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Eastern Canadian Grey Seal (*Halichoerus Gryplus*) Research Report and 1980 Stock Assessment

by

K. Zwanenburg, B. Beck and S.J. Smith
Marine Fish Division
Fisheries & Oceans
Dartmouth, Nova Scotia B2Y 4A2

ABSTRACT

The present document reviews the research which has been carried out on grey seals in eastern Canada during the 1979-1981 period, and presents an assessment of the population to 1980. This assessment is based on a number of data sources which will be detailed in the text. Foremost among these are the results of five years of complete cohort tagging carried out on Sable Island, Nova Scotia. The results of these tagging studies were used to estimate total pup production in eastern Canada, to provide guidelines for fine tuning of cohort analyses, and to estimate patterns of natural mortality in the population. The results of these analyses indicate that the level of the population in 1980 stood at between 44,000 and 48,000 age 1+ individuals with no evidence of any decline in population numbers or pup production in the past several years.

On trouvera dans le document qui suit une revue de la recherche menée sur les phoques gris de l'est du Canada pendant la période de 1979 à 1981. Nous y présentons également une évaluation de la population jusqu'à 1980. Cette évaluation est fondée sur des données provenant de plusieurs sources dont nous donnons les détails dans le texte. Les résultats de cinq années d'étiquetage de cohortes complètes effectuée à l'île de Sable (Nouvelle-Ecosse) sont les données les plus importantes. Nous les avons utilisées pour estimer la production totale des chiots de l'est du Canada, donner des lignes directrices dans l'ajustement précis des analyses des cohortes et estimer les caractéristiques de mortalité naturelle de la population. D'après ces analyses, l'effectif de la population en 1980 était compris entre 44 000 et 48 000 sujets d'âge 1+, sans qu'il y ait signe de déclin d'effectif de population ou de production de chiots depuis plusieurs années.

Description of the data

Three main sources of data have been utilized in the present assessment. In 1968, 1969, 1970, and 1975 random samples of grey seals were shot by trained collectors and each animal was aged (Table 1). From 1967 to the present the Department of Fisheries and Oceans have been carrying out a controlled cull of grey seals in the Gulf of St. Lawrence, and on the islands off the eastern shore of Nova Scotia. These animals, including both pups and adults are sexed but not aged (Table 2). From 1976 to the present a bounty has been put on grey seals providing another source of aged animals with which to determine the population age distribution (Table 3). In addition to these three sources of information all pups of the Sable Island breeding colony have been tagged since 1977. Returns from the bounty kill have provided returns of these tagged animals from which estimates of total population pup production can be obtained.

Tagging data

From 1977 to the present all pups born on Sable Island have been tagged. This program has provided valuable information on grey seal distribution and has been used, in the present assessment to obtain estimates of total pup production.

The most simplistic approach to estimating pup production is to treat the 0+ animals as the entire population and estimate their numbers using a Petersen index (Ricker 1975). This method has the following underlying assumptions:

(1) marked animals suffer the same natural mortality as the unmarked;

(2) marked animals are as vulnerable to hunting as the unmarked animals;

(3) marked animals do not lose their marks;

(4) marked animals become randomly mixed with the unmarked animals, or the distribution of hunting effort is proportional to the number of animals present in different parts of the animals distribution;

(5) all marks are recognized and reported on recovery; and,

(6) there is only a negligible amount of recruitment to the catchable population during the time recoveries are being made.

Observations made during the tagging operations on Sable Island indicate that tagging results in very little physical damage to the pups. Longer term observation of tagged pups gives no evidence of morbidity or mortality as a result of tagging. Furthermore, tagging of unweaned pups does not result in premature abandonment by the female, a major cause of pup mortality. From the foregoing observations it would seem that tagging itself does not result in any increased mortality. Whether or not the tag is the cause of higher mortality rates at some later date cannot be addressed at present, but there is no prior reason to assume that this is the case.

Preliminary results indicate that tag losses run at approximately 3% (Gray unpublished data). This figure was derived from a very small number of double tagged animals so that care must be taken in the interpretation. If this percentage of tag loss is realistic it is unlikely to seriously bias our estimates.

Assumption 5 states that all marks be recognized and reported on recovery. A substantial reward is paid for each tag returned in an attempt to ensure that this assumption is not violated. At present there is no available information to indicate the actual numbers of tags which are recovered but which are not reported. In the absence of this information there is the possibility that our estimates of pup production are biased slightly upwards.

Since grey seals pup only during a protracted period from December to January, and recoveries are only made after the pupping season, there is no recruitment to the catchable portion of the population during the time recoveries are being made.

If the assumption that marked and unmarked animals are equally vulnerable to hunting holds, then the proportion of marked to unmarked animals in successive samples should remain constant.

If we assume that marked and unmarked animals suffer the same mortality with time then taking samples from a single cohort in successive years should result in a constant ratio of marked to unmarked animals (capture probability). Table 4 indicates that this is not the case. For each of the three cohorts (1977, 1978, 1979) for which samples are available on successive years, the capture probability is highest for the pups and begins to stabilize at ages 1+. For this reason estimates of pup production in any given year were derived from recapture of that cohort at age 1+.

Several possible explanations exist for the increased capture probability of marked animals at age 0+. It may be that hunters will turn in the tag of a marked pup because of the reward paid for the tag; however if an untagged pup is shot this may not be reported unless the individual is aware of the bounty paid for the jaw alone. This problem is very evident with returns from Newfoundland where nearly all returns consist of tags only. Since these data were easily identified as a source of bias, they were excluded from subsequent analysis.

Finally there is some question as to the validity of assumption 4 which states that either marked animals become randomly mixed with the unmarked animals or the distribution of hunting effort is proportional to the number of animals present in different parts of the population. At present the data on distribution of tag returns have not been analyzed. In the absence of this analysis no definite statement as to the random distribution of marks in the population can be made. Even in the absence of this more definitive analysis it is obvious that marked animals do distribute themselves over the entire range of the population (as judged from the locations of returns). In 1979 and 1980 segments of the Gulf of St. Lawrence pup production were tagged in addition to the Sable born pup, thereby increasing the likelihood of attaining a random distribution of marks by increasing the number of localities from which pups were tagged.

A summary of the tag and recapture data used to estimate pup production in the last four years is presented in Table 4. These data indicates that capture probability is highest for pups and begins to stabilize at older ages. Pup production in each year was determined from the returns of 1+ animals since they consistently show the lowest variance in this older segment of the population.

To estimate total pup production (Table 5) in each of the years it is necessary to include those taken by the yearly cull since they are removed from the population prior to tagging. Since total production on Sable Island is known for 1962-1981 (Table 6), Gulf production can be estimated by substracting Sable Island production from total pup production (Table 5). These estimates indicate that both Gulf and Sable Island pup production have been increasing over the last four years.

Construction of the catch at age table

Two sources of aged animals were available to construct the catch at age table, the collector kill and the bounty kill. The third source of animals, those taken by the departmental cull, are not aged. The adult portion of the cull catch was aged in the following manner. For the years 1967, and 1971-1974, the total collector kill age distribution (Table 1) was calculated, this distribution was multiplied by a pregnancy rate vector, (Table 7) (Mansfield and Beck 1977) to adjust the age structure to that occurring on the breeding grounds. The total adult cull numbers were distributed over the resulting age structure. Thus for these years the total number of animals taken were those taken in the departmental cull. For the years 1968, 1969, 1970 and 1975 the collector hunt data for each of these years was used in a similar manner to break out the cull age structure. For these years the estimated numbers at age of the culls and the numbers at age in the collector kills were summed to arrive at the total yearly removals. From 1976 to the present the bounty kill samples were used in a similar manner to prorate the cull sample.

Age structures were calculated as follows:

$$C_i \times PR_i = B_i$$

where C_i is the number of animals killed at each age i, PR_i, is the pregnancy rate at age i, and B_i is the number of animals at age i which occur on the breeding grounds. The proportion of total numbers of animals at each age on the breeding ground is given by:

$$\frac{B_i}{\sum_{i=4}^{i=21^+} B_i} = P_i,$$

where P_i is the proportion of total animals at each age i. These proportions at age are then multiplied by the total numbers of adults in the cull, to get numbers at age for the culled animals, and finally, the cull and appropriate age samples are summed to give total removals at age for any given year.

In 1978 the bounty kill sample was only partially aged before the samples were destroyed by fire. For this year the age distribution was calculated from the aged portion (including all returns to Nov. 1, 1978) and this age structure applied to the remaining bounty kill sample to generate the complete bounty kill age structure. This age structure was in turn used to break out the breeding ground age composition of the controlled cull sample in the manner described above. Final removals at age are given in Table 8.

