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On population size and sustainable yield in Northwest Atlantic harp seals

by

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This paper presents new estimates of harp seal, (Pagophilus groenlandicus), population size, pup production and sustainable yield which incorporate 1979 findings. Two estimates of total pup production in 1979 are considered. The first is based upon the mean estimate from a mark-recapture experiment (352,000) and the second is based on the lower 95% confidence limit of this mark-recapture estimate (304,000). Population size projected to 1985, increases at an instantaneous rate of 0.02 per year and 0.01 per year respectively under these two levels of pup production. Assuming a mean age of whelping of 5.3 yrs, and a 1979 pup production of 352,000, sustainable yield is 190,000 pups and 47,000 1+ animals for a total of 237,000. If pup production in 1979 is 304,000, sustainable yield is 164,000 pups and 41,000 1+ animals for a total of 205,000.

Sequential Population Analysis

In recent years, the sequential population analysis developed by Pope (1972) has been used extensively to estimate age-specific population size and pup production of harp seals in the Northwest Atlantic (Lett et al., 1978; Lett and Benjaminsen, 1977; Winters, 1978). This method assumes that natural and hunting mortality occur somewhat seasonally, which is true to a great extent in harp seals. In this paper cohort analysis was again used. The formulation of cohort analysis is given in Pope (1972) and in the above references and hence will not be repeated.

The age distribution of harp seal catches from 1960 to 1976 are taken from Lett and Benjaminsen (1977) and for 1977 from Mohn, Lett, and Beck (unpubl. manuscript, 1978). Catch-at-age data for 1978 and 1979 were constructed from age samples collected by Sergeant (1978) and Bowen and Sergeant (1979) (Tables 1 and 2). The age structure of the 1978 and 1979 large vessel catch of 1+ seals was determined from the 1979 moulting sample.

Selectivity factors were determined in the following manner. Six samples of 1+ seals were taken from a moulting patch in April 1979, so that a comparison could be made of the percentage of pelage types in classified counts before the seals were disturbed and the percentage of pelage types in the sample shot by hunters from the vessel (Table 3). In this way, we calculated a hunting selectivity for bedlamers equal to 1.38 and for adults of 0.57. Sergeant (1976), using the same method but with more pelage categories, found that hunting selectivity for small bedlamers was 1.6 and for adults selectivity was 0.48. Large bedlamers (ages 3-5) were sampled in proportion to their abundance (Sergeant, 1976). Following Sergeant (1976) we assumed that the hunting selectivity of 1.38 applied to small bedlamers (ages 1 and 2) and that large bedlamers were sampled in proportion to their abundance. We then applied our hunting selectivities to an age sample of 358 males to produce a population age structure (Table 4). To estimate age-specific selectivity factors in the commercial harvest, we divided the proportion of each age in the 1979 catch by the corresponding proportion in the population age structure (Table 5). The selectivity factors produced in this way are somewhat erratic for older animals. This is probably caused by sampling error and errors in aging. Therefore, selectivity factors were smoothed by eye (Fig. 1); a selectivity factor of 1.00 was given to 25+ seals.

In the initial run of the model, we used a terminal F = 0.021 in 1979 for age-group 25+. This average hunting mortality was then multiplied by age-specific selectivity factors to distribute $\bar{F}$ over the age classes according to recent hunting patterns. Terminal hunting mortalities for the period 1960 to 1977 were taken from Lett et al. (1978) and were calculated in a similar manner for 1978. We used a natural mortality rate of 0.10 (Winters, 1978; Lett et al., 1978).

A series of runs were made until the numbers at age generated by the model, when combined with a fertility rate of .94 (Bowen, 1979a) and the most recent female maturity ogive (Table 6), produced the number of pups estimated by mark-recapture (Bowen 1979b). Two levels of pup production were considered. The first was calculated from an estimated Front production of 220,000 pups divided by 0.625; the porportion of Front to total production. This value is the average of 0.61 (Sergeant,1977) and 0.64 (Winters, 1978). From this, total production in 1979 was 352,000 pups. The second level of pup production was calculated using the lower 95% confidence limit of the Front mark-recapture estimate. To this value of 174,000 we added 16,000, which is a conservative estimate of the southern Front patch (Bowen, 1979b), to give a total production of 190,000/.625 = 304,000. The two runs which gave pup productions near 352,000 (Table 7) and 304,000 (Table 8) were used to project population behaviour to 1985.

