Canadian Atlantic Fisheries
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The 1977 Census of Western Atlantic Harp Seals

Pagophilus groenlandicus

by

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PREFACE

The results of this work must ultimately be discussed in relation to current management policy. However, for the sake of objectivity, only the census results will be discussed in this report. Discussion of related matters may be undertaken by one or more of the authors in future papers.

A preliminary report prepared for the Committee on Seals and Sealing, 21, 22 August, 1977 and subsequently made public is reproduced in Appendix 1 to clarify any misconception generated by an article in the Vancouver Sun and a Canadian Press news release in September.

INTRODUCTION

Although harp seals have been exploited for centuries, efforts to estimate their numbers and to manage the stocks are relatively recent developments. Aerial photographic surveys were first employed by Russian biologists working on harp seals in the White Sea about 50 years ago (Sergeant 1976). In the western Atlantic, aerial surveys using conventional black and white photography have been conducted at irregular intervals since the early 1950's (Fisher 1952, 1955; Sergeant 1975). In general, these aerial censuses have not however, produced satisfactory absolute estimates of pup production or population size (Sergeant 1975) which are necessary for the development of adequate management policies. Conventional black and white photography, used prior to 1974, accurately detects only adult seals on the surface of the ice (Lavigne 1976). On whelping patches the assumption has often been made that all adults on the ice are breeding females, each of which gives 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. Aerial surveys of moulting patches are plagued by similar problems because it is impossible to discriminate adult seals from immature seals, and male seals from female seals. Thus, although it is relatively easy to obtain photographs of large concentrations of animals, it is extremely difficult to know what, in fact, these seals represent.

In the case of the harp seal, the only factor that seems to remain constant for any 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 the young of the year are on the surface of the ice together. However, young harp seal pups, being white animals on a white background of ice and snow have not been accurately detected in the past using conventional photographic techniques (Sergeant 1975). This problem has recently been overcome with the introduction of ultraviolet photography as an appropriate sensor for detecting certain white animals, such as white-coated seal pups and polar bears in white environments (Lavigne and Øritsland 1974a, b, Lavigne 1976). Although the white coat of the harp seal pup reflects all wavelengths in the visible spectrum, and appears white to the human eye, it absorbs much of the ultraviolet component in solar radiation. Snow not only reflects visible light and appears white to the eye, but also reflects much of the invisible (to the human eye) ultraviolet radiation. Thus, an ultraviolet photograph of a white harp seal pup on snow results in a black image of the animal against a grey-white background (Lavigne 1976a).

Ultraviolet photography was initially tested in the field in March 1974 (Lavigne _et al_. 1974). The following year an experimental aerial survey was conducted over all known whelping patches in the Gulf of St. Lawrence and on the "Front" off the coast of Labrador. The results of this preliminary census suggested that pup production was somewhat lower than generally expected, perhaps less than 200,000 animals, implying that the number of animals aged one and older in the stock might be less than 1 million seals (Lavigne _et al_. 1975a; 1975b, Lavigne 1976a).

Further development of the ultraviolet aerial census technique was recognized as a priority for future research by the Scientific Advisors to the International Commission for Northwest Atlantic Fisheries (ICNAF) at their meetings in late 1975 (ICNAF 1975) and plans for a full scale census were made for March 1976. This survey was not completed because of unsuitable ice conditions in the Gulf of St. Lawrence and inclement weather on the Front. Nevertheless, the need for a complete census of western Atlantic harp seals was reiterated at the October 1976 ICNAF meetings (Benjaminsen and Lett 1976; Capstick et al. 1976; ICNAF 1976).

A census was subsequently completed in March 1977. This report outlines the design of the aerial survey, the field operations, data analyses, and the resulting estimates of pup production for Western Atlantic harp seals in March 1977.

METHODS

Aerial Survey Design

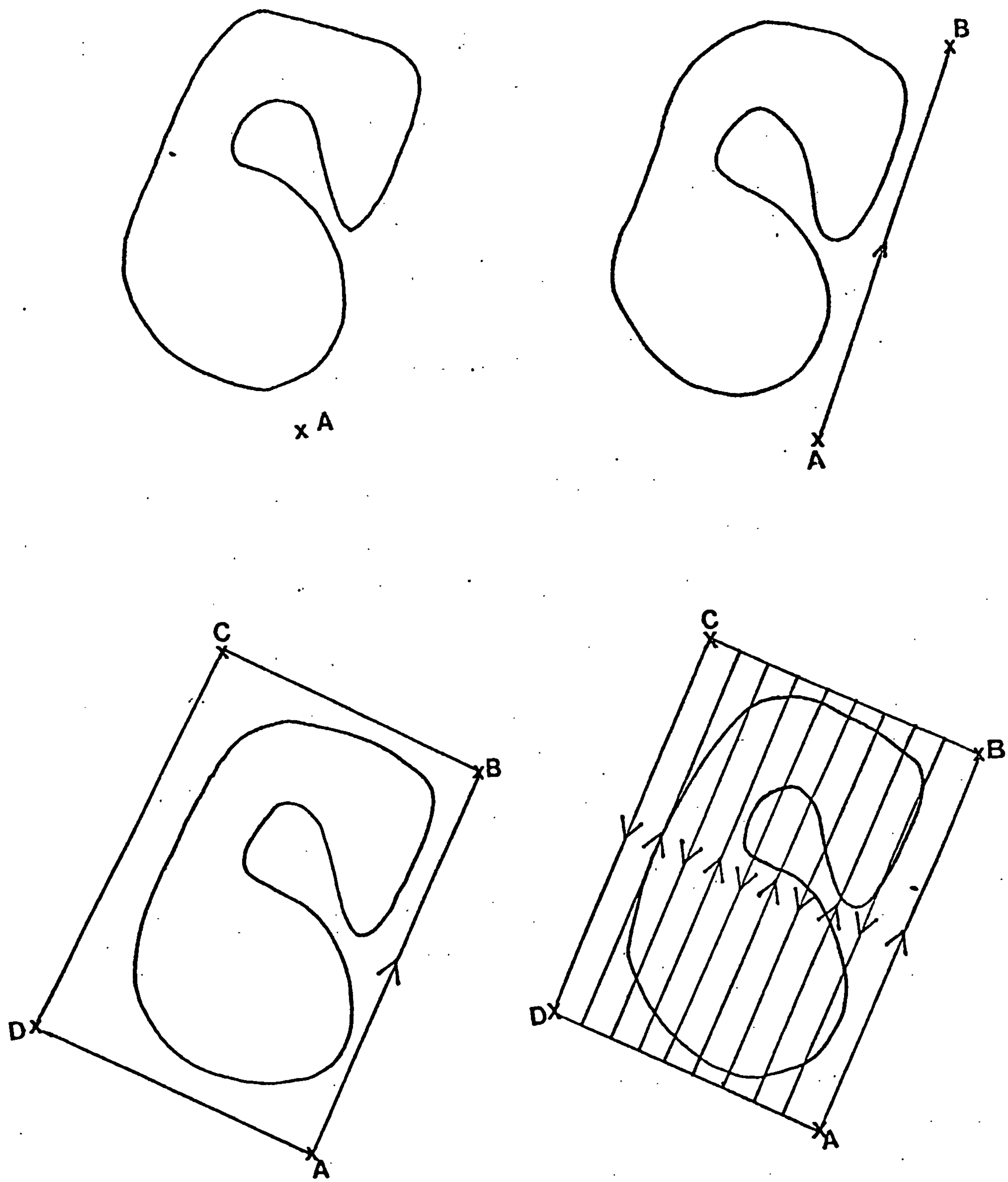
The design of the aerial survey was based on the results of the 1975 experimental census (Lavigne et al. 1975a, 1975b). Discussion among various collaborators in preparation for the subsequently aborted 1976 census, and prior to the 1977 census, resulted in further refinements and minor modifications in the survey design.

A research proposal outlining the objectives and methodology was accepted by the Canada Centre for Remote Sensing, Energy, Mines and Resources Canada. The survey was subsequently conducted using a DC-3 (Dakota) aircraft operated by Innotech Aviation Ltd. in conjunction with Intera Environmental Consultants Ltd., Ottawa.

The following general procedure was used with minor modifications (necessitated by field conditions), for each of the remote sensing flights in March 1977. Whelping patches were initially located and delineated as to approximate area and orientation by helicopter or small fixed-wing aircraft. Once pupping was judged to be virtually complete, and suitable weather conditions were obtained, the DC-3 flew to a position designated by one of the support aircraft as one corner of an imaginary rectangular grid superimposed over the entire whelping patch (Fig. 1, A). This position (A) was then entered into the inertial navigation system (INS) on board the DC-3. The supporting aircraft (usually a helicopter) would then fly a straight course to the other end of the whelping patch (Fig. 1, line AB). The DC-3 followed and entered this second position (B) into the INS. In this way, one side (AB) of the imaginary rectangle (ABCD) oriented in the direction of the long axis was established to provide a basis for constructing a grid over the entire whelping patch (Fig. 1). This grid was subsequently flown and photographed at 1220 m with 20 to 30% forward overlap between adjacent frames within each line. Attempts were made to obtain 20% overlap between adjacent lines to ensure complete coverage and to aid in mosaicing the imagery and reconstructing the whelping patch in the lab. For the 1220 m flights (scale 1:8000) the primary sensor was a Wild Heerbrugg RC-10, 23 cm x 23 cm format aerial survey camera with a 15.2 cm lens, a NAV filter, and Kodak Double-X Aerographic Film (2405).

