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THE SURVIVAL OF YEAR-CLASSES AND ESTIMATES OF PRODUCTION AND SUSTAINABLE YIELD OF NORTHWEST ATLANTIC HARP SEALS

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Introduction

Age-group frequencies of moulting harp seals (Pagophilus groenlandicus) in samples from Norwegian catches on the Front off Newfoundland - Labrador in 1964 and 1967-1970 were reported by Øritsland (1971). Additional age samples collected in each of the seasons 1971-1974 have been analysed, and a provisional report of the new data was given by Benjaminsen and Øritsland (MS 1975) with an attempt to estimate production and sustainable yield of Northwest Atlantic

harp seals. These estimates have now been revised, and the results are reported here.

Material and methods

Characteristics of all age samples collected from 1968 to 1974 are given in Table 1. Samples collected in 1964 and 1967 are omitted. They are both small (127 and 281 specimens) and the first one contains 33 breeding females. For the second sample it has been impractical to distinguish between specimens which could be ascribed to definite age-groups and specimens which could not be aged with certainty and therefore had to be given a minimum age. However, with the new data from recent samples available, the loss is not great.

For the purpose of this study which is based mainly on the frequencies of age-groups, only definite age determinations can be used. Specimens with minimum ages, enumerated under "Undetermined" in Table 1, therefore have been omitted.

Age-group frequencies of males and females together in all samples, included samples without separation on sex, were combined to produce average frequencies which were smoothed and used as a basis for comparison of frequencies in individual samples to give an estimate of survival of year-classes as they appeared in the Norwegian catches of moulting harp seals.

Survival indexes were calculated for each year-class frequency as a ratio of the corresponding smoothed average age-group frequency. Each sample was given a weight approximately proportional to its size, and weighted means were calculated for the survival indexes of individual year-classes, omitting age-group 1 because of segregation of young seals in the moul-

ting season. All age-groups older than 15 years also were omitted because of the wide confidence limits for these low frequency groups.

The average pup production in the years from 1960 to 1972 was then estimated by simple regression of weighted mean survival indexes for each year-class against total catches of pups in corresponding years (ICNAF, 1972 - 1974; ICNAF Ass.Exec.Secr., 1974).

Production also was estimated from the abundancy of individual adult age-groups in relation to the abundancy of all adult age-groups in the samples. The model can be described as follows: The number of seals $\underline{M}(\underline{i},\underline{t})$ at age $\underline{i}$ in the age sample taken in year $\underline{t}$ are divided by the number of adults $\underline{M}(\underline{a},\underline{t})$ in the sample and multiplied with the total number of adults in the population , $\underline{N}(\underline{a},\underline{t})$. This gives the number of animals at age $\underline{i}$ in the population. Dividing by the total survival rate, $\underline{S}$, $\underline{i}$ times, the year-class can be traced $\underline{i}$ years back. By adding the catch, $\underline{C}$ of pups in year $\underline{t}$-$\underline{i}$, we get an estimate of the production $\underline{B}$ in year $\underline{t}$-$\underline{i}$.

The model may be written

$$B(t-i) = C(t-i) + \frac{M(i,t)}{M(a,t)} \cdot N(a,t) \cdot \frac{1}{(S)^i}$$

The age samples are assumed to be unibiased for 7 years old and older animals. The total number of 7 years old and older animals in the population was recalculated from Allen's estimated population history Allen (1975). The mean total annual mortality in the years from 1960 to 1974 for animals up to an age of 10 years is assumed to be 13% alternatively 12%. We have not traced the year classes further back than 10 years as the uncertainity in age determinations and the confidence limits

of age-group frequencies increase for older seals. For these estimates the age-group frequencies in a Canadian sample collected in 1970 reported by Sergeant (1971 - Appendix Table 1 a-e) were used together with frequencies in the Norwegian samples from 1973 and 1974.

