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Estimates of Harp Seal Pup Production from Mark-recapture Experiments

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Abstract

In March 1980, 7,247 harp seal pups were marked in the Gulf of St. Lawrence and on the Front to estimate pup production of the Northwest Atlantic population. Gulf production was estimated to be 118,502 with nominal 95% confidence limits of 102,332 and 138,906. The number of pups in the northern Front patch was estimated to be 182,247 without nominal confidence limits of 163,878 and 204,482. The size of the southern Front patch is thought to have been about 45,000 pups, however, no estimate is possible from the mark-recapture experiment for this group. These mark-recapture estimates are likely to be biased because of the failure to satisfy the assumption of random sampling, however, the estimates produced are conservative. Estimates of pup production are also possible from long-term tag recoveries using the modified Petersen estimator. Combining these estimates with those based on short-term recoveries provides an average estimate of production during the period 1977-80 of 410,559 pups. Although this value may also be biased, it may well represent the best available estimate.

INTRODUCTION

The 1979 pup production of the Front herd of harp seals (Pagophilus groenlandicus) was estimated by means of mark-recapture. No estimate of Gulf production was possible from this experiment because the low catch of pups along the western coast of Newfoundland yielded insufficient tag returns. An estimate of total 1979 pup production was derived using an estimate of the ratio of Gulf to total production from past aerial surveys (Sergeant 1971) and from an analysis by Winters (1978). Unfortunately, empirical estimates of this ratio vary substantially and thus the estimated total production is subject to considerable error by this method. Here we report on a further attempt to estimate the total pup production of harp seals using mark-recapture methods.

MATERIALS AND METHODS

Chapman's (1951) modification of the 'Petersen estimate' of N was used to estimate pup production. When $M+n \geq N$, his estimate

$$N^* = \frac{(M+1)(n+1)}{(m+1)} - 1 \tag{1}$$

is exactly unbiased, while if M+n < N, N* is a biased estimate of N, although this bias is negligable when Mn ≈ 4N (Robson and Regier 1964) where M is the number of marked animals released at time t_1, n is the number of animals examined for marks at time t_2, and m is the number of marked animals in the second sample. Approximate confidence limits of N* may be obtained by calculating the limits of m from the poisson frequency distribution. The 95% confidence intervals of m are given by:

$$m + 1.92 \pm 1.960 \ \sqrt{m+1} \tag{2}$$

for m > 50 Ricker (1975: 343). Simulations by Roff (pers. comm.) show these limits to be valid if the underlying assumptions of the model are upheld. These assumptions are discussed in Seber (1973) and Bowen (1979) and will be considered later.

Harp seal pups were marked at whelping patches with individually numbered jumbo Roto-tags which were placed in the left hind flipper (single-tagged animals) or in both hind flippers in the case of double marking. The sex, pelage stage, and tag numbers of each double-tagged seal were recorded.

Helicopters, stationed in the Magdelan Islands, St. Anthony, Newfoundland, and aboard the M/V Hudson, were used to distribute tags as randomly as possible throughout the Gulf, Strait of Belle Isle, and Front whelping patches, respectively. Brightly coloured water soluble dye was used to mark the ice at locations where tagging took place. In this way, the chance of concentrating tags in one part of the whelping patch was minimized. The numbers on tags associated with a particular dye mark were recorded to test assumptions of uniform mixing of tagged seals in the recaptured sample.

RESULTS

Tagging

The number of harp seal pups tagged and location of tagging are given in Table 1. In the Gulf, 2,738 pups were single-tagged and 894 were double-tagged between 3 March and 13 March, 1980. A total of 1,205 seal pups were marked from 14 March to 24 March in the Strait of Belle Isle. Included in this figure are 279 pups tagged several km south of Ile de la Grande Passe, Quebec and thought to represent the Meccatina patch. At the Front, 2,080 pups were single-tagged and 330 were double-tagged between 15 March and 18 March. In total, 7,247 harp seal pups were marked in March, 1980. The number of marked seals surviving the large vessel hunt of whitecoats on the Front was 2,410-508 = 1,902. In the Gulf only 31 marked pups were recaptured during the whitecoat hunt leaving a total of 3,601 tagged animals.

