0.035	0.038	0.006	0.024	0.090
19	0.045	0.061	0.105	0.070	0.031	0.039	0.037	0.071	0.056	0.004	0.032	0.037
20	0.383	0.159	0.085	0.090	0.049	0.048	0.071	0.019	0.102	0.008	0.043	0.075
21	0.186	0.188	0.025	0.094	0.057	0.064	0.067	0.030	0.024	0.005	0.008	0.038
22	0.014	0.163	0.050	0.049	0.066	0.094	0.115	0.038	0.047	0.003	0.077	0.044
23	0.023	0.188	0.185	0.073	0.031	0.085	0.163	0.059	0.050	0.005	0.005	0.094
24	0.090	0.026	0.056	0.108	0.055	0.041	0.183	0.085	0.085	0.006	0.013	0.016
25	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020

Table 4. (cont'd) Hunting mortality levels of the northwest Atlantic harp seal calculated from cohort analysis assuming M = 0.114.

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
0	1.038	0.861	1.019	1.039	0.528	0.826	0.809	0.900	0.448	0.426	0.428
1	0.020	0.058	0.099	0.101	0.045	0.108	0.049	0.048	0.008	0.011	0.058
2	0.032	0.034	0.098	0.053	0.051	0.026	0.047	0.018	0.010	0.026	0.035
3	0.050	0.041	0.056	0.022	0.038	0.041	0.028	0.019	0.019	0.022	0.022
4	0.074	0.059	0.053	0.027	0.024	0.036	0.041	0.014	0.013	0.020	0.018
5	0.059	0.096	0.065	0.042	0.025	0.045	0.040	0.023	0.021	0.032	0.021
6	0.113	0.097	0.091	0.063	0.023	0.036	0.030	0.015	0.022	0.019	0.035
7	0.058	0.056	0.087	0.079	0.038	0.038	0.035	0.012	0.018	0.031	0.017
8	0.079	0.030	0.076	0.060	0.055	0.054	0.030	0.012	0.017	0.035	0.033
9	0.083	0.030	0.039	0.057	0.040	0.060	0.044	0.016	0.017	0.033	0.037
10	0.156	0.048	0.062	0.041	0.054	0.050	0.061	0.021	0.020	0.030	0.029
11	0.078	0.027	0.094	0.089	0.034	0.060	0.041	0.020	0.017	0.038	0.025
12	0.106	0.076	0.084	0.071	0.048	0.035	0.057	0.023	0.025	0.045	0.028
13	0.069	0.033	0.072	0.077	0.053	0.072	0.041	0.025	0.024	0.059	0.032
14	0.073	0.063	0.109	0.099	0.087	0.087	0.056	0.012	0.021	0.052	0.039
15	0.064	0.062	0.075	0.137	0.071	0.123	0.097	0.026	0.019	0.072	0.039
16	0.069	0.021	0.984	0.076	0.099	0.078	0.101	0.029	0.027	0.048	0.055
17	0.228	0.018	0.034	0.129	0.064	0.151	0.081	0.038	0.029	0.071	0.037
18	0.132	0.088	0.066	0.057	0.102	0.089	0.122	0.041	0.035	0.081	0.056
19	0.175	0.036	0.135	0.079	0.046	0.107	0.073	0.048	0.021	0.097	0.059
20	0.005	0.032	0.048	0.197	0.044	0.046	0.086	0.040	0.057	0.088	0.069
21	0.158	0.023	0.087	0.035	0.109	0.047	0.023	0.031	0.019	0.080	0.053
22	0.045	0.025	0.016	0.066	0.041	0.160	0.025	0.019	0.017	0.117	0.095
23	0.067	0.003	0.072	0.028	0.061	0.034	0.067	0.021	0.005	0.040	0.042
24	0.284	0.006	0.020	0.050	0.016	0.051	0.016	0.056	0.006	0.013	0.052
25	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020

Table 5. Numbers at age of the northwest Atlantic rp seal estimated by cohort analysis from catch data (Table 3) assuming M = 0.114.

Age	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
0	441614	473555	416283	482960	584822	463624	387829	495879	407345	426122	420630	453722
1	211501	206945	235528	197163	185312	194184	251288	204969	212675	214060	215132	175732
2	205981	184294	165109	176757	151356	151495	149186	181829	159100	162175	184776	165893
3	259377	172898	158272	133983	145907	128271	124030	113559	151113	127367	142249	132606
4	205951	224263	148708	137199	112439	126205	108187	98548	95018	127365	111220	117787
5	125093	178110	196404	126599	117252	97155	107620	85775	83024	77614	110663	90217
6	201628	105121	155153	171852	108484	102107	82675	87370	72415	70886	68244	92025
7	112067	168542	90766	134462	149663	94613	87661	65978	74331	59444	61988	58122
8	164385	92010	147697	77322	116795	131547	81344	71782	55690	62201	51787	52496
9	98334	138832	79461	128619	65996	102279	114627	66659	61194	46345	54733	43297
10	151167	82177	121293	68778	112317	57182	88787	97226	56898	53117	40623	46037
11	102492	128541	71185	105135	59088	98715	48666	74280	84403	50227	46269	34971
12	53662	85887	112103	62241	91768	51420	85921	38932	64229	74773	44143	39903
13	123154	46237	75061	97341	53616	80607	43907	72764	32885	58040	66330	37427
14	66875	108438	40059	64324	85188	46735	70149	35595	63231	27271	51399	58088
15	50322	57474	95814	34392	55826	74959	39991	59362	30115	56353	23952	44397
16	27505	40925	49478	83713	29206	48901	65306	32716	51459	26229	50089	19181
17	20122	23178	34720	41866	73291	25109	42177	55649	27794	47867	23096	43927
18	14974	15729	19363	29948	36117	64575	21113	35209	48408	25001	42476	18880
19	23533	11619	13205	16908	25625	31409	56480	16771	30350	42072	22185	37036
20	16550	20089	9762	10608	14077	22171	26974	48585	13949	27586	37391	19179
21	8641	10071	15293	8006	8654	11971	18871	22424	42543	11600	24431	31974
22	4570	6404	7446	13309	6507	7296	10024	15752	19425	48332	10300	21626
23	22539	4021	4855	6325	11316	5435	5929	7973	13537	18218	43025	8515
24	16632	19656	2975	3602	5249	9794	4456	4495	6711	12943	18181	38202
25	25698	13570	17096	2511	2885	4435	8388	3313	3687	5503	11487	14265
Number 1+ Animals	2312753	2145031	2066806	1932953	1823934	1768570	1743757	1597515	1554184	1532589	1556169	1335783

Table 5. (cont'd) Numbers at age of the northwest Atlantic harp seal estimated by cohort analysis from catch data (Table 3) assuming M=0.144.

Age	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
0	444307	343878	373190	458617	412971	445669	420976	380759	350972	313938	358976	376386
1	134689	140497	129826	120212	144853	217369	174225	167317	138207	200129	183062	208804
2	150394	117814	118357	104921	96986	123598	174127	148044	142380	122381	176726	154267
3	139722	130017	101632	95797	88799	82266	107454	148249	129748	125823	106481	152368
4	110721	118656	111382	85786	83626	76333	70485	83313	129829	113623	109894	93003
5	100392	91774	99819	94267	74569	72894	65736	60394	82161	114355	99410	96399
6	76516	84509	74434	83510	80723	64946	62238	56398	52706	71793	98854	86862
7	77792	60997	68462	60666	70016	70409	55942	53939	49600	46044	62884	85233
8	47790	65522	51477	56011	50029	60171	60482	48237	47555	43482	39856	55179
9	42732	39412	56737	42584	47086	42279	50870	52419	42528	41721	37493	34429
10	34860	35116	34144	48718	35892	40403	35528	43458	46038	37323	36050	32242
11	36749	26617	29893	28644	41741	30365	34320	29851	37985	40283	32322	31265
12	27010	30337	23130	24290	23403	36006	25520	29408	26111	33333	34628	28148
13	32513	21697	25096	18979	20190	19907	31038	21512	25667	22738	28457	30055
14	30145	27099	18736	20844	15692	17093	16539	26584	18732	22360	19132	24612
15	48465	25019	22712	14993	16849	12836	13992	13960	23458	16378	18964	16424
16	36942	40599	20987	18805	11668	14011	10138	11341	12140	20543	13606	16284
17	14999	30776	35475	17233	15561	9431	11566	8182	9838	10545	17471	11492
18	36970	10656	26977	30610	13522	13032	7236	9520	7032	8529	8764	15028
19	15408	28935	8709	22541	25809	10896	10646	5720	8157	6063	7022	7398
20	31873	11546	24909	6793	18598	22014	8738	8835	4867	7129	4913	5909
21	15879	28305	9981	21192	4981	15889	18767	7158	7579	4104	5826	4095
22	27488	12100	24895	8169	18263	3986	13535	16878	6195	6638	3381	4932
23	18479	23455	10530	21705	6825	15649	3034	11782	14343	5439	5271	2745
24	6920	15421	20873	8747	18845	5732	13499	2532	10296	12734	4663	4513
25	33551	4648	13677	18272	7427	16562	4862	11861	2137	9136	11220	3954
Number 1+ Animals	1328999	1221524	1062850	1074289	1031953	1094077	1080517	1076892	1075289	1142646	1166351	1205640

