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**Assessment of Northwest Atlantic Grey Seal
(Halichoerus grypus) Pup Production for 1977 to 1984**

by

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Abstract

This document outlines an assessment of Northwest Atlantic grey seal (*Halichoerus grypus*) pup production. The estimates are derived from long-term, large-scale mark and recapture experiments which were initiated in 1977 and have continued to the present. Each year since 1977 all pups whelped on Sable Island (the largest known colony of grey seals in the Northwest Atlantic) have been marked. Returns of these animals from a bounty system have provided the data used to estimate total pup production. The estimates derived from these experiments for the period 1977-1983 have been highly variable and have thus been couched in very wide confidence intervals of doubtful value. This variability is increased due to violations of the assumptions of the mark and recapture model used. Some of these violations have been quantified and corrected for in previous assessments. The present document attempts to adjust estimates of pup production for tag loss. During 1984, 1441 pups were marked on the pack ice in the Gulf of St. Lawrence. This marking experiment allowed us to calculate Gulf pup production independent of Sable production by observing the ratios of Gulf marked to unmarked animals occurring on Sable Island. This experiment, which does not suffer from the tag selection bias identified for previous experiments and appears to adhere more closely to the assumption of random mixing of marks in the population, gives a Gulf pup production estimate of 6336 pups in 1984. This coupled with the known Sable Island production of 5983 indicates a total Northwest Atlantic grey seal pup production of 12,319 (+ 2106) in 1984 and a total population of 72,465 (+ 12,388).

Résumé

Le présent document décrit une évaluation de la production de jeunes phoques gris (*Halichoerus grypus*) dans le nord-ouest de l'Atlantique. Les résultats de cette évaluation ont été obtenus à partir d'expériences, à long terme et de grande envergure, de marquage et de recapture qui ont débuté en 1977 et qui se poursuivent toujours. Chaque année, depuis 1977, on marque les jeunes phoques qui naissent sur l'île de Sable (la colonie de phoques gris la plus importante qui soit connue dans le nord-ouest de l'Atlantique). La reprise de ces animaux grâce à un système de primes a fourni les données nécessaires à l'estimation de la production totale de jeunes phoques. Les résultats obtenus à partir de ces expériences pour la période 1977-1983 présentent une variabilité élevée. On les a donc classés dans des intervalles de confiance très étendus dont la valeur est douteuse. Cette variabilité est d'autant plus grande que les principes de base du modèle de marquage et recapture utilisé ont été transgressés. Les répercussions de certaines de ces transgressions ont été déterminées et les évaluations antérieures ont été corrigées en conséquence. Dans le présent document, on a tenté d'ajuster les chiffres de production de jeunes phoques pour tenir compte de la perte des marques. En 1984, 1 441 jeunes phoques ont été marqués sur la banquise dans le golfe du Saint-Laurent. Cette expérience de marquage nous a permis de calculer la production de jeunes phoques provenant exclusivement du golfe (c'est-à-dire, sans compter la production de l'île de Sable) à partir du rapport des animaux marqués dans le golfe aux animaux non marqués, observés sur l'île de Sable. Cette expérience, qui n'est pas faussée par la sélection préférentielle des animaux marqués, comme ce fut le cas des expériences antérieures, et qui semble respecter davantage le principe de la répartition aléatoire des marques au sein de la population, a permis d'estimer à 6 336 la production de jeunes phoques pour 1984. Cette valeur, combinée à la production de 5 983 sur l'île de Sable, permet d'évaluer à 12 319 (+ 2 106) la production totale de jeunes phoques gris dans le nord-ouest de l'Atlantique et à 72 465 (+ 12 388), la population totale.

Introduction

Previous assessments of the Northwest Atlantic Grey seal population have resulted in estimates of total population size with wide or undefined confidence intervals (Zwanenburg et al. 1981; Zwanenburg 1984). This is the result of highly variable estimates of pup production derived for the years 1977 to 1983. The variability of these estimates in turn may be ascribed to possible violations of the assumptions of the mark and recapture model employed. These assumptions and possible mechanisms of their isolation are discussed in Zwanenburg (1984) and indicate that each of the assumptions of the mark and recapture model should be tested and their effects quantified. This paper attempts to quantify the effects of tag loss on estimates of pup production and makes recommendations for future studies aimed at improving their reliability.

