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Mortality and production of harp seals, with reference to a paper of Benjaminsen and Øritsland (1975)

by

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SUMMARY

1. The age frequency data presented in Benjaminsen and Øritsland's paper make possible new estimates of adult natural mortality rate, based on 7 years of sampling. These are 16.6-18.6% per year. Given that 24% of all pups surviving the age 0 harvest produce adult females at age 6, the sustainable yield is 22-31% of the number of reproducing females present at equilibrium. However 24% survival may be an optimistic estimate, and it would be rash to count on a sustainable yield greater than 20%.

2. There is a source of systematic error in Benjaminsen and Øritsland's estimate of population size, so that an estimate of 390,000 seal pups produced in 1966 should be substantially reduced, possibly to about 300,000.

3. Analyses of the state and the future of the seal herd made prior to 1975 have erred on the side of optimism, partly because estimates of adult mortality rate have been too small, partly because the survival rate of immatures has been overestimated.

4. Any serious attempt to salvage the harp seal herd as a commercially important resource requires the immediate cessation of all commercial sealing for at least 10 years, leaving only the arctic subsistence catch at no more than the present level. Anything less than this is fiddling while Rome burns; in fact, it is fiddling after 80% of the city has already been consumed.

INTRODUCTION

A paper by Benjaminsen and Øritsland (1975) endeavours to show that the harp seal herd is considerably larger than indicated by recent Canadian estimates. Sergeant (1975a) estimated about 220,000 producing females in 1974, whereas Benjaminsen and Øritsland estimate 340,000 to 370,000 (their figure 3). More important than the actual population estimate is the fact that Benjaminsen and Øritsland calculate that the stock can today produce a sustainable yield of 200,000 pups and eventually increase under such a regime. This conclusion depends heavily on a rather low estimate of natural mortality in the adult stock. Rather surprisingly, Benjaminsen and Øritsland do not attempt any direct estimate of mortality rate from their own data, even though they have age samples for 7 years from the vessel fishery, and these appear to be the most representative data available.

Any forecast of future events and sustainable yield of the seal herd requires information on seals killed at various ages in the past, on the natural mortality rate of immature seals, and on the natural mortality rate of adult female seals. Seal harvests have been tabulated by Ronald and Capstick (1975) and are shown here in Table 1. Of the mortality rates, that of adult seals will be considered first.

MORTALITY RATE OF ADULT SEALS

A number of Canadian workers have made analyses of harp seal vital statistics from age frequencies in samples. For example, Ricker (1971) concluded tentatively that adult mortality rate was 15% per year, when adjusted for a decline in recruitment during the period concerned. Of this total, 7% was estimated to result from the rather heavy adult kill during the period 1952-66, and 8% was natural mortality. However the age samples on which mortality rates were based were not very large and were from various sources, all of them potentially selective. Also, the estimates of adult population, and hence hunting mortality rate, were uncertain. As a result no great confidence can be placed in the result.

Recent Norwegian age samples are from vessel catches over a period of seven years, 1968-74 (Table 2). In this "fishery", according to Benjaminsen and Øritsland, seals of age 7 and older are taken without selection, presumably because all are of adult size by that age. Thus catch curves (Fig. 1) for these ages can be used to estimate mortality rate, provided two factors are taken into consideration: (1) any change in recruitment at age 7 to the year-classes represented in the table; and (2) any change in rate of hunting toll on the adults themselves.

Effect of the adult kill

Table 1 shows that there was a sharp reduction in number of adults killed from 1967 onward. The effect of this on the catch curves is to make numbers of seals larger than they would otherwise be for age 7 in 1968, for ages 7 and 8 in 1969, and so on. The result is that if all ages from 7 onward were considered together, the average rate of decrease with age would be too great. To avoid this error the frequencies have been divided by the stepped lines in Table 2. Estimates of present mortality rate can be made only from the entries from the upper stepped line to age 7, while the former mortality rate can be estimated below that line.

Effect of changing recruitments

Rates of decrease in frequency computed from the catch curves would be estimates of mortality rate if the recruitment to the adult seal population at age 7 had been the same for all the year-classes concerned. However this is not the case. For one thing, there was a period of increased recruitment from the year-classes born during the second world war. Allowing one year for "reading-down" of the older ages in Table 2, these would be age 16 and older in 1968, age 17 and older in 1969, and so on. Hence these ages have been omitted from computations of slope for the period prior to 1967: only the frequencies between the stepped lines are considered.

In addition to the above, all investigators are agreed that there has been a decline in recruitment to the seal herd from about 1952 onward. Ricker (1975, p. 38) showed that an annual decrease of, for example, 5% in recruits means that a survival rate estimated from a catch curve will be too large by 5% of its own value. In terms of mortality, this means that the instantaneous rate of decrease in recruits must be added to the instantaneous rate of decline measured from the catch curve, to obtain a true estimate of mortality in the sampled population.

In their table 4 Benjaminsen and Øritsland (1975) show two schedules of estimated decrease in pups born from 1960 to 1967. These are repeated in Table 3 here, the pup catch is subtracted, and natural logarithms taken.

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The rate of decrease of these logarithms is the instantaneous rate of decrease in recruitment to age 1, being 0.1370 per year for schedule "a" and 0.1344 for schedule "b", mean 0.136. These figures are based, in part, on estimated adult mortality rates of 13% and 12% respectively. Since the estimate of rate of decline in recruitment increases with increase in mortality, and since the true mortality rate, as computed below, is greater than 13%, the mean figure 0.136 must be considered conservative.[1]

The pups of 1960 to 1967 provide the 7-year-old recruits of 1967 to 1974, hence the figure 0.136 applies directly to the entries above the upper stepped line in Table 2.

What about pup production and survival prior to 1960? There is no direct estimate of this, but the mean rate of decrease must have been less than in the more recent period, because during 1952-59 the adult female stock, though decreasing, was larger than in the 1960's and the pup kill was somewhat less. Only an approximate figure is possible, but half of the recent value seems plausible, that is, an instantaneous rate of decrease of 0.068 per year.

Mortality rate since 1967

Of the 7 samples above the upper stepped line in Table 2, only 1973 and 1974 contain enough age-groups and enough seals to permit estimating rate of decrease with reasonable accuracy. The slopes of the natural logarithms of these two are -0.1843 and -0.0710 respectively; mean = -0.1276. To this figure (with sign changed) the rate of decrease in recruitment must be added, giving an instantaneous total mortality rate of 0.128 + 0.136 = 0.264. The corresponding actual mortality rate is 23.2% per year.

Mortality rate prior to 1967

The frequencies between the stepped lines in Table 2 can be used to estimate mortality rate prior to 1967. The samples that include reasonable numbers of seals are 1968, 1969, 1970, 1973 and 1974. The slopes of the natural logarithms of frequencies for these samples are shown in Table 4. The mean rate of decrease is 0.177. The tendency of the numerical values to

[1] A larger rate of decrease can be computed from Ronald and Capstick's (1975) tables, while Ricker's (1971) reconstruction yields a somewhat smaller one.

increase with increasing mean age of the seals represented may suggest that the true mortality rate of seals increases within this age interval. This would require confirmation; however the series used includes no seals older than age 21, so the value 0.177 should not be far from a true mean value weighted by age.

Adding to this the appropriate estimate of rate of decrease in recruitment (i.e. for year-classes older than 1960), we have an instantaneous mortality estimate of 0.177 + 0.068 = 0.245, corresponding to 21.7% actual mortality.

NATURAL MORTALITY RATE OF ADULT SEALS

To be most useful for prediction the total mortality estimates above must be adjusted to terms of natural mortality.

Consider first the estimate for recent years. Since 1967 there has been an effort to avoid killing mature females, so that about four-fifths of the kill has in fact been males. Accordingly the mortality rate computed from the 1973 and 1974 samples applies primarily to the male stock, and so too do the adult kills shown in Table 1 from 1967 onward. During 1968-74 the kill of adult seals was about 85,000, averaging 12,000 per year. The average number of males of age 7 and older present during the same period would be somewhat less than the number of females, because of the effect of the selective hunting mortality. From the estimates of females given below, the males could scarcely exceed 200,000, more likely about 150,000.[2] Thus the hunting mortality rate would be about 12,000/150,000 = 8%, an instantaneous rate of 0.083. Subtracting this figure from the total mortality estimate above gives a natural mortality rate of 0.264 - 0.083 = 0.181, corresponding to 16.6% actual mortality.

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[2]The mean figure of 150,000 adult males age 7 and older is much less than what is suggested by Benjaminsen and Øritsland's analysis. On page 7 they refer to a population of mature females of "at least 350,000" in 1972-74, and the number of males should not be too greatly different, perhaps 250,000. However, if the average male population in 1968-74 was in fact greater than 150,000 the estimate of natural mortality rate becomes greater, and the seal stock is in worse shape than is suggested here.

In later sections I will apply this estimate 0.181 to the adult females also. It would, of course, be preferable to have a direct estimate of female mortality from catch curves for females only. It is likely that Benjaminsen and Øritsland can supply data for the sexes separately, and the females in their samples for 1973 and 1974 should be numerous enough to give at least an indication of the situation.

Turning now to the period before 1968, the adult kill from 1952 to 1966 averaged 52,000 seals of both sexes, taken from a mean population variously estimated from 1 to 2 million. The hunting mortality rate would therefore be 0.026 to 0.052. Subtracting these values from the total mortality rate 0.245 gives a natural mortality rate of 0.193 to 0.219. Although their precision is not great, these values are of the same order as the figure 0.181 obtained for the more recent period. I will use a mean figure of 0.206, corresponding to an actual mortality of 18.6% per year.