While flying the survey at 1220 m observers in the DC-3 continually viewed the ice. If, upon completing the full programmed length of a line, there were still seals on the line of flight, then the line was continued until there were no seals in view. Similarly, although the width of the grid was initially estimated by observers in the support aircraft, observers in the DC-3 ultimately determined this as they ran out of seals on the ice.

Fig. 1. General procedure used to establish a survey grid over a whelping patch of harp seals.



Once the 1220 m coverage was completed, lower altitude samples were obtained at 305 m using ultraviolet photography as the primary sensor. A Hasselblad camera was equipped with a 105 m UV-Sonnar lens, a Kodak Wratten 18A filter (Lavigne and Øritsland 1974a) and Kodak Double-X Aerographic 2405 film produced imagery in 70 mm format at a scale of 1:2900.

The dimensions of the grid obtained at 1220 m defined the total number of possible sample lines which could be flown at 305 m, given unlimited time, fuel, and film. A single sample was then defined as one 305 m flight line running the complete length of the grid. For the purposes of stratification the grid was divided into a number of zones. The number of zones defined was dependent on the width of the grid, and the available flying time which remained.

The aerial survey flights were tentatively scheduled to begin about 1100 h local time and finish about 1500 h to take advantage of favourable sun angles and radiation intensities for photography and the fact that the largest proportion of adult seals congregates on the surface of the ice during this time (Lavigne 1976). The available flying time for obtaining the sample imagery was thus determined by the time of day the 1220 m imagery was completed, the amount of fuel remaining, and the transit time required for the DC-3 to return to base.

The average time taken to fly each 1220 m flight line, including positioning times, was then used to estimate the maximum number of 305 m sample lines which could be flown in the remaining time. This in turn dictated the number of sampling zones to be used in the stratification of the grid. Two 305 m flight lines were then selected from each zone using a random number table.

The resulting imagery was later processed and annotated by the Canada

Centre for Remote Sensing before being shipped to Guelph.

Preliminary evaluation of the census

After the field work was completed, participants from the University of Guelph and the Fisheries Marine Service, Environment Canada independently assessed the apparent completeness of the aerial surveys in the Gulf of St. Lawrence and on the Front. These evaluations, prepared prior to receiving the processed imagery from the Canada Centre for Remote Sensing, are documented in a memorandum from W.G. Doubleday to A.W. May (21 March 1977) and in a letter from K. Ronald to A.W. May (4 April 1977). Later, during the analysis of the aerial imagery, an interim meeting was held at the University of Guelph (6 June 1977) to discuss the above evaluations and various aspects of the field operations. The results of these discussions are recorded in the minutes of that meeting.

Preliminary results were discussed at a later meeting (17 August 1977) and an interim report was then submitted to the Committee on Seals and Sealing on 21 August 1977 (Appendix 1).

Evaluations and comments relevant to the analyses and interpretation of the survey results are summarized below.

RESULTS

Extent of photographic coverage

The remote sensing aircraft was positioned in Summerside, P.E.I. on 4 March. By this time two concentrations of whelping harp seals had been located, one to the west of the Magdalen Islands and another, east of Bird Rocks. Inclement weather and low cloud cover prevented any survey work however, from 5 through 8 March.

Suitable weather finally prevailed on 9 March and a survey was conducted over the whelping patch northwest (~47.30.4N, 62.45.1W) of the Grindstone Beacon on the Magdalen Islands. Twelve overlapping 1220 m flight lines were flown over this patch and 6 305 m samples were obtained using 70 mm ultraviolet photography (Table 1, Fig. 2).

On 10 March, an additional survey was conducted in the same general region as the previous day. The objective of this survey was to obtain coverage of whelping seals to the west and north-east of the area flown on 9 March. Details of the 1220 m flight lines, and the 305 m sample lines flown are given in Table 2 (also see Fig. 3 and Fig. 4).

On 11 March, an attempt was made to photograph the Bird Rocks' whelping patch. The support helicopter was not able to locate this patch, but after a systematic search the DC-3 remote sensing aircraft located and surveyed a whelping patch running east-west just north of Bird Rocks (Table 3, Figs. 5 and 6).

Having surveyed the known whelping concentrations in the Gulf, the DC-3 moved its base of operations to St. John's, Nfld. on 12 March. No flights were conducted on 13 March due in part to weather conditions, and the fact that the whelping patches on the Front were not adequately delineated by 12 March to warrant a survey.

On 13 March, a reconaissance flight by the support aircraft located and delineated the Front herd. The herd was essentially divided into two patches (see Curran, 1977) and located to the east of Belle Isle (Fig. 7). On 14 March the largest of the two patches was surveyed and sampled (Table 4, Fig. 7 and 8) and the remainder, essentially west of 54°34'W longitude, was surveyed on 15 March (Table 5, Figs. 7 and 8).

The Mecatina patch in the northern Gulf of St. Lawrence did not

TABLE 1

Survey and Sample Line Positions for

77.03.09

305 m[b]

Line no.	Displacement[a] (nm)	Position Commence	Position Finish	Random No.	Zone	No. Frames	Time (GMT)[c] Commence	Time (GMT)[c] Finish
1	8.1	47.51.1 N 62.21.6 W	47.29.8 N 62.38.7 W	90	10	177	18:16	18:32
2	7.7	47.38.6 N 62.31.- W	47.23.1 N 62.43.5 W	86	10	236	18:47	18:59
3	6.7	47.40.0 N 62.28.1 W	47.28.1 N 62.38.0 W	75	9	190	19:13	19:22
4	6.5	47.38.1 N 62.29.5 W	47.28.9 N 62.36.8 W	73	9	140	19:30	19:37
5[d]	6.3	47.36.7 N 62.30.1 W	47.29.6 N 62.35.9 W	70	8	109	19:45	19:50
6[d]	3.7	47.38.1 N 62.24.6 W	47.30.7 N 62.30.7 W	41	6	127	20:00	20:06

[a] Displacement from 1220 m - line 1.

[b] No record was made of positions of 12 - 1220 m survey lines flown.

[c] Local time (AST) = GMT - 4:00

[d] Only one sample was obtained from each of zones 5 and 6 due to lack of time and low sunangle. Zones 1-5 were not sampled since times 1-6 were outside herd area.

Fig. 2. 305 m sample lines obtained on 9 March 1977 in the Gulf of St. Lawrence, west of the Magdalen Islands, as recorded by the inertial navigation system in the remote sensing aircraft.