Estimating survival and exploitation rates from tag return data

Multiple mark recapture experiments when used for the pupose of estimating population abundance and related paramters fall into two general classes. In a live trapping type of experiment a random sample of animals is taken from the population of interest, each animal is usually marked or tagged and the sample is returned to the population. At a later time a second random sample is taken and the proportion of the marked individuals in the sample is noted. The unmarked animals in the sample are then marked and the sample is returned to the population. This process is repeated until the desired number of samples is obtained. If unique marks or tags are assigned to each individual captured, a complete capture history will be available for each individual caught, but more often than not the practice is to use time specific marks (tags) only. From this kind of data estimates of the population size, natality rate and mortality rate can be obtained. These methods are reviewed in Seber (1973).

For the grey seals the second kind of mark recapture experiment was carried out. In this case the tagged animals which are recaptured are not returned to the population because the recapture process requires that the animals are killed for a bounty. Because of this restriction the data from this type of experiment, the dead trapping (or recovery) method, cannot be readily used to obtain multiple estimates of population size but it can be used to obtain estimate of survival rates and exploitation rates assuming that the marked subpopulation behaves the same as the unmarked population (Brownie et al. 1978).

These estimates of survival and exploitation are obtained from the grey seal data by applying a multinominal model developed by Seber (1971). This model is specific for the case when pups only are tagged and released and assumes that survival rate (ϕ_i) depends on age i only. Two constraints are introduced to make the parameters identifiable. Firstly the exploitation rate (λ) is assummed constant over all the ages and secondly if the recovery period is carried out over t years (i = 1,..., t) the survival rate for age t-1 is assumed equal to the survival rate for age t i.e. $\phi_{t-1} = \phi_t$.

Maximum likelihood methods are used to drive the estimates $\hat{\phi}_i$ and Var ($\hat{\phi}_i$) from the multinominal model while λ (exploitation rate) is a weighted version of a moment type estimator. The variance estimators $\hat{Var}$ ($\hat{\phi}_i$) are conditional asymptotic variances but will be close in value to the unconditional form if the recovery rate tends to be large (generally 10% or greater).

For the grey seal recovery data (years 1977-1980) the following estimates of $\emptyset_i$ and their respective standard errors were obtained:

Age	$\emptyset_i$	$\left[\hat{Var}(\hat{\emptyset}_i)\right]^{1/2}$
1	0.4583	0.02387
2	0.7386	0.02964
3	0.7545	0.04061
4	0.7545	0.04061

The estimate of the exploitation rate (λ) was estimated to be equal to 0.07232.

In order to asses how well the multinominal model fit our observations a chi-squared test described in Seber (1971) was carried out. The expected and observed values are listed in the Table 10. The test statistic was equal to 7.31 (degrees of freedom = 5) indicating that the model fits the data extremely well (table critical value for $\alpha = 0.10$ is 9.24). Recently, however North and Cormack (1981) have pointed out that even though the goodness-of-fit test associated with this model may indicate that the model fits the data well there are problems with Seber's method. The main problem being that due to the constraint $\emptyset_{t-1} = \emptyset_t$, the estimates of survival at the earlier ages are highly dependent upon the few observations obtained at the older ages. In addition there is also the possibility that the survival estimates may fall outside the 0-1 range rendering them invalid. We hope to explore this matter further in order to determine if the tagging data can be analyzed by alternative approaches so that estimates of survival can be obtained.

Cohort Analysis

Gray (unpublished data) assumed a constant M of 0.067 over all age groups. This assumption is consistent with rates of instantaneous total mortality calculated from the catch at age matrix ($Z_{1-20} = 0.90$) since hunting mortality (F) is expected to be low in commercially unexploited populations. There is, however, some question as to the reliability of this estimate of Z since no accurate measure of effort, expended on the bounty each year, is available. It may be that bounty hunters have become more efficient over past years or that increased bounties have increased effort. If this is the case then the Z value assumed above may be an underestimate resulting in underestimates of M. For this reason two scenarios were employed in the cohort analyses, one with an M constant at 0.067 and a second with M constant at 0.10.

Each of these M values was used in turn to calculate F values at age, using the following relationship:

$$N_i = N_{i+1} \cdot (e^M) + C_i \cdot (e^{M/2})$$

$$\therefore N_{i+1} = \frac{N_i - C_i \cdot (e^{M/2})}{e^M}$$

Since pup productions in 1977-1980 have been estimated from the Petersen method (Table 5) these values can be used for the values of N_i at age 0 in those years to start the calculations. Catches at age in each succeeding year are given in Table 9. From these calculations it is possible to calculate values of Z by:

$$\log_e \left(\frac{N_{t+1}}{N_t}\right) = Z,$$

from Z, F can be calculated since M is assumed. The results of these calculations are given in Table 9 resulting in final F vectors of:

M = 0.067

Age	0	1	2	3	4	5	6
	0.087	0.0152	0.0069	0.0069	0.009	0.014	0.021

M = 0.10

Age	0	1	2	3	4	5	6
	0.0912	0.0160	0.0079	0.0079	0.009	0.014	0.023

These vectors of F reflect what is known about the population in question. The highest hunting mortality is suffered by the pups, since they represent the largest proportion of the animals removed both by the bounty and the yearly cull. Juveniles and subadults suffer a lower hunting mortality since they do not occur on the breeding grounds in large numbers, and this is where a major proportion of the total adult kill is taken each year. The hunting mortality again increases as these animals begin to frequent the breeding grounds and it has been assumed that all animals of age 6 or older would suffer the same hunting mortality. The values of F at ages 4 and 5 were estimated using the pregnancy rate vector and assuming that this reflects the proportions of animals at each of these ages occurring on the breeding grounds. To estimate the F values at age 6 and older cohort analyses (VPA, Rivard 1980) were run in an iterative manner until it resulted in a population which could account for the pup production figures in the latter years. Pup production from the numbers at age matrices were calculated as:

$$\text{TOTAL PUP PRODUCTION} = \sum_{i=1}^{i=20} \frac{N_{ij} \times P_i}{Z} + \left(.0819 \sum_{\frac{i=1}{2}}^{i=20} N_{ij} \right) \times P_i$$

where N_{ij} = numbers at age i and year and P_i is the percent pregnant at age i.

The resulting populations and their pup production are given in Tables 11, 11a, 12, 12a. With a constant M of 0.067 the estimated 1+ population in 1980 would be approximately 48,000 with a pup production of 10,806. Using an M of 0.1 results in a 1+ population of approximately 45,000 with a pup production of 10,154.

The preceding analyses indicate that the eastern Canada grey seal stock has been increasing at an average rate of 6.5% over the last four years. No evidence was found to indicate that this increasing trend is levelling off. The number of pups culled by the department in 1981 (1212) is higher than in past years indicating that large numbers of pups are still being produced in the Gulf. Table 6 indicates that pup production on Sable Island in 1981 is lower than in 1980. This may suggest a downturn of pup production on Sable Island but several factors must be taken into consideration before coming to this conclusion. In 1972 pup production on Sable decreased compared to that shown in 1971, however ice conditions in the Gulf of St. Lawrence were such that they may have prevented seals from reaching the island breeding colony that year. Further evidence for this is the fact that in 1973 pup production was again at levels which would have been predicted from the rate of increase in the population between 1962 and 1970. Ice conditions in the Gulf in early 1981 were similar to those seen in 1972. It is thus possible that a portion of the grey seal population, normally pupping on Sable Island was not able to reach their destination resulting in the lower number of pups observed.

Grey Seal Population Projection

Projections of grey seal population numbers, under various hunting strategies, were run. Three scenarios were investigated:

1) a hunting strategy which keeps the population numbers stable at 1980 levels for 10 years;

2) a hunting strategy which would result in a 33% reduction of the 1980 levels within 10 years; and

3) a hunting strategy which would result in a 66% reduction of the 1980 levels within 10 years.

Projections

In this paper were present two scenarios which differ in their values of M, therefore in the present projections each of the three hunting strategies will be calculated using each of the values of M (M=0.067, M=0.10).

The projections were run in the following manner. Numbers at age and catch at age for 1980 were projected forward using each of the above M values and their partial recruitment vectors. The vectors were calculated for each value of M from the final F vectors given previously.

$$\frac{F_i}{F_{max}} = PR_i$$

where F_i is the hunting mortality experienced at age i, F_{max} is the maximum hunting mortality experienced by all ages and PR_i is the partial recruitment to hunting at age i.

The resulting partial recruitment vectors used in the analyses were:

M = 0.067

Age	0	1	2	3	4	5	6
PR	1.00	0.1695	0.0769	0.0769	0.1003	0.1561	0.2341

M = 0.10

Age	0	1	2	3	4	5	6
PR	1.00	0.1754	0.0866	0.0866	0.0987	0.1535	0.2522

To establish a stable population, a constant recruitment equal to that calculated for 1980 was used over the 10 year period from 1981 to 1990. The resulting age structure was used to calculate pup productions in each of the 10 years and these calculated values were used as the recruitment input to a second iteration. This iterative procedure was repeated until:

1) the desired population levels in each of the years was reached, and

2) the pup productions generated from the resulting numbers at age values, remained constant after the final iteration.