MORTALITY RATE OF IMMATURE SEALS

Unfortunately there appear to be no representative samples of harp seals between the ages of 1 and 6. The catch curves of Fig. 1 are steeper in this region than at older ages. This would indicate a greater mortality rate, if samples were representative, and this seems unlikely: the younger animals, after reaching age 1, are likely to survive at least as well as those exposed to the hazards of reproductive activities. The young of the year, however, may well be more vulnerable to environmental hazards, both living and non-living, and so have a considerably greater mortality rate than the adult seals.

One possibility, then, is to project the natural mortality rate for older seals back to age 0 -- on the assumption that a high natural mortality of pups would balance the presumed lower mortality rate at ages 1-5. The 0.181 instantaneous rate above, projected over 6 years, is 1.086. This corresponds to 33.8% survival from pups surviving the whitecoat kill to adults of age 6.

Other estimates of survival rate of immature seals have been larger than this. The "Panel A Experts" (Mansfield 1972) estimated 63% survival if hunting were to be discontinued. However the basis for this figure is not given. Ricker (1971) estimated a 48% survival from natural causes on the basis of a reconstruction of the stock; however this reconstruction used somewhat too small an estimate of adult mortality rate.

Given that the sex ratio at first maturity is close to 50:50, the production of females from a unit number of pups is equal to half of the percentages above, namely 16.9%, 24% and 31.5%.

ESTIMATION OF SUSTAINABLE YIELD OF PUPS

From the natural mortality rates above the sustainable yield of pups can readily be computed, on the assumption that all other commercial hunting mortality is discontinued. It is only necessary to subtract the adult female natural mortality rate from the ratio of mature females to pups of both sexes, and divide by the latter. For the adult natural mortality rate we have the figures 16.6% and 18.6%. For mature female production from surviving pups we will try the three figures given in the last section. The corresponding percentage sustainable pup yields are as follows:

Ratio of adult females produced to surviving pups of both sexes	Adult female natural mortality rate	
	0.166	0.186
0.169	1.8%	-
0.240	30.8%	22.5%
0.315	47.3%	41.0%

Evidently 16.9% female production from pups cannot be reconciled with the above mortality rates. At 24% production the sustained yield is less than a third of the crop, while for 31.5% production it is less than half. Since the lowest production rate above is the only one supported by any direct evidence, it would be foolish to count on a sustainable yield greater than 15-20% of the pups born.

ESTIMATES OF PUP PRODUCTION IN PAST YEARS

Benjaminsen and Øritsland (1975) use two methods to estimate pup production by the harp seal stock in recent years. Both give larger figures than most Canadian estimates, so an analysis is of interest.

Benjaminsen and Øritsland's first method

This is essentially the method used by Sergeant (1975b, fig. 203), involving a relation between an index of abundance of successive year-classes and the number of young killed of the same year-class. Benjaminsen and Øritsland differ from Sergeant in that the line they fit to the data is the regression of abundance on catch, whereas Sergeant uses the regression of catch on abundance. Thus Sergeant's estimates will always be less than Benjaminsen and Øritsland's, from the same data. Since it is a catch that is to be estimated, Sergeant's procedure would be correct if the data were bivariate normal; Fig. 2 shows the two lines for Benjaminsen and Øritsland's data. However these data are probably not bivariate normal, but rather of the "open-ended" type described by Ricker (1973), so that an intermediate "functional" line would be more appropriate; one such line is drawn in Fig. 2. In any event it is incorrect to use the regression of abundance on catch to obtain an estimate of catch.

There is however a systematic error in Benjaminsen and Øritsland's application of this method that makes all the lines computed above of little interest. It arises from the "uncertainty of age determination" mentioned at the bottom of page 3 of their paper. Disagreements between different age readers have occurred whenever tests have been made, and these increase with increasing age. Even when two readers agree, there is no complete assurance that they are right. Assuming that the absolute number of misidentifications of each year-class is proportional simply to its true abundance in a sample, it follows that weak year-classes receive more misidentified seals than they themselves contribute to the strong year-classes. In this way the difference between strong and weak year-classes is subdued: the strong become less numerous than their true abundance, and the weak become more numerous. This is evident in Table 2. In 1956 the kill of pups was especially heavy (Table 1), hence we should expect that year-class to be weak in later samples. In Table 2 it appears first at age 12 in 1968, and is in fact weak; at age 13 in 1969, however, it is more numerous than the next younger age; and following it throughout later years it has no average inferiority in comparison with adjacent ages. By contrast, the strong 1965 and 1968 year-classes show obvious superiority at most of the (younger) ages where they are represented in Table 2. It would appear that readings become unreliable in the range between age 8 and age 12.

The effect of all this in Fig. 2 is to make the points at the left end of the line too low and those at the right end too high. The absolute error would be approximately the same at the two ends, which means that the relative error would be much greater for the small populations at the right end. I would judge that the latter can easily have become twice as large as their actual abundance. To introduce an approximate adjustment into the estimate from Fig. 2, I have averaged the values for 1968 and 1972, and also those for 1963, 1964 and 1967 -- i.e., the points near the two ends of the line. The mean survival index for 1963, 1964 and 1967 is then reduced by 50% and that for 1968 and 1972 is increased by the same absolute amount, as follows:

	Mean pup kill	Mean survival index	Adjusted survival index
1963, 1964, 1967	277.	0.68	0.34
1968 and 1972	136.5	1.74	2.08

The adjusted figures are plotted on Fig. 2 as line D, and when produced to the abscissa they indicate a pup production of about 305,000 for the median year. The true figure could of course be either larger or smaller.

Benjaminsen and Øritsland's second method

This method is not described in sufficient detail for a detailed analysis. It uses R. L. Allen's computations of number of adult seals, which are not available to me (cited as "in press 1975 in Rapp. Proc.-Verb. Cons. Expl. Mer"). However Ronald et al. (1973) say that Allen used a natural mortality rate of 8% for harp seals of all age groups. As shown earlier, this is much too low an estimate, and would (I think) make Allen's population estimates too large.

In any event it seems inconsistent to use Allen's estimates based on 8% mortality and combine them with estimates of 12% and 13% mortality in lines 1 and 2 of Benjaminsen and Øritsland's figure 3. Then in lines 3 and 4 they use 10%, according to the last paragraph of page 6. Why?

PRESENT SITUATION AND FUTURE PROSPECTS

The above estimate of about 305,000 pups born in 1966, from Benjaminsen and Øritsland's data, is similar to the 299,000 estimated for the same year by Ricker (1971), using a different method, and it agrees in general with Sergeant's (1975a, b) estimates. We might then provisionally use Ricker's estimates of pups born (= stock of producing females) from 1970 onward, and project it to later years (Table 5). The figure for 1975 in Table 5 is 181,000, which is close to the maximum estimate of 197,000 from ultraviolet photography by Lavigne et al. (1975); their median estimate was only 126,000.

Using a selection of the mortality rates from this paper, Table 5 projects the number of producing females to 1982, when they will have decreased to about 103,000 even if all commercial hunting for adults and immatures is discontinued immediately. Furthermore, in order to stop the decline at that point the pup kill must be reduced now to about half of that of recent years, say to 50,000. To start a slow upswing in 1983, all the available pups should be protected from 1976 onward.

The analyses of other Canadian investigators, using other methods, all converge to very similar figures for the breeding stock now on hand and projected into the immediate future. The only realistic management program for 1976, and for a considerable number of years beyond, is a total ban on all commercial sealing, both land-based and pelagic. The female breeding stock will unavoidably decrease to about 100,000 (possibly less) by 1982, so that all available reproduction will be needed to rebuild it to commercial size in any reasonable time, while providing for the indigenous catch in the arctic. A great opportunity was lost by not stopping vessel-based sealing in 1972.

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Table 1. Kill of harp seals from 1952 through 1975, in thousands. (From Ronald and Capstick, 1975.)

Years	Pups	Ages 1-6	Adults
1952	198	33	60
1923	198	18	45
1954	175	27	65
1955	252	25	57
1956	341	15	35
1957	165	20	58
1958	141	48	100
1959	239	26	51
1960	170	30	75
1961	179	7	11
1962	214	35	63
1963	278	22	41
1964	273	22	45
1965	190	17	29
1966	257	23	41
1967	280	29	9
1968	158	21	6
1969	235	30	9
1970	226	22	14
1971	210	15	10
1972	117	9	4
1973	102	22	13
1974	99	30	29
1975	142	27	16

Table 2. Combined male and female age-group frequencies and smoothed average frequencies of moulting harp seals in samples collected from Norwegian catches off Newfoundland - Labrador 1968 - 1974. **(From Benjaminsen and Øritsland, 1975, Table 2.)**

Age-group	1968	1969	1970	1971	1972	1973	1974	1968-1974 No	1968-1974 %	Smoothed average %
1	135	371	132	239	12	171	360	1420	25.9	25.0
2	74	42	109	66	9	232	227	759	13.8	13.7
3	42	34	33	43	9	188	86	435	7.9	10.0
4	27	30	30	19	24	173	65	368	6.7	7.8
5	30	39	29	18	9	293	67	485	8.8	6.2
6	20	28	15	11	10	81	88	253	4.6	5.2
7	46	36	18	10	13	67	21	211	3.8	4.2
8	38	44	26	8	9	79	21	225	4.1	3.5
9	31	35	15	17	6	42	36	182	3.3	3.0
10	28	29	22	15	6	35	20	155	2.8	2.6
11	22	23	13	10	4	44	12	128	2.3	2.2
12	12	16	7	11	5	27	19	97	1.8	2.0
13	15	19	6	7	2	32	20	101	1.8	1.8
14	18	21	11	2	1	17	13	83	1.5	1.6
15	14	21	8	4	4	22	12	85	1.6	1.5
16	12	12	11	4	3	17	10	69	1.3	1.4
17	15	25	3	2	2	8	10	65	1.2	1.3
18	26	16	6	3	2	4	8	65	1.2	1.2
19	21	19	5	3	0	10	6	64	1.2	1.1
20	16	16	4	1	3	12	2	54	1.0	0.9
21	10	10	5	1	0	0	2	28	0.5	0.7
22	17	5	2	2	1	0	4	31	0.6	0.6
23	8	7	2	1	0	2	2	22	0.4	0.4
24	7	3	0	0	0	2	5	17	0.3	0.3
25	3	4	1	1	0	4	3	16	0.3	0.3
26+	15	10	2	9	1	19	19	75	1.4	1.4
Sum	702	915	515	507	135	1581	1138	5493	100.1	99.9

Table 3. Weighted mean pup productions of harp seals, based on two different adult survival rates (schedules "a" and "b"), pup catches, survivors, and natural logarithms of survivors. (After Benjaminsen and Øritsland 1975, Tables 3 and 4.)