Population projection

Harp seal population size is projected to 1985 in Fig. 2 using the two levels of pup production in 1979 referred to above. The projections (dashed line in Fig. 2) assume the following: 1) M = 0.10, 2) fertility rate = .94, 3) maturity ogive as in Table 6, 4) no density-dependence in parameters, 5) hunting mortality is distributed over the age groups as in 1979, and 6) a yearly catch of 180,000 animals of which 80% are pups and 20% are 1+ seals. Under these conditions and using the population age structure from a cohort analysis that produces 352,000 pups in 1979, the 1+ population increases at an instantaneous rate of 0.02 per year. If pup production in 1979 is about 304,000, the 1+ population increases at an instantaneous rate of only 0.01 per year. Also under the first scenario, pup production increases from 352,000 in 1979 to 397,500 in 1985; whereas in the second case, production increases from 306,000 to 339,400 pups.

Sustainable yield

Let R denote the number of female recruits to the breeding stock at time t. Then

$$R = \frac{e^{-M+\left(-Z_b t-1\right)}}{2} \qquad (1)$$

where Z_b is the average total mortality of bedlamers.

Let A be the annual rate of adult mortality such that

$$A = 1 - e^{-Z_a} \qquad (2)$$

where Z_a is the average total mortality of adult harp seals and let F be the population fertility rate. Then surplus production of pups (sustainable yield rate (%)) is given in Winters (1978) as

$$S.P. = \frac{FR - A}{FR} \times 100 \qquad (3)$$

Fertility rate in 1979 is .94 (Bowen 1979a). Average total mortality was calculated using average hunting mortalities from 1976 to 1979 and assuming M = 0.10. Average adult mortality (Z_a) = 0.109 and average bedlamer (ages 1-4) mortality (Z_b) = 0.150. Given an 80:20 ratio of pups to adults in the kill, the surplus production of pups under various whelping ages is shown in Table 9. Mean age of whelping in 1979 is 5.3 yrs. (Bowen 1979a). If pup production in 1979 is taken as 352,000, then sustainable yield is 190,000 pups and 47,000 1+ seals for a total of 237,000. (All values rounded to the nearest thousand.) By contrast, if 1979 production is 304,000 pups, then sustainable yield is 164,000 pups and 41,000 1+ seals for a total of 205,000 animals.

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Table 1. Distribution of ages in 1978 1+ harp seal catch

Age	Large vessels (Front & Gulf)	Quebec Northshore	Longliners	Landsmen (net)	Landsmen (shot)	Total
1	1,073	94	7,172	976	6,305	15,620
2	493	571	4,127	664	3,628	9,483
3	358	1,194	2,013	304	1,770	5,639
4	252	1,057	1,314	412	1,156	4,191
5	252	1,048	699	352	600	2,951
6	200	537	532	260	468	1,997
7	230	196	134	128	117	805
8	158	239	218	92	190	897
9	53	171		108		332
10	72	196	134	108	117	627
11	117	68	33	60	29	307
12	94	77	33	52	29	285
13	64	25	67	44	58	258
14	41	43		76		160
15	53	9	67	44	58	231
16	30	34		60		124
17	23			68		91
18	41		33	44	29	147
19	53	9		44		106
20	30	17	33	24	29	133
21	31	9	33	8	29	109
22			33	16	29	78
23	24	9		8		40
24		9		8		17
25+	24	34		52		109
TOTAL	3,767	5,646	16,640	4,000	14,684	44,737

Table 2. Age distribution of 1+ harp seal catch in 1979

Age	Large Vessel (Front & Gulf)	Large Vessel (Front moulters)	Quebec northshore (shot & net)	Longliners (Front)	Longliners (Gulf)	Landsmen Front (net)	Landsmen Front (Shot)	Landsmen (Gulf)	Total
1	114	173	186	5,070	180	326	6,480	67	12,596
2	52	64	496	1,931	137	386	2,468	50	5,584
3	38	57	465	805	91	256	1,029	33	2,774
4	27	41	455	448	73	190	544	27	1,805
5	27	32	320	311	58	192	398	22	1,360
6	21	23	238	183	41	134	234	15	889
7	24	28	155	92	24	72	117	9	521
8	17	19	41	46	10	50	59	4	246
9	6	9	41	46	10	48	59	4	223
10	8	10	52		12	28		4	114
11	12	15	21		8	32		3	91
12	10	12	41		11	32		4	110
13	7	8	10		8	40		3	76
14	4	4	10	46	4	16	59	2	145
15	6	5		46	5	20	59	2	143
16	3	5	10		4	16		2	40
17	2	4			11	32		4	53
18	4	4	10		6	28		2	54
19	6	6	10		5	20		2	49
20	3	3	10		3	10		1	30
21	3	3				12		1	19
22						8		2	10
23	3	2	10		2	2		1	20
24						8		1	9
25+	3			137	11	34	177	4	366
TOTAL	400	527	2,581	9,161	714	1,992	11,683	269	27,327