To achieve the requisite reduction in population number, the final value for 1+ animals required by 1990 was calculated and an approximate vector of recruits entered for the initial run. The iterations were again continued until the above mentioned criteria were met.

With a natural mortality of 0.100 the population will remain constant at approximately 45,000 1+ animals (Table 13a) under the hunting pressures given in Table 13b. Reducing this population by 33% (Table 14a) requires removing 8000 animals from 1981-1985, 6000 animals in 1986 and 1987 and 5000 animals in 1988-1990 (Table 14b). To reduce this population by 66%, (Table 15a) a total of 8000 animals should be removed between 1981 and 1986 whereafter the kill should be increased to 9000 animals for the next four years (Table 15b). These three hunting strategies are summarized in Figure 1.

With a natural mortality of 0.067 the population remains at approximately 48,000 1+ animals (Table 16a) under the hunting pressures given in Table 16b. In this case, 10,000 animals, as opposed to the 8,000 in the previous scenario, should be removed for the first two years; after which the hunt can be gradually reduced to 7,000 animals in 1989. Reducing this population by 33% (Table 17a) requires culling 10,000 animals from 1981-1987 followed by three years of hunting at 9,000 animals per year (Table 17b). A reduction of 66% (Table 18a) requires the removal of 10,000 animals from 1981-1985, 15,000 animals for the next two years a reduced kill of 10,000 animals in 1988, and a further reduction to a cull of 9,000 animals in 1989 and 1990 (Table 18b). These three hunting strategies are summarized in Figure 2.

In each of Tables 13 through 18 the sums of population numbers i.e. 1+, 2+, etc., refer to total numbers from age 1-20, 2-20 etc. In the figures following each set of tables the 1+ numbers refer to the actual totals including those animals aged 21 and older. This segment of the population comprises some 8% of the total 1-20 population numbers.

In each of the preceding hunting strategies previously the partial recruitment vectors, calculated from the F vectors given were maintained, because they were felt to reflect the hunting patterns actually impinging on the population. This recruitment vector indicates high hunting pressures on pups, which are most heavily exploited during the cull, a decreased hunting pressure on juveniles, which do not occur on the breeding grounds where a large proportion of the animals are killed, and a somewhat higher hunting mortality on adults. This hunting pattern requires that of the total number of animals killed each year approximately half are pups (Tables 13-18b).

Since these projections are based on estimates of population parameters with wide variance estimates, caution should be used in their interpretation. Implementation of the long-term hunting strategies presented would not be advisable in the absence of further, more long-term estimates of the input parameters. However, in light of the fact that the population appears to expanding any measures to check their growth in the future would become more and more difficult. It is therefore recommended that, as a short-term strategy, aimed at either stabilization or future reduction of the grey seal population, between 8,000 and 10,000 animals be killed each year for the next two years. Approximately half this number should be pups with the other half composed of juveniles and adults.

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Table 1 . Age distributions of collector killed samples.

Age	1968	1969	1970	1975	Total 1968-1975
0	10	46	110	30	196
1	2	6	28	19	55
2	5	10	28	17	60
3	9	11	28	8	56
4	7	9	21	16	53
5	6	11	19	8	44
6	0	7	15	5	27
7	4	4	4	3	15
8	4	8	8	1	21
9	2	7	2	3	14
10	4	6	8	0	18
11	2	1	6	1	10
12	1	3	8	0	12
13	1	0	2	0	3
14	0	1	2	1	4
15	1	1	1	1	4
16	0	1	0	1	2
17	8*	8*	15*	4*	5
18	-	-	-	-	3
19	-	-	-	-	3
20	-	-	-	-	4
21	-	-	-	-	20
Total 1+	56	94	195	88	433
Total 0+	66	140	305	118	629

*Indicates that these include animals older than 17. The data on detailed 17+ distribution for individual years was lost.

Table 2. Controlled cull[1].

Year	Males	Females	Total Adults[2]	Pups	Total
1967	14	3	17	212	229
1968	16	2	18	134	152
1969	3	19	189	589	778
1970	-	-	125	520	645
1971	-	-	122	743	865
1972	22	110	132	599	731
1973	4	35	64	558	622
1974	17	109	126	1042	1168
1975	54	480	534	1619	2153
1976	13	83	96	545	641
1977	150	192	342	1046	1388
1978	59	88	147	569	716
1979	15	30	45	269	314
1980	46	165	211	921	1132
1981	119	277	396	1212	1608

[1] Includes seals killed by others and found during the cull.

[2] Not all adults are sexed so the total may be different from males plus females.

Table 3. Age distributions of bounty kill samples.

Age	1976	1977	1978[1]	1979	1980
0	188	202	363	420	379
1	51	29	63	133	81
2	66	31	17	51	50
3	53	30	33	26	35
4	61	24	9	28	19
5	48	32	22	22	24
6	45	31	14	29	24
7	26	27	15	32	30
8	35	32	17	23	26
9	16	24	9	29	28
10	16	19	7	23	23
11	24	19	9	21	19
12	18	16	14	18	22
13	7	16	5	14	15
14	14	15	10	9	22
15	13	10	3	13	9
16	14	11	3	13	9
17	5	8	14	13	8
18	4	6	3	8	8
19	5	5	2	4	9
20	5	5	3	0	6
21+	20	21	15	32	38
Total 0+	734	613	650	961	884
Total 1+	546	411	287	541	505

[1] See text for explanation.

Table. 4. Mark and recapture results, and pup production estimates. M = total numbers marked, n = total numbers of animals caught at age i, and m = the total numbers of marked animals caught at age i.

1977 (M = 1967)

Age at Recapture	n	m	m/n	$\hat{N}$	$\hat{N}^*$	$\hat{V}[\hat{N}]^{\frac{1}{2}}$	$\hat{V}[\hat{N}^*]^{\frac{1}{2}}$
0	187	55	0.2941	6,688	6,607	757.65	733.27
1	62	13	0.2097	9,381	8,856	2,313.04	2,016.60
2	50	10	0.2000	9,835	9,124	2,781.76	2,436.40
3	35	8	0.2286	8,606	7,872	2,672.30	2,155.84

1978 (M = 2266)

Age at Recapture	n	m	m/n	$\hat{N}$	$\hat{N}^*$	$\hat{V}[\hat{N}]^{\frac{1}{2}}$	$\hat{V}[\hat{N}^*]^{\frac{1}{2}}$
0	175	48	0.2743	8,262	8,143	1,015.8	978.2
1	132	29	0.2197	10,314	10,050	1,691.9	1,588.5
2	48	12	0.2500	9,064	8,545	2,266.0	1,957.5

1979 (M = 3180)

Age at Recapture	n	m	m/n	$\hat{N}$	$\hat{N}^*$	$\hat{V}[\hat{N}]^{\frac{1}{2}}$	$\hat{V}[\hat{N}^*]^{\frac{1}{2}}$
0	385	131	0.3403	9,345	9,301	663.23	654.30
1	79	25	0.3165	10,047	9,788	1,661.55	1,547.57

1980 (M = 3410)

Age at Recapture	n	m	m/n	$\hat{N}$	$\hat{N}^*$	$\hat{V}[\hat{N}]^{\frac{1}{2}}$	$\hat{V}[\hat{N}^*]^{\frac{1}{2}}$
0	349	72	0.2063	16,529	16,349	1,735.43	1,691.29

Note: $\hat{N} = \dfrac{Mn}{m}$, $V[\hat{N}] = \dfrac{M^2 n(n-m)}{m^3}$

$$\hat{N}^* = \frac{(M+1)(n+1)}{(m+1)}, \hat{V}[N^*] = \frac{(M+1)^2\,(n+1)\,(n-m)}{(m+1)^2\,(m+2)}$$

Table 5. Grey seal pup production estimates from tag recapture data.

Year	Total Pup Population	Total Pup Production*	Gulf Pup Production	Sable Pup Production
1977	8856	9902	7721	2181
1978	10050	10619	7932	2687
1979	9788	10057	7057	3000
1980	16349	17270	13525	3745

*Total pup production was calculated by adding the number of pups removed by the departmental cull (Table 2) to our estimates of total pup population from age 1+ recaptures (Table 4).

Table 6. Pup production on Sable Island.

Year	Number of Pups[1]
1962	350
1963	400
1964	550
1965	660
1966	-
1967	580
1968	750
1969	836
1970	930
1971	1060
1972	982
1973	1226
1974	1278
1975	-
1976	2006
1977	2181
1978	2687[2]
1979	3000
1980	3745
1981	3142

[1] These data include both actual counts and estimates of actual counts from a figure in Mansfield and Beck (1977).

[2] This total may include part of the Camp Island group disturbed by hunters early in the pupping season.