	1960	1961	1962	1963	1964	1965	1966	1967
Schedule "a"								
Pup production	474	430	416	394	401	395	393	369
Pup catch	171	179	214	278	273	190	257	280
Survivors	303	251	202	116	128	205	136	89
Log_e Survivors	5.71	5.53	5.31	4.75	4.85	5.32	4.91	4.49
Schedule "b"								
Pup production	444	406	399	384	387	377	382	362
Pup catch	171	179	214	278	273	190	257	280
Survivors	273	227	185	106	114	187	125	82
Log_e Survivors	5.61	5.42	5.22	4.66	4.74	5.23	4.83	4.41

Table 4. Slopes of catch curves based on frequencies between the stepped lines of Table 2.

Sample year	Ages included	Slope
1968	8-15	-0.1449
1969	9-16	-0.1112
1970	10-17	-0.1635
1973	13-20	-0.1837
1974	14-21	-0.2832
Mean		-0.1773

Table 5. Producing female seals (= pups born), pup kill and survival, and female recruits and mortality. Estimates through 1976 are from Ricker's (1971) analysis; later figures are computed from the two righthand columns.

Year	Producing females	Pups killed	Pups surviving	Female recruits[a]	Female mortality[b]
1970	251	226	25		
1971	224	210	14		
1972	221	117	104		
1973	198	102	96		
1974	173	99	74		
1975	181	142	39		
1976	166			5	28
1977	143			3	24
1978	122			21	21
1979	122			19	21
1980	120			15	20
1981	115			8	20
1982	103				

[a] Equal to 20% of the surviving pups 6 years earlier.

[b] Equal to 17% of the producing females.

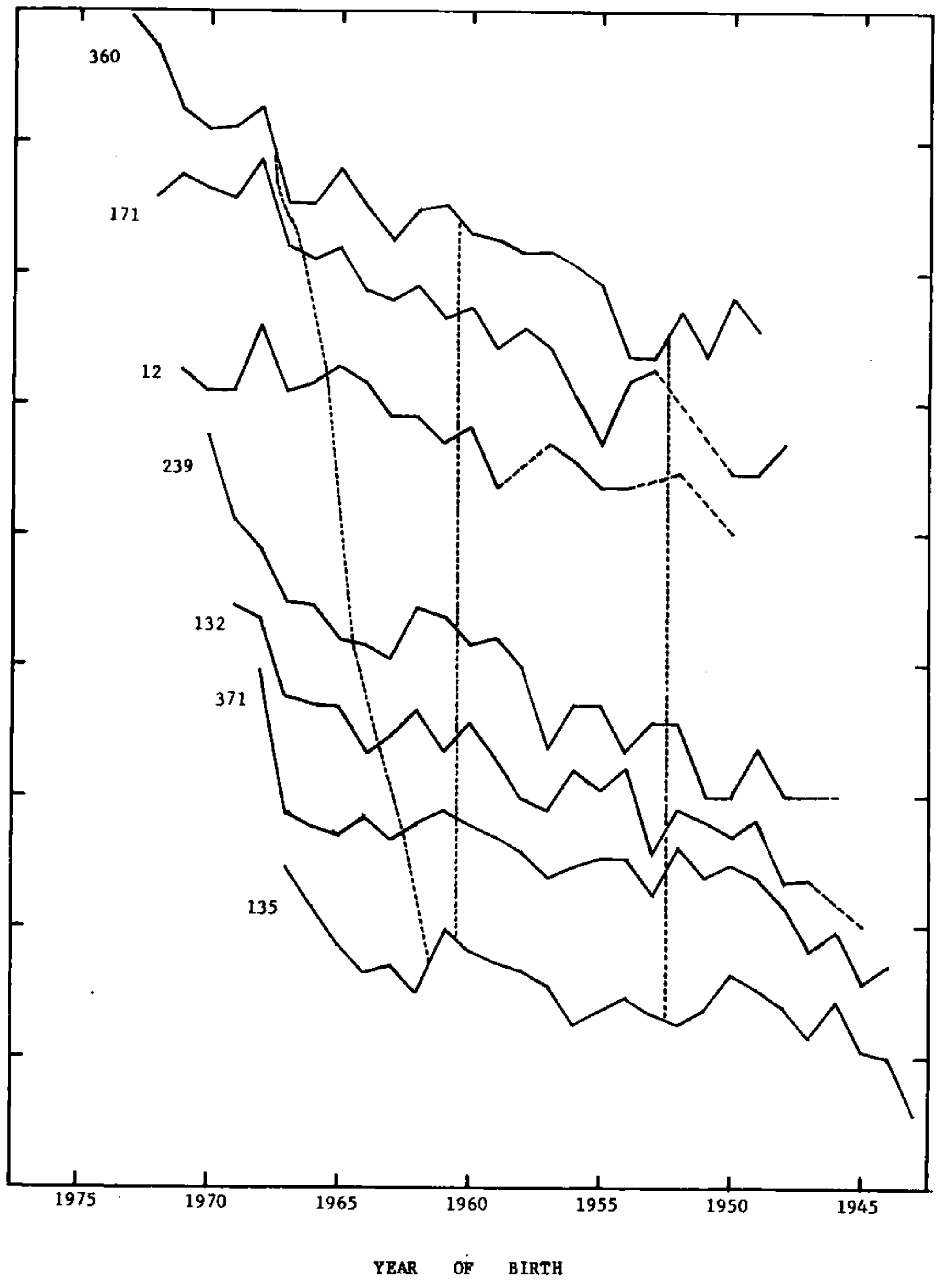

Fig. 1. Natural logarithms of the number of seals in the samples of Table 2, starting with 1968 at the bottom. Broken sections of the lines indicate that a blank age intervenes between the points joined. Points to the left of the slanting dotted line are seals less than age 7. Points between the vertical dotted lines include year-classes that recruited to age 7 before the adult kill was reduced. The ordinate scale is 2 log units, and numerals show the number of seals of age 1 in each sample.