Table 3. Classified pelage counts (A) and Shot Samples (B) from M/V LADY JOHNSON II. April 15-29, 1979.

A. Classified Counts

Date	Time	Pelage Class: Bedlamer	Pelage Class: Saddle	Total	% Bedlamer
April 23	1830	74	87	161	46.0
April 24	0900	142	100	242	58.7
April 27	1030	62	51	113	54.9
	1430	68	59	127	53.5
April 28	1000	109	97	206	52.9
	1530	73	78	151	48.3
TOTAL		528	472	1,000	52.8

B. Shot Samples

Date	Time	Pelage Class: Bedlamer	Pelage Class: Saddle	Total	% Bedlamer
April 23	1830	18	8	26	69.2
April 24	0900	63	22	85	74.1
April 27	1030	25	7	32	78.1
	1430	90	16	106	84.9
April 28	1000	41	7	48	85.4
	1530	129	74	203	63.6
TOTAL		366	134	500	73.2

Hunting selectivity:

Count shows .53 bedlamers: .47 adults

Kill shows .73 bedlamers: .27 adults

Selectivity for bedlamers = $.73/_{.53}$ = 1.38

Selectivity for adults = $.27/_{.47}$ = .57

Table 4. Age frequency distribution of males in moulting sample, April 1979, corrected for hunting selectivity to represent the population age distribution

Age (yrs.)	Raw Freq.	Hunting Selectivity	Correct Freq.	%
1	102	÷ 1.38	74	17.9
2	47	1.38	34	8.2
3	34	1.00	34	8.2
4	24	1.00	24	5.8
5	24	1.00	24	5.8
6	19	.57	33	8.0
7	22		39	9.4
8	15		26	6.3
9	5		9	2.2
10	7		12	2.9
11	11		19	4.6
12	9		16	3.9
13	6		10	2.4
14	4		7	1.7
15	5		9	2.2
16	3		5	1.2
17	2		4	1.0
18	4		7	1.7
19	5		9	2.2
20	3		5	1.2
21	3		5	1.2
22				
23	2		4	1.0
24				
25+	2		4	1.0
TOTAL	358		413	

Table 5. Age-specific selectivity factor in the 1979 commercial harvest.

Age	Percentage 1979 Catch	Percentage 1979 Population	Selectivity
1	45.7	17.9	2.55
2	20.4	8.2	2.49
3	10.3	8.2	1.26
4	6.8	5.8	1.17
5	5.2	5.8	0.90
6	3.3	8.0	0.41
7	1.9	9.4	0.20
8	0.9	6.3	0.14
9	0.8	2.2	0.36
10	0.4	2.9	0.14
11	0.3	4.6	0.07
12	0.4	3.9	0.10
13	0.3	2.4	0.13
14	0.5	1.7	0.29
15	0.5	2.2	0.23
16	0.15	1.2	0.13
17	0.18	1.0	0.18
18	0.18	1.7	0.11
19	0.16	2.2	0.07
20	0.11	1.2	0.09
21	0.06	1.2	0.03
22	0.04	1.0	0.03
23	0.06	1.0	0.06
24	0.04	0.7	0.06
25+	1.3	1.0	1.30

Table 6. Female maturity ogive for 1978 and 1979[a]

Age of whelping	Percentage mature
1	0.0
2	0.0
3	1.9
4	7.8
5	60.5
6	92.7
7	84.6
8	94.4
9+	100.0

[a] Data taken from Appendices A and B (Bowen, 1979a)

Table 7. Numbers at age generated from cohort analysis. M = .10 and in 1979 FT = .0195