Validity of Assumptions

1. N is constant: There were two major whelping patches on the Front in 1980. A northern patch, located 40 km east-northeast of South Wolf Island (53°35'N, 56°05'W), and a southern patch, located 45 km true east of Spotted Islands (53°25'N, 56°15'W), were both observed on 8 March (Fig. 1). At this time the northern patch covered an area of about 55 km², while the southern patch was about half this area. Subsequent observations to 18 March showed that this relative size difference was maintained as both patches drifted south, although the size of both patches increased. When tagging commenced in the northern patch on 15 March approximately 50 km separated it from the southern patch which was not tagged because of logistic and weather factors. The distance between these patches was maintained up until 18 March, the last time both patches were observed on the same day. Catch statistics and tag returns indicate that this separation was maintained well into the landsmen hunt of beaters. This will be discussed in more detail below.

Two whelping patches formed in the Gulf in 1980. The major patch was situated near the Magdalen Islands and was tagged by personnel from the Arctic Biological Station between 3 and 13 March. The second patch was located on 22 March 6 km south of Ile de la Grande Passe, Quebec, and was tagged on 22 and 23 March. This was most likely the Meccatina patch.

In the Strait of Belle Isle, two small whelping patches were spotted from a reconnaissance helicopter on 8 March: one approximately 6 km west of Boat Harbour, Newfoundland, and another 6 km east of Lance au Claire, Newfoundland (Fig. 1). These patches were tagged on 14 and 17 March. Total production in the Strait of Belle Isle and the Meccatina patches was likely 12,000 to 15,000 pups (Brodie, pers. comm.).

Between late March and May 1980, only 6 of 263 (2.3%) Gulf-tagged pups taken were recaptured on the Front, but 16 of 211 (7.6%) Front-tagged pups recaptured were killed in the Strait of Belle Isle and northern Gulf. Thus, there appears to be a net increase in the Gulf herd over this period and a net decrease in the Front herd. However, as tagged and untagged seals are not uniformly mixed in either herd (see below), we cannot assume an increase in Gulf production equal to 5% of Front production. Also, pups whelped in the Straits were recaptured both in the Straits where they would be mixed mainly with Gulf pups and on the Front where they would be mixed mainly with Front pups. However, since the total production was small and relatively little mixing occurred between the Gulf and Front herds, we may assume the size of each herd is constant without introducing serious bias.

2. Animals do not lose their marks: In 1979 and 1980, 1,871 harp seal pups were double-tagged to test this assumption. Recaptures to date are presented in Table 2. Of 379 returns, 23 require more information before we can conclude the tag was lost, both tags were returned in 351 cases, and only one tag was returned 5 times. Therefore, we estimate that 1.4% of pups lose their tags from the time of application in March to late May of the same year.

3. All marks are reported on recovery: To test this assumption, a survey of 35 communities was conducted by one of us (Bowen) from September 2 to 20, 1980. A more detailed analysis of these data will appear elsewhere. Tags were recovered in 18 of these communities from Port Saunders to Durrell, Newfoundland (Table 3). Prior to the survey the tags from 801 pups tagged in 1980 had been returned from these communities. During the survey we purchased the tags from 162 additional pups that were killed during this same period. Thus, 20% of tags recovered from pups tagged and captured in 1980 were not reported.

4. Second sample is simple random sample: In practice it is difficult to know if random sampling has been achieved in the harp seal landsmen hunt of beaters. However, if random sampling of the population has occurred then the relative proportion of tags recaptured in any large area (for the same time period) from different parts of the whelping patch should be equal. Recoveries of Gulf-tagged pups in unit areas 402 and 401 (Fig.1) show a marked trend in return rates with pups tagged early in March being recovered at a higher rate than those tagged in other parts of the patch later in March (Table 4). Thus, it seems unlikely that the second sample was a simple random sample of Gulf pups. Return rates for five areas in the northern Front whelping patch are shown in Table 5. There is significant heterogeneity in return rates which vary from 5.8 to 12.5%. Again, it is unlikely that random sampling of the recaptured sample was achieved.