Table 7. Pregnancy rates for females grey seals from Mansfield and Beck 1977.

Age	Percent Pregnant
0	0
1	0
2	0
3	0
4	0.16
5	0.71
6	0.85
7	0.85
8	0.85

Table 8. Grey seal removals at age.

AGE	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
0	212	144	635	630	743	599	558	1042	1649	733	1248	932	689	1300
1	0	2	6	28	0	0	0	0	19	51	29	63	133	81
2	0	5	10	28	0	0	0	0	17	66	31	17	51	50
3	0	9	11	28	0	0	0	0	8	53	30	33	26	35
4	1	8	15	26	6	6	3	6	70	64	29	11	29	21
5	3	9	41	41	21	23	11	22	128	60	63	39	25	37
6	2	0	30	36	16	17	8	16	95	59	67	27	33	40
7	1	6	17	10	9	9	5	9	57	34	58	29	37	50
8	2	6	34	19	12	13	6	13	19	46	69	32	26	43
9	1	3	30	5	8	9	4	8	57	21	52	17	33	46
10	2	6	26	19	10	11	5	11	0	21	41	13	26	38
11	1	3	4	14	6	6	3	6	19	31	41	17	24	32
12	1	2	13	19	7	7	4	7	0	23	34	27	21	37
13	0	2	0	5	2	2	1	2	0	9	34	10	16	25
14	0	0	4	5	2	3	1	2	19	18	32	19	10	37
15	0	2	4	2	2	3	1	2	19	17	22	5	15	15
16	0	0	4	0	1	1	1	1	19	18	24	5	15	15
17	1	3	4	2	3	3	2	3	19	7	17	27	15	13
18	0	0	9	0	2	2	1	2	19	5	13	5	9	13
19	0	2	4	2	2	2	1	2	0	7	11	4	5	15
20	0	2	0	5	2	3	1	2	19	7	11	5	0	10
21+	2	6	17	26	11	12	6	12	19	26	45	29	37	63
1+	17	76	283	320	122	132	64	126	622	643	753	434	586	716
0+	229	220	918	950	865	731	622	1168	2271	1376	2001	1366	1275	2016
NK										2	9	0	57	11

Table 9. Calculation of F at-age using pup production estimates from Petersen mark recapture data.

A. Assume M = 0.067 and is constant at all ages.

AGE	1977 $N_i(C_i)$	1978 $N_i(C_i)$	1979 $N_i(C_i)$	1980 $N_i(C_i)$
0	9902 (1233)	10619 (895)	10057 (834)	-
1	-	8067 (62)	9065 (132)	8598
2	-	-	7484 (50)	8350
3	-	-	-	6951

F in 1979 at age	0	1	2
	0.0897	0.0152	0.0069

B. Assume M = 0.10 and is constant at all ages.

AGE	1977 $N_i(C_i)$	1978 $N_i(C_i)$	1979 $N_i(C_i)$	1980 $N_i(C_i)$
0	9902 (1233)	10619 (895)	10057 (834)	-
1	-	7787 (62)	8757 (132)	8307
2	-	-	6987 (50)	7798
3	-	-	-	6274

F in 1979 at	0	1	2
	0.0912	0.0160	0.0079

Table 10. Observed and expected values (in brackets) of grey seal recoveries.

	AGE OF RECAPTURE			
Year of release	0	1	2	3
1977	70(69.11)	14(15.29)	11(10.6)	8(8)
1978	85(93.85)	30(20.76)	14(14.4)	
1979	166(158)	27(34.96)		
1980	103(103)			

Table 11. Population numbers-at-age and pup production resulting from cohort analysis with M = 0.067 (constant)

POPULATION NUMBERS 15/10/81

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
1	4850	3115	4258	3540	3921	4265	3691	3936	2957	3760	3042	6138	8176	5551
2	2091	4535	2911	3976	3283	3667	3989	3452	3681	2747	3467	2817	5680	7517
3	2162	1956	4237	2713	3691	3071	3430	3730	3278	3426	2506	3212	2618	5262
4	1778	2022	1820	3951	2510	3452	2872	3207	3489	3011	3153	2314	2972	2423
5	1759	1662	1883	1688	3670	2341	3223	2683	2994	3195	2754	2921	2154	2751
6	2063	1642	1546	1722	1539	3412	2167	3003	2487	2676	2930	2515	2694	1990
7	314	1927	1536	1416	1575	1424	3175	2019	2793	2234	2445	2675	2326	2487
8	162	293	1797	1420	1315	1465	1323	2964	1880	2557	2057	2231	2474	2139
9	156	149	268	1647	1309	1218	1357	1231	2759	1740	2347	1866	2055	2288
10	177	144	137	222	1536	1217	1130	1265	1144	2525	1606	2144	1729	1890
11	74	164	129	103	189	1427	1127	1052	1173	1070	2341	1463	1993	1592
12	157	68	150	117	83	171	1328	1051	978	1078	970	2150	1352	1841
13	27	146	62	128	91	70	153	1238	977	915	986	875	1985	1244
14	21	25	135	58	115	83	64	142	1156	913	847	889	808	1841
15	25	20	23	122	49	106	75	59	131	1063	837	761	813	746
16	27	23	17	18	112	44	96	69	53	104	978	761	707	746
17	31	26	22	12	17	104	40	89	64	31	80	891	707	647
18	7	28	21	17	9	13	94	36	80	41	23	59	807	647
19	9	7	27	11	16	7	10	87	31	57	34	9	50	746
20	4	8	4	21	8	13	4	8	80	29	46	21	4	42
1+	15896	17962	20982	22901	25040	27569	29348	31324	32135	33173	33448	36712	42102	44390
2+	11046	14847	16724	19362	21118	23304	25657	27387	29178	29414	30406	30574	33926	38839
3+	8955	10312	13813	15385	17835	19636	21669	23936	25496	26666	26940	27757	28247	31322
4+	6792	8356	9577	12673	14144	16566	18239	20205	22268	23240	24434	24545	25629	26060

PUPS

2313 2944 3561 4200 5258 6115 7029 7844 8659 9265 9792 10141 10450 10806

Table 11a. F values for the cohort analysis given in Table 11.

FISHING MORTALITY 15/10/81

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
1	0.000	0.001	0.001	0.008	0.000	0.000	0.000	0.000	0.007	0.014	0.010	0.011	0.017	0.015
2	0.000	0.001	0.004	0.007	0.000	0.000	0.000	0.000	0.005	0.025	0.009	0.006	0.009	0.007
3	0.000	0.005	0.003	0.011	0.000	0.000	0.000	0.000	0.003	0.016	0.012	0.011	0.010	0.007
4	0.001	0.004	0.009	0.007	0.002	0.002	0.001	0.002	0.021	0.022	0.010	0.005	0.010	0.009
5	0.002	0.006	0.023	0.025	0.006	0.010	0.004	0.009	0.045	0.020	0.024	0.014	0.012	0.014
6	0.001	0.000	0.020	0.022	0.011	0.005	0.004	0.006	0.040	0.023	0.024	0.011	0.013	0.021
7	0.003	0.003	0.012	0.007	0.006	0.007	0.002	0.005	0.021	0.016	0.025	0.011	0.017	0.021
8	0.013	0.021	0.020	0.014	0.009	0.009	0.005	0.005	0.011	0.019	0.030	0.015	0.011	0.021
9	0.007	0.021	0.123	0.003	0.006	0.008	0.003	0.007	0.022	0.013	0.023	0.009	0.017	0.021
10	0.012	0.044	0.219	0.093	0.007	0.009	0.005	0.009	0.000	0.009	0.027	0.006	0.016	0.021
11	0.014	0.019	0.032	0.152	0.033	0.004	0.003	0.006	0.017	0.030	0.018	0.012	0.013	0.021
12	0.007	0.031	0.094	0.183	0.092	0.043	0.003	0.007	0.000	0.022	0.037	0.013	0.016	0.021
13	0.000	0.014	0.000	0.041	0.023	0.030	0.007	0.002	0.000	0.010	0.036	0.012	0.008	0.021
14	0.000	0.000	0.031	0.094	0.018	0.038	0.016	0.015	0.017	0.021	0.040	0.022	0.013	0.021
15	0.000	0.110	0.195	0.017	0.043	0.030	0.014	0.036	0.162	0.017	0.028	0.007	0.019	0.021
16	0.000	0.000	0.284	0.000	0.009	0.024	0.011	0.015	0.460	0.196	0.026	0.007	0.022	0.021
17	0.034	0.129	0.209	0.193	0.205	0.030	0.053	0.036	0.368	0.262	0.247	0.032	0.022	0.021
18	0.000	0.000	0.580	0.000	0.259	0.177	0.011	0.060	0.281	0.134	0.898	0.092	0.012	0.021
19	0.000	0.379	0.169	0.207	0.143	0.379	0.109	0.024	0.000	0.137	0.410	0.652	0.109	0.021
20	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
1+	0.001	0.004	0.014	0.013	0.005	0.004	0.002	0.004	0.019	0.019	0.022	0.011	0.014	0.015