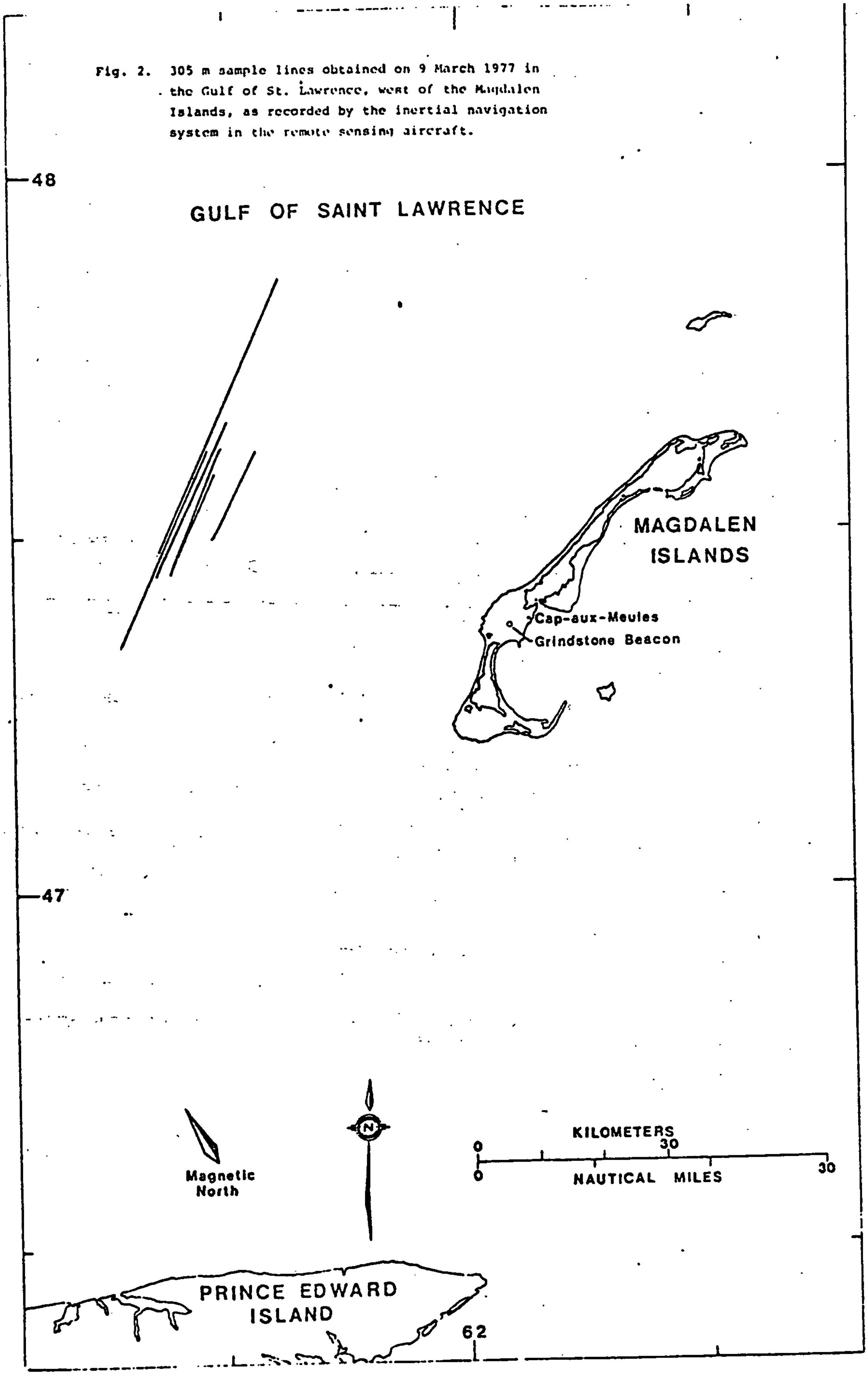


TABLE 2

Survey and Sample Line Positions for

77.03.10

Line no.	Displacement[a] (nm)	Position Commence	Position Finish	Random No.	Zone	No. Frames	Time (GMT)[c] Commence	Time (GMT)[c] Finish
				1220 m				
1	0	47.40.9 N 62.20.7 W	47.34.8 N 62.29.5 W	-	-	14	15:56	16:02
2	0.7	47.35.4 N 62.28.9 W	47.41.0 N 62.21.1 W	-	-	11	16:06	16:09
3	1.4	47.42.0 N 62.22.4 W	47.34.9 N 62.32.3 W	-	-	13	16:13	16:20
4	2.1	47.35.3 N 62.32.2 W	47.42.9 N 62.21.3 W	-	-	15	16:25	16:29
5	2.8	47.42.8 N 62.24.1 W	47.35.7 N 62.33.9 W	-	-	13	16:35	16:41
6	3.5	47.37.0 N 62.32.3 W	47.43.7 N 62.23.0 W	-	-	13	16:45	16:48
7[b]	-	-	-	-	-	-	17:01	17:04
8	4.2	47.38.1 N 62.32.2 W	47.44.3 N 62.23.7 W	-	-	11	17:20	17:23
9	4.9	47.45.1 N 62.23.7 W	47.38.1 N 62.33.3 W	-	-	12	17:28	17:33
				305 m				
1	1.1	47.40.9 N 62.22.9 W	47.34.9 N 62.31.4 W	13	1	126	18:14	18:21
2	1.5	47.41.0 N 62.24.0 W	47.35.4 N 62.31.3 W	17	1	79	18:28	18:34
3	2.0	47.41.1 N 62.24.4 W	47.35.7 N 62.32.1 W	23	2	73	18:41	18:46
4	2.7	47.41.6 N 62.25.4 W	47.36.9 N 62.31.8 W	30	2	65	18:53	18:57
5	3.0	47.41.3 N 62.26.3 W	47.37.6 N 62.31.4 W	34	3	47	19:04	19:17
6	3.8	47.41.6 N 62.27.3 W	47.38.9 N 62.31.2 W	43	4	35	19:16	19:18

[a] Displacement from 1220 m - line 1.

[b] 1220 m - line 7 aborted due to navigational malfunction.

[c] Local time (AST) = GMT - 4:00

Fig. 3. 1220 m survey lines obtained on 10 March 1977 in the Gulf of St. Lawrence, west of the Magdalen Islands, as recorded by the inertial navigation system in the remote sensing aircraft.

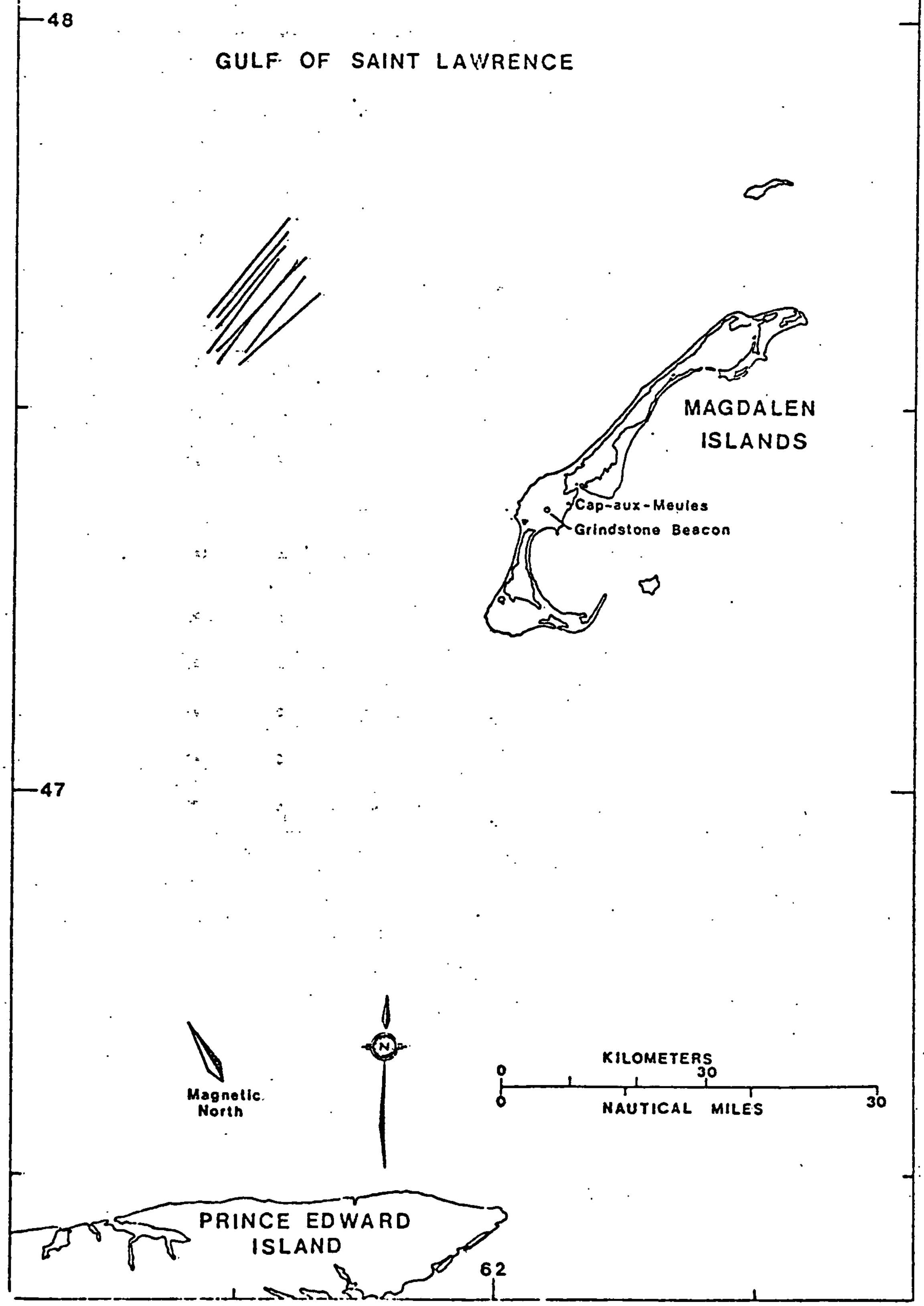


Fig. 4. 305 m sample lines obtained on 10 March 1977 in the Gulf of St. Lawrence, west of the Magdalen Islands, as recorded by the inertial navigation system in the remote sensing aircraft.