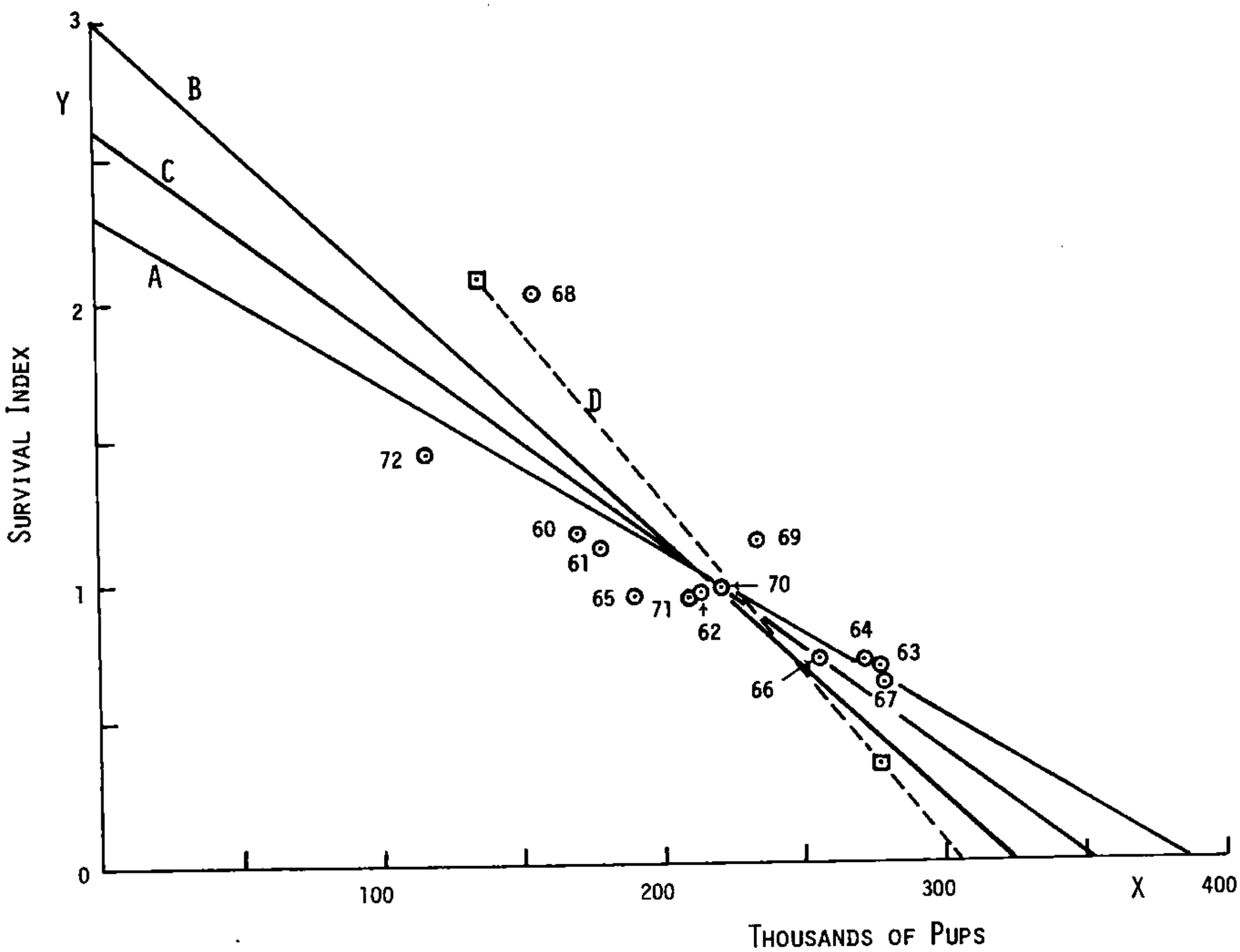

Fig. 2. Relation between survival index and pup production, after Benjaminsen and Øritsland (1971, figure 2). A: Regression of Y on X. B: Regression of X on Y. C: GM functional regression, or standard major axis. D: Line adjusted for error in age determination.

A P P E N D I X

Comments on the West Atlantic harp seal herd and proposals for the 1972 harvest[1]

by

W.E. Ricker

Summary

1. The breeding stock of female harp seals will decrease to about 133,000 in 1978, as compared with 300,000 in 1967 and a primitive level approaching a million.

2. To prevent further decline beyond 1978 a severe reduction in the annual pup harvest must be initiated in 1972.

3. If a major reduction is delayed 3 or 4 years, the remaining stock will barely sustain the 40,000 "landsmen's" catch.

4. Figure 5 shows the rate of decline or recuperation of the stock under several different harvesting regimes.

[1] Presented to Special Meeting of Panel A Experts, Charlottenlund, Denmark, 23-24 September 1971.

1. Harp seals consume many kinds commercial fishes, though they specialize in capelin which are not yet used commercially in large quantities [1]. They are also a host for cod worms, though not the most important host [2]. If these activities are or become sufficiently damaging, then a major and permanent reduction in the seal herd may be desirable[1]. However I will assume that the seals are more valuable than the fish they eat, and that it is desirable to manage the herd at at least a moderately high level of production for this or other reasons.

I have also assumed that there is enough mixing and/or similarity of exploitation between the Gulf and Front herds of seals that they can be treated as a unit for purpose of the computations being made [3].

For an analysis of the dynamics of the breeding stock of seals we should know:

(a) the annual mortality rate of the breeding stock;

(b) the absolute size of this stock in at least one year;

(c) the number of recruits that the breeding stock receives each year.

2. The mortality rate of seals from about age 5 can be estimated from their age distribution in samples taken in various years. It is convenient to plot these data logarithmically: two examples are shown in Figure 1, for mean

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[1] Actually a reduction of at least 75% has already occurred--see Section 10.

age 1963 and 1968. The slope of the line in such a graph estimates the instantaneous mortality rate, provided recruitment has been unchanging. Actually there is a flattish region on each graph which corresponds to a period of rapidly decreasing recruitment from the year-classes 1945-51, a period during which sealing was resumed following World War II (Fig. 4, below). From the parts of the lines in Figure 1 (and in other similar graphs) which are not affected by this rapid decline, a mean annual mortality rate for adult seals (age 6 and up) has been estimated as 15% (instantaneous rate 0.1625).

This annual loss of 15% consists partly of natural mortality, partly of the harvest of older seals. The latter is not known exactly because some nations do not separate "bedlamers" (ages 1-5 approximately) from "old harps" (age 6 and up) in the statistics. However the kill of old harps has averaged about 25,000 females a year from 1950 to 1967, or 7% of the average stock (as estimated below) during the same period. Thus the natural mortality rate has been about 8% per year.

Female seals produce pups for the first time at age 6 mainly, though some mature at age 5 and others at age 7. Of all females age 6 and older present in a given year, more than 90% produce pups [3]; probably about 95% do so. However it simplifies the computations to define the <u>breeding stock</u> as the number of females that actually produce pups, so that the breeding stock in any year is the same as the number of pups produced.

The seals from age 1 to age 6 are also subject to natural mortality and to some hunting. It seems likely that their annual rate of loss would be somewhat less than that of the adults, but it cannot be estimated directly because seals less than 4 or 5 years old are not taken representatively in any samples available. Actually what directly interests us is the ratio of female recruits at age 6 to total pup escapement; this is estimated in Section 4 as 0.24, and allowing for the 95% fecundity above, the derived mean mortality rate for ages 0-6 is 10.73% per year (instantaneous rate = 0.1135).

3. Dr. D. E. Sergeant [3] introduced a method of estimating the absolute number of pups produced, using age samples from accumulations hunted during the winter. A modification of this method is as follows. There are samples of seals of age 1 and older taken in 1967-1971 near St. Anthony, and in 1967-1970 on the Front icefields. From both localities it is possible to compute for each year the ratio of age 1 seals (J) to age 6 and older seals (M); let $k = J/M$. The mature seals include many age groups and are a rather steady component with which the fluctuations in age 1 abundance can be compared.

The ratio of age 1 to mature stock (k) is plotted against the catch (C) of the same year-class the previous year. If any two years have the same stock M, k will be proportional to M - C, and M will be the X-axis intercept of the straight line joining the two percentages. Alternatively, M can be obtained from the expression:

$$M = \frac{k_1C_2 - k_2C_1}{k_1 - k_2}$$

Notice that for this computation it is not necessary that the age 1 and the older seals be sampled in proportion to their respective abundances in the total stock in a given year, but there must be consistency between years in this respect.

The data are given in Table 1. For a first trial we assume that the breeding stock was constant during the period 1966-70. During this time the year 1968 had a much smaller pup kill than the others, so the greatest contrast and hence the most reliable comparisons will be between the 1968 year-class and the others (Fig. 2). The estimates are as follows, in thousands:

Year-Class	St. Anthony samples	Front samples	Mean
1966	263	289	276
1967	284	299	292
1969	241	268	254
1970	224	-	224
1968 (mean)	253	285	269

According to the model used, each of these estimates represents the stock in 1968 as well as in the year indicated, so the figure for 1968 is the mean of the estimates above it.

The figures obtained suggest a trend toward decrease in stock during 1966-70 of about 5% per year (St. Anthony) or 2.5% per year (Front). This of course is contrary to the model, and computations show that a rather small rate of decrease in stock can have a fairly large effect on the estimate when the rate of utilization of pups is large. From this point of view, then, the estimates from the comparison of year-classes 1967 and 1969 with 1968 should be superior to those from the more distant year-classes. The mean value from the 1967 and 1969 comparisons is 273,000 seals. This is our first estimate of the breeding stock, centered on the year 1968.

4. The years 1960-64 produced the pups that provided the age-6 recruits to the stock during 1966-70. Looking at the catches for these years in Fig. 3, we see that they were quite variable, much more so than the stock could possibly be. Hence there is a possibility of using the escapements of these earlier years to obtain a better picture of the changes that occurred during 1966-70. For a trial estimate of the size of these stocks, we may notice that in 1956 there were 341,000 pups killed. Since the industry was technically less developed then than now, we may assume that it could not have captured <u>all</u> the pups; 400,000 seems a possible pup production for that year (i.e. 85% of the pups were killed). This point was then joined to 273,000 in 1968 by a straight line (Fig. 3) in order to obtain interpolated estimates of the pup production in intervening years, as follows:

Year	Stock	Catch	Escapement
1956	400	341	59
1957	390	165	225
1958	379	141	238
1959	368	239	129
1960	357	170	187
1961	347	179	168
1962	336	214	122
1963	326	278	48
1964	315	273	42
1965	304	190	114
1966	294	257	37
1967	283	280	3
1968	273	158	115

The difference between the stocks and catches above is the pup escapement shown in the last column. It appears that 1966 and 1967 should have had good recruitment at age 6 from the fairly large escapements of 1960 and 1961, while 1969 and 1970 must have had quite poor recruitment.

To become quantitative it is necessary to have an estimate of the number of age-6 females produced by a given pup escapement. As a trial, notice that the linear rate of decrease of stock from 1956 to 1968 is estimated to be 10,600 females per year. This represents the deficit of recruitment below what is needed to maintain the stock. For 1962-68 the mean stock was 304,000, of which 15% or 45,600 die. Thus the mean recruitment during this period must have been 45,600 - 10,600 = 35,000 age-6 females per year. The mean pup escapement in 1956-62 was 161,000. Thus a first estimate of the ratio of female recruits to total pup escapement is 35/161 = 0.217. Applying this figure to the escapements for 1960-64 gives the series of age-6 recruits (in thousands) shown in column 4 of the schedule below. Then, working from a 1968 stock of 273,000 and a mortality rate of 15%, it is easy to compute the stocks for earlier and later years (column 2).