Sustainable yields of pups can be estimated from the basic assumption that constant production requires an equilibrium between recruitment and mortality among sexually mature females. Female harp seals at Newfoundland on the average do not attain sexual maturity before they are about 5 years old (Øritsland, 1971). Changes in the current regulatory measures for the next sealing season therefore cannot influence the recruitment of mature females or the production of pups until 1981. However, the sustainable catch of pups in 1976 which allows for a constant production from 1981 onwards, may be estimated on the basis of an equilibrium between the number of female pups surviving to 1981 and the number of mature females dying in 1981, this equilibrium therefore can be expressed by the following simple equation:

$$(B(i) - C(i)) \cdot F = A(i+5) \cdot Z$$

where $B(i)$ = production of female pups in the year i, $C(i)$ = catch of female pups in the year i, F = survival to productive maturity, A = number of sexually mature females , and Z = total mortality rate of mature females.

Sustainable yields of pups were estimated from this equation for alternative survivals to maturity and mortalities. Catches of immatures and adult seals are included in the total mortalities used to calculate the sustainable yield of pups. The total sustainable yield of harp seals at Newfoundland therefore

can be estimated by adding to the sustainable yield of pups a proportional number derived from the ratio of one year old and older seals in catches taken since quota regulations were introduced in 1972. Catch statistics for the Newfoundland hunt are available for 1972 (ICNAF, 1974) and 1973 (ICNAF Ass.Exec.Secr., 1974) and provisional statistics are available for 1974 (Bigg, 1974), and these were used in the estimates.

Results

Age composition

Combined male and female age-group frequencies in the samples collected at Newfoundland from 1968 to 1974 are listed in Table 2. The table also gives total and average relative frequencies for all samples together, and the smoothed average relative frequencies derived from the actual frequencies. The actual and smoothed average frequencies are illustrated in Figure 1.

Catch and survival

Survival indexes calculated for 1-15 years old seals in each sample, are given in Table 3 with weighted means calculated for each of the year-classes 1954-1972. Total catches of pups at Newfoundland (Front and Gulf) are also listed in Table 3.

The weighted mean survival indexes for the year-classes 1960-1973 are plotted against total pup catches in Figure 2. The graph suggests good survival after pup catches below 185 thousand and poor survival resulting from catches of more than 250 thousand pups. In the interval between these catch levels, the survival indexes are close to 1.0 and pup catches do not appear to have influenced year-class strengths

either way.

Production

The regression of weighted mean survival indexes for the year-classes 1960-1972 against pup catches in these years is y = - 0.0060x + 2.3372(Figure 2). The regression indicates an average pup production of 390 thousand per year in this period with 1966 as mid-year.

Production estimates for the years 1960-1967 from the abundancy of adult year-classes in one Canadian and two Norwegian age samples, selected because they contain large numbers of specimens, are given in Table 4. Weighted mean estimates range from 369 to 474 thousand for a total adult mortality of 13%, and from 362 to 444 thousand for 12% mortality. The regression estimate from catch and survival indexes of 390 thousand is very close to the average of the two mean estimates for 1966, which is 387.5 thousand pups.

The alternative sets of mean production estimates for the years 1960-1966 from adult year-class abundancies in Table 4 are illustrated by the two upper lefthand graphs in Figure 3. The estimates for 1967 are omitted because they are based only on the smallest age sample collected in 1974 . The average of the two mean estimates for 1966 (387.5 thousand) is used to predict production in the period from 1967 to 1980 by the method used by Ulltang (MS 1971). Two sets of predictions based on the alternative survivals of female pups to age of productive maturity of 40% and 45%, are shown in the two upper righthand graphs in Figure 3. Both sets of predictions are based on an assumed total annual mortality of 10% for adult females. A previous set of production estimates by Allen (1975) is shown in the lower graph of Figure 3 for comparison. All three sets indicate a minimum production

in 1976 or 1977, although at different levels.

Sustainable yield

Alternative estimates of the sustainable yield of harp seals at Newfoundland (Front and Gulf) are given in Table 5.