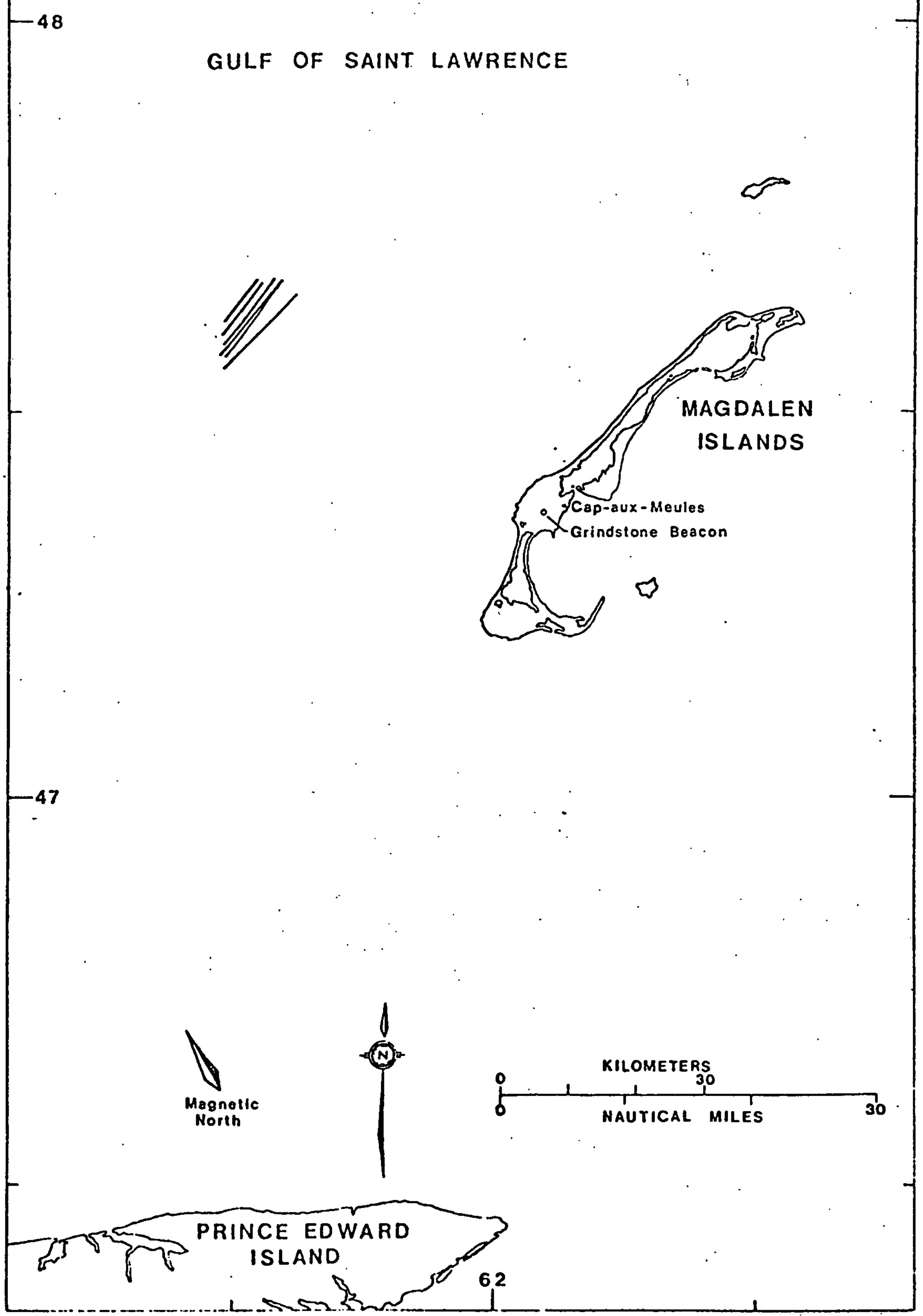


TABLE 3

Survey and Sample Line Positions for

77.03.11

Line no.	Displacement[a] (nm)	Position Commence	Position Finish	Random No.	Zone	No. Frames	Time (GMT)[d] Commence	Time (GMT)[d] Finish
				1220 m				
1	0	47.51.9 N 61.22.5 W	47.49.3 N 61.10.7 W	-	-	11	16:41	16:44
2	0.7	47.49.7 N 61.08.2 W	47.53.0 N 61.25.4 W	-	-	18	16:46	16:53
3	1.4	47.53.7 N 61.24.8 W	47.50.0 N 61.05.6 W	-	-	17	16:56	17:01
4	2.1	47.50.6 N 61.05.9 W	47.54.7 N 61.26.3 W	-	-	19	17:04	17:12
5	2.8	47.55.5 N 61.26.6 W	47.51.4 N 61.06.7 W	-	-	19	17:19	17:24
6	3.5	47.51.7 N 61.03.8 W	47.55.7 N 61.23.6 W	-	-	18	17:27	17:35
7	4.2	47.56.5 N 61.24.4 W	47.52.7 N 61.05.7 W	-	-	17	17:37	17:42
8	4.9	47.46.2 N 60.57.5 W	47.50.3 N 61.05.0 W	-	-	10	19:24	19:28
				305 m				
1	0.9	47.50.2 N 61.09.8 W	47.53.1 N 61.24.6 W	10	1	125	17:52	17:58
2	1.3	47.49.9 N 61.06.3 W	47.53.3 N 61.23.2 W	15	1	158	18:08	18:15
3	2.4	47.51.1 N 61.07.1 W	47.54.5 N 61.23.8 W	27	2	155	18:25	18:32
4	3.2	47.51.8 N 61.06.1 W	47.53.3 N 61.23.6 W	36	2	162	18:42	18:49
5[b]	2.5	47.51.1 N 61.06.3 W	47.54.5 N 61.23.0 W	-	2	155	18:59	19:06
6[c]	-	47.45.9 N 60.58.0 W	47.49.2 N 61.03.8 W	-		76	19:34	19:38

[a] Displacement from 1220 m - line 1.

[b] Sample not randomly chosen but instead, chosen to fall in seal concentrations.

[c] No displacement recorded; sample was taken from center line of 1220 m - line 8 by line of sight.

[d] Local time (AST) = GMT - 4:00

Fig. 5. 1220 m survey lines obtained on 11 March 1977 in the Gulf of St. Lawrence near Bird Rocks, as recorded by the inertial navigation system in the remote sensing aircraft.

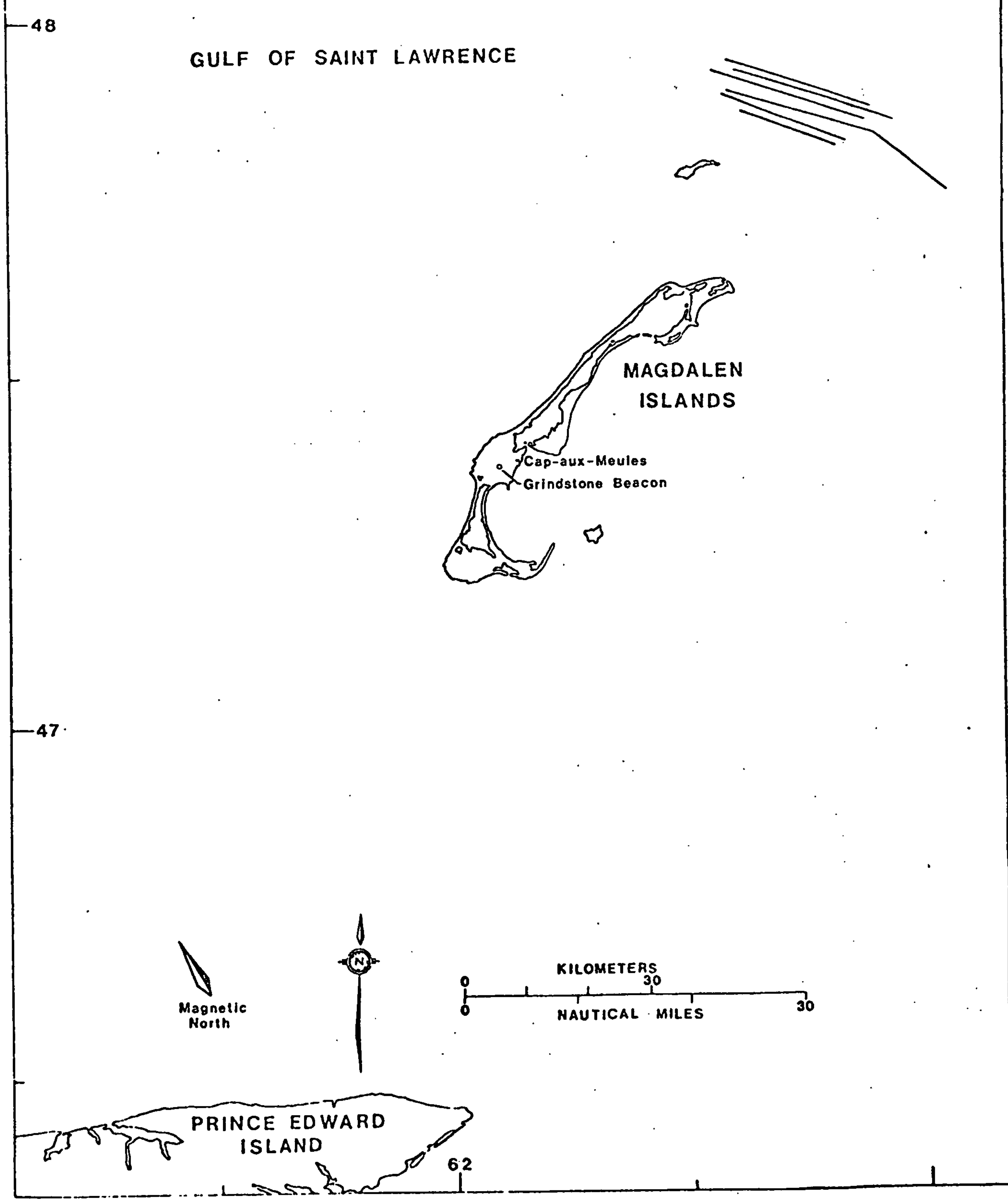


Fig. 6. 305 m sample lines obtained on 11 March 1977 in the Gulf of St. Lawrence near Bird Rocks, as recorded by the inertial navigation system in the remote sensing aircraft.