An unbiased estimate of N may still be determined even though random sampling is not achieved providing that there is uniform mixing of tagged and untagged animals in the population. We used the X^2 test to look for heterogeneity in the proportion of marked pups in the recaptured sample both by area and over time. The data and results are given in Tables 6 and 7 for the Front and Gulf, respectively. Both samples show highly significant heterogeneity which may be reduced but not eliminated by eliminating certain weeks or areas from the analysis. Thus, it is clear that tagged pups are not uniformly distributed throughout the population and hence this assumption is not upheld for either area.

A substantial amount of the heterogeneity in the Front herd data is removed if we consider only unit areas 342 and 341 (see Fig. 1). Seals taken in these areas consist mainly of northern Front pups while, seals taken in areas 340 and 339 most likely comprise mainly southern Front pups. In fact, within both 342 and 341 the proportion of marked pups in the catch is constant over time but different between unit areas. Hence, we tried to reduce the bias resulting from the violation of assumption

4 by pooling the data from these areas and eliminating the high catches in areas 339 and 340 from the analysis which would tend to over-estimate production. For the Gulf estimate we have adopted a similar approach in trying to minimize the bias towards over-estimating production. We have used data from area 401 as the basis for estimating Gulf production. The reasons for this are threefold. First, pups in this more northerly area will have had a longer time to mix. Second, the powerful current system in the Strait of Belle Isle will undoubtedly also enhance uniform mixing and finally, the high rate of tag returns per unit catch in this area will produce a conservative estimate which is preferable when uncertainty is high.

The assumptions of marking not affecting catchability, of all pups having the same probability of being marked and of animals being correctly classified as marked or unmarked were discussed in connection with the 1979 mark-recapture experiment (Bowen 1979) and as far as can be judged were upheld again this year.

Estimates of Pup Production

The catch of beaters by landsmen by week and unit area were obtained from the Economics and Intelligence Branch of the Department of Fisheries and Oceans, St. John's (Table 8). Pups whelped in the Strait of Belle Isle and in the small Meccatina patch were caught in both the Gulf and on the Front. Since it was impossible to separate the catch of these animals from Gulf and Front seals and since we know the number of pups involved was a small fraction of total production, we have not considered them separately, but assume they are included in the Gulf and Front estimates. The southern Front patch is assumed to be discrete from the northern Front patch and an estimate is produced only for the latter. We know from aerial surveys that the southern Front patch covered approximately half the area of the northern patch. Hence, if we make some assumption about the pup density in each patch, we might reasonably guess a minimum size for the southern Front patch. Finally, the estimates of pup production from this experiment are most likely biased estimates as the assumption of random sampling (uniform mixing) is violated. Furthermore, the direction of the bias is not clear. Therefore, we recommend that caution be used in interpreting the results.

Gulf

As stated above this estimate is based on tag returns and pup harvest from unit area 401. Between 16 March and 31 May, 3,421 pups were taken in area 401 of which 113 were marked. A total of 3,601 marked pups survived the large vessel and landsmen kills in the whelping patch. Applying the corrections for non-reporting (20%) and tag loss (1.4%), the number of tagged animals in the second sample becomes 113 x 1.20 x 1.014 = 138. The estimated beater population is calculated as:

$$N^* = \frac{(M+1)\ (n+1)}{(m+1)} = \frac{(3601+1)\ (3421+1)}{138+1} = 88,676$$

The 95% confidence limits of N* are approximated by finding the limits on m from the poisson distribution and the limits on the percentage non-reporting from the binomial distribution. The limits on m = 113 are 94 and 136 and for the percentage non-reporting are 17.3 and 22.9%. Entering these values into equation (1) we have the lower limit of N* equal to 72,506 and the upper limit equal to 109,080. Pup production in the Gulf is then 88,676 plus the large vessel and landsmen pup kill of 29,826 pups or a total of 118,502. The approximate 95% confidence limits of this estimate are 102,332 and 138,906.