Table 12. Population numbers at age and pup production resulting from cohort analysis with M = 01 (constant)

Age	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
1	6875	4271	5659	4549	4886	5150	4319	4457	3237	4345	3408	5834	7519	5362
2	2944	6221	3862	5114	4089	4421	4660	3908	4033	2911	3883	3056	5219	6677
3	3037	2664	5624	3485	4601	3700	4000	4217	3536	3633	2571	3484	2749	4674
4	2508	2748	2402	5079	3127	4163	3348	3620	3815	3192	3237	2298	3121	2463
5	2486	2268	2479	2159	4571	2824	3761	3027	3269	3386	2827	2901	2069	2796
6	2914	2246	2044	2204	1914	4116	2533	3393	2718	2837	3007	2498	2588	1848
7	470	2635	2032	1821	1960	1717	3708	2285	3055	2369	2511	2657	2235	2310
8	209	424	2379	1823	1638	1765	1545	3350	2059	2710	2111	2217	2376	1987
9	221	187	378	2120	1631	1471	1585	1392	3019	1845	2408	1854	1975	2126
10	268	199	166	314	1914	1469	1322	1430	1252	2678	1649	2130	1661	1756
11	115	241	175	126	266	1722	1318	1192	1283	1133	2403	1453	1915	1479
12	250	104	215	154	101	235	1552	1190	1072	1143	996	2130	1299	1710
13	37	226	92	182	122	84	206	1401	1070	970	1013	869	1906	1155
14	27	33	202	83	160	108	74	185	1266	968	870	884	777	1710
15	35	24	30	179	70	143	95	66	166	1127	859	756	782	693
16	34	31	20	23	160	62	127	85	58	132	1004	756	680	693
17	42	31	28	14	21	144	55	114	76	35	102	885	680	601
18	9	37	25	22	11	16	127	48	100	51	25	76	775	601
19	12	8	34	14	20	8	13	114	41	72	41	10	64	693
20	5	11	5	27	11	16	5	11	102	37	59	27	5	53
1+	22498	24609	27851	29492	31273	33334	34354	35483	35227	35573	34982	36781	40395	41386
2+	15623	20338	22193	24943	26387	28183	30036	31026	31990	31228	31574	30947	32876	36024
3+	12679	14117	18330	19829	22297	23762	25376	27118	27957	28317	27691	27981	27657	29347
4+	9642	11453	12706	16343	17696	20062	21375	22902	24422	24684	25120	24407	24908	24673
Pups	3290	4045	4731	5424	6585	7413	8245	8898	9501	9844	10069	10085	10072	10154

Table 12a: F values for the cohort analysis given in Table 12.

FISHING MORTALITY 15/10/81

	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
1	0.000	0.000	0.001	0.006	0.000	0.000	0.000	0.000	0.006	0.012	0.009	0.011	0.019	0.016
2	0.000	0.001	0.003	0.006	0.000	0.000	0.000	0.000	0.004	0.024	0.008	0.006	0.010	0.008
3	0.000	0.004	0.002	0.008	0.000	0.000	0.000	0.000	0.002	0.015	0.012	0.010	0.010	0.008
4	0.000	0.003	0.007	0.005	0.002	0.002	0.001	0.002	0.019	0.021	0.009	0.005	0.010	0.009
5	0.001	0.004	0.018	0.020	0.005	0.009	0.003	0.008	0.042	0.019	0.024	0.014	0.013	0.014
6	0.001	0.000	0.016	0.017	0.009	0.004	0.003	0.005	0.037	0.022	0.024	0.011	0.013	0.023
7	0.002	0.002	0.009	0.006	0.005	0.006	0.001	0.004	0.020	0.015	0.025	0.012	0.018	0.023
8	0.010	0.015	0.015	0.011	0.008	0.008	0.004	0.004	0.010	0.018	0.030	0.015	0.012	0.023
9	0.005	0.017	0.087	0.002	0.005	0.006	0.003	0.006	0.020	0.012	0.023	0.010	0.018	0.023
10	0.008	0.032	0.179	0.066	0.006	0.008	0.004	0.008	0.000	0.008	0.026	0.006	0.017	0.023
11	0.009	0.013	0.024	0.124	0.024	0.004	0.002	0.005	0.016	0.029	0.018	0.012	0.013	0.023
12	0.004	0.021	0.066	0.138	0.076	0.032	0.003	0.006	0.000	0.021	0.037	0.013	0.017	0.023
13	0.000	0.009	0.000	0.029	0.017	0.025	0.005	0.002	0.000	0.010	0.036	0.012	0.009	0.023
14	0.000	0.000	0.021	0.065	0.013	0.030	0.014	0.011	0.016	0.020	0.039	0.023	0.014	0.023
15	0.000	0.091	0.150	0.012	0.030	0.022	0.011	0.032	0.128	0.016	0.027	0.007	0.020	0.023
16	0.000	0.000	0.237	0.000	0.007	0.017	0.008	0.012	0.418	0.155	0.025	0.007	0.023	0.023
17	0.025	0.109	0.160	0.160	0.161	0.022	0.039	0.028	0.304	0.238	0.192	0.033	0.023	0.023
18	0.000	0.000	0.478	0.000	0.213	0.138	0.008	0.045	0.223	0.109	0.796	0.071	0.012	0.023
19	0.000	0.304	0.133	0.163	0.112	0.304	0.085	0.019	0.000	0.107	0.329	0.535	0.085	0.023
20	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
1+	0.001	0.003	0.010	0.010	0.004	0.004	0.002	0.003	0.018	0.018	0.021	0.012	0.014	0.017

Table 13a. Grey seal population age structure at population numbers stable between 1980 and 1990 (M = 0.10)

POPULATION NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	10882	11034	10391	10050	9908	10341	10301	10036	10025	10141	10126
1	5362	8612	5980	5359	5956	6833	6709	6695	6476	6460	6069
2	6677	4775	7122	4903	4502	5138	5832	5728	5709	5521	5436
3	4647	5994	4133	6138	4277	3979	4517	5178	5034	5016	4820
4	2463	4172	5188	3562	5354	3780	3498	3972	4506	4423	4379
5	2796	2209	3588	4441	3091	4717	3310	3064	3476	3943	3842
6	1848	2495	1847	2978	3766	2683	4055	2846	2632	2985	3348
7	2310	1634	1984	1451	2422	3182	2232	3376	2365	2186	2434
8	1987	2043	1299	1558	1180	2047	2647	1658	2805	1964	1782
9	2126	1757	1624	1020	1267	997	1703	2204	1544	2330	1601
10	1756	1880	1397	1275	830	1070	829	1417	1831	1282	1899
11	1479	1553	1495	1097	1037	701	890	690	1178	1521	1045
12	1710	1308	1235	1174	892	876	583	741	574	978	1240
13	1155	1512	1040	969	955	754	729	486	616	476	797
14	1710	1021	1202	817	788	807	627	607	403	512	388
15	693	1512	812	944	664	666	671	522	504	335	417
16	693	613	1202	638	768	561	554	559	434	419	273
17	601	613	487	944	519	649	467	461	464	360	341
18	601	531	487	383	768	438	540	389	383	385	294
19	693	531	423	383	311	649	365	449	323	318	314
20	53	613	423	332	311	263	540	303	373	268	260
0+	52242	56411	53360	50416	49565	51129	51600	51530	51654	51824	51106
1+	41360	45377	42969	40366	39656	40788	41299	41495	41629	41683	40981
2+	35998	36765	36989	35006	33701	33955	34590	34866	35153	35223	34912
3+	29321	31990	29866	30103	29198	28817	28758	29071	29444	29702	29476

Table 13b. Removals at age necessary to achieve the stable population shown in Table 13a.