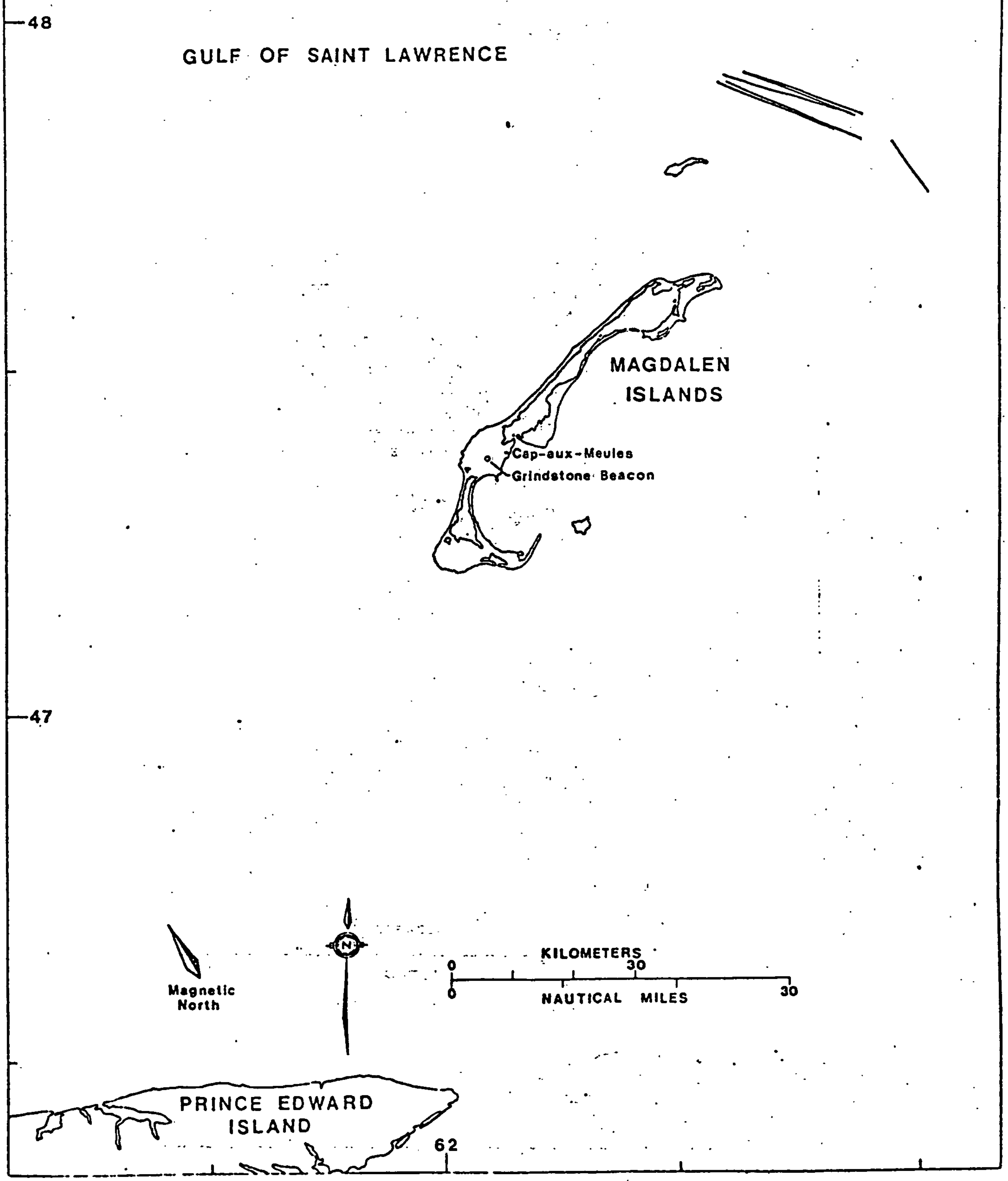


TABLE 4

Survey and Sample Line Positions for

77.03.14

1220 m

Line No.	Displacement[a] (nm)	Position Commence	Position Finish	Random No.	Zone	No. Frames	Time (GMT)[c] Commence	Time (GMT)[c] Finish
1	0	51.52.0 N 54.02.6 W	51.39.0 N 54.08.0 W	-	-	19	15:01	15:06
2	0.7	51.37.6 N 54.10.0 W	51.55.1 N 54.02.5 W	-	-	25	15:09	15:20
3	1.4	51.55.1 N 54.03.5 W	51.37.9 N 54.10.8 W	-	-	25	15:23	15:29
4	2.1	51.35.9 N 54.13.0 W	51.55.7 N 54.04.7 W	-	-	29	15:32	15:44
5	2.8	51.54.5 N 54.05.9 W	51.35.6 N 54.14.2 W	-	-	30	15:47	15:55
6	3.5	51.33.8 N 54.16.3 W	51.55.8 N 54.06.8 W	-	-	31	15:58	16:11
7	4.2	51.55.7 N 54.08.1 W	51.33.2 N 54.17.6 W	-	-	31	16:19	16:28
8	4.9	51.32.3 N 54.19.0 W	51.55.1 N 54.09.7 W	-	-	29	16:31	16:45
9	5.6	51.55.1 N 54.10.5 W	51.34.8 N 54.19.1 W	-	-	29	16:47	16:55
10	6.3	51.34.0 N 54.20.7 W	51.54.8 N 54.12.1 W	-	-	30	16:59	17:11
11	7.0	51.54.6 N 54.13.2 W	51.40.8 N 54.18.9 W	-	-	20	17:13	17:19
12	7.7	51.39.5 N 54.20.5 W	51.48.4 N 54.17.0 W	-	-	13	17:22	17:27
				305 m				
1	3.6	51.53.2 N 54.08.0 W	51.34.1 N 54.16.1 W	40	1	256	17:35	17:44
2[b]	5.7	51.34.9 N 54.19.1 W	51.54.7 N 54.10.9 W	64	2	255	17:48	18:01

[a] Displacement from 1220 m - line 1.

[b] more 30 m sample lines were not flown due to lack of fuel.

[c] Local time (NST) = GMT - 3:30

TABLE 5

Survey and Sample Line Positions for

77.03.15

1220 m

Line No.	Displacement[a] (nm)	Position Commence	Position Finish	Random No.	Zone	No. Frames	Time (GMT)[c] Commence	Time (GMT)[c] Finish
1	0	51.44.3 N 54.48.3 W	51.37.7 N 54.30.0 W	-	-	19	14:24	14:30
2	0.7	51.42.1 N 54.39.4 W	51.37.9 N 54.28.2 W	-	-	12	15:09	15:11
3	1.4	51.37.9 N 54.25.7 W	51.41.1 N 54.34.8 W	-	-	10	15:13	15:17
4	2.1	51.42.3 N 54.36.0 W	51.38.1 N 54.24.3 W	-	-	12	15:20	15:23
5	2.8	51.37.9 N 54.21.3 W	51.42.8 N 54.34.9 W	-	-	13	15:26	15:31
6	3.5	51.43.5 N 54.34.7 W	51.38.1 N 54.20.2 W	-	-	15	15:33	15:38
7	4.2	51.38.3 N 54.18.4 W	51.43.7 N 54.33.2 W	-	-	13	15:40	15:46
8	4.9	51.44.4 N 54.32.8 W	51.38.4 N 54.16.5 W	-	-	16	15:50	15:55
9	5.6	51.38.1 N 54.13.2 W	51.44.8 N 54.31.6 W	-	-	18	15:58	16:05
				305 m				
1	0.5	51.40.7 N 54.36.6 W	51.37.6 N 54.27.9 W	5	1	78	16:11	16:14
2	1.0	51.37.6 N 54.27.0 W	51.40.7 N 54.34.9 W	10	1	83	16:17	16:21
3	2.8	51.42.5 N 54.34.6 W	51.37.6 N 54.21.1 W	31	2	125	16:23	16:28
4	3.5	51.37.9 N 54.19.3 W	51.43.5 N 54.34.2 W	39	2	144	16:32	16:38
5	3.6	51.43.8 N 54.35.5 W	51.39.3 N 54.23.0 W	41	3	117	16:41	16:45
6	4.6	51.40.1 N 54.21.9 W	51.43.2 N 54.30.5 W	51	3	91	16:48	16:53
7[b]	2.3	51.43.4 N 54.37.5 W	51.38.9 N 54.26.0 W	-	2	112	17:01	17:05
8[b]	4.0	51.38.7 N 54.20.2 W	51.44.8 N 54.37.3 W	-	3	168	17:09	17:16

[a] Displacement from 1220 m - line 1.

[b] Samples not randomly chosen but instead, chosen to fall in seal concentrations.

[c] Local time (NST) = GMT - 3:30

Fig. 7. 1220 m survey lines obtained on 14 (A) and 15 (B) March 1977 on the Front off Newfoundland.