Norwegian catches of adult moulting harp seals in the period 1967 - 1974 include an average of 6% adult. (7 years old and older) females (Benjaminsen and Øritsland, MS 1975). This obviously is a maximum estimate for Norwegian catches since quota regulations were introduced in 1972. However, the composition of Canadian catches is not known, and this percentage therefore has been applied to the average annual total take of one year old and older harp seals, which is is 22 thousand for the three years 1972 - 1974. In these years with a quota regulation in force, the average total catch of adult females therefore can be estimated to 1.3 thousand per year. This catch corresponds to a maximum hunting mortality of 0.31% in a population of at least 350 thousand (Table 4). Total mortality of adult or breeding females therefore can be only slightly higher than the 8% natural mortality used by Ulltang (MS 1971 b) and Allen (1975). In Table 5 sustainable yields therefore have been estimated for the alternative total mortalities of 8 and 9%.

At the Special Meeting of ICNAF Panel A Experts in September 1971 (Mansfield, 1972) the survival of (female) pups to productive) maturity was estimated at 40% under the hunting strategy as in years before 1971. The Meeting suggested, however, that a reduction in the catch rate of juveniles would increase the survival to maturity to 50%. Such a reduction seems to have occured for catches by Norwegian ships. The average annual catch at 27 thousand one year old and older harps in 1967-1971 changed to 10 thousand in 1972-1975.

Even if Canadian catches are not strictly comparable, the process has started, and in Table 5 estimates are given for alternative survivals of 40, 45 and 50%. The estimates for 50% survival are based on a survival of 45% from 1967 to 1971, and 50% from 1972 on.

The minimum estimate in Table 5 of 178 thousand harp seals in 1976, is based on a survival to maturity of 40% and a total mortality of adult females of 9%. A reasonable assessment of the sustainable yield of harp seals at Newfoundland appears to be higher than 200 thousand seals per year.

Conclusion

The production of harp seal pups at Newfoundland in 1966 has been estimated[V] to 390 thousand by two different methods, based partly on different sets of data. We therefore are confident that production in the mid 1960'ies was higher by about 50 thousand than estimated in the previous ICNAF assessment (Mansfield 1972) or assessed by Allen (1975). The present sustainable yield therefore also is higher than assumed.

We conclude that 200 thousand, a figure on the low side of the mid-point between the minimum estimate of 178 thousand and the maximum of 254 thousand, is a conservative assessment of the total sustainable yield of harp seals (all age groups) at Newfoundland, when catches of mature females are kept on the present low level by quotas and the protection of adults in the breeding lairs.

Acknowledgements

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Table 1. Age samples collected from Norwegian catches of moulting harp seals off Newfoundland - Labrador 1968 - 1974 .

Year	Ship	% by date in April			No	Undetermined		Mean	Males
		1-10	11-20	21-30		No	%	age	%
1968	Polarstar	(5)	(90)	(5)	737	35	4.8	8.7	-
1969	Norvarg	56.5	40.5	3.0	1021	106	10.4	6.7	69.2
1970a	Polarbjørn	0.0	15.6	84.4	323	16	5.0	6.4	62.2
b	Kvitungen	-	-	-	218	10	4.6	4.4	-
1971	Norvarg	78.3	21.7	0.0	568	61	10.7	4.1	63.4
1972	Polarstar	100.0	0.0	0.0	148	13	8.8	(7.0)	-
1973a	Norvarg	0.0	100.0	0.0	813	116	14.3	5.8	66.8
b	Polarstar	0.0	100.0	0.0	988	104	10.5	5.6	-
1974	Norvarg	27.1	72.9	0.0	1232	94	7.6	4.7	64.4
Sum		29.9	64.5	5.6	6048	555	9.2	-	65.8

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.

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. Pup catches of harp seals at Newfoundland and the survival of corresponding year-classes expressed by revised survival index (frequency in sample/smoothed average frequency, uncertain age determinations omitted). Below the year of sampling is given the number of specimens and the weight given to the sample in calculating the weighted mean for 2-15 years old seals.