	Age	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
	0	540,847	464,336	403,085	398,558	468,456	350,085	335,557	418,432	401,522	411,330
	1	301,537	333,227	253,910	163,746	88,584	166,139	138,620	89,360	112,403	211,143
	2	216,856	236,840	295,251	203,505	141,714	77,774	243,277	114,434	70,510	96,018
	3	140,389	178,888	211,831	234,666	175,782	124,026	66,860	119,766	98,693	59,500
	4	176,497	117,414	159,424	182,387	204,683	153,001	107,564	55,567	106,505	86,382
	5	122,608	150,677	103,240	135,169	160,293	178,138	132,345	92,178	48,291	94,636
	6	179,825	104,778	135,324	86,654	118,297	139,937	153,682	114,158	79,994	42,096
	7	120,010	157,211	93,537	119,657	74,058	99,713	119,630	133,268	98,766	70,754
	8	71,314	103,951	140,989	81,803	104,172	63,095	87,255	103,134	116,456	87,049
	9	74,767	60,532	93,287	124,642	69,882	91,007	55,353	75,582	90,410	102,998
	10	93,267	64,097	54,038	81,591	108,982	60,198	81,318	48,166	66,271	80,185
Total	11+	723,403	707,555	644,746	595,696	566,963	534,404	535,117	524,462	481,473	472,609
Total	1+	2,220,473	2,215,170	2,185,577	2,009,516	1,813,410	1,687,432	1,621,021	1,470,075	1,369,772	1,403,370

	Age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
	0	359,743	391,361	338,235	322,205	326,400	326,745	307,348	318,558	377,018	351,600
	1	147,190	115,744	151,174	192,225	193,810	183,060	161,880	152,457	169,404	230,797
	2	171,088	125,722	97,771	134,895	172,079	166,231	156,480	136,080	131,474	139,385
	3	84,034	147,640	111,396	87,241	119,324	150,349	144,972	135,652	117,746	110,050
	4	50,900	73,455	131,125	98,634	76,551	105,949	132,926	127,394	117,894	100,762
	5	75,772	43,451	65,359	117,151	87,262	67,599	93,966	117,542	111,888	102,258
	6	82,809	66,291	38,209	57,613	102,800	77,108	59,195	83,533	104,400	98,007
	7	36,069	73,324	59,256	33,582	50,948	90,026	67,994	52,360	74,437	92,415
	8	61,663	30,947	65,770	52,837	29,151	45,163	79,716	60,503	46,535	66,680
	9	75,928	54,238	27,486	58,795	46,496	25,235	39,737	71,154	54,080	41,250
	10	90,985	66,757	48,338	24,244	52,016	40,851	22,130	35,449	64,049	48,560
Total	11+	468,533	488,279	466,771	455,076	412,247	395,584	378,333	351,597	342,649	354,446
Total	1+	1,344,971	1,285,938	1,262,655	1,312,293	1,342,684	1,347,155	1,337,329	1,323,770	1,334,556	1,384,614

Table 8. Numbers at age from cohort analysis for the period 1960-79, assuming pup production of 304,000 in 1979

	Age	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
	0	515,112	445,813	389,934	392,340	453,306	338,082	329,176	407,656	381,975	396,348
	1	281,748	309,940	237,149	151,847	82,958	152,431	127,759	83,586	102,653	193,456
	2	202,935	218,934	274,181	188,339	130,947	72,684	130,874	104,607	65,285	87,196
	3	132,200	166,292	195,629	215,601	162,060	114,284	62,254	108,543	89,801	54,772
	4	162,576	110,005	148,027	167,727	187,432	140,584	98,749	51,399	96,350	78,336
	5	114,419	138,082	96,535	124,857	147,028	162,529	121,110	84,202	44,520	85,447
	6	164,881	97,369	123,926	80,587	108,966	127,934	139,558	103,992	72,777	38,683
	7	120,010	143,690	86,833	109,344	68,570	91,270	108,769	120,488	89,568	64,224
	8	71,314	103,951	128,754	75,737	94,841	58,128	79,615	93,307	104,893	78,726
	9	74,767	60,532	93,287	113,571	64,393	82,563	50,859	68,669	81,518	92,535
	10	93,267	64,097	54,038	81,591	98,965	55,231	73,678	44,100	60,016	72,139
Total	11+	723,403	707,555	644,746	595,696	566,963	545,340	522,422	505,963	461,144	448,556
	1+	2,141,520	2,120,447	2,083,105	1,904,897	1,713,123	1,602,978	1,515,647	1,367,856	1,268,525	1,294,070