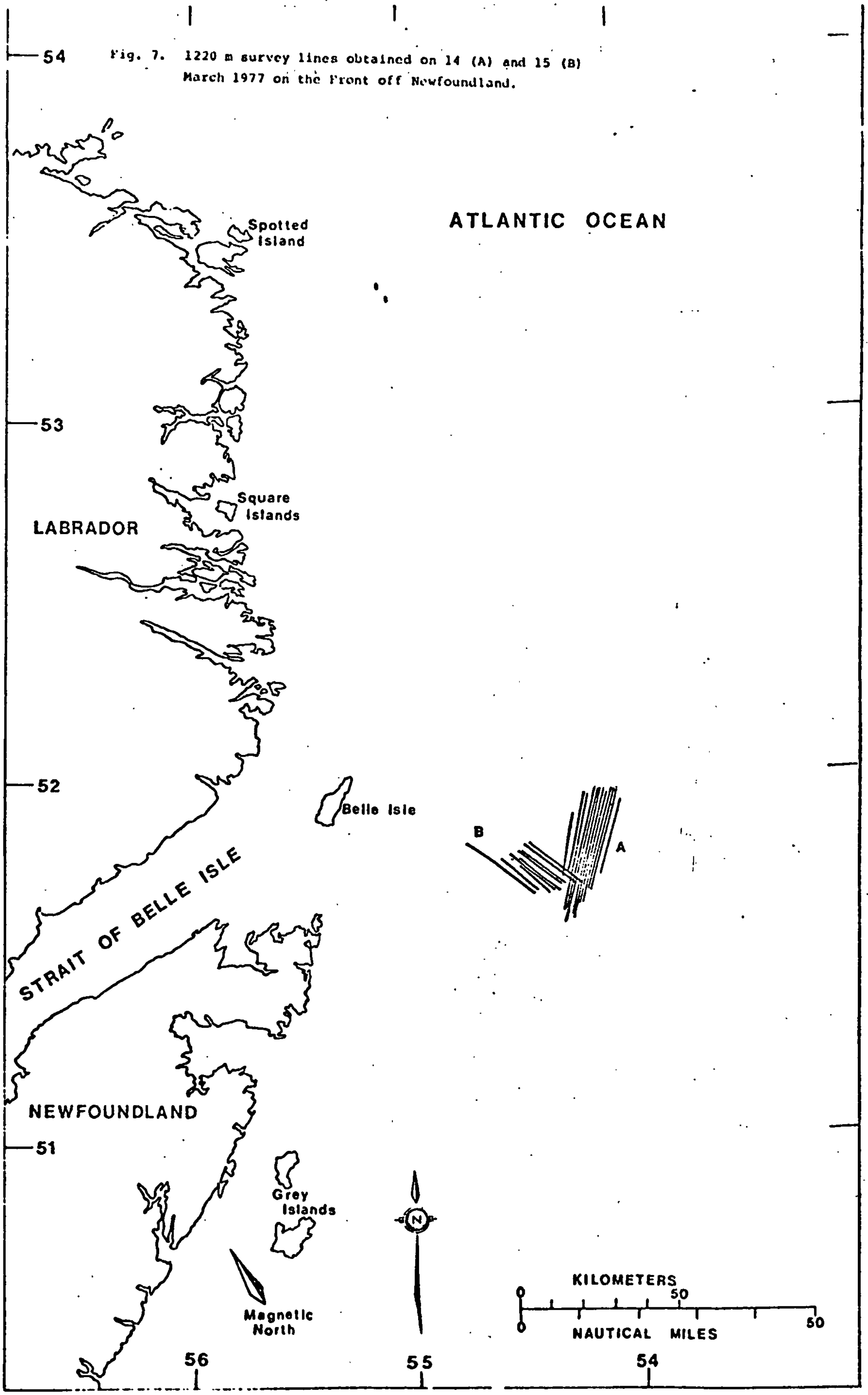
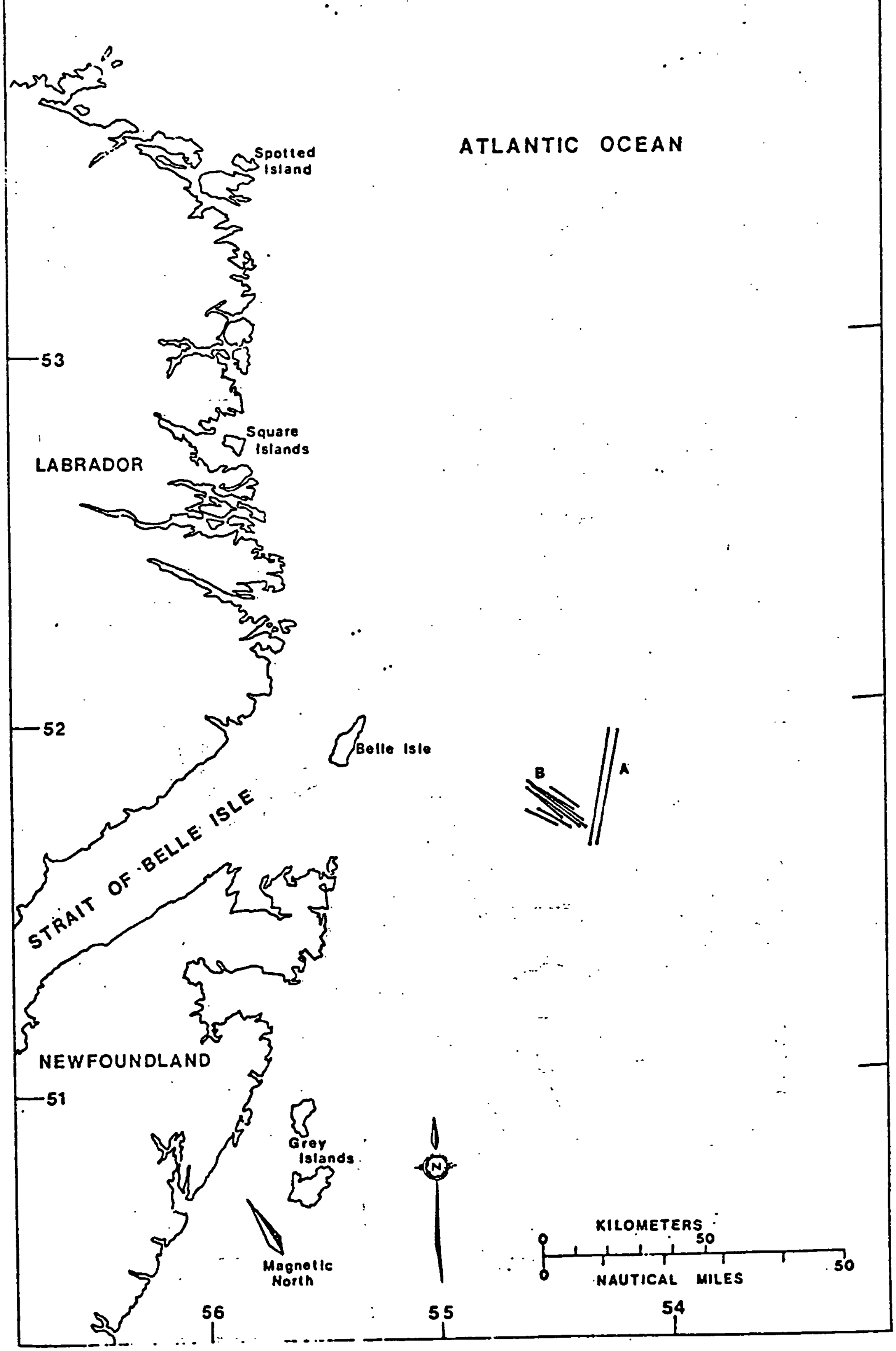


Fig. 8. 305 m sample lines obtained on 14 (A) and 15 (B) March 1977 on the Front off Newfoundland.



apparently form up in 1977, and plans to survey this patch were thus cancelled. Since all known concentrations of whelping harp seals in the western Atlantic off eastern Canada had been surveyed, the field work was terminated on 15 March 1977.

Preliminary evaluation of the census

It was generally agreed by all the participants that the 1977 aerial survey of harp seals was extremely successful (Doubleday, in Litt., 1977; Ronald, in Litt., 1977).

There were two large concentrations of whelping harp seals in the Gulf of St. Lawrence, one to the west of the Magdalen Islands and another off Bird Rocks (Figs.2-6). These two whelping patches were located by 4 March 1977 and remained in their respective positions, aside from relatively unsignificant ice movements, until they were photographed between 9 and 11 March 1977.

A small group of seals was observed to the southwest of Bird Rocks and this group of seals may not have been photographed as part of the main Bird Rock patch. A report of harp seals to the west of Deadman's Island was followed up but no seals were located.

The main patch to the West of the Magdalen Islands was surveyed on 9 and 10 March. Using the sealing vessel Nadine, dye markers and recognizable leads, it was possible to obtain overlap between the two days, and extend coverage on 10 March to cover seals not photographed on the 9th.

The smaller Bird Rocks' patch was located and flown on 11 March 1977. In general, it was concluded that all known significant concentrations of harp seals in the Gulf of St. Lawrence during March 1977 were photographed.

On the Front, systematic and thorough searches for seals from Cape St. Anthony to beyond Hamilton Inlet resulted in the location of only one major concentration of seals. This patch was photographed on 14 and 15 March and it was concluded that "coverage of the Front herd was virtually complete with only scattered seals being missed" (Doubleday, _in Litt._, 1977). It was later suggested at the 6 June meeting that a source of error may have been introduced by flying the Front herd on successive days. This approach was necessitated because of the area of the patch, but ice movements from the 14th to the 15th made it difficult to be certain that total coverage was in fact, obtained.

It was agreed that a small group of seals (perhaps 1000 pups) south of the main Front patch, and the historical Mecatina patch in the north Gulf (about 30 seals) were not surveyed.

Doubleday (_in Litt._, 1977) concluded that "Even if the coverage is not 100% the estimates of pup production from this aerial survey should represent a proven reserve of harp seals not far from the total population".

A number of other comments were made which will be dealt with below in more detail. These included the possibility that disturbance of seals by sealing vessels in the Gulf on 10 March and on the Front on 15 March should be taken into account during the statistical analysis of data. Similarly the presence of carcasses on the ice around the boats may bias the estimates. However, daily kill records may be used to reduce this error or to at least identify the magnitude of probable error introduced by this unexpected complication. It was also suggested that correction factors for the number of whitecoats in the water at the time of the survey, for animals hidden from the view of the camera, and for the varying number of adults on the ice during the surveys, may be applied to the results of the census.

ANALYSIS OF PHOTOGRAPHIC IMAGERY

Preliminary assessment of the quality of the imagery obtained was made by the Canada Centre for Remote Sensing. The 70 mm ultraviolet imagery appeared to be of good quality. However, an apparent malfunction of the motor drive observed in the field, and attributed in part to the power pack, resulted in erratic movement of the film through the camera. When this occurred, less than 20 per cent forward overlap was obtained on adjacent frames, and in some instances there were small gaps between adjacent frames of the sample line coverage recorded on film. This did not cause major problems during the subsequent quantitative assessment of the imagery.