Year class	Total pup catch $\times 10^{-3}$	Revised survival index							
		1968 702 5	1969 915 7	1970 490 4	1971 507 4	1972 135 1	1973 1581 11	1974 1138 8	Weighted mean
53	198	1.33							(1.33)
54	175	1.60	1.53						1.56
1955	252	1.19	1.43	1.04					1.26
56	341	0.85	1.15	1.34	0.56				1.00
57	165	1.42	0.87	0.65	0.25	1.98			0.89
58	141	1.53	1.14	0.68	0.77	0.46	0.93		1.00
59	239	1.47	1.22	1.15	1.08	0.82	0.67	0.70	0.97
1960	171	1.55	1.28	1.64	0.90	1.85	1.12	0.71	1.17
61	179	1.56	1.37	0.97	1.14	1.35	0.85	0.98	1.11
62	214	0.55	0.94	1.44	1.12	1.71	1.27	0.83	1.05
63	278	0.69	0.59	0.83	0.45	1.48	0.85	0.48	0.68
64	273	0.49	0.69	0.56	0.47	1.90	0.89	0.68	0.71
1965	190	0.60	0.42	0.91	0.42	2.29	1.43	1.05	0.94
66	257	0.77	0.37	0.75	0.57	1.42	1.01	0.53	0.71
67	280	(0.77)	0.34	0.64	0.48	1.08	0.99	0.44	0.64
68	156		(1.62)	1.55	0.85	2.28	2.99	1.49	2.02
69	235			(1.03)	0.95	0.67	1.40	0.95	1.14
1970	222				(1.89)	0.49	1.19	0.73	0.97
71	211					(0.36)	1.07	0.76	0.94
72	117						(0.43)	1.46	1.46
73	98							(1.27)	(1.27)

Table 4. Production of harp seal pups at Newfoundland estimated from the abandancy of adult year classes in a Canadian sample collected in 1970 and the Norwegian 1973 and 1974 samples. Alternative estimates have been calculated for total annual mortalities of 13% (a) and 12% (b). The numbers of 7 years old and older animals in the samples are given in brackets. Weights given to the samples for calculation of weighted means are given below the year of sampling.

Year-class	1970 4 (1425)		1973 2 (663)		1974 1 (338)		Weighted mean	
	a	b	a	b	a	b	a	b
1960	474	444					474	444
61	430	406					430	406
62	416	399					416	399
63	391	383	399	386			394	384
64			400	387	402	388	401	387
1965			397	379	392	372	395	377
66			410	398	360	351	393	382
67					369	362	369	362

Table 5. Sustainable yield in thousands of Newfoundland harp seals in 1976, estimated for alternative rates of total mortality of adult females and alternative rates of survival of females to productive maturity.

Mortality %	Survival - %					
	40		45		50	
	Pups	Total	Pups	Total	Pups	Total
8	168	202	196	236	211	254
9	148	178	177	213	194	234