Front

A total of 2,409 pups were tagged in the northern Front patch of which 1,902 survived the large vessel hunt. The catch of beaters between 16 March and 17 May 1980, in unit areas 341 and 342, was 11,222 of which 157 were tagged. Adjusting this number for non-reporting of tags and tag loss, the number of tagged seals in the second sample is 191. The number of pups

surviving the large vessel kill, as calculated from equation (1), is 111,178 with lower and upper 95% confidence limits of 92,809 and 133,413. To this we must add the large vessel kill of pups, 71,069, to give total production of the northern Front patch of 182,247 with confidence bounds of 163,878 and 204,482.

The number of pups produced in the southern Front patch can only be guessed. We know it covered approximately half the area of the northern patch and if, to be conservative, we assume the density of pups to be also half that in the northern patch then we have an estimate of about 45,000.

Total production of the Northwest Atlantic population from mark-recapture is estimated to be 300,749 ± 28,500. To this we must add about 45,000 to account for the production of the southern Front patch.

Estimates from long-term recoveries

In addition to estimates based on short-term recoveries (0-group), it is possible to estimate production in year t from recoveries in year t+n using the Petersen estimator where n = 1, 2, 3 ... etc. In practice it is unlikely that there would be sufficient recoveries beyond age 3 to allow reliable estimation, but up to four estimates of pup production might be expected from a single marking. This method is valid only if we assume that tagged and untagged seals suffer the same rate of total mortality and that on average the probability of capture of a marked and unmarked animal is the same. In any particular case, we need not assume that the sample in year t+n is random or that the proportion of marked individuals in the population is uniform, only that there is no systematic tendency toward over- or under-estimation. In this present circumstance this seems reasonable, since in some years too many tags will be recovered while in others not enough depending on the mixture of tagged seals in the population at any point in time. If we have a series of annual tagging episodes, each will yield multiple independent estimates of the same parameter (assuming little change in pup production over the course of 2 to 4 years).

Several other points need to be considered before proceeding. Although estimated tag loss in the first 3 months of life is minimal, at present we do not have estimates of longer term tag loss. On a priori grounds it is not clear for harp seals whether or not tag loss should increase or decrease with time. We have arbitrarily assumed a 5% annual tag loss. Estimates of non-reporting of recovered tags in 1979 (25%) and 1980 (20%) are unlikely to apply to recoveries prior to 1979. The reasons for this are two-fold. First, prior to 1979 the value of the reward for a seal tag was only $4.00 compared to $10.00 since 1979, and second, considerably greater effort was made in recent years to inform hunters of the importance of returning recovered tags and to make it easier for them to do so. We have assumed a value of 50% non-reporting for tags recovered prior to 1979.

It is also necessary to estimate the catch of one-, two- and three-year-olds from which tags of a particular cohort were recovered. We use only the landsmen and large vessel catches of harp seals from January to May for this purpose. These estimated catches for the Front and Gulf are given in Table 9. The age composition of the Gulf catch (NAFO Subareas 4R and 4S) was determined using the average age composition of net samples from the La Tabatiere from 1975 to 1978 and shot samples from les Ecoumins, 1978-80. The age composition of the Front catch (NAFO Subareas 3K and 3L) was determined by applying the appropriate annual age sample to each component of the hunt. As there was no large vessel sample in 1980, the 1979 sample was used.

To date five estimates of pup production in the Northwest Atlantic are possible between 1977 and 1979 from long-term recoveries: two in 1977, two in 1978, and one in 1979 (Table 10). Catches and tag returns from Gulf and Front are combined in these analyses. For the 1977 cohort, estimated pup production is 325,568 and 314,863 from tag recoveries at age 1 and age 2, respectively. The 1978 pup production is estimated to be 515,021 and 534,102 from tag returns at age 1 and age 2, respectively, and the 1979 production is estimated to be 573,772 from recoveries at age 1. Clearly pup production could not have increased from approximately 320,000 in 1977 to over 500,000 in 1978-79. Results of simulation studies of harp seal population dynamics suggest that on average no more than a 5% change in pup production can be expected from year to year (Roff and Bowen 1980).

