International Council for the
Exploration of the Sea

C.M. 1975/N:12
Marine Mammals Committee

IMPROVED REMOTE SENSING TECHNIQUES FOR EVALUATING SEAL POPULATIONS

D.M. Lavigne and K. Ronald
Department of Zoology
College of Biological Science
University of Guelph
Guelph, Ontario, Canada

Many pinniped populations, if not all, are presently under some form of scientific scrutiny, either because the animals in question are of some economic, aesthetic or cultural value, or because they are considered pests in the local environment. Accurate estimates of population numbers are required in order to determine annual quotas or allotments for seal hunters or a sealing industry, or to establish the numbers and types (age, sex, species) of individuals to be removed by controlled culling programs, or to ensure the protection and conservation of threatened species.

Pinnipeds tend to concentrate in large groups at certain times of the year, usually in conjunction with annual whelping and breeding seasons, or the moult. Such congregations often occur in remote areas, on islands, rocky coastal rookeries, sand beaches, or in the case of pagophilic seals, on ice some distance from land, areas generally devoid of overhead cover such as dense vegetation. For these reasons, aerial remote sensing techniques would seem ideally suited for population assessment of seals, perhaps more than for any other group of mammals.

In reality, however, aerial censuses of seal populations have been carried out with very limited success to date. Such data have provided information on the relative abundance of seals in certain areas during the year (Summers and Mountford, 1975) or very approximate estimates of population numbers (Smith, 1973) often based on arbitrary and sometime invalid assumptions. Aerial censuses have failed, in general, to pro-

duce statistically sound and absolute estimates of population numbers (Sergeant, 1975).

The harp seal, Pagophilus groenlandicus, for example, has been subjected to aerial photographic surveys for more than forty years. On whelping patches the assumption has often been made that all adults on the ice are breeding females which each give birth to a single pup. In reality, adult males have been observed on the ice at the time of parturition and during the nursing period. In addition, the number of adult seals on the ice varies with the time of day and it is difficult to estimate the number of animals in the water at any given time. Young harp seal pups have not been accurately detected using conventional photographic techniques, being white animals on a white background of ice or snow (Sergeant, 1975). Aerial surveys of moulting patches are plagued by similar problems because it is impossible to separate adult seals from immature seals, male seals from female seals. Thus, although it is relatively easy to get photographs of large concentrations of animals, it is extremely difficult to know what, in fact, these seals represent.

Recent developments in remote sensing techniques suggest that it may now be possible to greatly improve population estimates of some seal populations derived through aerial surveys. This paper summarizes research conducted over the last two years to evaluate remote sensing techniques for detecting seals, and to investigate suitable censusing techniques for obtaining accurate estimates of certain population parameters.

Sensing Techniques

In the case of the harp seal, the one factor that does remain constant for some time during the whelping season is the number of white-coated pups. They remain on the ice for the first two or three weeks of life and tend not to enter the water in significant numbers. Consequently, once pupping is completed there is a brief period when virtually all young of the year are on the ice together. With the introduction of ultraviolet photography as a new method for remote sensing some animals (Lavigne and Øritsland, 1974a) it is now possible to detect these pups on aerial photographs. The white coat absorbs much of the incident ultraviolet radiation in sunlight and the resulting photographic image is a black seal. Snow, in comparison, reflects most of this ultraviolet radiation and registers white. Accurate counts of whitecoats at the end of the pupping period will give a direct estimate of annual production. This will simultaneously provide an estimate of the number of breeding females in the population, since each gives birth to a single pup.

In March 1974, following considerable laboratory and field experimentation (Lavigne and Øritsland, 1974a, b), two experimental flights were made in the Gulf of St. Lawrence to assess a variety of remote sensing techniques (Table 1), including ultraviolet photography, for detecting harp seals and their white-coated offspring. Aerial coverage was concentrated over a number of representative areas on the ice which were marked and designated so that aerial counts of seals could be correlated with counts made by observers at or near ice level.