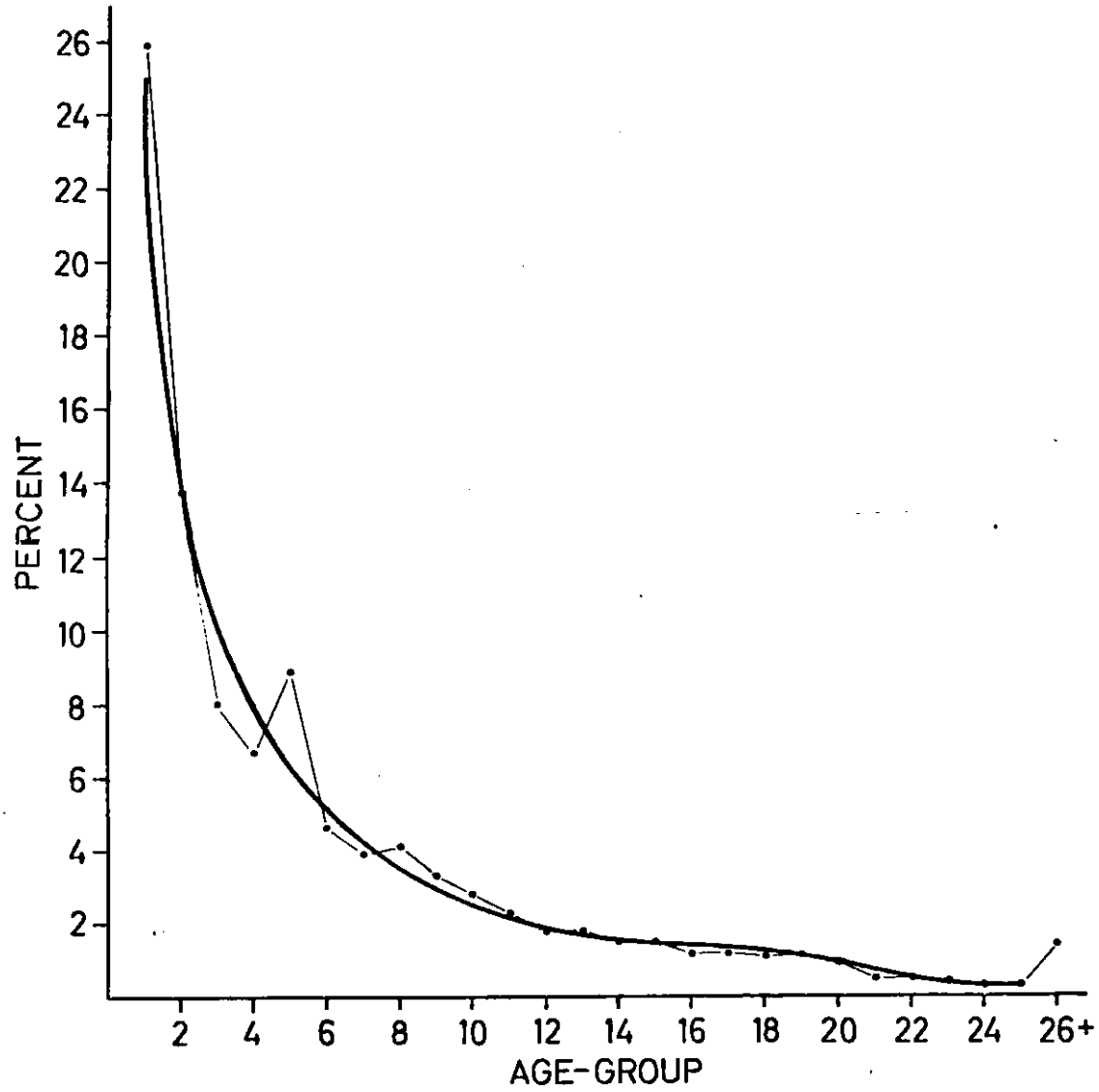

Figure 1. Actual and smoothed average relative age-group frequencies derived from combined male and female samples of moulting harp seals, collected from Norwegian catches off Newfoundland - Labrador 1968 - 1974. Heavy line represents smoothed frequencies, thin graph with points represent actual frequencies.