In 1984, 1441 pups were tagged on the pack ice in the Gulf of St. Lawrence. These animals provided a source of information from which we estimated Gulf pup production independent of pup production on Sable Island.

Materials and Methods

The recapture histories of all marked cohorts are given in Table 1. To reduce the potential bias inherent in these recaptures (Zwanenburg 1984) only those tags which were accompanied by the animal's lower jaw were used as input to the analysis. The total number of animals taken for the bounty and by the departmental cull are given in Tables 2 and 3. These data were used as input to the mark recapture model described by Seber (1982).

First define;

M_0 = Total number of marked animals released to the population and available for recapture.

m_i = The number of marked animals recaptured during the i th period.
Only marks accompanied by a jaw were used as input to the model.

n_i = The total number of animals turned in for bounty payment during the i th period.

\hat{N}_0 = The estimated pup population.

\hat{N}_{0adj} = The estimated pup population corrected for tag loss.

λ = The proportion of animals which lose their marks (Table 4).

Initial estimates of pup production are then given by:

$$(1) \hat{N}_0 = \frac{M_0 \sum_i n_i}{\sum_i m_i} \quad \text{or}$$

$$(2) \hat{N}_0 = \frac{(M_0 + 1) [(\sum_i n_i) + 1]}{(\sum_i m_i) + 1} - 1$$

for those cohorts where total returns were less than or equal to 7 marks.

These estimates were then adjusted for tag loss (ℓ) by:

$$(3) \hat{N}_{0adj} = \hat{N}_0 (1 - \ell)$$

The variance of the unadjusted estimate (\hat{N}_0) (Seber 1973) was estimated by:

$$(4) \text{Var}(\hat{N}_0) = \frac{(M_0+1) \times [(\sum_i n_i)+1] \times (M_0 - \sum_i m_i) \times (\sum_i n_i - \sum_i m_i)}{[(\sum_i m_i)+1]^2 \times [(\sum_i m_i)+2]}$$

The variance of the tag loss rate was calculated assuming a binomial distribution of events by:

$$(5) \text{Var}(\ell) = \frac{(\ell) \times (1 - \ell)}{n}$$

The coefficient of variation of \hat{N}_0 was derived from

$$(6) \text{cv}(\hat{N}_0) = \frac{\sqrt{\text{Var}(\hat{N}_0)}}{\hat{N}_0}$$

The coefficient of variation of tag loss was derived from

$$(7) \text{cv}(1-\ell) = \frac{\sqrt{\text{Var}(1-\ell)}}{1-\ell}$$

The variance of the adjusted estimates of pup population (\hat{N}_{0adj}) was estimated by:

$$(8) \text{Var}(\hat{N}_{0adj}) = (\hat{N}_0 \times 1-\ell)^2 [\text{cv}(\hat{N}_0)^2 + \text{cv}(1-\ell)^2]$$

The 95% percent confidence intervals for all \hat{N}_{0adj} (after Bowen and Sergeant 1983) were approximated by

$$\hat{N}_{0adj} \pm 2 \sqrt{\text{Var}\hat{N}_{0adj}}$$

Results and Discussion

During 1984 1441 pups were tagged on the ice in the Gulf of St. Lawrence. Resightings of these tagged animals and their returns in the bounty provided an alternate source of information from which to estimate total pup production for the Northwest Atlantic. Since all pups whelped on Sable Island are tagged the total production of that colony is a known quantity and any returns from that source can be excluded from further calculations. This then results in a data set consisting only of Gulf marked animals and unmarked animals whelped either in the Gulf or in some other location. These observations can then be used as input to a mark-recapture model described above to estimate total non-Sable pup production. Combining this estimate with known Sable Island production results in an estimate of total pup production.