Table 6. Projected populations of male and female northwest Atlantic harp seals, and age specific sex ratios starting from 1961. The sex ratio of the large vessel catch was determined empirically, while the sex ratio of the landsmen catch was considered to be that of the population. A maturity ogive was applied to calculate the breeding stock size.

Age	1962			1963			1964			1965			1966			1967		
	Males	Females	% F	Males	Females	% F	Males	Females	% F	Males	Females	% F	Males	Females	% F	Males	Females	% F
1	107566	107566	50.00	87866	87866	50.00	67345	67345	50.00	70249	70249	50.00	64913	64913	50.00	60106	60106	50.00
2	93245	93245	50.00	84090	84090	49.99	75864	75864	49.99	59040	59033	50.00	59649	59646	50.00	53005	52998	50.00
3	71465	71465	50.00	68484	68484	49.99	71746	71743	49.99	65837	65826	50.00	51174	51156	50.00	48815	48792	49.99
4	55941	55956	50.01	59542	59660	50.05	57990	58204	50.09	61260	61415	50.06	56654	56813	50.07	43342	43554	50.12
5	55729	55765	50.02	45695	45925	50.13	51154	51482	50.16	48383	49042	50.34	51829	52381	50.26	47999	48638	50.33
6	34253	34273	50.01	46552	46811	50.14	39055	39541	50.31	43162	43901	50.42	39434	41037	51.00	43315	44667	50.77
7	31154	31185	50.02	29235	29384	50.13	39578	40307	50.46	31089	32562	51.16	34849	36819	51.37	32020	34604	51.94
8	26045	26090	50.04	26444	26617	50.16	24131	24950	50.83	33258	34557	50.96	26205	28032	51.68	28084	31281	52.68
9	27458	27490	50.03	21821	22047	50.26	21564	22528	51.09	19768	21149	51.69	28845	30167	51.12	21267	24113	53.14
10	20400	20428	50.04	23125	23352	50.24	17590	18565	51.35	17573	19086	52.06	17109	18515	51.97	24588	27351	51.73
11	23260	23321	50.07	17587	17682	50.14	18479	19564	51.43	13174	15090	53.39	14830	16632	52.86	14112	16034	53.19
12	22148	22183	50.04	20079	20227	50.18	13602	14546	51.68	15135	16625	52.35	11444	13239	53.64	11707	14220	54.85
13	33214	33226	50.01	18793	18976	50.24	16379	17136	51.13	10806	12170	52.97	12332	14297	53.69	9128	11401	55.53
14	25747	25761	50.01	29103	29182	50.07	15131	15995	51.39	13568	14635	51.89	9376	10583	53.02	10012	12355	55.24
15	12019	12041	50.04	22254	22371	50.13	24291	25049	50.77	12470	13631	52.22	11245	12649	52.94	7255	9002	55.37
16	25071	25074	50.00	9657	9816	50.41	18541	19161	50.82	20170	21502	51.60	10368	11763	53.15	9101	10904	54.51
17	11583	11601	50.04	21998	22048	50.05	7036	7840	52.71	15309	16386	51.70	17583	18950	51.87	8804	10099	54.88
18	21264	21279	50.02	9478	9633	50.41	18526	19012	50.65	4737	6109	56.33	13406	14455	51.88	15022	16635	52.55
19	11107	11114	50.02	18551	18622	50.10	7740	8174	51.36	14202	15686	52.48	3744	5241	58.33	10937	12546	53.43
20	18711	18722	50.01	9606	9659	50.14	15978	16262	50.44	5664	6575	53.72	12143	13738	53.08	2703	4434	62.13
21	12238	12245	50.00	16010	16124	50.18	7973	8241	50.83	14197	14449	50.44	4870	5772	54.24	10152	12010	54.19
22	5176	5176	50.00	10835	10853	50.04	13767	14077	50.56	5931	6695	53.02	12334	12741	50.81	3855	4977	56.35
23	21523	21531	50.01	4287	4334	50.27	9271	9434	50.44	11677	12217	51.13	5131	5904	53.50	10798	11279	51.09
24	8100	8103	50.01	19177	19184	50.01	3502	3654	51.06	7666	8073	51.29	10396	10876	51.13	4148	5114	55.22
25	5771	5771	50.00	7143	7158	50.05	16850	16954	50.15	2249	2778	55.26	6805	7168	51.30	9038	9625	51.57

	1962	1963	1964	1965	1966	1967
Fraction males in catch	0.550	0.550	0.65	0.65	0.75	0.75
Fraction females	0.500	0.501	0.505	0.509	0.511	0.517
Fraction females in breeding population	0.500	0.502	0.508	0.516	0.519	0.528
Breeding population size	424561	404631	384887	356267	350906	338231

Table 6. (cont.'d) Projected populations of male and female northwest Atlantic harp seals, and age specific sex ratios starting from 1961. The sex ratio of the large vessel catch was determined empirically, while the sex ratio of the landsmen catch was considered to be that of the population. A maturity ogive was applied to calculate the breeding stock size.