Ultraviolet photography detected adult harp seals with equal accuracy ($p<0.05$) to any of the photographic sensors tested. In addition, it also provided the best contrast between white-coated harp seal pups and the ice and snow background. At an altitude of 305 m (1000 ft) ultraviolet photography detected the same number, or more seals than the ground count made by two experienced observers in a low flying helicopter over the designated area. It also detected significantly more white-coated seals than any other sensor tested. For example, on one experimental flight, the sensor used previously to survey the harp seal in the western Atlantic, black and white photography, with a yellow (minus blue) filter, detected only 21% of the pups which were visible on the ultraviolet imagery. Similarily, ordinary black and white photography in the absence of filters, detected 52%, and colour photography, 35%, of the pups which were counted with ultraviolet photography. It was not possible to differentiate adults and pups using the thermal infrared scanner. There was, however, no significant difference ($p<0.05$) in counts of total seals on the ice made from the thermal infrared data, and ultraviolet photography, with the ambient environmental conditions present during the 1974 flights. Under certain weather conditions, such as occurred the following year, there is little difference in the surface temperature of a well-insulated seal and its environment. As a result, counts of seals on the thermal infrared imagery underestimated the number of seals present in 1975.

Once a suitable sensing technique was available for detecting adult harp seals and their white-coated offspring, the

next step was to develop and test suitable censusing techniques for obtaining accurate estimates of population numbers.

Aerial Censusing Techniques

The usual method of estimating seal numbers from data derived from aerial surveys of harp seals in the Gulf of St. Lawrence has been outlined by Mansfield (1970) and Sergeant (1975). Densities of adult seals found within a sample area, i.e. counted on aerial photographs, are then extrapolated to the estimated area of the herd.

Such estimates of seal numbers do not provide information on the variability of the estimates, no measures of confidence which can be placed on these estimates, and in fact, no certain information on the sex of the individuals counted and estimated, although a large percentage can be assumed to be females.

Aerial survey data obtained in 1974 were used to make preliminary estimates of total numbers of adult seals and white-coated pups on ice in the Gulf of St. Lawrence at the time of the flights. A variety of extrapolations were made in attempts to get reasonable estimates and define 95% confidence limits (Table 2a).

Research was continued in 1975 in an attempt to develop suitable and feasible, in terms of logistics and economics, sampling techniques for obtaining aerial census information for western Atlantic stocks of whelping harp seals. Briefly, four experimental aerial surveys were made, two over the whelping herd in the Gulf of St. Lawrence west of the Magdalen Islands on the 10 and 17 March, and two over harp seals whelp-

ing on the Front off the east coast of Newfoundland on the 11 and 15 March. The latter group was divided into a northern patch and a smaller southern patch. Attempts were made to obtain total coverage of these areas by flying parallel grid lines over the herd at an altitude of 1220 m (4000 ft) guided by an inertial navigational system on board the remote sensing aircraft. A 9" x 9" (22.9 cm x 22.9 cm) aerial survey camera and black and white photography (Kodak 2402 aerial film) were used, since ultraviolet photography in this large format is not presently available. Subsequently sampling was conducted at random areas over the herd at an altitude of 305 m using ultraviolet photography and the infrared thermal scanner. The rationale was that the 1220 m imagery should provide a second estimate of herd area, the first being made by observers in the field, as well as a direct count of the number of adult seals on the ice at the time of the flight. The sample obtained with ultraviolet photography at a lower altitude would give numbers of adults and pups which could then be extrapolated to the area of the herd. The estimate of adults would then be compared with the direct count of adults to evaluate the accuracy of the sampling technique. If satisfactory, the samples could then be used to estimate the numbers of white-coated pups on the ice (annual production), and in turn lead to a direct extrapolation of the number of breeding females in the population.

The black and white photography of the Gulf herd from 1220 m on 10 March 1975 produced a direct count of 35,418 adult seals on the ice at the time of the flight. This figure is important only as it serves as a reference point for extrapolat-

ions from the samples collected at 305 m using ultraviolet photography. On the basis of a simple random sample (Mendenhall et al., 1971) the number of adults on the ice, predicted from 69 samples, was about 38,000 or within about 8% of the direct count (Table 2b).