Year	Stock	Mortality	Recruits	Net change
1966	279	42	41	-1
1967	278	42	36	-5
1968	273	41	26	-15
1969	258	39	10	-29
1970	229	34	9	-25

Thus it appears that the stock in 1966 and 1967 was rather close to that of 1968, whereas 1969 and 1970 were considerably smaller. The preferred estimates of stock, from

Figure 2, are therefore the following:

Year	St. Anthony	Front
1966	263	289
1967	284	299
1968 (mean)	274	294

The grand mean is 284,000, or 11,000 more than the first estimate of Section 3; it applies best to the median year 1967.

It could be argued that the year-class 1968 might be altogether exceptional somehow (apart from its reduced pup harvest), and should not be relied upon for stock estimates. In that case estimates might be made by joining the points for the other years in Fig. 3. Since 1966 and 1967 had almost the same population, the estimates from these two years should be unbiased, though their sampling variability is very large. Joining their points in Figure 2 gives estimates of 315,000 for St. Anthony and 307,000 for the Front samples. These are not dissimilar to the 284,000 estimate from the comparisons involving 1968, hence they do not suggest that there is anything wrong with the latter.

5. Using the new estimate of 284,000 pups produced in 1967, a new series of stocks was estimated by linear interpolation between 400,000 in 1956 and 284,000 in 1967, and revised estimates of the 1966-70 stocks were obtained. When the possibilities of linear interpolation were exhausted, the stock estimates from 1956 to 1961 were adjusted on the basis of the catch history prior to 1956 and reasonable estimates of the stock present then: because of the small catches made during the war, it is evident that the stock must have increased during 1946-51, then levelled off as catches increased following the war. These 1956-61 estimates were

then used to estimate subsequent years up to 1970. In addition, the 400,000 figure for 1956 was varied somewhat, experimentally, but no other starting point seemed any better.

The last stage to which this iterative procedure was carried is shown in Table 2 and Figure 4. It produces stock estimates of 299,000 for 1966-68; this is somewhat higher than the best estimate of 284,000 obtained by Sergeant's method, but the difference is not great enough to warrant another run.

For the recruitment years 1962-68 of this sequence the ratio of female recruits to pups 6 years earlier is 0.251, whereas 0.24 was used in computing it. It seems better to accept the figure 0.24 for purpose of prediction, since it is known to be consistent with the best available reconstruction of the history of the stock.

The statistics used in or flowing from the reconstruction of Table 2 can be summarized as follows:

(a) mortality rate of the (female) breeding stock = 0.15 (this is also the age-6 recruitment needed to maintain a stock in equilibrium);

(b) ratio of age-6 female recruits to total pup escapement = 0.24;

(c) permissible rate of utilization of pups for a stock in equilibrium = (0.24 - 0.15)/0.24 = 37.5%.

6. What is the outlook for the future? The mean pup escapement during 1965-70 was 69,000 (Table 2), producing 17,000 recruits a year. This is 26,000 per annum less than

the 43,000 needed to maintain the mean 1966-70 stock of 287,000 breeding females. It is also only 60% of the probable mean pup escapement during the previous 6 years. Thus we can expect the stock to decline in 1971-76 much more rapidly than in 1966-70.

For quantitative orientation, the actual change in stock size for each year since 1966 has been computed on the basis of the pup escapements 6 years earlier, using the 0.24 ratio of female recruits to escapement (Table 2, Fig. 4). The computation can be made up to 1978, since pup escapements are known through 1971 and this determines the change that will occur in 1977.

The final figure obtained is a breeding stock of 133,000 in 1978. <u>There is no way of avoiding this decrease</u>, which has been established by the harvesting regime of recent years. It will occur even if the pup harvest were to be discontinued forthwith.

7. Table 3 compares these results with the harvests currently being proposed for 1972 and later. The original <u>Norwegian proposal</u> to harvest 220,000 young seals in 1972 represents the number that are likely to be born. Their modified proposal (200,000 decreasing to 160,000) would leave an average escapement of only 17,000 per year in 1972-74. This is much less than even during 1966-70, which was a disastrous period. It would add only 4,000 females a year to a breeding stock that will be losing 18,000 to 20,000 a year in 1979-81.

<u>Canada's proposal</u> of a 160,000 harvest for 1972 would permit about 61,000 pups to escape. This can be com-

pared with average escapements of 116,000 a year in 1960-64 and 69,000 a year in 1965-70. Hence such a quota would accelerate the current precipitous decline in the stock.

Figure 5 shows the effects, on the breeding stock, of several alternative harvesting plans, starting in 1972. Stocks through 1978 are already determined, so changes can begin in 1979.

<u>No pup harvest at all</u> is shown by line A. The stock reaches a temporary plateau of 225,000 in 1983-85, then begins an accelerating increase. By 1992 the breeding stock is up to 300,000, approximately the level of 1966-68, which would provide an equilibrium catch of 113,000 pups ayear if a pup harvest were resumed then. If the closure were continued, however, the equilibrium level for a catch of 200,000 pups will be reached in 2007. This requires a breeding stock of 530,000 females at the 37.5% equilibrium rate of exploitation. Two hundred thousand seems a reasonable catch, though by no means a large one (more than 200,000 a year were taken in 1966-70). Figure 5 follows the recovery (with no pup kill) as far as 700,000 breeders in 2014, but density-dependent effects might begin to slow down the rate of increase before this level is reached.

Line D of Figure 3 represents the opposite extreme: <u>all the pups are taken</u>, which is not very different from the harvesting practice of most recent years. The stock declines at its established rate of 15% per year. It sinks below 100,000 in 1980; by 1986 the 40,000 "landsmen's" catch* will no longer

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* **Assumed (incorrectly) to be all pups.**

be available, and in the year 2000 only 4,000 females remain, these being 28 years old or older. In actuality there would probably be fewer, because there is some indication that mortality rate increases among seals older than age 25 or so.

Line B of Figure 5 shows the effect of taking the landsmen's catch of 40,000 pups a year, starting in 1972. By 1990 the stock reaches 200,000, and then begins to increase at an accelerating rate. By 2005 it would support an equilibrium take of 100,000 pups; but if the smaller harvest were continued, 200,000 pups a year would become available in 2030.

Line C shows the effect of using the modified Norwegian proposal for 1972-74 (i.e. catches of 200,000, 180,000 and 160,000 respectively). The stock declines at almost the maximum rate, and in 1981 is down to 91,000 breeders. Continuation of such harvests, even with a comparable reduction each year, would quickly result in commercial extinction of the herd. If however the quota were reduced to 40,000 in 1975 and maintained there, the stock will survive and eventually increase gradually. However it would be 2045 before there were the 267,000 breeders needed for a sustained yield of 100,000, while 200,000 a year could be taken starting in 2070.

Summarizing, if the landsmen's catch is the irreducible minimum, it will permit satisfactory restoration of the stock in 58 years <u>if it is introduced now</u>. (This is considering "satisfactory restoration" to be the 530,000 breeders needed to maintain a catch of 200,000 pups.) If however there are three more years of intensive sealing before the 40,000 quota is introduced, it will take a century to reach a sustained yield of 200,000, while to get to even the 100,000 yield level will require a human lifetime (74 years).

Discussion

8. The stock estimates above will be somewhat optimistic if the number of breeders present in 1967 was 284,000 (the best estimate from Sergeant's method) rather than the 299,000 shown in Table 2. However there is a small compensating factor. If, for example, the breeding stock reaches 530,000 on any rehabilitation regime involving no catch or constant catch, there will already be more seals of ages 1-6 than are needed to stabilize the stock at 530,000, hence the equilibrium harvest of 200,000 pups could in fact begin 2 or 3 years earlier than the year in which 530,000 is achieved.

9. All the above estimates are on the basis that mortality rates for bedlamers and for older seals remain the same as now. This means that the catch taken from these groups should be decreased proportionally as stocks decrease to 1978, otherwise recovery will be further delayed. Alternatively, if the harvest of seals of age 1 and older could be lowered to a smaller percentage than at present, then recovery could be speeded up somewhat.

I have assumed that the proposed quotas apply to age 0 seals only. If this is wrong and total catch of all ages is meant, then the various harvesting regimes are somewhat less damaging than indicated above.

10. The analysis has been made on the basis that changes in stock density within the range being considered do not affect the rates of natural mortality or fecundity. That is, effects of crowding have disappeared at those stock levels, so natural mortality is a minimum and fecundity a maximum. This seems very likely to be substantially true at least for the critical period from 1965 onward: during this period the breeding stock was never more than 300,000, whereas in its primitive state it was more than twice as large. Chafe [5] gives the history of Newfoundland sealing up to 1920. Catches reached a peak during the forties of the last century (Fig. 6). The largest catch recorded was 685,000 in 1844, while in 8 of the years from 1832 to 1857 it was more than 500,000. These figures included harp seals of all ages, and also some hood seals. Dr. Sergeant estimates that 60 to 65% were harp seals of age 0, so that the pup take of 1844 would be close to 450,000. This represents the minimum breeding stock of those years; considering that it was before the introduction of steam to the sealing fleet, the breeding stock on hand might well have been up to twice as great. Taking a conservative intermediate figure of 700,000, and using statistics similar to those from the earlier analysis (adult mortality rates of 0.12-0.15, and the 0.24 ratio of age 6 females to total pup escapement) it is easy to show that the long decline in the seal herd could be a result

of moderate but persistent overexploitation that began back in the 1830's. Figure 6 shows a generalized picture of the decline.

For the future, what is pertinent is that the sustained-yield level of 200,000 pups projected in Figure 5 requires a stock considerably less than the maximum, so that density-dependent effects would not affect mortality or reproduction rates seriously. If they did, the rate of recovery to that level would be even slower than indicated in the figure.