The number of Gulf tagged and untagged pups resighted on Sable Island during April, May, and June of 1984 and returned for bounty are presented in Table 5.

A chi-square test of independence indicates that each of these samples are independent estimates of a common ratio (of Gulf tagged to untagged animals). Therefore all data were combined and used as input to equation (2) to estimate non-Sable pup production in 1984. Based on these data, we estimate a total pup production of $12,319 \pm 2106$ in 1984.

Estimates of total grey seal pup production corrected for tag loss based on earlier Sable Island experiments (1977-1983) and the 1984 result are given in Table 6. The calculated value of \hat{N}_{0adj} does not include those pups which died prior to tagging, either as a result of natural mortality or via the departmental culls. Since these animals are part of the total production in each year they were added to the final estimate and are reported on Table 7.

The 1984 estimate is considered the most reliable and therefore was used to calculate total population size assuming the stable age distribution calculated by Zwanenburg (1984). This distribution indicates that 17% of the population should be at age 0 resulting in a total population size of 72,465 (95% confidence interval 60,076 - 84,853).

Mark-recapture experiments prior to 1984 have not provided satisfactory estimates of population size due to violations of the assumptions of the mark-recapture model (Zwanenburg 1984). The salient points for this discussion are that: (1) attachment of brightly coloured ribbons to the tags may have caused preferential selection of marked over

unmarked animals by bounty hunters attempting to maximize their earnings, (2) the returns of marked animals may have been further biased by returns from non-bounty hunters which report only marked animals found and not unmarked animals (hence the reason for using only those returns acquired through the bounty system), (3) returns of marked vs unmarked animals at ages 0 indicate that marked animals retain a high degree of aggregation for at least the first year after release thus violating the assumption of random mixing (therefore only returns at age 1+ were used), and (4) tag loss rates were assumed values rather than measured values.

The present analysis corrects for tag loss by using measured rates for those years in which the data are available. For those years where measurements of tag loss rate were not available rates were assumed to be equal to those for which the method of tag application were similar. Loss rates varied from 2 to 50% between years.

The 1984 estimate is based on observed ratios of Gulf tagged to untagged animals in 1984. Observations of this ratio were made by trained observers on Sable Island. These observations do not suffer from the potential bias introduced by preferential selection of marked versus unmarked animals because all animals encountered were carefully examined.

The assumption of random mixing of marked and unmarked animals at age 0 was violated in the Sable Island mark-recapture experiment. This was likely due to the fact that tagging occurred at a point source. Gulf born pups were marked over a much wider area on the pack ice in the Gulf of St. Lawrence. This serves to distribute the tags more widely within the population and is thus more likely to approximate random mixing making the 1984 estimate more reliable than estimates in previous years.

In conclusion, since pup production on Sable Island can be completely censused, future mark-recapture experiments should be estimates of Gulf production to arrive at an estimate of total production. Since it is generally agreed that the pack ice in the southern Gulf of St. Lawrence is the focus of the non-Sable Island breeders, every attempt should be made to mark a significant number of animals in this area annually. This coupled with annual enumeration of Sable pup production will allow us to follow the dynamics of both these groups.

Although it was assumed that Gulf marked and unmarked animals are randomly mixed, this assumption has not been rigorously examined as a result of the relatively small numbers of animals which have been marked to date in the Gulf. As these numbers accumulate the spatial distribution of the ratio of marked to unmarked animals can be examined to test this assumption. Since these data will be collected via the bounty system it is imperative that both the bounty and mark-recapture programs should be well advertised and efficiently administered in all regions. This includes: (1) advertisement of the bounty in all fisheries offices and areas frequented by fishermen, (2) information sessions and literature which outline the aims of the program should be disseminated to educate the fishermen and

fisheries officers, (3) hunters should be provided with simple data sheets which record date, location, and method of capture, (4) the establishment of well defined regional data collection centers which are aware of how these data are to be kept, and (5) the establishment of a central repository for all bounty and tag data.

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Table 1.