The Canada Centre for Remote Sensing also reported that the imagery obtained at 1220 m with the RC-10 camera was somewhat overexposed, and steps were taken to compensate for this during production of contact transparencies. Subsequently, when this imagery was being counted, it became obvious that image quality was much inferior to that obtained in 1974 and 1975 (Lavigne et al., 1974; 1975[a]). The main problem was a distinct lack of resolution, especially near the edges of each frame. The centre of the frame was in better focus but not up to the quality obtained in previous years.

A comparison of ultraviolet imagery (305 m) and black and white imagery (1220 m) from identical areas on the ice confirmed that many adult seals detected at 305 m were present on the 1220 m imagery, but that they would not have been positively identified because of the lack of focus on this imagery.

Problems associated with the malfunctioning of the RC-10 camera which resulted in this poor quality imagery may have been due in part to a loss of vaccuum in the camera detected on 15 March. However, the results are not totally consistent with a loss of vaccuum and other, unknown factors may have been involved. The limited usefulness of the 1220 m black and white imagery necessitated consideration of various estimation methods other than the original method proposed, i.e. ratio estimation, in the research outline.

305 m ultraviolet imagery

The ultraviolet imagery obtained from the Gulf of St. Lawrence and on the Front in March 1977 is summarized in Table 6. For convenience, film roll numbers assigned in the field have been retained. The imagery will be referred to by either roll number or date, depending on the context of the reference. This imagery represents samples obtained at 305 m, using ultraviolet photography to detect adult harp seals and their pups, including whitecoats (Lavigne *et al.*, 1975a). These samples were obtained on a random or stratified random basis using a random number table.

All of the ultraviolet imagery was assessed and counted by two or three photointerpreters. A variety of approaches was undertaken in order to investigate further, the most effective and efficient procedure for use in future surveys, if such surveys are undertaken.

Initially the photointerpreters spent approximately two weeks learning to recognize seals and to interpret correctly, various types of imagery at different scales. During this time they also assessed the imagery obtained from the experimental ground-truth work described elsewhere (Capstick *et al.*, 1977).

The ultraviolet imagery was then analysed as follows. Rolls 478 and 483 were counted by all three photointerpreters to provide data on variation between counters. The remaining six rolls were counted by two

TABLE 6

Summary of ultraviolet imagery obtained in March 1977

Date	Location	Roll No.	Counted by[1]
9 March	N.W. of Magdalen Is.	478 UV	1, 2, 3
9 March	N.W. of Magdalen Is.	483 UV	1, 2, 3
10 March	N.W. of Magdalen Is.	484 UV	2, 3
11 March	Bird Rocks	486 UV	1, 3
11 March	Bird Rocks	488 UV	1, 3
11 March	Bird Rocks	489 UV part	1, 2
14 March	Front	489 UV part	1, 2
15 March	Front	492 UV	2, 3
15 March	Front	494 UV	1, 2

1 Numbers refer to each of three photointerpreters

of the three photointerpreters. During this initial count, frames in each roll were analysed separately and in random order by each counter. For rolls 478 and 483., adults and pups were counted on separate occasions without reference to previous counts. On all other rolls, adults and pups were counted simultaneously on each frame, in random order, by each counter involved. This procedure was adopted to test whether counts of pups were more precise when made in reference to adult counts (adults are easier to count) on the same frame.

The results of all counts were tabulated by individuals not involved in counting. Thus all counts by each counter were made independently and without reference to counts by other individuals.

Preliminary assessment of these initial counts involved separating the frames into the following categories:

1) frames which all counters reported to be devoid of seals (both adults and pups).

2) frames which at least one counter reported seals(either adult or pups). This category was for then, subdivided as follows:

   a) frames on which all counters reported an identical number of adult seals and pups

   b) frames on which all counters did not report an identical number of adults and pups

When all the ultraviolet imagery had been counted for the first time, the photointerpreters also began to analyse the 1220 m imagery (see below). During this time replicate counts were made on the ultraviolet imagery. The main purposes of this exercise were to quantify within counter variation, and to verify the previous counts.

Replicate counts were made on every frame in which any seal (adult and/or pup) was reported. In addition a number of frames with no seals, equal to or in excess of the number of frames with seals on which total agreement had been obtained, were selected at random, and included in the replicate counts. These counts were made by frame number (in chronological order) within each roll. Adults and pups were counted simultaneously. This procedure is more straightforward than the previous method and also provided additional data on counting procedures and counter variability. The counters did not have access to their previous counts or the counts of others and these counts were again made independently.

These data were compiled so that the initial counts and replicates by each counter for each frame were compared. Means and standard deviations for adult and pup counts for each frame were then determined. These data were examined and obvious "outliers" (Snedecor and Cochran, 1969) were rejected, i.e. if one out of six of the counts (on rolls 478 and 483) or one out of four (on the remaining rolls) were significantly different from the remaining counts, that count was rejected.

Additional counts were subsequently completed to confirm earlier counts and the final data matrix for the ultraviolet samples was tabulated. This matrix included the frame number (within each roll), the mean ($\pm$ S.D.) number of adult seals and pups counted on each frame, and the area of each frame as measured using a digital planimeter (Numonics Corp., North Wales, PA, U.S.A.).

1220 m Black and white imagery

Initially the black and white transparencies for each flight were mosaiced together. In this way the area covered on the ice by the survey was reconstructed in the lab. At this time areas of overlap were marked on adjacent frames to prevent duplicate counts. This imagery was obtained to provide a good estimate of the area of the patch, or the area surveyed on a particular day, and to provide a count of adult seals on the ice at the time of the survey (Lavigne et al., 1975a).

In the original plan, counting of adult seals on 1220 m imagery was to be as rigorous as the counting of ultraviolet imagery outlined above. However, after a number of frames had been counted in duplicate, considerable variation was observed both between and within counters. At this point, comparison of the 1977 imagery with similar imagery from previous flights in 1974 and 1975 revealed the resolution problem noted above. As a result, all frames were counted a minimum of two times each and no attempt was made to resolve differences between or within counters. Areas on the ice covered by each frame were again measured using a planimeter.

Maps of each of the aerial survey flights were then constructed from the mosaiced transparencies (Figs. 9, 10, 11, 12, 13, 14, 15). It was known that some areas of the whelping patch west of the Magdalen Islands had been covered on both 9 and 10 March. When the imagery from these two surveys was mosaiced between days, it became obvious that little additional coverage had been obtained on 10 March. As a result, it became evident that total coverage of this patch had not been obtained. Discussion of this previously unrecognized problem at a meeting of participants in August, resulted in the decision to place top priority on a detailed analysis of the Front coverage. Thus, only preliminary calculations have been completed for the Gulf of St. Lawrence whelping herds, since any estimate would not include those seals not photographed, and estimates of the area not covered would be highly speculative at best.

Fig. 9. Mosaic of 1220 m imagery obtained on 9 March 1977 to the northwest of the Magdalen Islands in the Gulf of St. Lawrence.