11. The present analysis of seal statistics has been made independently, but it agrees in all essentials with the picture presented in recent contributions by Sergeant [3], and with the earlier analysis by Sergeant and Fisher [6]. The latter had noticed as early as 1960 that years of large pup harvests produced weak year-classes that were recognizable in samples taken at older ages, indicating a high rate of utilization. They also suggested that the sustainable yield would be about 8% of the total stock, divided between pups and older individuals much as at present; this agrees quite well with the 37% pup take plus limited older kill that is computed above.

11. The present state of the western seal herd is very similar to that which faced the Antarctic blue whale industry 20 years ago. When customary catches could no longer be taken easily and a major reduction was urgent, the whaling captains insisted that there were still lots of blues down in the ice, or that unusually stormy weather was making it

difficult to locate them. By the time everyone was convinced, the blue whales had become as scarce as bowheads, and will not provide a commercial harvest for 100 years or more. All available information indicates the harp seal herd is in precisely the same critical condition.

References

[1] The food of harp seals in the Northwest Atlantic, by D. E. Sergeant. MS 1971, FRB Arctic Station. See also the letter of February 9, 1971 from Dr. Templeman to W. R. Martin, Ottawa file No. 769-79-1.

[2] Letter of March 1, 1971, from A. W. Mansfield to the Deputy Chairman, Operations, Ottawa file No. 769-79-1. Also Dr. Templeman's letter cited above.

[3] Calculation of production of harp seals in the western North Atlantic, by D. E. Sergeant. ICNAF Document No. 2476, 1971. Also by the same author: Canadian studies on harp seals in 1971. FRB Arctic Biological Station, 1971.

[4] International Commission for the Northwest Atlantic Fisheries, Statistical Bulletins for 1968 and 1969.

[5] Chafe, O. G. 1923. Chafe's sealing book. Trade Printers and Publishers Ltd., St. John's, Nfld. 108 pp.

[6] D. E. Sergeant and H. D. Fisher. Harp seal populations in the western North Atlantic from 1950 to 1960. FRB Arctic Unit Circular No. 5, 58 pages, 1960.

APPENDIX

Table 1. Age-1 and age-4-and-older groups in the samples taken at St. Anthony and the Front icefields.

Year-class	Total catch (thousands)	St. Anthony sample			Front icefields sample		
		Age 1	Age 6 and older	Ratio	Age 1	Age 6 and older	Ratio
1966	257	18	261	0.069	176	377	0.467
1967	280	7	165	0.042	84	332	0.253
1968	158	87	68	1.280	62	33	1.879
1969	235	41	434	0.094	105	186	0.565
1970	217	39	285	0.137	-	-	-

APPENDIX

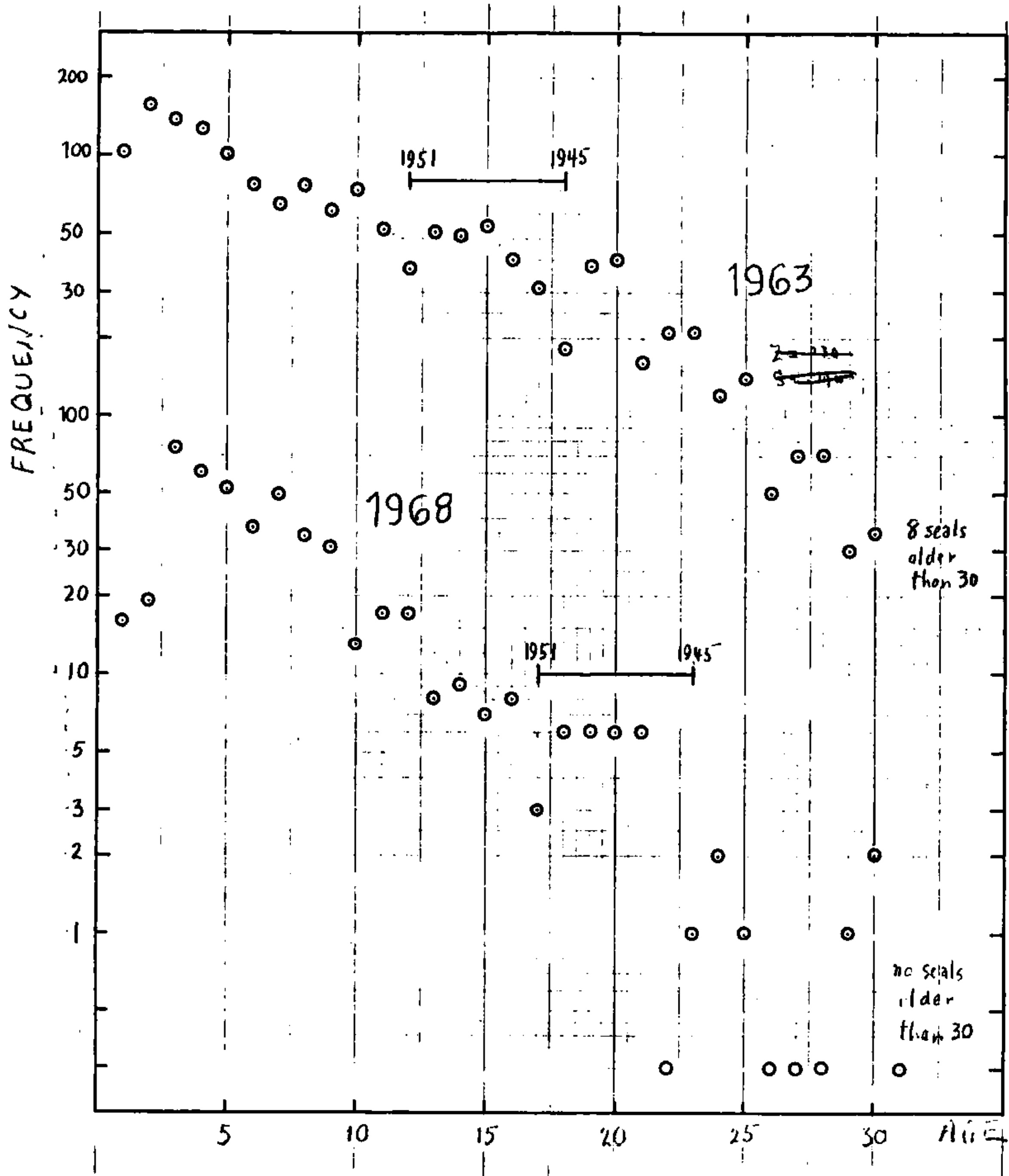
Table 2. Catches of age 0 seals from 1938 (column 2), female breeding stock estimates (column 4) and escapements (column 3) from 1943, and mortality and recruitment to the breeding stock from 1949 (columns 5 and 6). Column 5 equals 0.15 times column 4; column 6 is equal to 0.24 times the column 3 entry of 6 years earlier. Catches are from ICNAF statistics for 1938-69; the 1970 and 1971 figures are preliminary catch statistics supplied by Dr. D. E. Sergeant.

1	2	3	4	5	6
	Age 0 seals			Breeding stock (pregnant ♀♀)	
Year	Harvest	Escapement	Initial number	Mortality	Recruits
1938	221				
1939	102				
1940	132				
1941	17				
1942	2				
1943	0	287	287		
1944	6	304	310		
1945	10	310	320		
1946	73	267	340		
1947	102	258	360		
1948	137	243	380		
1949	227	172	399	60	69
1950	226	182	408	61	73
1951	319	101	420	63	74
1952	198	233	431	65	64
1953	198	231	429	64	62
1954	175	252	427	64	58
1955	252	169	421	63	42
1956	341	59	400	60	44
1957	165	219	384	58	24
1958	141	209	350	52	56
1959	239	115	354	53	55
1960	170	186	356	53	60
1961	179	184	363	54	41
1962	214	136	350	53	14
1963	278	33	311	47	53
1964	273	44	317	48	50
1965	190	129	319	48	28
1966	257	42	299	45	45
1967	280	19	299	45	44
1968	158	140	298	45	33
1969	235	51	286	43	8
1970	217	34	251	38	11
1971	197	27	224	34	31
1972			221	33	10
1973			198	30	5
1974			173	26	34
1975			181	27	12
1976			166	25	8
1977			149	22	6
1978			133		