Given that the underlying assumptions of simple random sampling or uniform
distribution of tags are not upheld for all cases, the above variability
might be expected. Hence, to gain a more accurate estimate of pup
production for this period, we must increase sample size. This may be
done by considering the estimates of pup production of these same cohorts
made from recoveries in the same year (0-group) or from aerial surveys
(Table 11 and Fig. 2).

An aerial photographic census was conducted in 1977 to determine pup
production of the Northwest Atlantic population (Lavigne et al. 1980).
Photographic coverage of the main whelping concentrations on the Front was
judged to be reasonably complete and the numbers of pups estimated to be
in the order of 200,000 (200,504 actually the best estimate). The survey
in the Gulf was incomplete and accounted for fewer than 30,000 pups.
Nevertheless, total production can be estimated using information from
previous aerial surveys on the ratio of Gulf to total production. Of all
the surveys attempted only three, 1959 and 1960 (Sergeant and Fisher 1960)
and 1970 (Sergeant 1971) achieved complete coverage of both herds. The
percentage of the total in the Gulf were 46.8%, 31.9%, and 35.6%, respectively;
a mean of 38.1%. Total production in 1977 then becomes 323,394 pups. This
compares favourably with the estimates of pup production in 1977 from
mark-recapture.

No estimate of 1978 production is possible from short-term recoveries
(Bowen and Sergeant 1979). However, estimates are available for 1979 and
1980 production from mark-recapture (Bowen 1979, this paper). The 1979
estimate, like the 1977 estimate based on aerial survey data, is based on
an estimate of Front production ($\bar{x} \approx 220,000$) and the ratio of Gulf to
total production (38%). Total production in 1979 by this method is
352,000 pups. Given that the estimate of Front production in 1979 is
reliable (i.e. the assumptions of the model were upheld as far as can be
tested) the value of 573,772 must be considered optimistic, since 1979
production would be only 440,000 if we assume Gulf production was 50% of
the total rather than 38%. The 1980 estimate of 345,000 agrees with the
1979 value, but it must be remembered that these data were analyzed in
such a fashion as to minimize the estimate and associated bias.

In total, therefore, we have eight estimates of pup production for
the period 1977-80. Taken separately each estimate is thought or known
to be biased in one direction or the other, either by assuming an average
ratio of Gulf to total production which may vary from 30% to 50%, by
failing to uphold assumptions of random sampling or by failing to account
for some portion of production. However, taken as a whole and assuming
no systematic bias, these may well provide the best available estimate of
total production. Taking the average of these values production is estimated
to be 410,559 pups with approximate 95% confidence bounds of 318,733 and
502,385. Note, the approximate limits given here are most likely under-
estimates as they do not reflect the variation associated with each of the
individual estimates (see Fig. 2).

DISCUSSION

The mark-recapture method used in this study depends heavily upon
there being random sampling, or at least, uniform mixing of tag and
untagged members of the population, for the estimate of N to be unbiased.
Failing to satisfy this assumption, as in the present case, seriously
undermines the confidence that we can have in the estimates. The difficulty
lies in not being able to estimate the magnitude of the bias or its
direction. Although the assumptions of the Petersen model can be satisfied
in this type of experiment (Bowen 1979), we cannot insure their validity
in any given experiment.

Estimates from long-term tag recoveries will provide valuable insight
in determining the level of pup production. If a large number of estimates
begin to cluster about a certain value or range of values, then greater
weight must be attached to this range. However, even here caution must be
exercised, for we must assume that over the long-term and given a large
number of estimates that the biases will cancel one another. While we have

no a priori reasons for expecting a systematic bias in the application of mark-recapture methods to estimating harp seal production, we also have no reason to expect that biases will exactly cancel.