Age	1968			1969			1970			1971			1972			1973		
	Males	Females	% F	Males	Females	% F	Males	Females	% F	Males	Females	% F	Males	Females	% F	Males	Females	% F
1	72427	72427	50.00	108685	108685	50.00	87113	87113	50.00	83659	83659	50.00	69104	69104	50.00	100065	100065	50.00
2	48961	48947	50.00	62195	62189	50.00	88146	88097	49.99	74493	74467	49.99	71782	71766	49.99	61388	61369	49.99
3	45115	45081	49.98	41856	41826	49.98	54241	54217	49.99	75554	75461	49.97	65503	65458	49.98	63512	63453	49.98
4	42689	42716	50.02	38904	39078	50.11	35964	36097	50.09	47232	47291	50.03	65344	66365	50.01	58045	57983	49.97
5	37710	38025	50.21	37241	37480	50.16	33530	33932	50.30	30882	31225	50.28	41646	41780	50.08	58486	58512	50.01
6	41074	42066	50.60	32786	33422	50.48	31703	32466	50.59	28808	29407	50.51	27004	27429	50.39	36800	36924	50.08
7	36187	38221	51.37	35747	37044	50.89	28074	29208	50.99	27426	28433	50.90	25353	25990	50.62	23704	24104	50.42
8	26253	29459	52.88	30835	33574	52.13	30442	32416	51.57	24019	25621	51.61	24171	25194	51.04	22360	22992	50.70
9	23353	26994	53.62	21837	25840	54.20	25606	29348	53.40	26296	28432	51.95	21159	22707	51.76	21296	22256	51.10
10	17761	20814	53.96	19742	23794	54.65	17981	22599	55.69	21707	25632	54.15	23025	25198	52.25	18723	20137	51.82
11	20931	22946	52.30	14717	18273	55.39	16476	20825	55.83	14976	19610	56.70	18916	22666	54.51	20370	22341	52.31
12	11272	13663	54.79	17831	20253	53.18	12087	15944	56.88	14003	18214	56.54	13068	17356	57.05	16580	19931	54.59
13	9546	12238	56.18	9417	11993	56.02	15182	17826	54.00	10012	13897	58.13	12164	16107	56.97	11389	15231	57.22
14	7402	9783	56.93	7882	10761	57.72	7563	10449	58.01	12864	15615	54.83	8680	12268	58.56	10713	14235	57.06
15	7864	10499	57.17	5790	8541	59.60	6137	9373	60.43	6263	9110	59.26	11339	13854	54.99	7465	10656	58.81
16	5412	7536	58.20	6317	9188	59.26	4245	7367	63.44	4769	8067	62.85	5411	8043	59.78	9926	12199	55.14
17	7378	9362	55.93	4154	6556	61.21	4988	8011	61.63	3265	6339	66.00	4092	7128	63.53	4723	7094	60.03
18	6222	8509	57.76	6009	8195	57.69	2872	5632	66.23	3974	6924	63.54	2755	5592	66.99	3485	6203	64.03
19	12444	14434	53.70	4720	7419	61.12	4653	7144	60.56	2093	4849	69.85	3334	6109	64.70	2266	4795	67.91
20	8781	10789	55.13	10383	12727	55.07	3488	6464	64.96	3741	6203	62.38	1722	4276	71.30	2887	5355	64.98
21	1741	3644	67.67	7331	9527	56.51	8615	11224	56.58	2731	5589	67.18	3148	5472	63.48	1248	3540	73.95
22	8651	10536	54.91	1229	3181	72.13	6074	8395	58.02	7457	9923	57.09	2317	4947	68.10	2642	4709	64.06
23	3143	4315	57.86	7261	9302	56.16	708	2760	79.59	5230	7422	58.66	6468	8815	57.68	1954	4314	68.83
24	9292	9932	51.66	2546	3801	59.89	6129	8236	57.33	531	2412	81.98	4521	6590	59.31	5728	7825	57.74
25	3473	4447	56.15	8108	8829	52.13	2081	3357	61.74	5354	7302	57.70	391	2134	84.54	3964	5819	59.48
Fraction males in catch		0.75			0.86			0.86			0.86			0.86			0.86	
Fraction females		0.520			0.521			0.524			0.524			0.522			0.518	
Fraction females in breeding population		0.534			0.541			0.549			0.549			0.545			0.538	
Breeding population size		321977			315332			302092			296103			294071			299838	

Table 6. (cont'd) Projected populations of male and female northwest Atlantic harp seals, and age specific sex ratios starting from 1961. The sex ratio of the large vessel catch was determined empiricalley, while the sex ratio of the landsmen catch was considered to be that of the population. A maturity ogive was applied to calculate the breeding stock size.

Age	1974 Males	1974 Females	1974 % F	1975 Males	1975 Females	1975 % F	1976 Males	1976 Females	1976 % F	1977 Males	1977 Females	1977 % F
1	91531	91531	50.00	104402	104402	50.00	73598	73598	50.00	79888	79877	50.00
2	88545	88539	50.00	77800	77733	49.98	88916	88760	49.96	61790	61619	49.93
3	53788	53656	49.99	76733	76697	49.99	66909	66743	49.94	77242	77002	49.92
4	55636	55739	50.05	46964	47090	50.07	66984	66982	50.00	58269	58097	49.93
5	50844	51096	50.12	48811	49142	50.17	40965	41165	50.12	58725	58724	50.00
6	50507	51322	50.40	44389	44987	50.33	42565	42978	50.24	35969	36176	50.14
7	32220	32616	50.30	43466	44838	50.78	38682	39393	50.46	37512	37898	50.26
8	20512	21158	50.77	28255	28796	50.47	37919	39231	50.85	34100	34785	50.50
9	19217	20199	51.25	17704	18502	51.10	24628	25214	50.59	33440	34653	50.89
10	18425	19489	51.40	16424	17703	51.87	15390	16253	51.37	21779	22345	50.64
11	16219	17666	52.14	15938	17117	51.78	14240	15459	52.05	13449	14233	51.42
12	17536	19515	52.67	14087	15553	52.47	13846	15045	52.08	12507	13612	52.12
13	14209	17335	54.95	15151	17185	53.15	12256	13648	52.69	12212	13299	52.13
14	9610	13212	57.89	12215	15261	55.54	13179	15095	53.39	10808	12083	52.78
15	9100	12352	57.58	8190	11617	58.65	10625	13417	55.81	11638	13365	53.45
16	6166	9192	59.85	7734	10860	58.41	7111	10247	59.04	9287	11792	55.94
17	8431	10620	55.74	5135	8011	60.94	6710	9567	58.78	6265	9084	59.18
18	3892	6134	61.18	7192	9323	56.45	4436	7073	61.46	5897	8466	58.94
19	2815	5356	65.55	3212	5370	62.57	6248	8200	56.76	3900	6264	61.63
20	1746	4155	70.42	2291	4694	67.20	2774	4742	63.10	5522	7270	56.83
21	2273	4651	67.17	1377	3640	72.56	1972	4148	67.78	2418	4176	63.33
22	952	3093	76.47	1869	4080	68.58	1175	3222	73.28	1743	3689	67.91
23	2053	3982	65.99	682	2695	79.80	1601	3612	69.29	1027	2862	73.59
24	1612	3828	70.37	1710	3511	67.25	569	2392	80.80	1413	3211	69.45
25	5012	6966	58.16	1286	3391	72.51	1466	3106	67.94	497	2123	81.04

	1974	1975	1976	1977
Fraction males in catch	0.86	0.86	0.86	0.86
Fraction females	0.517	0.516	0.514	0.512
Fraction females in breeding population	0.536	0.534	0.529	0.524
Breeding population size	302165	305609	311502	319914

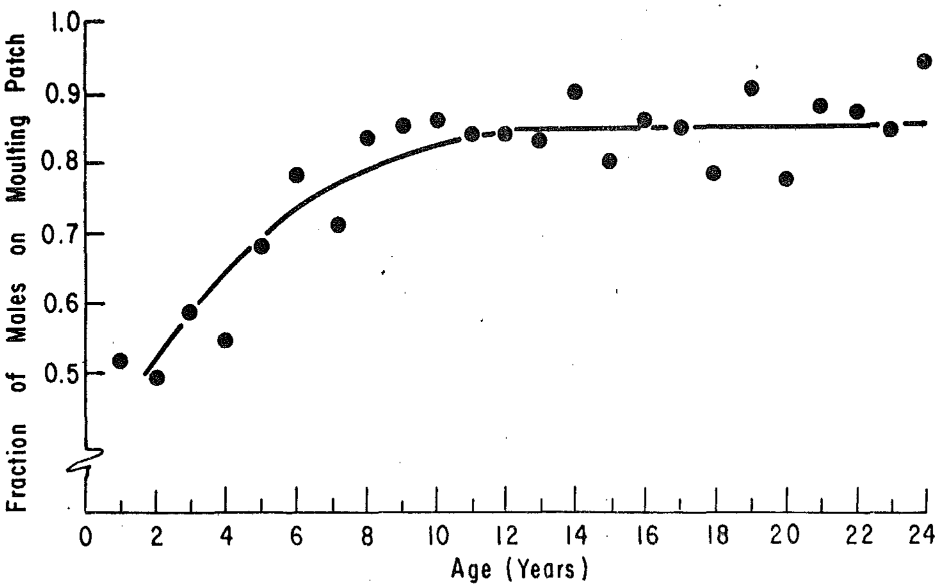

Figure 1. The fraction of males in the Norwegian catch of moulting northwest Atlantic harp seals from 1969 to 1974 (from Benjaminsen and Øritsland MS 1975)