CATCH NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	1300	4229	4272	3312	2248	2793	2769	2747	2754	3279	3293
1	81	705	535	365	264	369	360	367	356	430	407
2	50	197	322	168	100	139	157	157	157	185	183
3	35	248	187	210	95	108	121	141	139	168	162
4	21	196	267	139	135	116	107	124	141	168	168
5	37	159	282	266	120	224	156	148	168	231	226
6	40	288	233	287	237	206	309	222	206	282	318
7	50	189	250	140	153	244	170	263	185	206	231
8	43	236	164	150	74	157	202	145	219	185	169
9	46	203	205	98	80	76	130	172	121	220	152
10	38	217	176	123	52	82	63	110	143	121	180
11	32	179	188	106	65	54	68	54	92	143	99
12	37	151	155	113	56	67	44	58	45	92	118
13	25	175	131	93	60	58	56	38	48	45	76
14	37	118	151	79	50	62	48	47	32	48	37
15	15	175	102	91	42	51	51	41	39	32	40
16	15	71	151	61	48	43	42	43	34	39	26
17	13	71	61	91	33	50	36	36	36	34	32
18	13	61	61	37	48	34	41	30	30	36	28
19	15	61	53	37	20	50	28	35	25	30	30
20	10	71	53	32	20	20	41	24	29	25	25
0+	1953	8000	8000	6000	4000	5000	5000	5000	5000	6000	6000
1+	653	3771	3728	2688	1752	2207	2231	2253	2246	2721	2707
2+	572	3066	3193	2322	1488	1839	1871	1886	1889	2291	2300
3+	522	2869	2871	2154	1388	1700	1714	1728	1732	2106	2117

Table 14a. Grey seal population age structure under a hunting strategy which reduces the population by ~33% of its 1980 level (M=0.10)

POPULATION NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	10882	11034	10391	10050	9552	9262	8659	8163	7695	7340	7023
1	5362	8612	5980	5359	5027	4600	4297	4703	4300	4361	4065
2	6677	4775	7122	4903	4371	4073	3702	3555	3870	3584	3621
3	4647	5994	4133	6138	4214	3745	3478	3205	3069	3363	3108
4	2463	4172	5188	3562	5276	3611	3198	3011	2767	2667	2916
5	2796	2209	3588	4441	3040	4486	3059	2751	2583	2391	2299
6	1848	2495	1847	2978	3669	2497	3664	2559	2291	2175	2006
7	2310	1634	1984	1451	2321	2832	1909	2914	2020	1842	1739
8	1987	2043	1299	1558	1130	1791	2165	1519	2301	1624	1473
9	2126	1757	1624	1020	1214	872	1369	1722	1199	1850	1299
10	1756	1880	1397	1275	795	937	667	1089	1360	964	1479
11	1479	1553	1495	1097	994	614	716	531	860	1093	771
12	1710	1308	1235	1174	855	767	469	570	419	692	874
13	1155	1512	1040	969	915	660	586	373	450	337	553
14	1710	1021	1202	817	755	706	504	466	295	362	269
15	693	1512	812	944	636	583	540	401	368	237	289
16	693	613	1202	638	736	491	446	422	317	296	189
17	601	613	487	944	497	568	375	355	339	255	237
18	601	531	487	383	736	383	434	299	280	273	204
19	693	531	423	383	298	568	293	345	236	225	218
20	53	613	423	332	298	230	434	233	273	190	180
0+	52242	56411	53360	50416	47328	44274	40964	39197	37289	36119	34811
1+	41360	45377	42969	40366	37777	35013	32305	31031	29594	28779	27788
2+	35998	36765	36989	35006	32749	30412	28009	26328	25294	24418	23723
3+	29321	31990	29866	30103	28379	26340	24306	22774	21424	20834	20102

Table 14b. Removals at age necessary to reduce the population by 33% over 10 years (M=0.10)

CATCH NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	1300	4229	4272	4298	4274	4319	3308	3263	2747	2720	2708
1	81	705	535	504	501	485	350	406	323	343	335
2	50	197	322	234	221	218	152	155	146	142	151
3	35	248	187	292	213	200	143	140	116	133	129
4	21	196	267	193	303	219	150	149	119	120	138
5	37	159	282	368	267	416	219	209	170	165	167
6	40	288	233	394	514	369	422	311	243	241	234
7	50	189	250	192	325	418	220	354	214	204	202
8	43	236	164	206	158	265	249	185	244	180	171
9	46	203	205	135	170	129	158	209	127	205	151
10	38	217	176	169	111	138	77	132	144	107	172
11	32	179	188	145	139	91	82	65	91	121	90
12	37	151	155	155	120	113	54	69	44	77	102
13	25	175	131	128	128	97	67	45	48	37	64
14	37	118	151	108	106	104	58	57	31	40	31
15	15	175	102	125	89	86	62	49	39	26	34
16	15	71	151	84	103	73	51	52	34	33	22
17	13	71	61	125	70	84	43	43	36	28	28
18	13	61	61	51	103	57	50	36	30	30	24
19	15	61	53	51	42	84	34	42	25	25	25
20	10	71	53	44	42	34	50	28	29	21	21
0+	1953	8000	8000	8000	8000	8000	6000	6000	5000	5000	5000
1+	653	3771	3728	3702	3726	3681	2692	2737	2253	2280	2292
2+	572	3066	3193	3198	3225	3197	2341	2331	1930	1937	1956
3+	522	2869	2871	2965	3004	2979	2189	2176	1784	1795	1805

Table 15a. Grey seal population age structure under a hunting strategy which reduces the population by ~66% of its 1980 level (M = 0.10)

POPULATION NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	10882	11034	10391	10050	9552	9262	8659	7791	6723	5540	4234
1	5362	8612	5980	5359	5027	4600	4297	3802	2689	1838	986
2	6677	4775	7122	4903	4371	4073	3702	3425	2905	1972	1251
3	4647	5994	4133	6138	4214	3745	3478	3147	2851	2370	1550
4	2463	4172	5188	3562	5276	3611	3198	2956	2619	2325	1863
5	2796	2209	3588	4441	3040	4486	3059	2694	2432	2106	1792
6	1848	2495	1847	2978	3669	2497	3664	2477	2102	1831	1485
7	2310	1634	1984	1451	2321	2832	1909	2762	1757	1407	1100
8	1987	2043	1299	1558	1130	1791	2165	1439	1960	1176	845
9	2126	1757	1624	1020	1214	872	1369	1632	1021	1311	706
10	1756	1880	1397	1275	795	937	667	1033	1158	683	788
11	1479	1553	1495	1097	994	614	716	503	733	775	410
12	1710	1308	1235	1174	855	767	469	510	357	490	465
13	1155	1512	1040	969	915	660	586	354	383	239	294
14	1710	1021	1202	817	755	706	504	442	251	256	143
15	693	1512	812	944	636	583	540	380	314	168	154
16	693	613	1202	638	736	491	446	407	270	210	101
17	601	613	487	944	497	568	375	336	289	181	126
18	601	531	487	383	736	383	434	283	238	193	108
19	693	531	423	383	298	568	293	327	201	160	116
20	53	613	423	332	298	230	434	221	232	134	96
0+	52242	56411	53360	50416	47328	44274	40964	36952	31486	25367	18613
1+	41360	45377	42969	40366	37777	35013	32305	29161	24762	19827	14379
2+	35998	36765	36989	35006	32749	30412	28009	25358	22074	17988	13393
3+	29321	31990	29866	30103	28379	26340	24306	21934	19169	16016	12142

Table 15b. Removals at age necessary to reduce the population by 66% over 10 years (M=0.10)

CATCH NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	1300	4229	4272	4298	4274	4319	4267	4623	4508	4290	3831
1	81	705	535	504	501	485	488	564	485	435	354
2	50	197	322	234	221	218	214	261	272	247	248
3	35	248	187	292	213	200	201	240	267	297	307
4	21	196	267	193	303	219	210	256	278	329	414
5	37	159	282	368	267	416	306	353	389	444	578
6	40	288	233	394	514	369	582	510	523	588	699
7	50	189	250	192	325	418	303	568	437	452	518
8	43	236	164	206	158	265	344	296	487	378	398
9	46	203	205	135	170	.129	218	336	254	421	333
10	38	217	176	169	111	138	106	213	288	219	371
11	32	179	188	145	139	91	114	103	182	249	193
12	37	151	155	155	120	113	75	111	89	157	219
13	25	175	131	128	128	97	93	73	95	77	139
14	37	118	151	108	106	104	80	91	62	82	68
15	15	175	102	125	89	86	86	78	76	54	73
16	15	71	151	84	103	73	71	84	67	67	48
17	13	71	61	125	70	84	60	69	72	58	59
18	13	61	61	51	103	57	69	58	59	62	51
19	15	61	53	51	42	84	47	67	50	51	55
20	10	71	53	44	42	34	69	45	58	43	45
0+	1953	8000	8000	8000	8000	8000	8000	9000	9000	9000	9000
1+	653	3771	3728	3702	3726	3681	3733	4377	4492	4710	5169
2+	572	3066	3193	3198	3225	3197	3246	3813	4007	4275	4815
3+	522	2869	2871	2965	3004	2979	3032	3552	3734	4028	4567

Table 16a. Grey seal population age structure under a hunting strategy which maintains approximately stable population numbers between 1980 and 1990 (M=0.067)