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Table 1. Number and location of pups tagged in March, 1980.

Number	Location			
	Gulf	Strait of Belle Isle	Front	Total
Single-tagged	2,738	978	2,080	5,796
Double-tagged	894	227	330	1,451
TOTAL	3,632	1,205	2,410	7,247

Table 2. Estimates of tag loss[1] from double-tagged harp seal pups.

Year	Number tagged	Number returned	Require information	Both tags returned	Only single tag returned	Tag loss (%)
1979	420	95	10	83	2	2.4
1980	1,451	284	13	268	3	1.1
TOTAL	1,871	379	23	351	5	1.4

[1] from March to May of the same year

Table 3. Results of 1980 community survey to investigate non-reporting of tags.

Community	1980 Front and Strait tags		1980 Gulf tags		Total	
	Before	After	Before	After	Before	After
St. Anthony	170	10	1		171	10
St. Lunaire	18	4		1	18	5
St. Carols	13	11			13	11
Griquet	23	11			23	11
Quirpon	3	1			3	1
Boat Harbour		17		2		19
Englee	80	18			80	18
Brig Bay		1	1		1	1
Wild Cove		12				12
La Scie	40	15			40	15
Shoe Cove	2	1			2	1
Summerford	13	13			13	13
Herring Neck		1				1
Fleur de Lys	10	17		2	10	19
Brighton		3				3
Twillingate	43	1			43	1
Durrell	75	20	1		76	20
Port Saunders	9		14	1	23	1
Pacquet	2				2	
Eddies Cove	6				6	
Roberts Arm	4				4	
Roddington	13				13	
Baie Verte	15				15	
Springdale	2				2	
Wesleyville	1				1	
Nippers Harbour	1				1	
Whales Gulch	2				2	
Lumsden	77				77	
Total	622	156	17	6	639	162

Non-reporting rate = 162/801 = 20.2%

Table 4. Return rates of Gulf-tagged pups by day of tagging
in unit areas 401 and 402 between 23 March and
17 May, 1980.

Day of Tagging (March, 1980)	Number tagged	Number recovered		% recovered	
		401	402	401	402
3	400	24	18	6.0	4.5
4	600	35	10	5.8	1.7
5	200	13	4	6.5	2.0
7	795	11	8	1.4	1.0
8	298	5	3	1.7	1.0
10	600	16	6	2.7	1.0
11	200	3	0	1.5	0.0
13	370	6	1	1.6	0.3
Total	3,463	113	50		

Table 5. Test of heterogeneity in return rates of Front-tagged
pups (from different parts of the whelping patch)
recaptured between 22 March and 17 May, 1980.

Day of Tagging (March)	Number tagged	Number tagged surviving large vessels	Number returns	% Recovery
15	237	152	19	12.5
16	599	383	22	5.8
17	611	611	76	12.4
18	170	161	12	7.5
18[1]	412	255	26	10.2
Total	2,029	1,562	155	

$X^2 = 12.53$, df = 4, P < .05

[1] different area of patch

Table 6. Test of independence of the proportion of Front-tagged pups in the recaptured sample by week and unit area.

					Unit Area							
	339		340		341		342		401		Total	
Date	M	NM	M	NM	M	NM	M	NM	M	NM	M	NM
Mar. 9-22	0	0	2	0	2	22	2	80	3	18	9	120
Mar. 23-Apr. 5	2	875	1	691	27	1,245	9	315	4	410	43	3,536
Apr. 6-19	9	4,806	22	5,153	56	1,628	39	2,579	8	1,298	134	15,464
Apr. 20-May 3	1	659	1	1,317	9	2,016	13	2,894	1	1,257	25	8,143
May 4-17	0	0	0	69	0	23	0	206	0	387	0	685
Total	12	6,340	26	8,230	94	4,934	63	6,074	16	3,370	211	27,948

$X^2 = 372.63$, df = 19, P > 0.001

Table 7. Test of independence of the proportion of Gulf-tagged pups in the recapture sample by week and unit area.