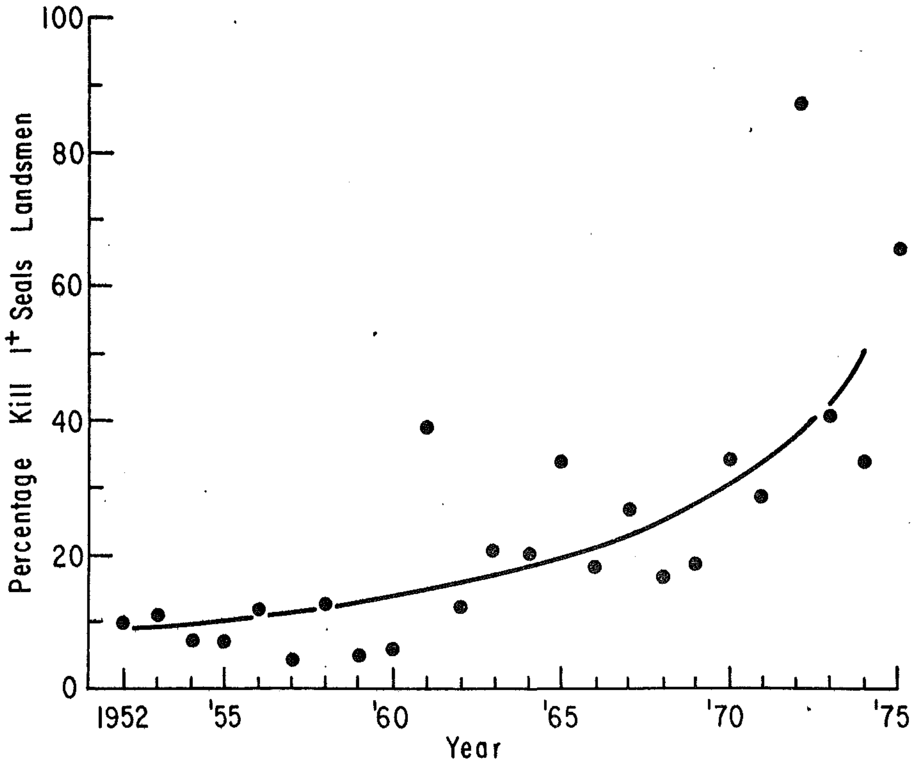

Figure 2. The percentage landsmen hunt of one year and and older harp seals from 1952 to 1975.

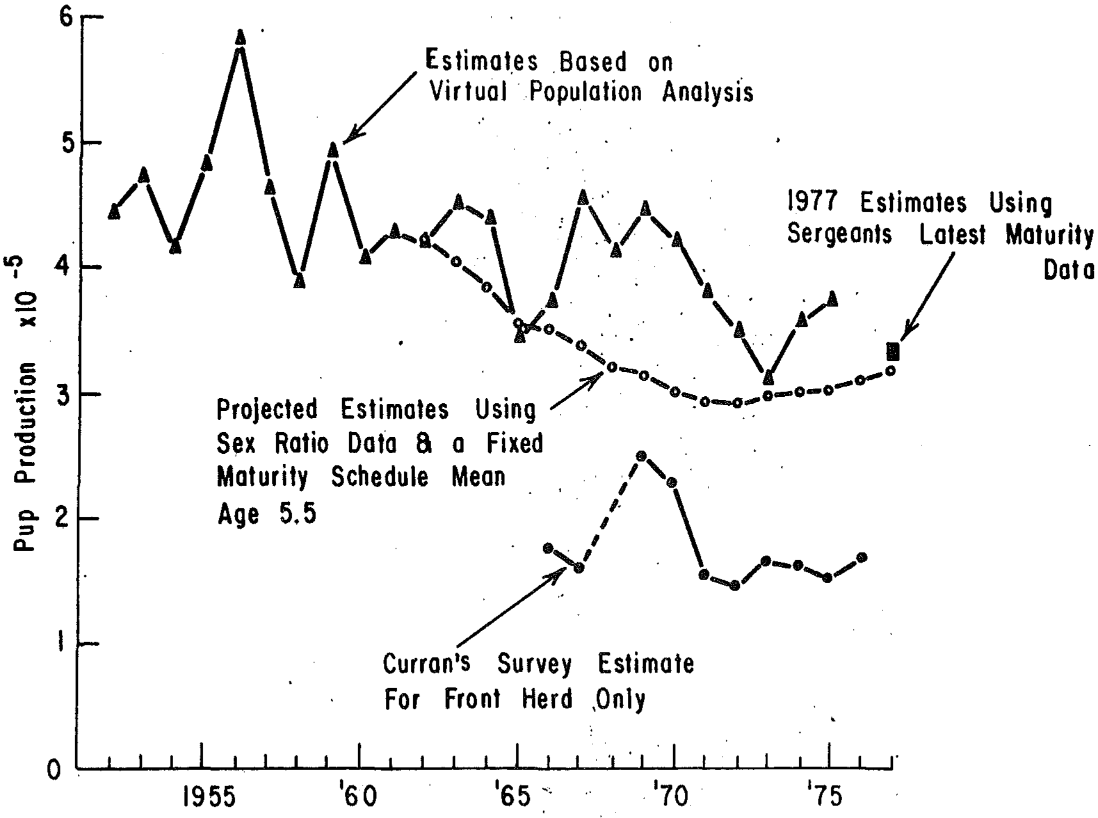

Figure 3. A comparison of three different methods of estimating pup production.

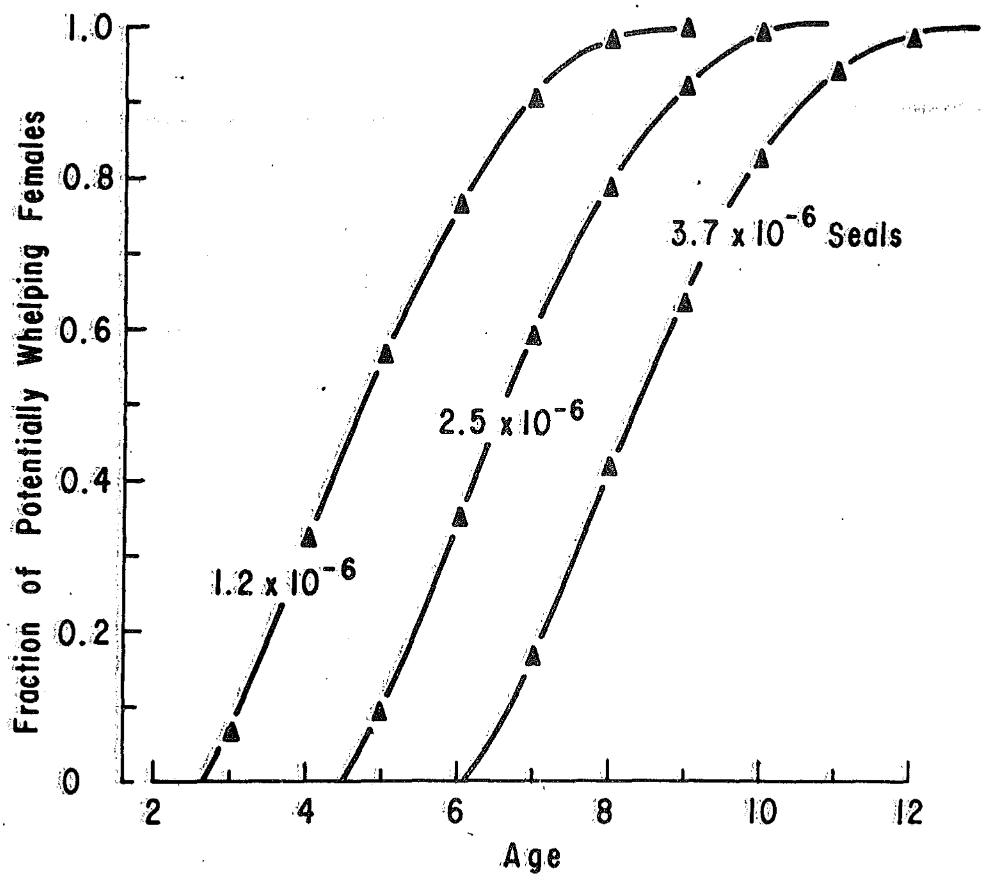

Figure 4. A shifting maturity ogive in relation to population size. The ogive is constrained in the model so it cannot shift further to the left than the 1.2×10^{-6} ogive although the population may continue to decline.