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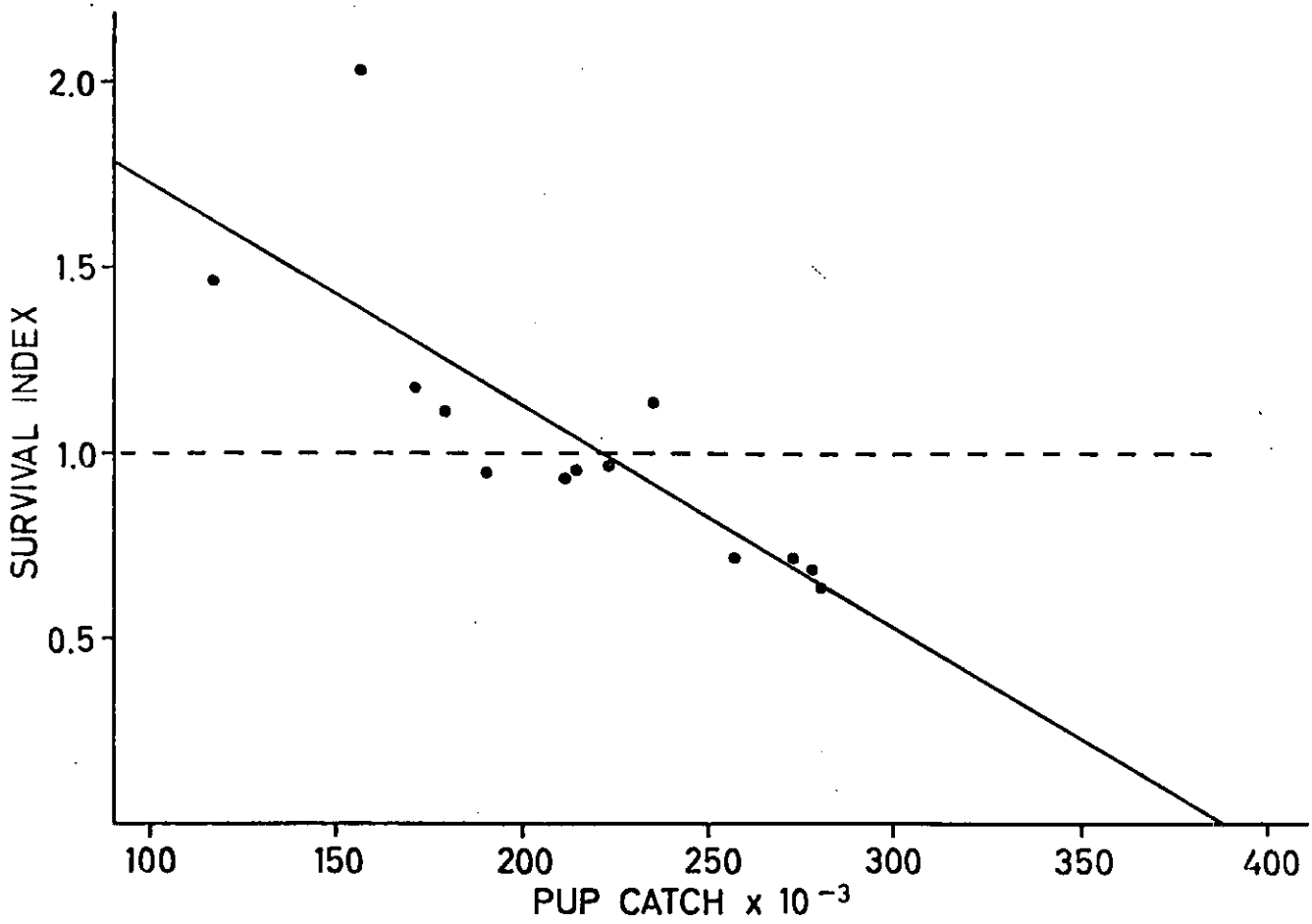

Figure 2. Total catches of harp seal pups at Newfoundland and the survival of the year-classes 1960-1973 as indicated by weighted mean survival indexes (Table 3) from age samples collected from Norwegian catches of moulting seals in 1968 - 1975. The calculated regression is $Y = 0.0060x + 2.3372$.