Since the distribution of the adults in the whelping herd reflects in general the distribution of pups on the ice, the number of pups may then be extrapolated from the samples. This results in an estimate of about 47,500 young seals on the ice at the time of the flight (Table 2b). This should be a good estimate of the annual production, since pupping was observed in the field to be completed on about 7 March 1975, and an accurate representation of the number of breeding females in the Gulf herd in March 1975 because of the 1:1 ratio of whelping females and pups.

Adult harp seals and their pups may be shown to be distributed in a contagious or clumped manner on the ice using such criteria as the coefficient of dispersion (Woolf, 1968) and Morisita's Index (Poole, 1974). This means that in an aerial survey of the whelping herd, there is an excess of areas (or quadrats) on the ice with no seals and an excess of quadrats with many seals, as compared with expected values based on a random or Poisson distribution (Woolf, 1968). In general, gregarious animals, and the harp seal is a gregarious species (Mansfield, 1967), occurring in quantity at a given position, are distributed in this manner (Woolf, 1968). This implies that the presence of one seal at a given position in-

creases the probability that other seals will occur close by, and that the seals will, as a result, be clumped together in groups on the ice. Habitat heterogeneity, often an important factor in such distributions of animals (Poole, 1974), may also pertain to harp seals, which may actively seek out certain ice conditions for whelping.

The confidence intervals given in Table 2 must be interpreted with some care. Although they appear wide on first inspection, they merely reflect the fact that 69 samples of this contagious distribution of seals is not sufficient to obtain a normal distribution of means (Remington and Schork, 1970; Snedecor and Cochrane, 1967). In other words the large variances, relative to the population means determined using our remotely sensed data, reflect a biological characteristic of the population rather than any serious deficiency in the censusing technique. The means become normally distributed and the variances are reduced simply by increasing sample size.

In order to demonstrate this, the absolute numbers of adult seals counted on the 1220 m imagery were entered into a computer matrix. Numbers of adult seals were then estimated using a variety of sample sizes. The variance decreased with increasing sample sizes as predicted. For example, 69 samples produced a standard error of the estimate which was 45.8% higher than that determined for 300 samples. It is well known that whatever the shape of the frequency distribution of the original population, the frequency distribution of means in repeated random samples tends to become normal as the number

of samples increase (Snedecor and Cochrane, 1967). The frequency distribution of means for 69 samples is positively skewed whereas for 300 samples, the frequency distribution approaches the normal. Thus because of the clumped distribution of harp seals in whelping patches, a large sample size is a prerequisite for high precision in estimates of numbers of seals. Another alternative is to obtain a direct total count as was done in the Gulf this year.

This is the first time an accurate estimate of annual production has been obtained for the Gulf herd using aerial censusing techniques. Comparable data have only been obtained in years previous when the total production of pups in the Gulf has been harvested by sealers. Such was the case in 1971 when the total catch of young seals was in excess of 70,000 (Sergeant, 1975). Our data for 1975, supported by the 1974 results (Table 2) suggest that a marked decline in the annual production of harp seals in the Gulf of St. Lawrence has occurred since 1971. This, of course, may only reflect a redistribution of whelping harp seals from the Gulf to the Front, but may also reflect a further decline in harp seal stocks in the western Atlantic in recent years. Aerial survey data obtained in the Gulf and on the Front in 1975, and presently under analysis, should provide some valuable information in this regard.

Summary

Ultraviolet photography has recently been introduced as a remote sensing technique for counting white-coated seal pups on snow and ice. For species such as the harp seal it may now be

possible to use aerial censusing techniques to obtain very accurate estimates of certain population parameters such as annual production, and the number of adult female seals in the breeding population. The design and analyses of suitable sampling procedures must take into account the contagious distribution of harp seals on the ice. In addition, the area of ice covered by the seal herd must be accurately determined.