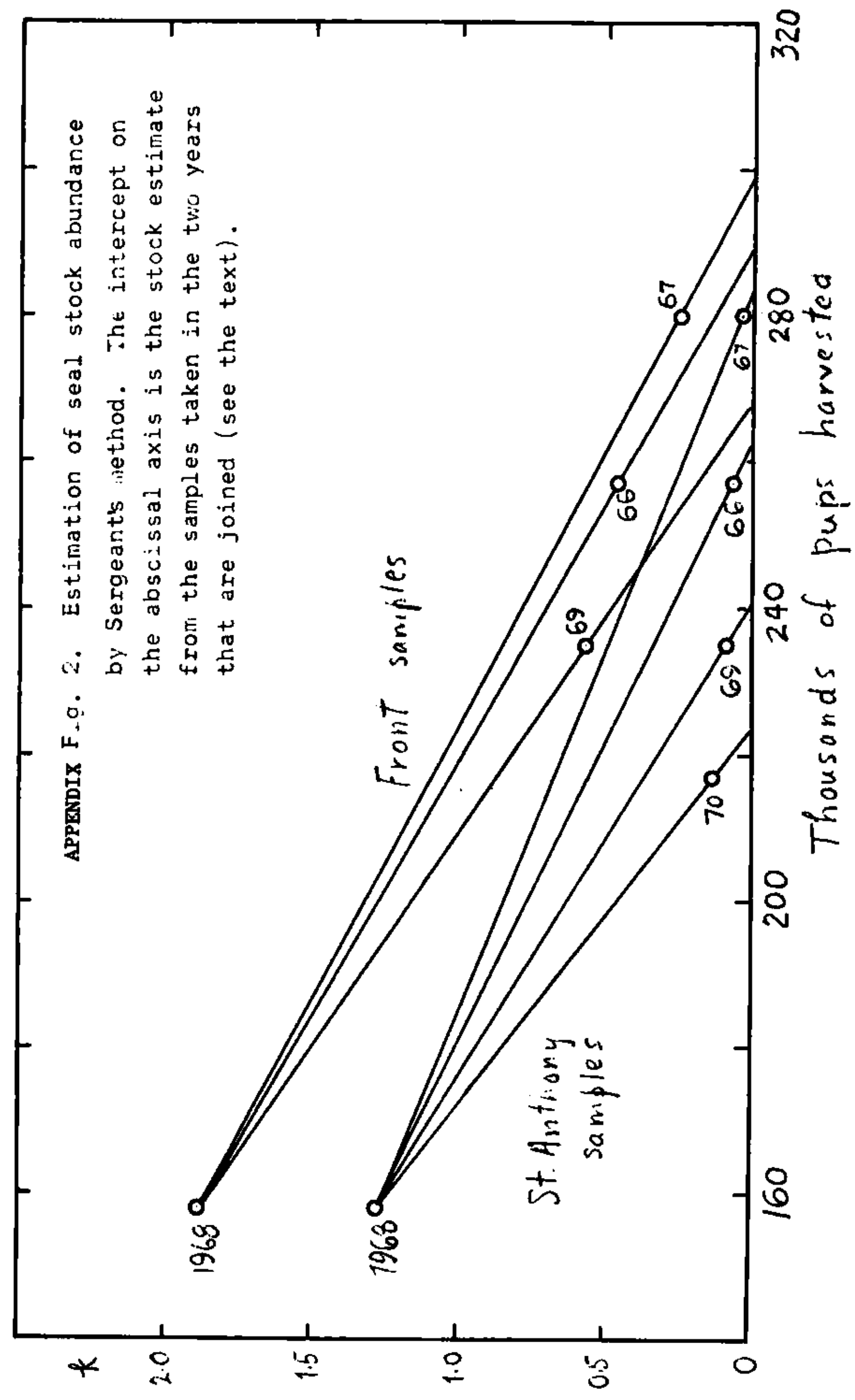
APPENDIX

Table 3. Comparison of expected pup production and harvest proposals, in thousands of animals. (In all years the proposed harvest includes 40,000 seals for landsmen in Canada and Greenland, the remainder to be taken by ships.)

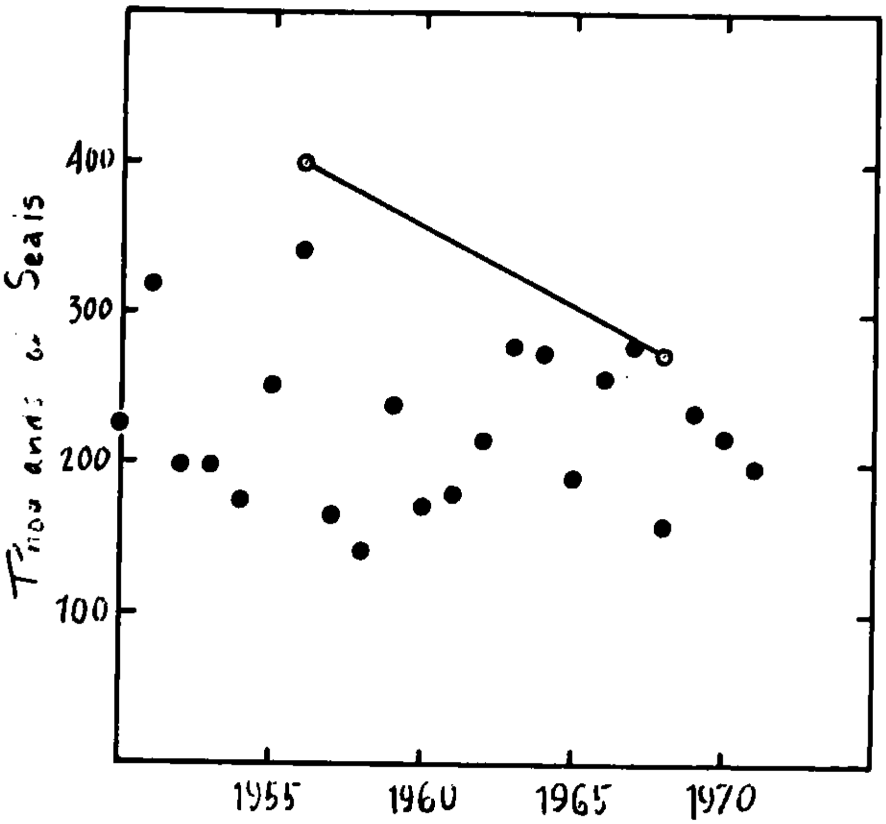
		Harvest proposals				Escapements			
Year	Pups available	Original Norwegian	Modified Norwegian	Canadian	Landsmen's harvest only	Modified Norwegian	Canadian	Landsmen's harvest only	Needed for stock maintenance at 1968 level
1972	221	220	200	160	40	21	61	181	186
1973	198		180		40	18		158	186
1974	173		160		40	13		133	186
1975	181				40			141	186
1976	166				40			126	186
1977	149				40			109	186
1978	133				40			93	186



APPENDIX Fig. 1. Two age frequency curves of harp seals based on catches taken in Labrador between January of the year shown and the previous November. The curve marked "1963" is a composite of samples taken in 1962, 1963 and 1964, each year being given approximately equal weight. The "1968" curve is a similar composite of samples taken in 1967 and 1969. Blank year-classes are plotted on the 0.3 line. Data from Appendix table 1 of [3]. The horizontal lines show the year-classes of 1945-51, when pup survival was decreasing rapidly.



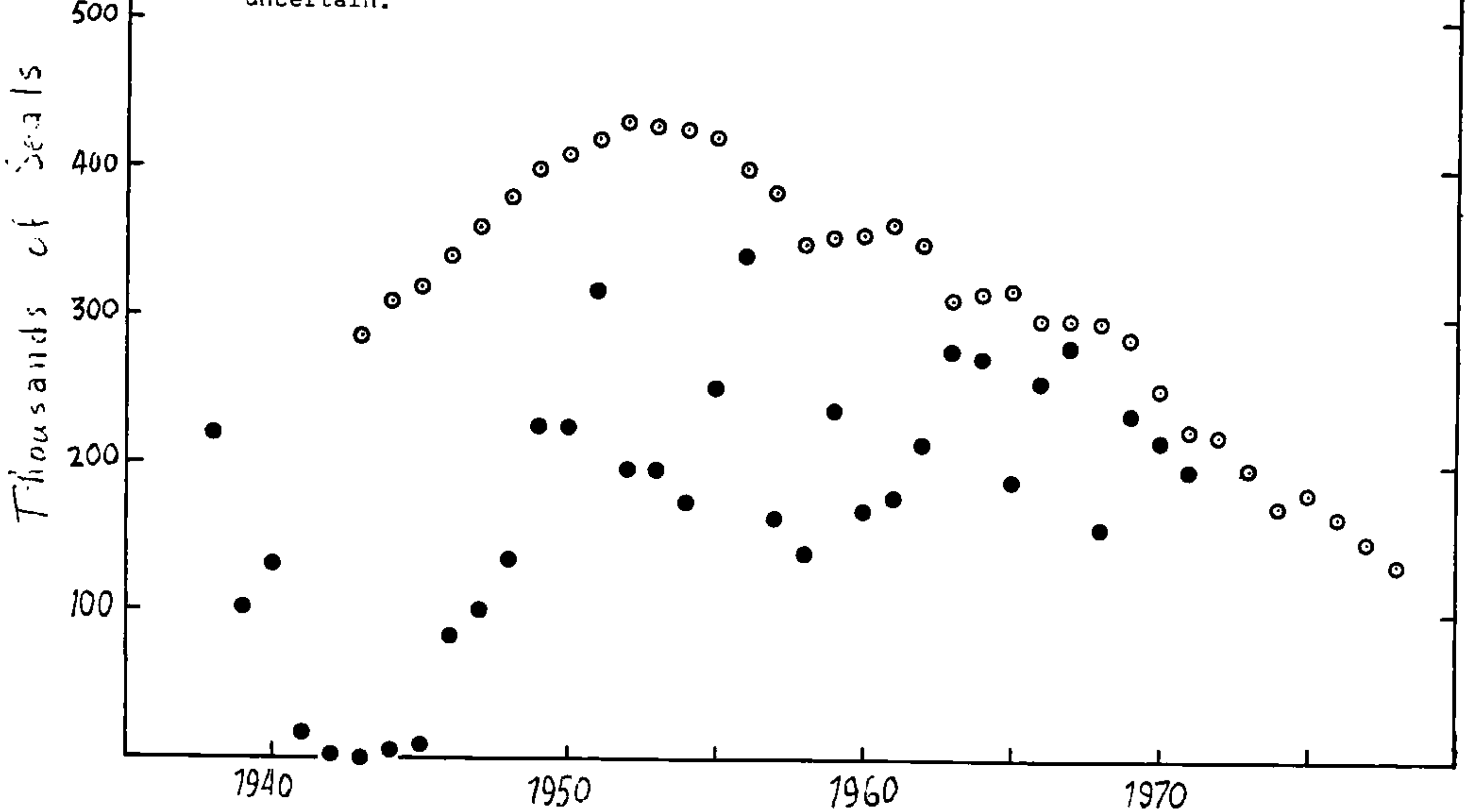
APPENDIX Fig. 2. Estimation of seal stock abundance by Sergeant's method. The intercept on the abscissal axis is the stock estimate from the samples taken in the two years that are joined (see the text).