POPULATION NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	11592	12134	11747	11713	11609	11788	11716	11361	11181	11028	11202
1	5551	9585	6206	5753	6131	6057	6648	6626	63[illegible]9	6168	6518
2	7517	5113	8092	5201	4876	5193	5199	5709	5675	5412	5367
3	5262	6982	4565	7200	4652	4360	4672	4678	5131	5097	4886
4	2423	4887	6233	4062	6440	4159	3922	4203	4204	4607	4601
5	2751	2246	4302	5463	3584	5680	3697	3487	3732	3729	4115
6	1990	2537	1911	3637	4666	3060	4909	3197	3008	3214	3246
7	2487	1822	2060	1536	2969	3807	2542	4081	2648	2486	2699
8	2139	2277	1480	1656	1254	2422	3162	2113	3380	2189	2088
9	2288	1959	1849	1189	1352	1023	2012	2679	1750	2794	1838
10	1890	2095	1591	1486	971	1103	850	1673	2178	1447	2347
11	1592	1731	1701	1278	1213	792	916	707	1386	1800	1215
12	1841	1458	1405	1367	1044	990	658	762	585	1145	1512
13	1244	1686	1184	1130	1116	851	822	547	631	484	962
14	1841	1139	1369	952	922	911	707	684	453	521	40
15	746	1686	925	1100	777	752	757	538	566	375	438
16	746	683	1369	744	898	634	625	629	487	468	315
17	647	683	555	1100	607	733	526	520	521	403	393
18	647	593	555	446	898	495	609	438	430	431	338
19	746	593	481	446	364	733	411	566	363	356	362
20	42	683	481	387	364	297	609	312	419	300	299
0+	55982	62572	60060	57847	56708	55841	55971	55477	55059	54452`	55117
1+	44390	50437	48313	46134	45099	44052	44254	44116	43878	43424	43915
2+	38839	40852	42107	40381	38968	37995	37606	37491	37548	37256	37397
3+	31322	35739	34015	35180	34092	32802	32407	31781	31873	31843	32060

Table 16b. Removals at age necessary to maintain the stable population shown in Table 16a.

CATCH NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	1300	5336	5431	5005	4980	4539	4492	4455	4449	3936	3942
1	81	902	624	522	559	482	526	539	524	447	464
2	50	224	380	220	207	192	191	216	218	182	176
3	35	306	214	304	198	161	171	177	197	171	161
4	21	278	379	222	354	199	187	206	210	201	197
5	37	195	400	458	302	417	270	262	286	249	271
6	40	324	260	447	577	331	528	353	338	317	315
7	50	232	280	189	367	411	273	451	298	245	262
8	43	290	201	204	155	262	340	234	380	216	202
9	46	250	252	146	167	111	216	291	197	275	178
10	38	267	216	183	120	119	91	185	245	143	227
11	32	221	231	157	150	86	98	78	156	177	118
12	37	186	191	168	129	107	71	84	66	113	147
13	25	215	161	139	138	92	88	60	71	48	93
14	37	145	186	117	114	98	76	76	51	51	39
15	15	215	126	135	96	81	81	65	64	37	42
16	15	87	186	91	111	68	67	70	55	46	30
17	13	87	75	135	75	79	57	57	59	40	38
18	13	76	75	55	111	54	65	48	48	42	33
19	15	76	65	55	45	79	44	56	41	35	35
20	10	87	65	48	45	32	65	38	47	30	29
0+	1953	10000	10000	9000	9000	8000	8000	8000	8000	7000	7000
1+	653	4664	4569	3995	4020	3461	3508	3545	3551	3064	3058
2+	572	3762	3946	3473	3461	2979	2982	3006	3027	2618	2594
3+	522	3538	3566	3254	3254	2788	2791	2790	2809	2436	2418

Table 17a. Grey seal population age structure under a hunting strategy which reduces the population by 33% of the 1980 level (M= 0.067)

POPULATION NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	11592	12134	11747	11713	11423	11397	10925	10133	9393	8772	8137
1	5551	9585	6206	5753	5663	5416	5324	4939	4269	4062	3533
2	7517	5113	8092	5201	4811	4720	4502	4402	4035	3503	3294
3	5262	6982	4565	7200	4624	4271	4185	3982	3872	3556	3071
4	2423	4887	6233	4062	6401	4104	3786	3701	3502	3412	3117
5	2751	2246	4302	5463	3555	5592	3580	3292	3195	3032	2933
6	1990	2537	1911	3637	4609	2990	4692	2989	2718	2649	2486
7	2487	1822	2060	1536	2914	3677	2377	3702	2319	2122	2034
8	2139	2277	1480	1656	1231	2325	2923	1875	2672	1811	1629
9	2288	1959	1849	1189	1327	982	1848	2304	1455	2242	1390
10	1890	2095	1591	1486	953	1058	781	1458	1789	1136	1722
11	1592	1731	1701	1278	1191	760	841	616	1131	1397	872
12	1841	1458	1105	1367	1025	950	604	644	478	883	1072
13	1244	1686	1184	1130	1096	817	755	477	515	373	678
14	1841	1139	1369	952	905	874	650	596	370	402	286
15	746	1686	925	1100	763	722	695	512	462	289	309
16	746	683	1369	744	882	608	574	548	398	361	222
17	647	683	555	1100	596	703	484	453	425	310	277
18	647	593	555	446	882	475	559	381	351	332	230
19	746	593	481	446	357	703	378	441	296	274	255
20	42	683	481	387	357	285	559	298	342	231	211
0+	55982	62572	60060	57847	55565	53431	51022	47764	44188	41151	37767
1+	44390	50437	48313	46134	44142	42034	40097	37631	34796	32379	29630
2+	38839	40852	42107	40381	38479	36618	34773	32691	30526	28316	26097
3+	31322	35739	34015	35180	33668	31898	30271	28290	26491	24813	22803

Table 17b. Removals at age necessary to reduce the population by 33% over 10 years (M=0.067)

CATCH NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	1300	5336	5431	5492	5468	5539	5481	5410	4904	4852	4800
1	81	902	624	589	596	582	597	604	506	523	502
2	50	224	380	249	237	237	237	253	225	213	221
3	35	306	214	345	228	215	220	229	216	216	206
4	21	278	379	252	408	267	258	275	252	267	270
5	37	195	400	517	346	556	372	373	351	362	386
6	40	324	260	504	656	434	711	493	435	459	474
7	50	232	280	213	415	534	360	610	371	368	388
8	43	290	201	229	175	338	443	309	459	314	310
9	46	250	252	165	189	143	280	390	233	389	265
10	38	267	216	206	136	154	118	240	286	197	328
11	32	221	231	177	170	110	127	102	181	242	166
12	37	186	191	189	146	138	92	109	76	153	204
13	25	215	161	156	156	119	114	79	82	65	129
14	37	145	186	132	129	127	98	98	59	70	55
15	15	215	126	152	109	105	105	84	74	50	59
16	15	87	186	103	126	88	87	90	64	63	42
17	13	87	75	152	85	102	73	75	68	54	53
18	13	76	75	62	126	69	85	63	56	58	45
19	15	76	65	62	51	102	57	73	47	48	49
20	10	87	65	54	51	41	85	49	55	40	40
0+	1953	10000	10000	10000	10000	10000	10000	10000	9000	9000	9000
1+	653	4664	4569	4508	4532	4461	4519	4590	4096	4148	4192
2+	572	3762	3946	3919	3936	3879	3922	3986	3590	3624	3691
3+	522	3538	3566	3670	3699	3642	3685	3732	3365	3412	3469

Table 18a. Grey seal population age structure under a hunting strategy which reduces the population by 66% of its 1980 level (M= 0.067)

POPULATION NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	11592	12134	11747	11713	11423	11397	10925	9094	7116	6065	5015
1	5551	9585	6206	5753	5663	5416	5324	2925	1568	1709	1275
2	7517	5113	8092	5201	4811	4720	4502	4038	2054	1164	1241
3	5262	6982	4565	7200	4624	4271	4185	3825	3307	1730	971
4	2423	4887	6233	4062	6401	4104	3786	3555	3141	2786	1442
5	2751	2246	4302	5463	3555	5592	3560	3123	2606	2563	2243
6	1990	2537	1911	3637	4609	2990	4692	2754	2243	2122	1899
7	2487	1822	2060	1536	2914	3677	2377	3274	1734	1526	1399
8	2139	2277	1480	1656	1231	2325	2923	1659	2061	1179	1006
9	2288	1959	1849	1189	1327	982	1848	2039	1044	1402	778
10	1890	2095	1591	1486	953	1058	781	1290	1284	710	925
11	1592	1731	1701	1278	1191	760	841	545	812	873	468
12	1841	1458	1405	1367	1025	950	604	587	343	552	576
13	1244	1686	1184	1130	1096	817	755	422	370	233	364
14	1841	1139	1369	952	905	874	650	527	265	251	154
15	746	1686	925	1100	763	722	695	453	332	181	166
16	746	683	1369	744	882	608	574	485	285	226	119
17	647	683	555	1100	596	703	484	401	305	194	149
18	647	593	555	446	882	475	559	337	252	208	128
19	746	593	481	446	357	703	378	390	212	172	137
20	42	683	481	387	357	285	559	264	246	144	113
0+	55982	62572	60060	57847	55565	53431	51022	41976	31779	25992	20568
1+	44390	50437	48313	46134	44142	42034	40097	32882	24663	19927	15553
2+	38839	40852	42107	40381	38479	36618	34773	29957	23095	18218	14278
3+	31322	35739	34015	35180	33668	31898	30271	25939	21042	17053	13037