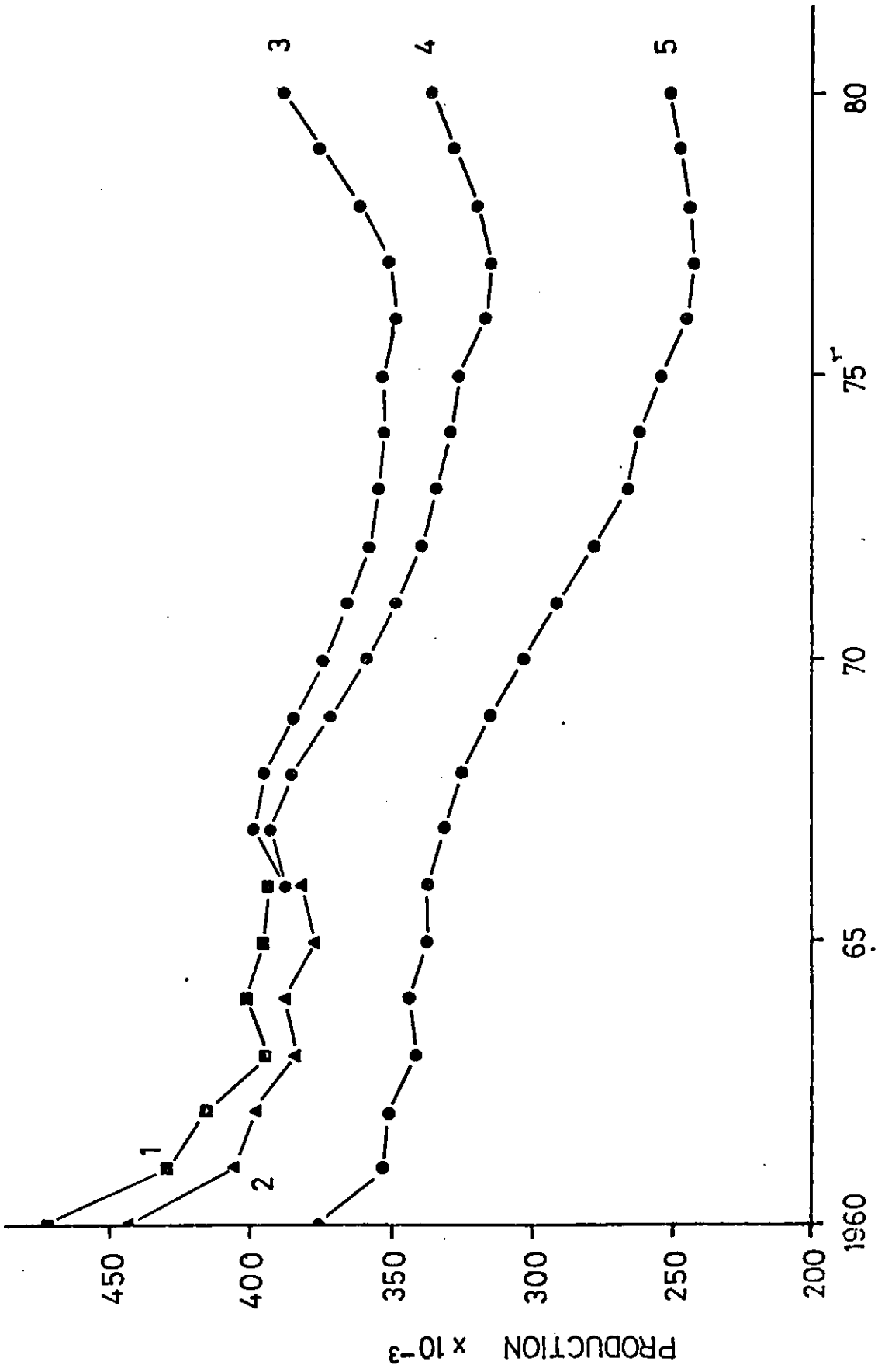

Figure 3. Production of harp seal pups in the Northwest Atlantic calculated from age samples and catch statistics. 1) and 2) Production estimated from a Canadian age sample collected in 1970 and Norwegian samples collected in 1973 and 1974 (Table 4). Graph 1) is based on an assumed total adult mortality of 13%, graph 2) on a mortality of 12%. Graph 3) is based on an assumed survival to productive maturity of 45% and 4) on a survival of 40%. Graph 5) represents the estimates by Allen (1975).