Our preliminary estimates indicate a decline in the number of harp seals breeding in the Gulf of St. Lawrence in recent years. Whether this merely implies that a greater number of harp seals are now breeding on the Front, or in fact is the result of a further decline in harp seal stocks in the western Atlantic, will not be known until the 1975 aerial survey data are completely analysed.

Acknowledgements

We thank the many individuals and organizations which have participated and/or cooperated in aspects of this work. Specifically we recognize Cand. real. Nils Øritsland who played a significant role in the initiation of this research; S. Innes, K. Kalpakis, and P. Watts for their contribution to the analysis of field data; Dr. D.E. Sergeant, Arctic Biological Station, Fisheries and Marine Service Environment Canada; Major E.J. McLaren, Head, Airborne Operations Section, Canada Centre for Remote Sensing, Energy, Mines, and Resources Canada; Mr. C. Levelton, Director-General, Operations Directorate, Fisheries and Marine Service, Environment Canada; and Mr. Stan Dudka,

Fisheries and Marine Service, Halifax.

Financial support was obtained through the Special Advisory Committee on Seals and Sealing to the Minister of State for Fisheries, from the National Research Council of Canada, and the Arctic Biological Station, Ste. Anne de Bellevue.

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TABLE 1

Sensor packages tested for use in remote sensing harp seals (*Pagophilus groenlandicus*) in the Gulf of St. Lawrence in 1974.

Camera	Format	Lens	Film	Filter	Altitude	Scale	Remarks
RC-8	9"x9"	6"	2405	NAV	305 m	1:2000	B/W Photography
					457 m	1:3000	
RC-8	9"x9"	6"	2445	NAV	305 m	1:2000	Colour Photography
					610 m	1:4000	
					915 m	1:6000	
					1220 m	1:8000	
Hasselblad	70 mm.	105 mm. U-V sonnar	2405	18A	305 m	1:2900	UV Photography
					457 m	1:4350	
					610 m	1:5800	
					915 m	1:8700	
					1220 m	1:8700	
Vinten	70 mm.	3"	2405	NAV	305 m	1:4000	B/W Photography
					610 m	1:8000	
					915 m	1:12,000	
					1220 m	1:16,000	
Vinten	70 mm.	3"	2405	12	305 m	1:4000	B/W photography with minus blue filter as used in previous years.
					610 m	1:8000	
					915 m	1:12,000	
					1220 m	1:16,000	

Other Sensors: A Daedalus infrared line scanner with an 8-14μ (8000-14000 nm) detector was also tested at altitudes of 305, 610, 915, and 1220 metres.

TABLE 2

Summary of estimates of harp seals (Pagophilus groenlandicus) on ice in the Gulf of St. Lawrence

	PUPS		ADULTS[c]	
2a March 6, 1974[a]	$\hat{t}$	95% CI	$\hat{t}$	95% CI
Direct extrapolation	35,620	---	32,898	---
Simple random sampling (approx.)	35,620	13,797 - 57,443	32,898	12,192 - 53,604
Line by line analysis	31,058	19,078 - 43,098	24,834	15,415 - 42,253
Single stage cluster sampling	35,618	17,512 - 53,725	32,897	18,268 - 47,527
2B March 10, 1975[b]				
Direct extrapolation	47,552	---	38,331	---
Simple random sampling	47,552	32,251 - 62,853	38,331	12,727 - 63,934
Line by line analysis	48,611	8,592 - 88,630	39,362	5,499 - 73,225
Single stage cluster sampling	47,552	15,481 - 79,629	38,331	11,603 - 65,149
Two stage cluster sampling	45,548	-2,882 - 97,978	38,350	9,191 - 67,511
Total number of adult seals[d]			35,418	

a Pupping was incomplete, based on 11 samples covering an area of 5.3 km^2 or 5.8% of the estimated herd area.

b Pupping was complete, based on 69 samples covering an area of 15.4 km^2 or 3.0% of the estimated herd area.

c Represents adult seals on the ice at the time of the flight only.

d Counted from black and white aerial imagery, 1220 m AGL.