Table 18b. Removals at age necessary to reduce the population by 66% over 10 years (M=0.067)

CATCH NUMBERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
0	1300	5336	5431	5492	5468	5539	7594	7240	5153	4585	4298
1	81	902	624	589	596	582	985	706	312	370	369
2	50	224	380	249	237	237	400	475	197	122	178
3	35	306	214	345	228	215	371	451	318	182	140
4	21	278	379	252	408	267	432	537	387	375	264
5	37	195	400	517	346	556	615	702	519	516	605
6	40	324	260	504	656	434	1154	873	592	607	713
7	50	232	280	213	415	534	585	1038	458	436	525
8	43	290	201	229	175	338	719	526	544	337	378
9	46	250	252	165	189	143	454	646	276	401	292
10	38	267	216	206	136	154	192	409	339	203	347
11	32	221	231	177	170	110	207	173	214	250	176
12	37	186	191	189	146	138	149	186	91	158	216
13	25	215	161	156	156	119	186	134	98	67	137
14	37	145	186	132	129	127	160	167	70	72	58
15	15	215	126	152	109	105	171	144	88	52	62
16	15	87	186	103	126	88	141	154	75	65	45
17	13	87	75	152	85	102	119	127	81	55	56
18	13	76	75	62	126	69	138	107	67	59	48
19	15	76	65	62	51	102	93	124	56	49	51
20	10	87	65	54	51	41	138	84	65	41	42
0+	1953	10000	10000	10000	10000	10000	15000	15000	10000	9000	9000
1+	653	4664	4569	4508	4532	4461	7406	7760	4847	4415	4702
2+	572	3762	3946	3919	3936	3879	6422	7051	4535	4045	4334
3+	522	3538	3566	3670	3699	3642	6022	6579	4338	3923	4155

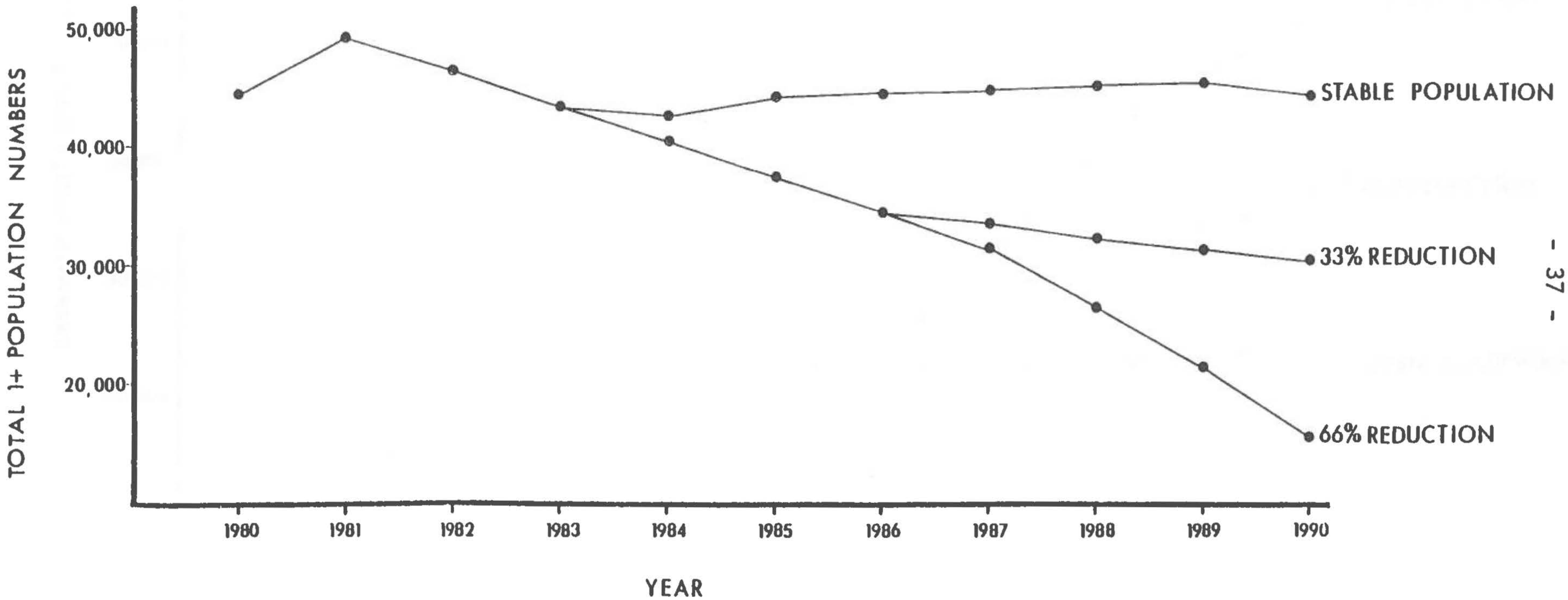

Figure 1. Grey seal population responses to hunting strategies outlined in Tables 13b, 14b, and 15b. M = 0.10

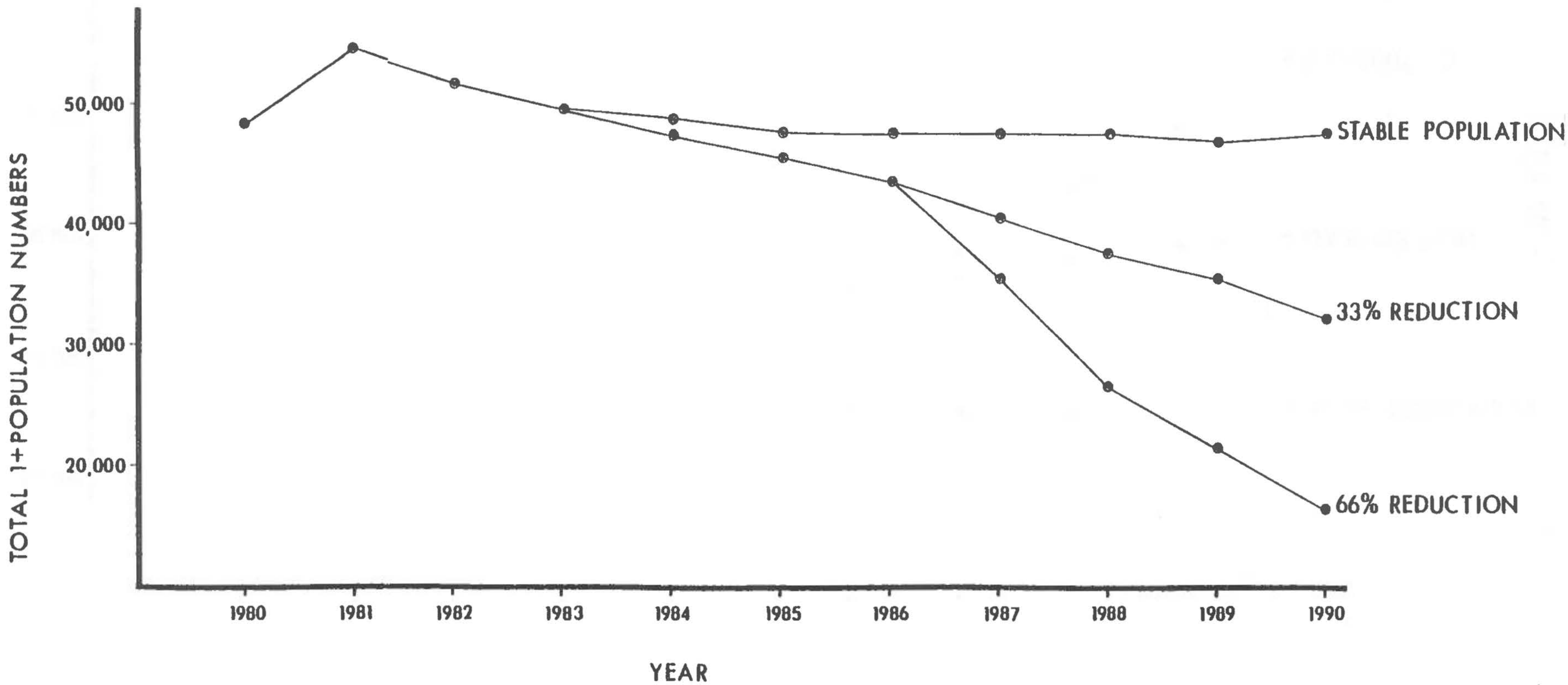

Figure 2. Grey seal population responses to hunting strategies outlined in Tables 16b, 17b, 18b. M = 0.067.