		Area				
	401		402		Total	
Date	Marked	Not Marked	Marked	Not Marked	Marked	Not Marked
Mar. 16-29	2	468	4	42	6	510
Mar. 30-Apr. 12	16	161	25	1360	41	1521
Apr. 13-26	56	2199	0	1873	56	4072
Apr. 27-May 10	1	502	-	-	1	502
May 11-24	3	6	-	-	3	6
Total	78	3336	29	3275	107	6611
Unknown date Apr.	28		20			
Unknown date	12		1			

$X^2 = 187.73$, df = 7, P > .001

Table 8. Pup catch landsmen[1], 1980.

Date[2]	Week	201	208	336	337	338	339	340	341	342	401	402	404	Total
										Unit area				
Mar. 15	12					19								19
Mar. 22	13								24	82	21	3		144
Mar. 29	14						2	6	2	324	414	43		812
Apr. 5	15			1			875	686	1271					2833
Apr. 12	16				27	403	3487	1451	5	805	177	1385	42	7782
Apr. 19	17			7		58	1328	3724	1679	1813	1129	1200		10938
Apr. 26	18	62	1	4		2	638	1175	1715	2713	1125	673		8108
May 3	19				1	1	22	143	310	194	133			804
May 10	20				3	1				202	369			575
May 17	21			3	4	1		69	19	4	7			107
May 24	22			1	1						2			4
May 31	23			2							9			11
June 7	24				1									1
Total		62	1	18	37	485	6352	7254	5025	6197	3421	3314	42	32,208

[1] includes small boats, long-liners, nets and beater catch of ships in area 342

[2] week seals were killed

Table 9. Catch of seals age 1 to 4 from January to May, 1978-80, by landsmen and large vessels.

Age	1978			1979			1980		
	Front	Gulf	TOTAL	Front	Gulf	TOTAL	Front	Gulf	TOTAL
1	15147	118	15265	13231	259	13490	13564	361	13925
2	9080	411	9491	5361	487	5848	5890	762	6652
3	4677	789	5466	2352	743	3095	3133	1238	4371
4	3267	746	4013	1368	591	1959	1582	1037	2619

Table 10. Estimates of pup production in 1977, 1978, and 1979 from long-term recoveries of tags.

Cohort	Year tags recovered	Estimate at age	M	m	m^1	n	$\hat{N}_S$	K	$\hat{N}_T$
1977[2]	1978	1	1230	48	74	15147	253952	71616	325568
1977	1979	2	1230	22	29	5848	243247	71616	314863
1978[3]	1979	1	9167	214	278	13490	443000	72021	515021
1978	1980	2	9167	105	131	6652	462081	72021	534102
1979[3]	1980	1	4939	118	148	13925	461708	112064	573772

[1] Corrected for non-reporting of tag and tag loss.
[2] Tags applied only in Gulf.
[3] Tags applied Gulf and Front.

$\hat{N}_S$ = no. of pups surviving whitecoat hunt by large vessels and landsmen from Magdelen Island.

K = kill of whitecoats by large vessels and landsmen from Magdelen Islands.

$\hat{N}_T$ = total pup production.

Table 11. Estimates of pup production between 1977 and 1980 from mark-recapture and aerial surveys.

Cohort	Estimate of age		
	0	1	2
1977	323394[1]	325568	314863
1978	N/A	515021	534102
1979	352000	573772	
1980	345749		
Mean	410559 ± 91826	(± approx. 95% C.I.)	