1977 Cohort (Sable) Total Marks = 1967

Return Year	Bounty (with jaw)	Shot	A R E A S		Total	Drowned	Not Reported	Other
			NFLD.	Other				
1977	7	19	14	2	69	34	13	3
1978	2	5	1	1	13	2	-	6
1979	9	7	1	0	13	2	2	2
1980	6	5	0	0	8	2	1	-
1981	3	2	0	0	5	0	2	1
1982	6	6	0	0	7	0	1	0
1983	3	3	0	0	3	0	0	0
1984	1	0	0	0	1	0	1	0

1978 Cohort (Sable) Total Marks = 2266

Return Year	Bounty (with jaw)	Shot	A R E A S		Total	Drowned	Not Reported	Other
			NFLD.	Other				
1978	32	36	27	3	92	46	5	5
1979	28	20	0	1	33	2	9	2
1980	7	6	2	0	15	0	8	1
1981	8	4	0	0	12	1	7	0
1982	5	6	3	0	11	1	4	0
1983	6	7	1	0	9	1	1	0
1984	1	1	0	0	1	0	0	0

1979 Cohort (Sable) Total Marks = 2720

Return Year	Bounty (with jaw)	Shot	A R E A S		Total	Drowned	Not Reported	Other
			NFLD.	Other				
1979	52	37	31	1	119	49	23	10
1980	9	4	0	0	15	2	5	4
1981	8	0	1	0	18	4	10	4
1982	4	3	1	0	10	4	3	0
1983	4	1	1	0	6	2	3	0
1984	1	2	0	0	3	0	0	1

1979 Cohort (Gulf) Total Marks = 460

Return Year	Bounty (with jaw)	A R E A S			Total	Drowned	Not	
		Shot	NFLD.	Other			Reported	Other
1979	32				55			
1980	8				15			
1981	2				4			
1982	0				0			
1983	1				2			
1984	-				-			

1980 Cohort (Sable) Total Marks = 3250

Return Year	Bounty (with jaw)	A R E A S			Total	Drowned	Not	
		Shot	NFLD.	Other			Reported	Other
1980	31	25	33	0	88	32	20	11
1981	2	1	5	0	15	5	6	3
1982	2	3	1	0	8	0	3	2
1983	1	1	1	0	3	2	0	0
1984	0	0	1	0	1	1	0	0

1980 Cohort (Gulf) Total Marks = 160

Return Year	Bounty (with jaw)	A R E A S			Total	Drowned	Not	
		Shot	NFLD.	Other			Reported	Other
1980	9				16			
1981	2				3			
1982	0				2			
1983	0				0			
1984	-				-			

1981 Cohort (Sable) Total Marks = 2843

Return Year	Bounty (with jaw)	Shot	A R E A S		Total	Drowned	Not Reported	Other
			NFLD.	Other				
1981	35	31	20	2	114	35	39	9
1982	4	6	6	0	21	5	6	4
1983	3	3	0	0	6	0	2	1
1984	0	0	1	0	3	0	2	1

1982 Cohort (Sable) Total Marks = 4122

Return Year	Bounty (with jaw)	Shot	A R E A S		Total	Drowned	Not Reported	Other
			NFLD.	Other				
1982	32	26	18	3	87	22	20	19
1983	8	9	3	0	23	3	3	8
1984	2	2	1	0	11	3	2	4

1982 Cohort (Gulf) Total Marks = 652

Return Year	Bounty (with jaw)	Shot	A R E A S		Total	Drowned	Not Reported	Other
			NFLD.	Other				
1982	7				39			
1983	6				17			
1984	1				2			

1983 Cohort (Sable) Total Marks = 4702

Return Year	Bounty (with jaw)	Shot	A R E A S		Total	Drowned	Not Reported	Other
			NFLD.	Other				
1983	64	58	47	4	151	57	31	5
1984	3	3	4	0	15	6	4	2

1984 Cohort (Sable) Total Marks = 5169

Return Year	Bounty (with jaw)	Shot	A R E A S		Total	Drowned	Not Reported	Other
			NFLD.	Other				
1984	47	23	67	2	142	75	36	8

Table 2. Age distributions of bounty kill samples.