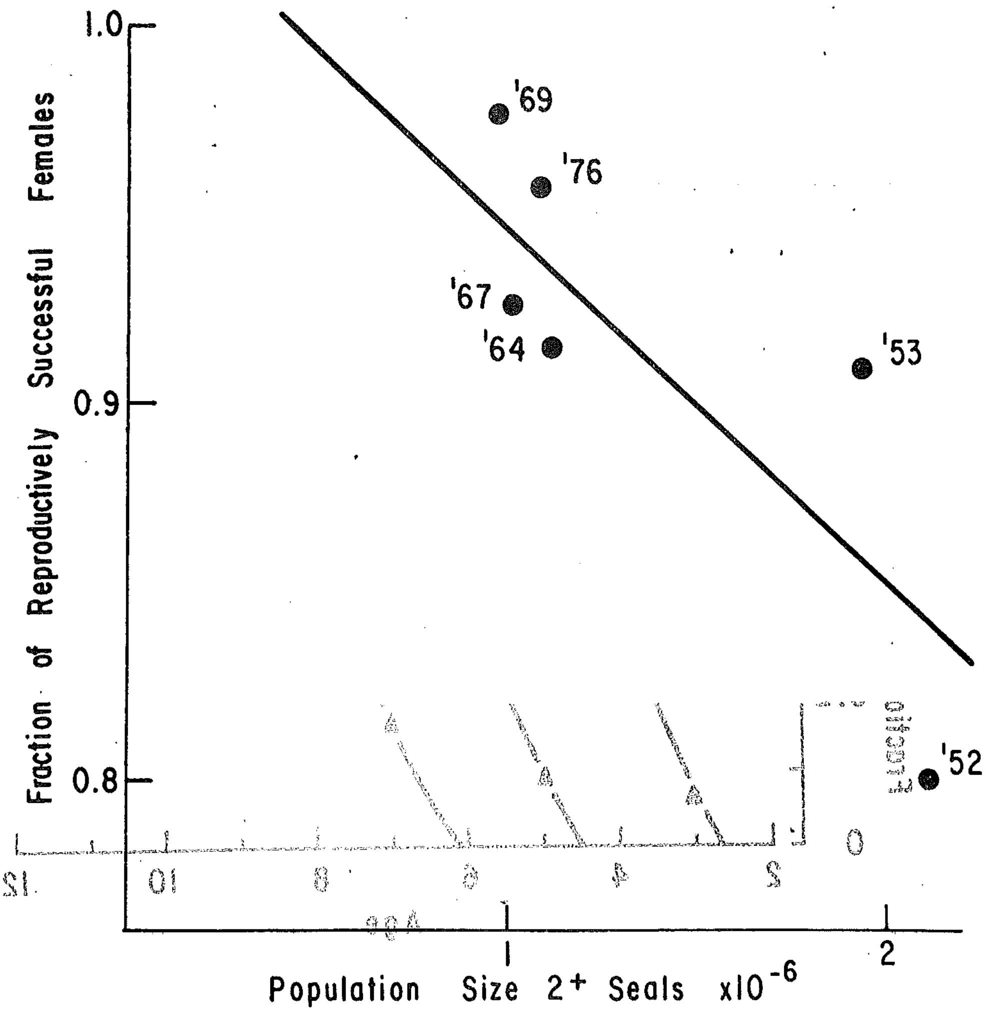

Figure 5. The decline in reproductive successful northwest Atlantic female harp seals in relation to population size.

```
      ∇HARP[⎕]∇
    ∇ HARP
[1]   'STARTING POP ONE AND OLDER'
[2]   POP1←POP←⎕
[3]   'NUMBER OF YEARS'
[4]   X←⎕
[5]   'ENTER FIRST YEAR'
[6]   DAY←DATE←⎕
[7]   'LARGE VESSEL CATCH'
[8]   LVC←⎕
[9]   'PUP CATCH'
[10]  PC←⎕
[11]  'MAGDALLEN QUOTA ON PUPS'
[12]  MPQ←⎕
[13]  'MAGDALLEN QUOTA ON ONE PLUS'
[14]  MAQ←⎕
[15]  'NUMBER OF RUNS'
[16]  Z←⎕
[17]  STAR←0
[18]  BPOP←YEAR←TPOP←TSEX←BSEX←TCA←TCP←⍳0
[19]  →START
[20] TAKEOFF:→(QM<23.58)/BACK
[21]  MAT← 0 0 0.16 0.4 0.68 0.89 0.97 ,(18⍴1)
[22]  →AA
[23] FIX1:QM←0
[24]  →LETT
[25] FIX2:QM←90
[26]  →LETT
[27] AAAA:BREED←0
[28]  →ABC
[29] BBBB:TOTALP←0
[30]  →BCD
[31] START:STAR←STAR+1
[32]  POP←POP1
[33]  DATE←DAY
[34]  CR← 0.5 0.4993 0.4992 0.4993 0.4999 0.5014 0.5026 0.505 0.5089 0.5064 0.5142 0.5211 0.5213
      0.5278 0.5345
[35]  CR←CR, 0.5594 0.5918 0.5894 0.6163 0.5683 0.6333 0.6791 0.7359 0.6945 0.8104
[36]  FPOP←POP×CR
[37]  MPOP←POP-FPOP
[38]  →AROUND
[39] GO1:PREG←1
[40]  →SKIP
[41]  XX←0
[42] AROUND:XX←YY←0
[43] GO2:XX←XX+1
[44]  DATE←DATE+1
[45]  CORR← 0.528 0.528 0.591 0.645 0.693 0.731 0.764 0.79 0.811 0.826 0.838 0.846 0.851 0.853 ,(11⍴
      0.854)
[46]  PLV← 0.3071 0.14 0.077 0.0602 0.049 0.042 0.0364 0.0328 0.0294 0.0272 0.0246 0.227 0.021
      0.0196 0.0182
[47]  PLV←PLV, 0.0174 0.0154 0.0134 0.0126 0.0101 0.0076 0.0067 0.005 0.0042 0.0006
[48]  PLC← 0.1187 0.107 0.0978 0.0877 0.0781 0.0701 0.0618 0.0544 0.048 0.0424 0.0369 0.0323 0.0277
      0.024 0.0207
[49]  PLC←PLC, 0.01077 0.0151 0.0129 0.0109 0.0092 0.0076 0.0063 0.0052 0.0041 0.0031
[50]  PGC← 0.3059 0.1851 0.1253 0.0839 0.0575 0.0425 0.031 0.0241 0.0184 0.0149 0.0126 0.0108 0.0097
      0.0086 0.0078
[51]  PGC←PGC, 0.0074 0.0069 0.0067 0.0063 0.0061 0.0059 0.0057 0.0056 0.0055 0.0054
[52]  PNC← 0.1312 0.1602 0.2123 0.1158 0.083 0.0617 0.0463 0.0367 0.0289 0.0232 0.0183 0.0154 0.0125
      0.0104 0.0085
[53]  PNC←PNC, 0.0071 0.0058 0.005 0.0042 0.0034 0.0031 0.0027 0.0023 0.0019 0
[54]  MLVC←LVC×PLV×CORR
[55]  FLVC←(LVC×PLV)-MLVC
[56]  →(MAQ>0)/YYY
[57]  LC←(5048×((+/((12?1000)÷1000))-6))+13026
[58]  →BBB
[59] YYY:LC←((5051×((+/((12?1000)÷1000))-6))+12451)+MAQ
[60] BBB:PF←FPOP÷(FPOP+MPOP)
[61]  FLC←PF×PLC×LC
[62]  MLC←(PLC×LC)-FLC
[63]  GC←(1040×((+/((12?1000)÷1000))-6))+3784
[64]  FGC←PF×PGC×GC
[65]  MGC←(PGC×GC)-FGC
[66]  NC←(729×((+/((12?1000)÷1000))-6))+1294
[67]  FNC←PF×PNC×NC
[68]  MNC←(PNC×NC)-FNC
[69]  POPU←+/(¯24↑POP)
[70]  PREG←(1.048-(0.097458×1E¯6×POPU))
[71]  →(PREG>1)/GO1
[72] SKIP:AGE←⍳25
[73]  M←(15.5223×AGE)+(¯2.245E¯5×(+/POP))+(¯16.01743)
[74]  MAT←⍳0
[75] GOTO:YY←YY+1
[76]  QM←1↑M
[77]  →(YY=4)/TAKEOFF
[78] BACK:→(QM<0)/FIX1
[79]  →(QM>90)/FIX2
```