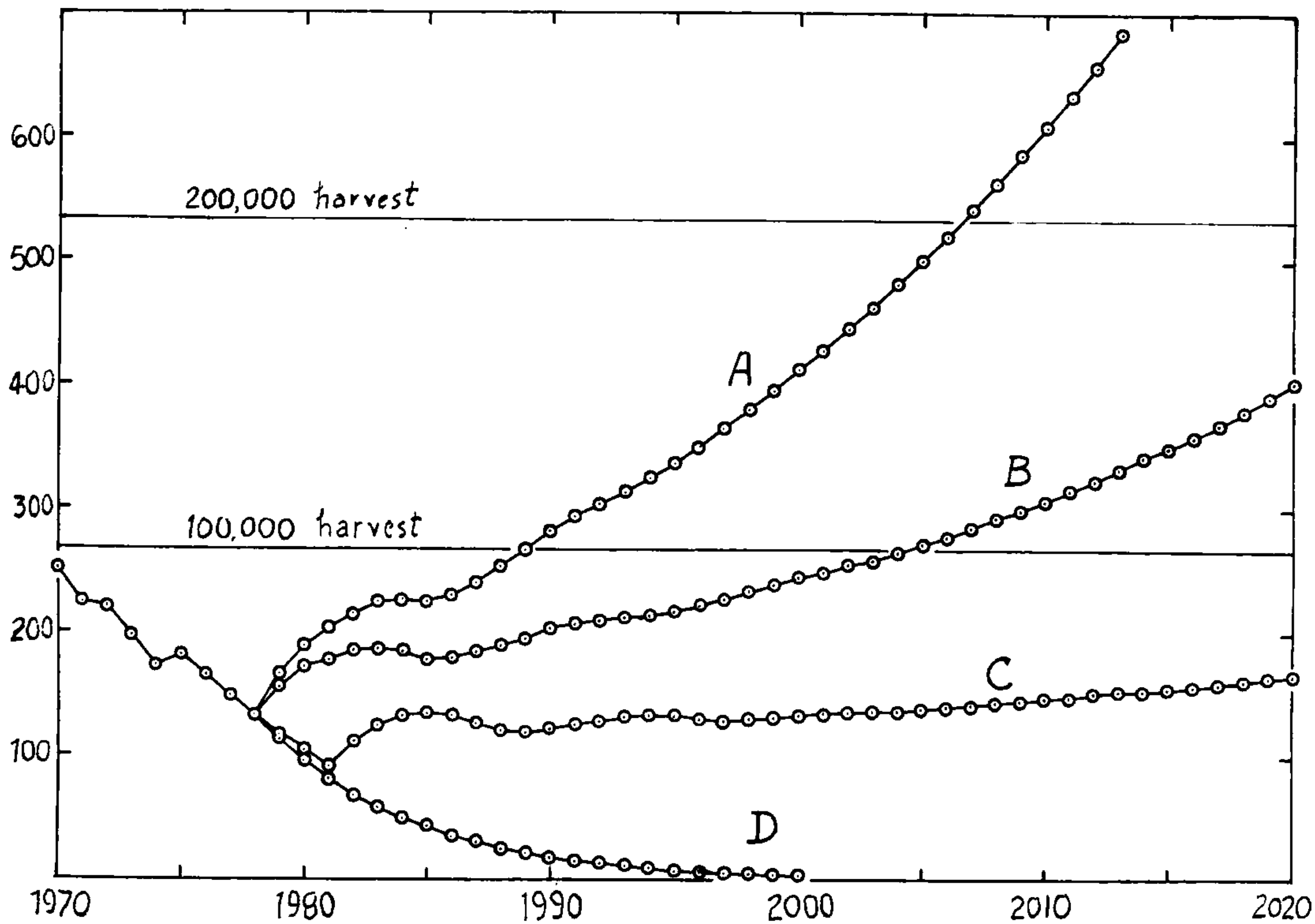


APPENDIX Fig. 3. Seal pup catches for 1950-71 (solid dots), and the preliminary estimate of stock abundance from 1956 to 1968 (straight line).

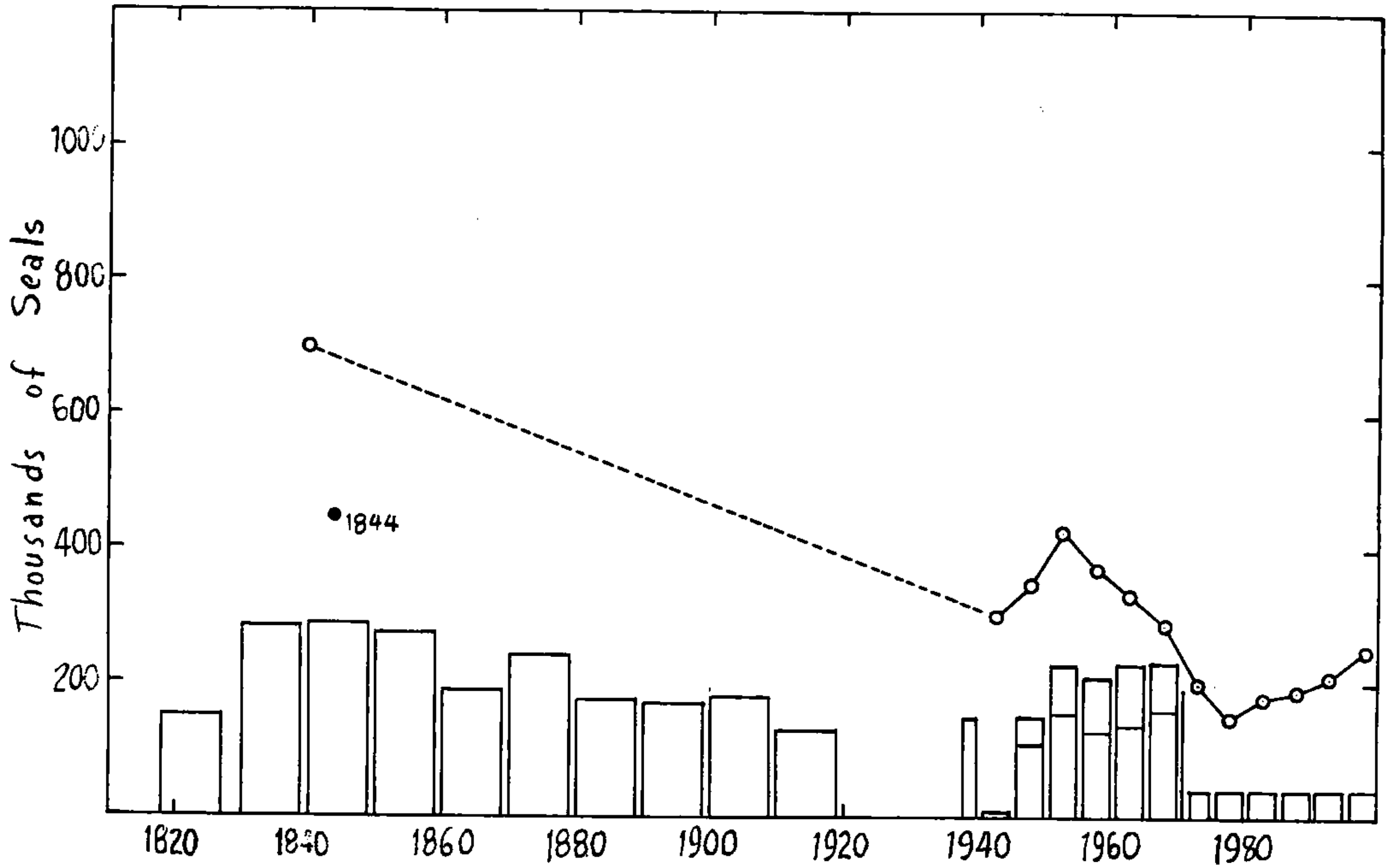
APPENDIX

Fig. 4. Seal pup catches from 1938 to 1971 (solid dots), and computed female breeding stocks (open circles). The stock estimates previous to 1956 become increasingly uncertain.





APPENDIX Fig. 5. Projected levels of breeding stock under four management schedules: A - complete cessation of pup harvest from 1972; B - harvest of 40,000 pups a year, starting in 1972; C - 200,000 pups taken in 1972, 180,000 in 1973, 160,000 in 1974, and 40,000 a year thereafter; D - all pups are killed each year, starting in 1972. Stock levels required for sustained yields of 100,000 and 200,000 pups are indicated.



APPENDIX Fig. 6. Columns through 1945: average catches of harp seal pups (data for 1818-1919 are 62.5% of the means given by Chafe [5]). Columns from 1946 to 1971: average catches of seal pups from the Front (lower part) and from the Gulf (upper part), from [4]. Columns from 1972 onward: a projected total pup catch of 40,000 a year. Open circles: estimates of the total stock in recent years (from Table 2), and a projection to the year 2000 consistent with the 40,000 harvest. Broken line: generalized course of decline in the female breeding stock of harp seals.