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984*
0	188	202	363	420	408	362	125	238	75
1	51	29	63	133	84	73	82	47	5
2	66	31	17	51	56	62	26	48	7
3	53	30	33	26	45	47	23	25	6
4	61	24	9	28	20	23	25	40	7
5	48	32	22	22	26	10	22	29	3
6	45	31	14	29	25	11	10	22	4
7	26	27	15	32	31	15	12	10	6
8	35	32	17	23	28	9	13	7	7
9	16	24	9	29	30	10	8	7	1
10	16	19	7	23	23	6	10	16	5
11	24	19	9	21	21	12	10	7	2
12	18	16	14	18	25	15	16	10	2
13	7	16	5	14	15	13	12	7	0
14	14	15	10	9	23	7	15	12	3
15	13	10	3	13	10	5	12	12	4
16	14	11	3	13	10	11	9	8	1
17	5	8	14	13	9	5	10	9	0
18	4	6	3	8	9	3	9	7	0
19	5	5	2	4	10	5	9	2	0
20	5	5	3	0	6	5	5	9	0
21+	20	21	15	32	38	26	33	16	4
Total 0+	734	613	650	961	952	735	496	588	142
Total 1+	546	411	287	541	544	373	371	350	67

* Maritimes data only.

Table 3. Controlled cull¹.

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
1982	140	578	718	1009	1727
1983				1627	2385
1984				n o c u l l	

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 4. Tag loss rates applied to estimates of numbers of pups born.

1977	0.0244	+
1978	0.0244	*
1979	0.5	+
1980	0.5	+
1981	0.5	+
1982	0.5	*
1983	0.263	*

* Cohorts for which tag loss rates were measured.

+ Cohorts for which tag loss rates were assumed.

Table 5. Recaptures and resightings of 1984 Gulf marked pups in 1984.

Location	Gulf Tagged	Untagged	Total
Sable Island			
April	5	24	29
May	8	20	28
June	11	47	58
Gulf Bounty	<u>9</u>	<u>41</u>	<u>50</u>
TOTAL:	33	132	165

$$\chi^2 = 1.59 \text{ N.S.}$$

Table 6. Estimates of pup production corrected for tag loss.

Year	\hat{N}_{0adj}	95% Confidence Limits		(Known Pup Production)			Total Minimum
				Sable Production	Culled	Gulf Tagged	
1977	14,221	+	4,543	2,181	1,046	0	3,227
1978	11,175	+	2,618	2,687	569	0	3,256
1979	8,873	+	5,365	3,000	269	460	3,729
1980	29,009	+	23,526	3,745	921	160	4,826
1981	23,478	+	19,684	3,142	1,212	0	4,354
1982	7,387	+	4,766	4,456	1,009	652	6,117
1983	5,169	+	3,020	5,516	1,627	72	7,215
1984	12,319	+	2,106	5,983	0	1,441	7,424

Table 7. Estimated grey seal pup production corrected for losses prior to and during tagging.

Year	M_0	n	m	\hat{N}_{0adj}	N_{TOT}	95% Confidence Limits	
						Upper	Lower
1977	1,885	232	30	14,221	15,481	10,930	20,024
1978	2,180	290	55	11,175	12,165	14,783	9,547
1979	3,054	215	37	8,873	9,422	14,787	3,729*
1980	3,322	131	7	29,009	30,425	53,951	5,483
1981	2,741	136	7	23,478	24,909	44,673	4,354*
1982	4,651	54	17	7,387	8,730	13,496	6,117*
1983	4,675	6	4	5,169	7,610	10,630	7,610*
1984	⁺ 1,441	165	33	6,336	12,319	14,425	10,213

* The lower limit of the calculated interval was replaced by the observed minimum pup production.

⁺ Calculation based on Gulf marks only. Sable production added to estimated Gulf production to arrive at N_{TOT} .