Figure 6. Program listing of APL simulation of north-west Atlantic harp seal.

```
LETT:QM←1○(QM÷57.296)
 MAT←MAT,QM
 M←1↓M
 →(YY<25)/GOTO
AA:PUP←BREEDPOP←(+/(FPOP×PREG×MAT))×1.06
 YY←0
 FPOP←FPOP−(FLVC+FLC+FGC+FNC)
 MPOP←MPOP−(MLVC+MLC+MGC+MNC)
 TAC←+/(FLVC+FLC+FGC+FNC+MLVC+MLC+MGC+MNC)
 →(MPQ>0)/XX
 LPC←(13492×((+/((12?1000)÷1000))−6))+36949
 →AAA
XXX:LPC←((13938×((+/((12?1000)÷1000))−6))+24177)+MPQ
AAA:GPC←(1040×((+/((12?1000)÷1000))−6))+3784
 PUP←PUP−(PC+LPC+GPC)
 TPC←PC+LPC+GPC
 NMORT←(0.0302×((+/((12?1000)÷1000))−6))+0.114
 FPOP←FPOP×(*(−NMORT))
 MPOP←MPOP×(*(−NMORT))
 PUP←PUP×(*(−NMORT))
ONE←PUP÷2
FPOP←ONE,24↑FPOP
MPOP←ONE,24↑MPOP
POP←FPOP+MPOP
BREED←⌈(+/BREEDPOP)
→(BREED<0)/AAAA
ABC:BPOP←BPOP,BREED
TOTALP←⌈(+/POP)
→(TOTALP<0)/BBBB
BCD:TPOP←TPOP,TOTALP
SEXRT←⌈(((+/FPOP)÷(+/POP))×100)
SEXRB←⌈(((+/(FPOP×MAT))÷(+/POP×MAT))×100)
TCA←TCA,TAC
TCP←TCP,TPC
TSEX←TSEX,SEXRT
BSEX←BSEX,SEXRB
YEAR←YEAR,DATE
→(XX<X)/GO2
→(Z=1)/GO3
DATA←⌈(⍉(7,X)⍴(YEAR,BPOP,TPOP,TSEX,BSEX,TCA,TCP))
DATA
→0
GO3:→(Z>STAR)/START
BPOP←⌈⍉((Z,X)⍴BPOP)
TPOP←⌈⍉((Z,X)⍴TPOP)
TCA←⌈⍉((Z,X)⍴TCA)
TCP←⌈⍉((Z,X)⍴TCP)
X←Z
MBPOP←(+/[2] BPOP)÷X
SDBPOP←(((+/[2]((BPOP)*2))−(Z×(MBPOP*2)))÷(Z−1))*0.5
MATBPOP←BPOP,MBPOP
MATBPOP←⌈(MATBPOP,SDBPOP)
MTPOP←(+/[2] TPOP)÷X
SDTPOP←(((+/[2]((TPOP)*2))−(Z×(MTPOP*2)))÷(Z−1))*0.5
MATTPOP←TPOP,MTPOP
MATTPOP←⌈(MATTPOP,SDTPOP)
MTCA←(+/[2] TCA)÷X
SDTCA←(((+/[2]((TCA)*2))−(Z×(MTCA*2)))÷(Z+1))*0.5
MATTCA←TCA,MTCA
MATTCA←⌈(MATTCA,SDTCA)
MTCP←(+/[2] TCP)÷X
SDTCP←(((+/[2]((TCP)*2))−(Z×(MTCP*2)))÷(Z+1))*0.5
MATTCP←TCP,MTCP
MATTCP←⌈(MATTCP,SDTCP)
'                TOTAL POPULATION'
MATTPOP
''
''
'                BREEDING POPULATION'
MATBPOP
''
''
'                CATCH OF PUPS '
MATTCP
''
''
'                CATCH OF ADULTS'
MATTCA
 ∇
```

Figure 6. (cont'd) Program listing of APL simulation of north-west Atlantic harp seal.

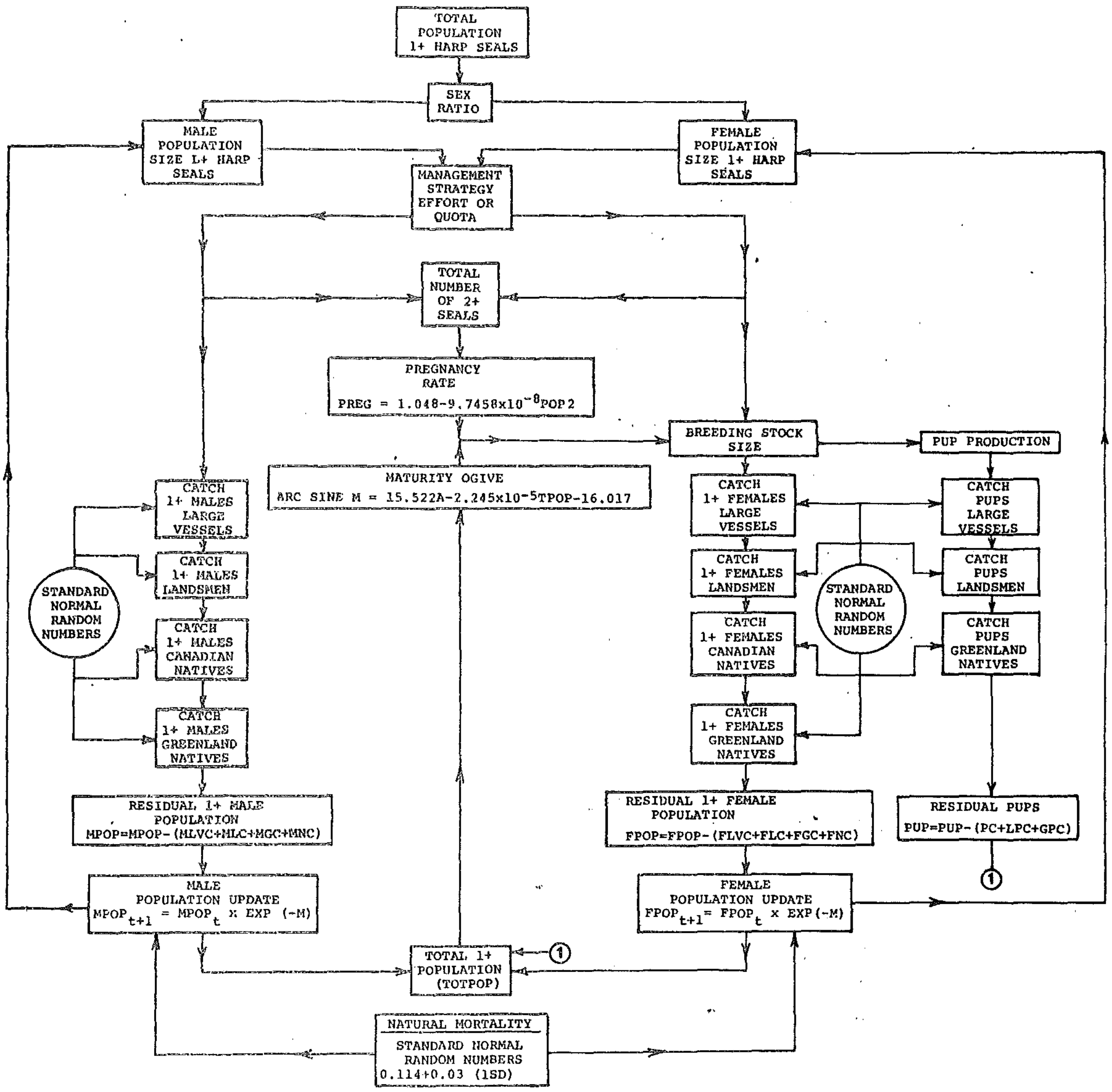

Figure 7. Flow chart of the APL program simulating the northwest Atlantic harp seal.