[1]based on 1977 aerial photographic census

Fig. 1. Map showing locations of whelping patches on the Front and in the Strait of
Bell Isle from 4 to 26 March, 1980. Recapture unit areas also shown:
▲ - northern Front; ⨯ - southern Front; ● - Strait of Belle Isle;
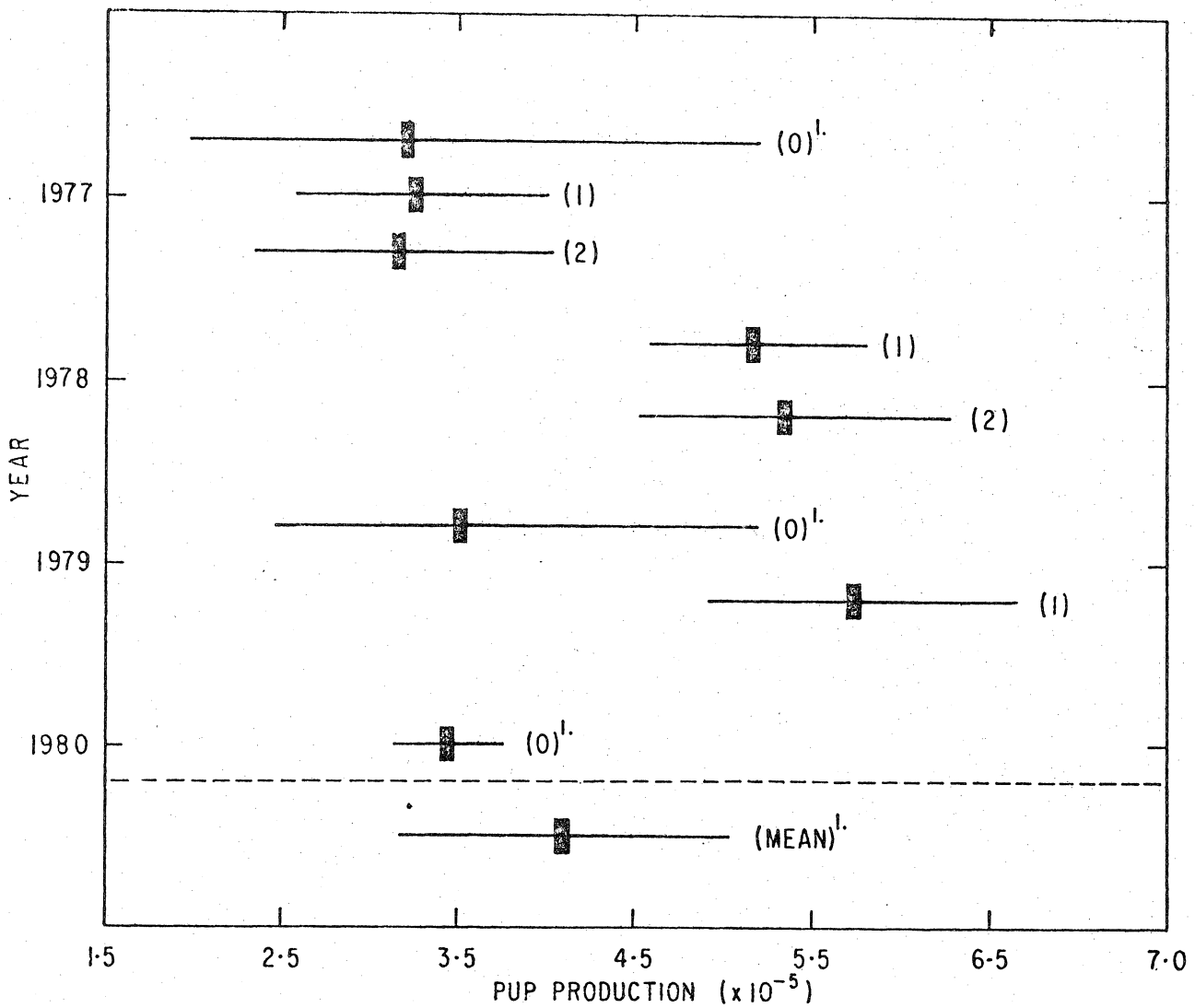☆ - Meccatina patch.

Fig. 2. Estimates of pup production between 1977 and 1980 from short- and long-term tag recoveries and from the 1977 aerial survey. Number in parenthesis indicates age of seals from which tags were recovered. Mean (■) and 95% confidence limits (——) are given for each estimate.

[1]Confidence limits are rough approximations only and are not statistically valid.