	Age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
	0	348,246	374,529	317,148	302,008	307,379	309,826	290,693	299,617	348,859	306,000
	1	133,634	105,341	135,944	173,145	175,535	165,849	146,572	137,386	152,266	205,318
	2	155,085	113,456	88,358	121,115	154,814	149,695	140,907	122,229	117,838	123,877
	3	76,051	133,159	100,297	78,724	106,855	134,727	130,010	121,561	105,212	97,711
	4	46,622	66,232	118,023	88,592	68,844	94,667	118,791	113,856	105,144	89,421
	5	68,492	39,671	58,823	105,295	78,176	60,626	83,757	104,753	99,638	90,722
	6	74,495	59,704	34,706	51,700	92,072	68,886	52,886	74,296	92,827	86,923
	7	32,981	65,801	53,295	30,413	45,597	80,330	60,555	46,650	66,078	81,944
	8	55,754	28,153	58,962	47,444	26,284	40,321	70,934	53,772	41,369	59,118
	9	68,397	48,891	24,958	52,636	41,616	22,641	35,356	63,207	47,989	36,579
	10	81,517	59,943	43,500	21,956	46,443	36,435	19,782	31,534	56,859	43,049
Total	11+	439,490	453,432	429,074	416,590	375,356	335,332	329,570	314,397	305,404	314,237
Total	1+	1,232,518	1,173,783	1,145,940	1,187,610	1,211,592	1,189,499	1,199,120	1,183,641	1,190,624	1,228,899

Table 9. Surplus production (%) of pups given an 80:20 ratio of pups to adults in the kill under various whelping ages.

Mean whelping age (yr)	R 80:20 kill	Surplus production of pups (%)
4	.288	62.0
5	.248	55.8
5.3	.237	53.8
6	.214	48.8
7	.184	40.4
8	.158	30.6
9	.136	19.4
10	.117	6.3
11	.101	0.0

Mean Adult Mortality (Z_a) = .109
Mean Bedlamer Mortality[a] (Z_b) = .150
M = 0.10
F = 94%

Fig. 1. Age-specific selection factors used to distribute $\bar{F}$ over the commercial catch. Values are taken from the curve.

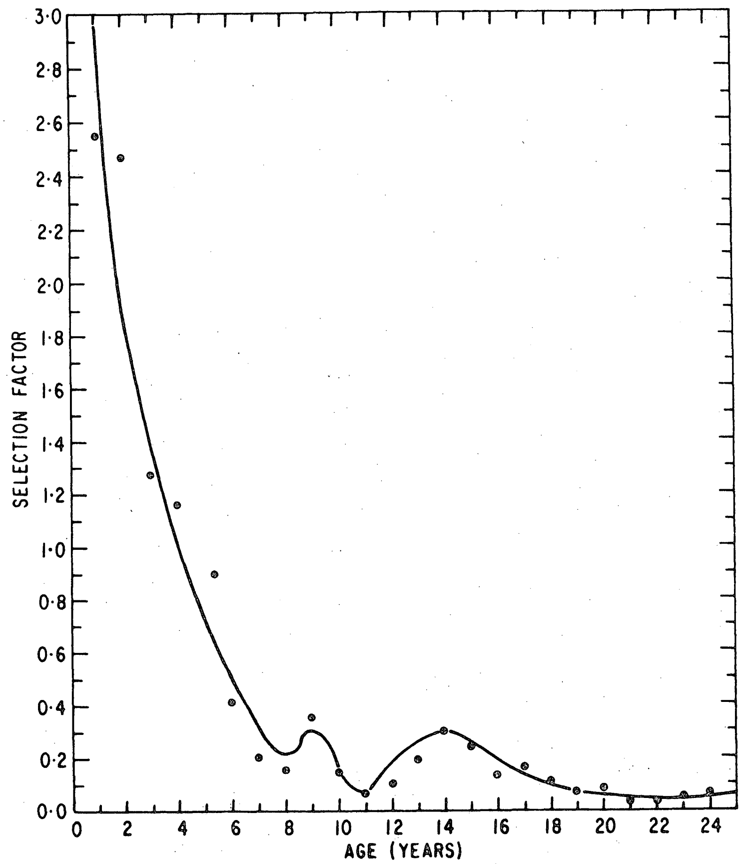

Fig. 2. Population projection to 1985 assuming two levels of pup production in 1979: 352,000 (upper curve) and 306,000 (lower curve).