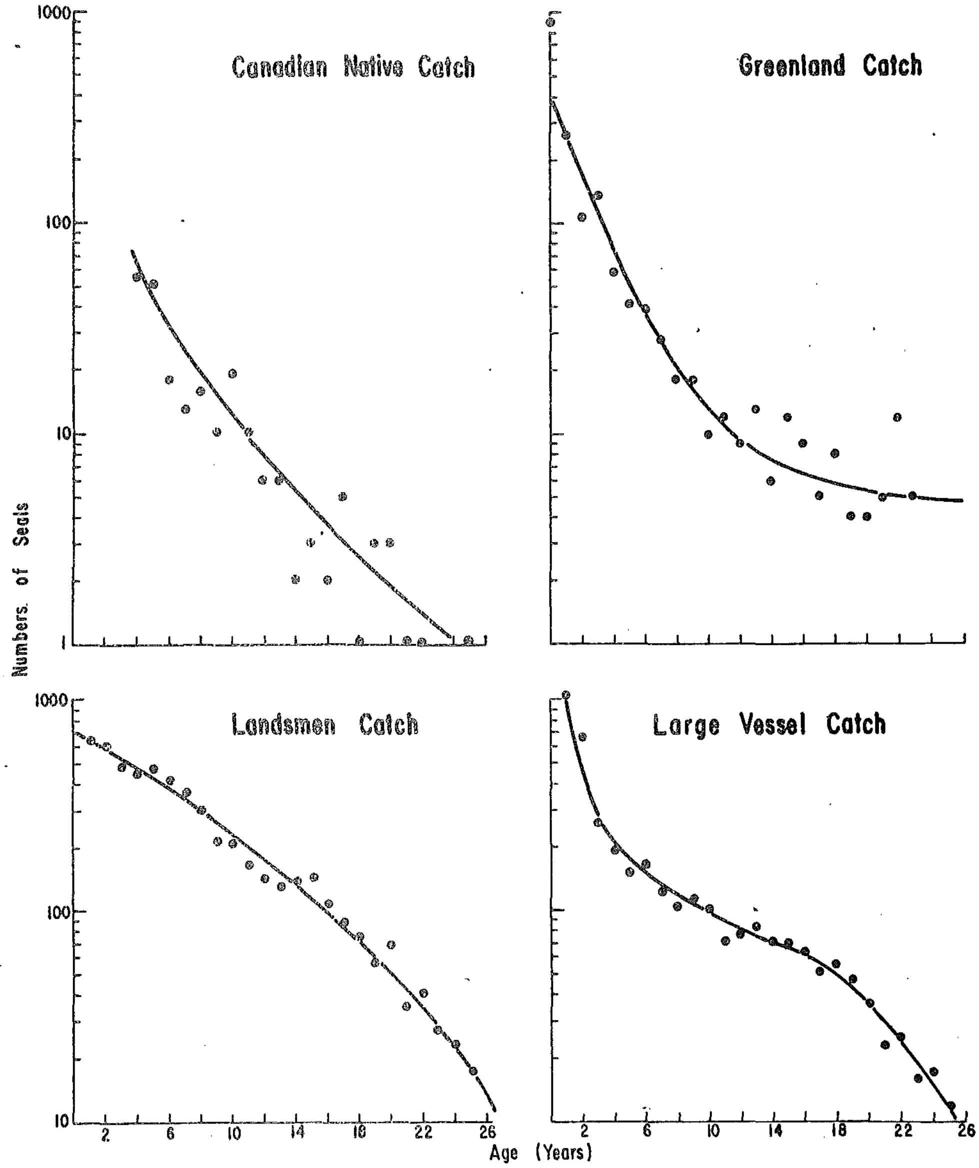

Figure 8. Catch distribution from the different fisheries for the northwest Atlantic harp seal.

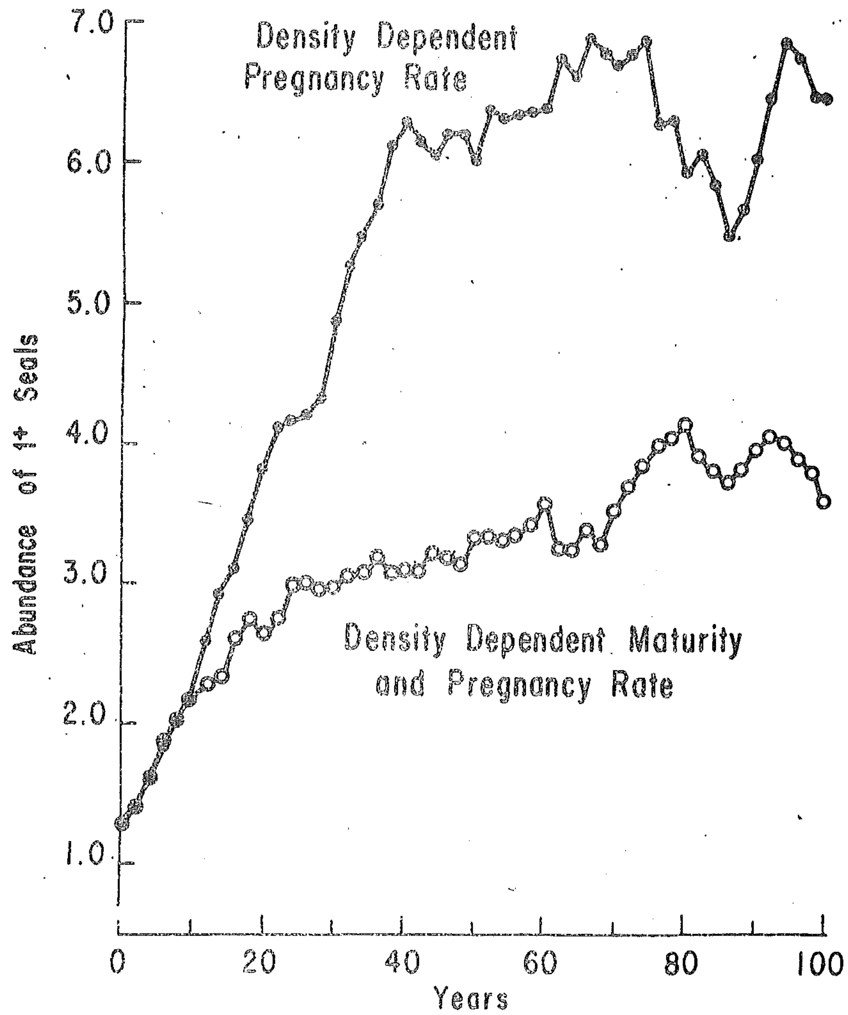

Figure 9. Two similated relationships showing the effects of density dependent age of maturity and pregnancy rates on the northwest Atlantic harp seal.

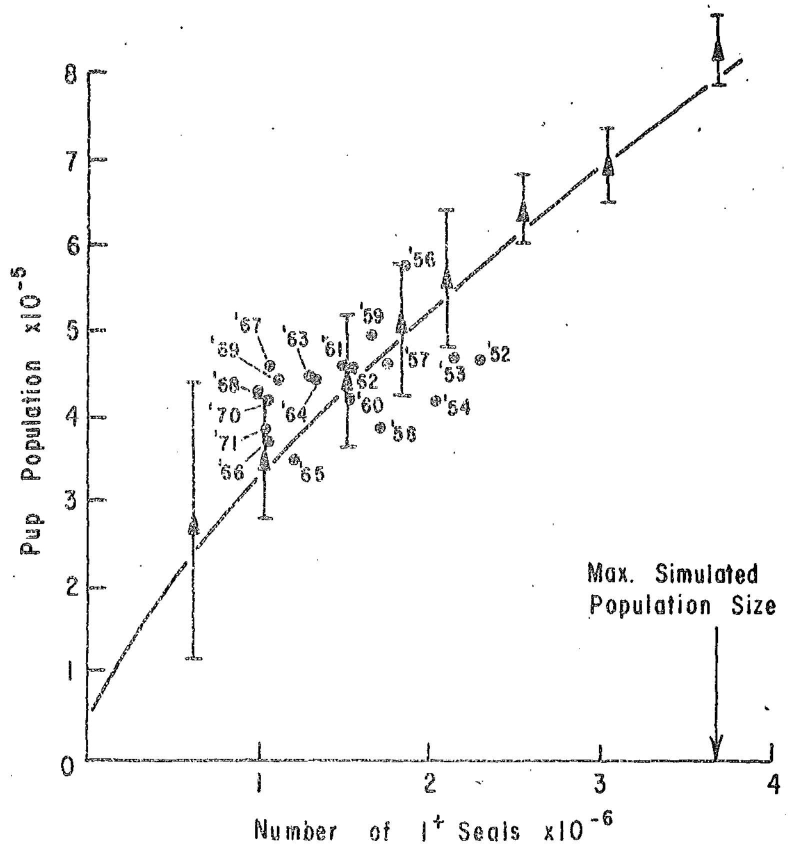

Figure 10. Simulated recruitment curve, and pup production from cohort analysis of the northwest Atlantic harp seal. Bars represent 2 (SD).

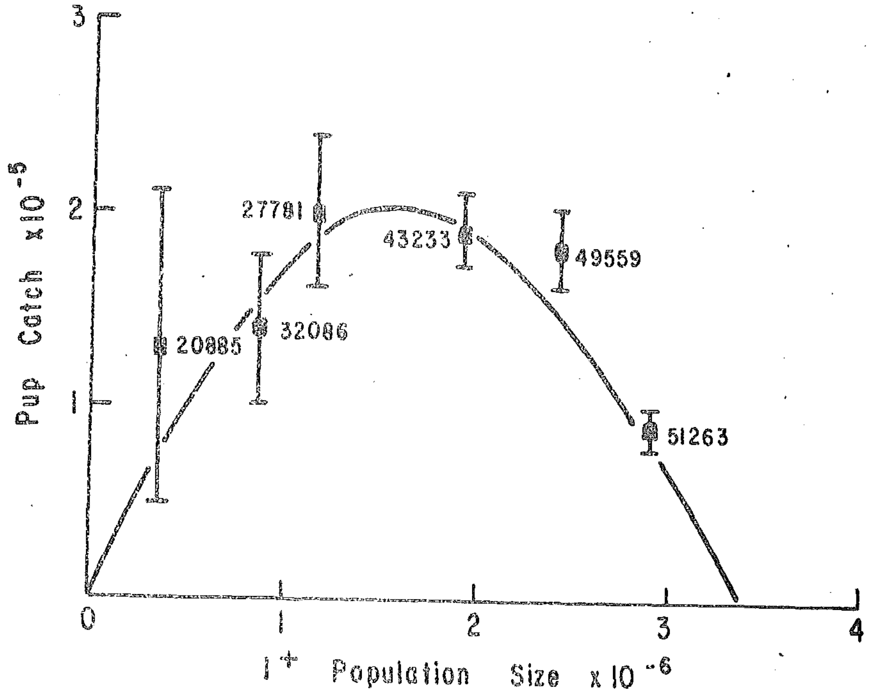

Figure 11. Shaefer type curve illustrating the MSY population level of ~ 1.6 million for catch of pups and 1+ northwest Atlantic harp seal in their present proportions. Since lower catches of pups allows for larger population sizes a constant hunting mortality by large vessel will allow for a greater catch of 1+ seals. Bars represent 2(SD).

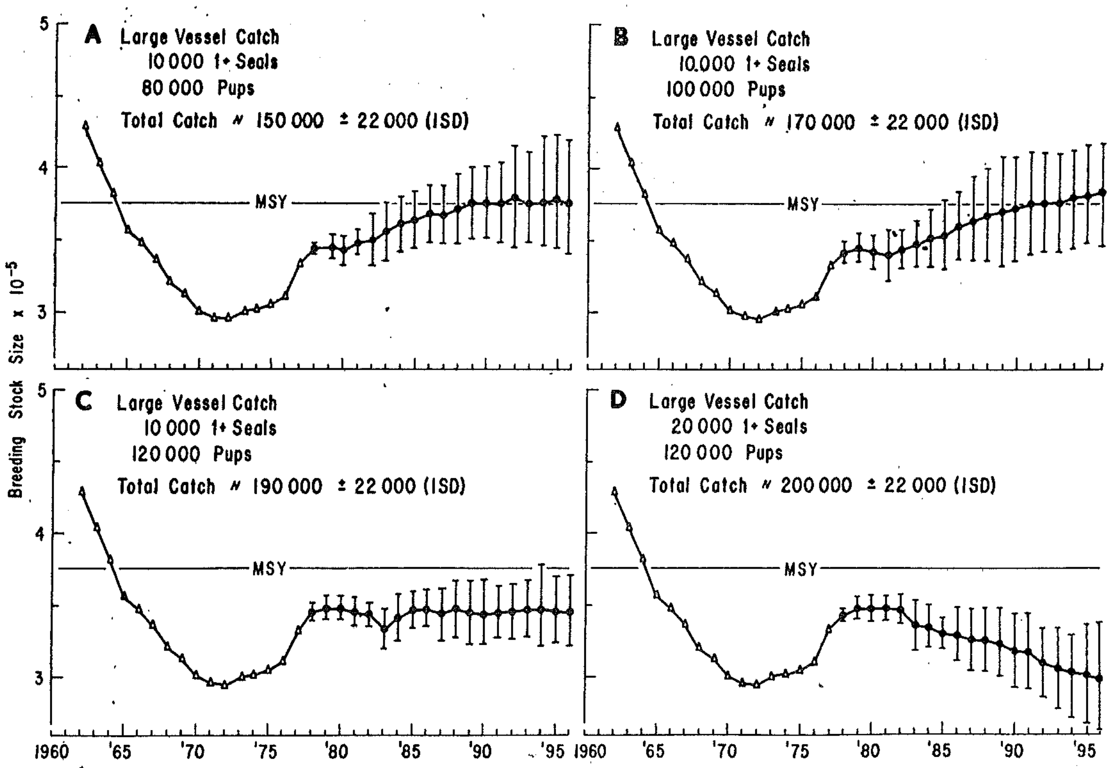

Figure 12. Projected breeding stock of the northwest Atlantic harp seal in relation to varying management strategies. Confidence limits indicate we can put little reliance in projections further than 5 years.

Additional References

Ricker, W. E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559-623.

Ricker, W. E. 1973. Linear regressions in fishery research. J. Fish. Res. Bd Can., 30:409-434.

Sergeant, D. E. 1969. On the population dynamics and size of stocks of harp seals in the northwest Atlantic. Int. Comm. Northwest Atl. Fish. Res. Doc. 69/31:1-25.

Sergeant, D. E. 1970. Results of research on harp seals in 1969-70. Int. Comm. Northwest Atl. Fish. Res. Doc. 70/61:1-15.

Øritsland, T., and Benjaminsen, T. MS 1975. Further documentation of comments of Canadian harp seal estimates. Int. Comm NW. Atlant. Fish. Working Pap., 1975(XII/7):1-9.

Ulltang, Ø. MS 1971. Estimates of mortality and production of harp seals at Newfoundland. Working Pap. int. Commn NW. Atlant Fish. Special Meet. Panel A Experts, Charlottenlund, Denmark, 23-24 Sept. 1971. 13 p.