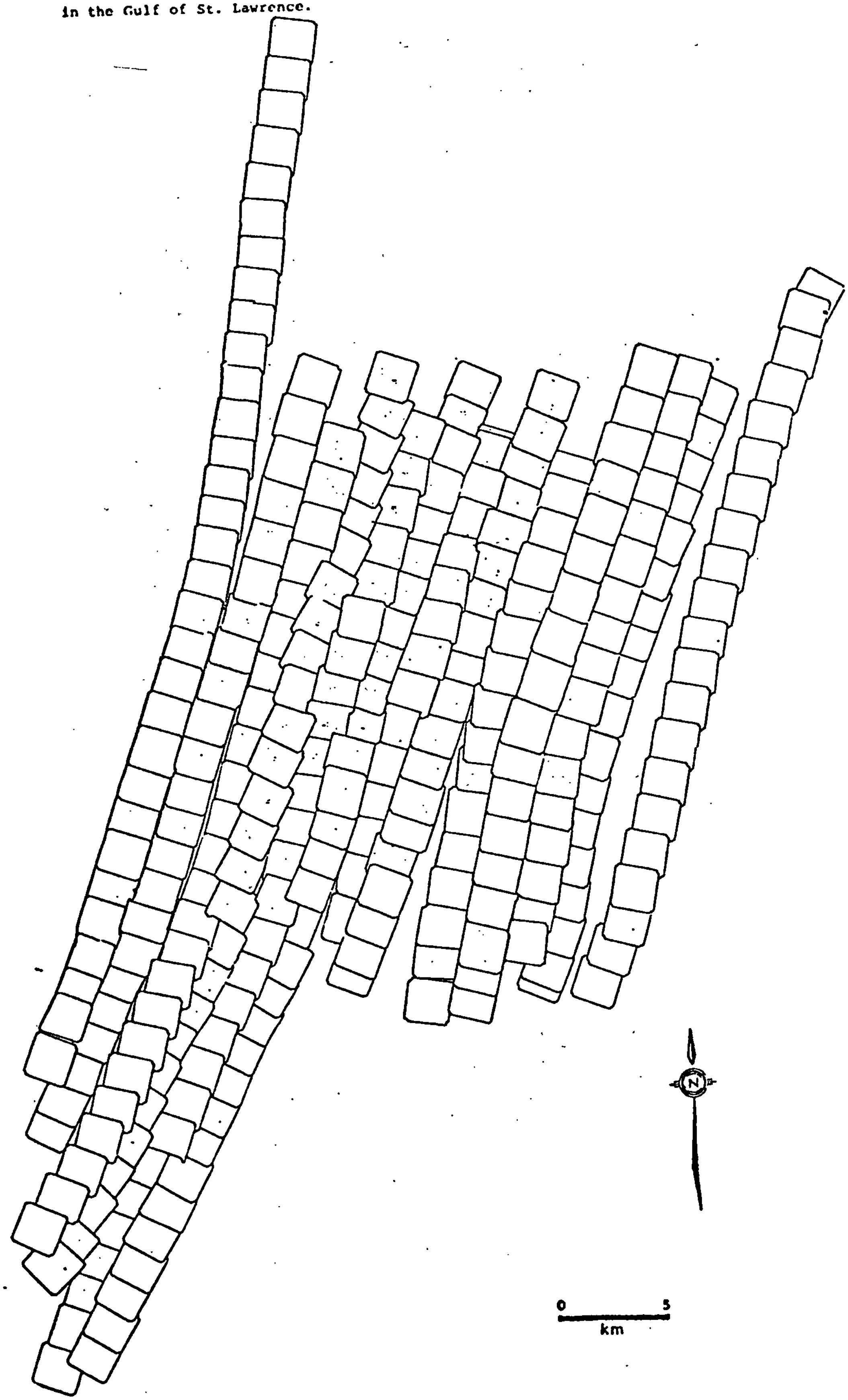


Fig. 10. Mosaic of 1220 m imagery obtained on 10 March 1977 to the northwest of the Magdalen Islands in the Gulf of St. Lawrence.

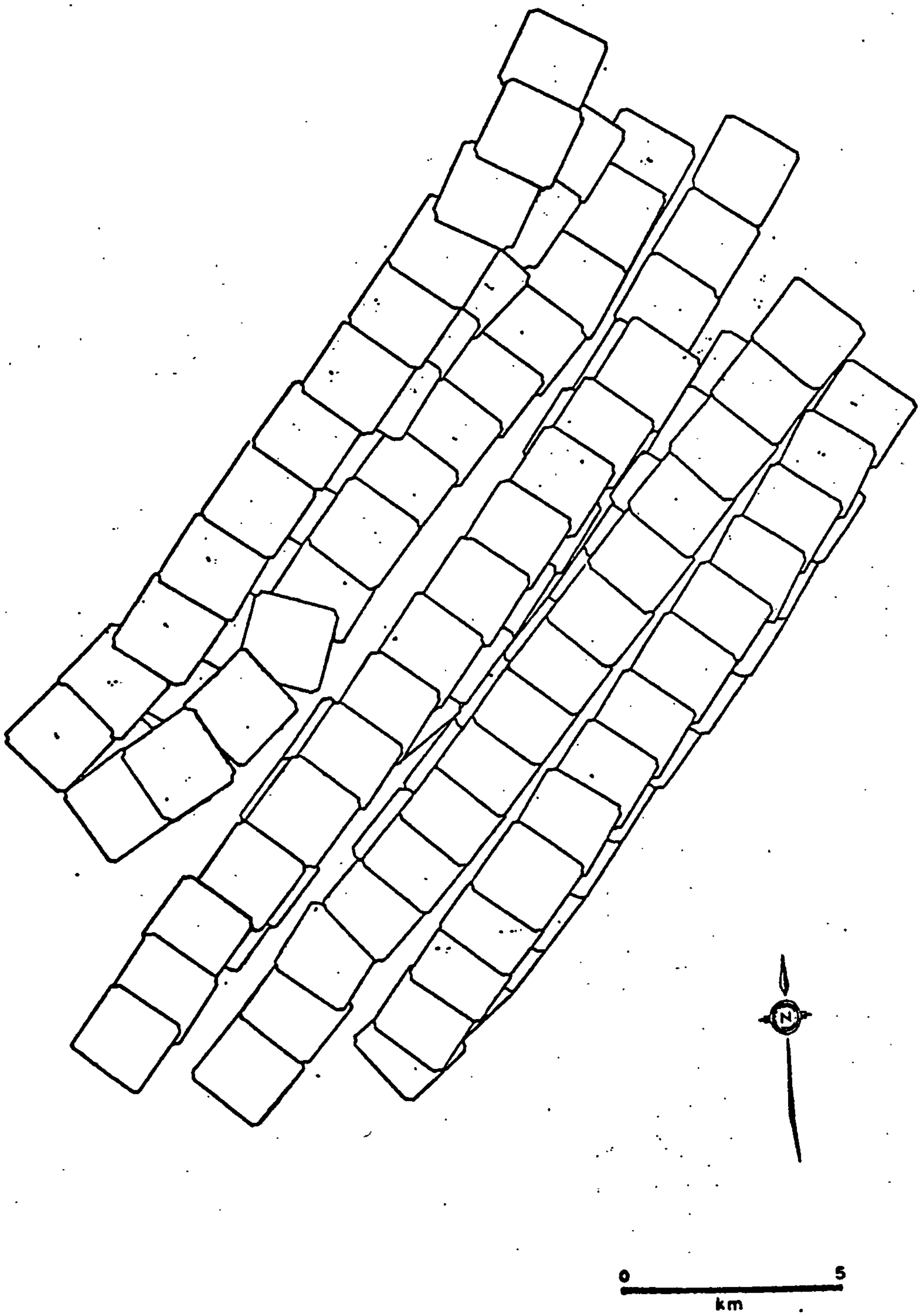


Fig. 11. Mosaic of 1220 m imagery obtained on 11 March 1977 near Bird Rocks in the Gulf of St. Lawrence.

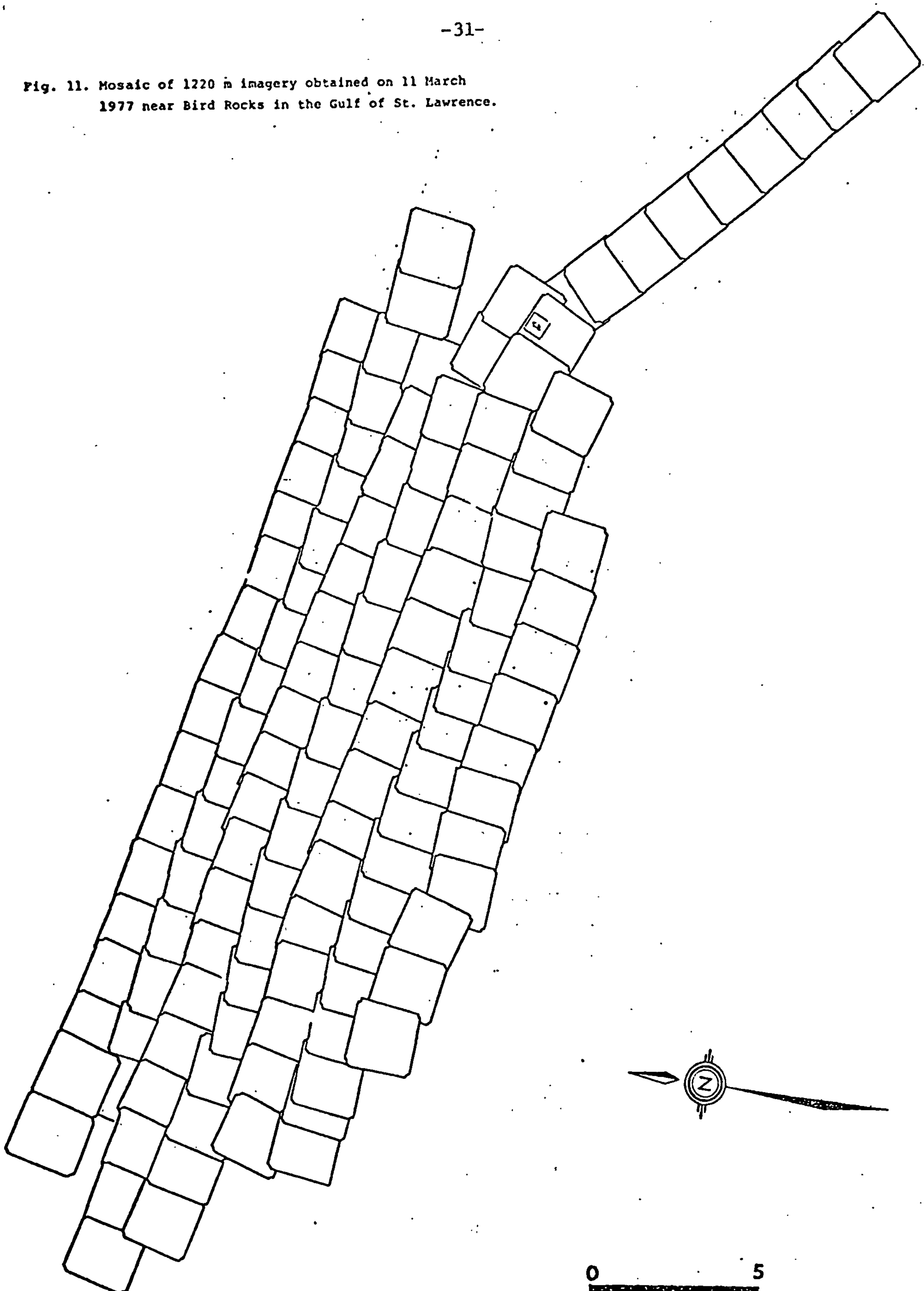


Fig. 12. Mosaic of 1220 m imagery obtained on 14 March 1977 on the Front off Newfoundland.

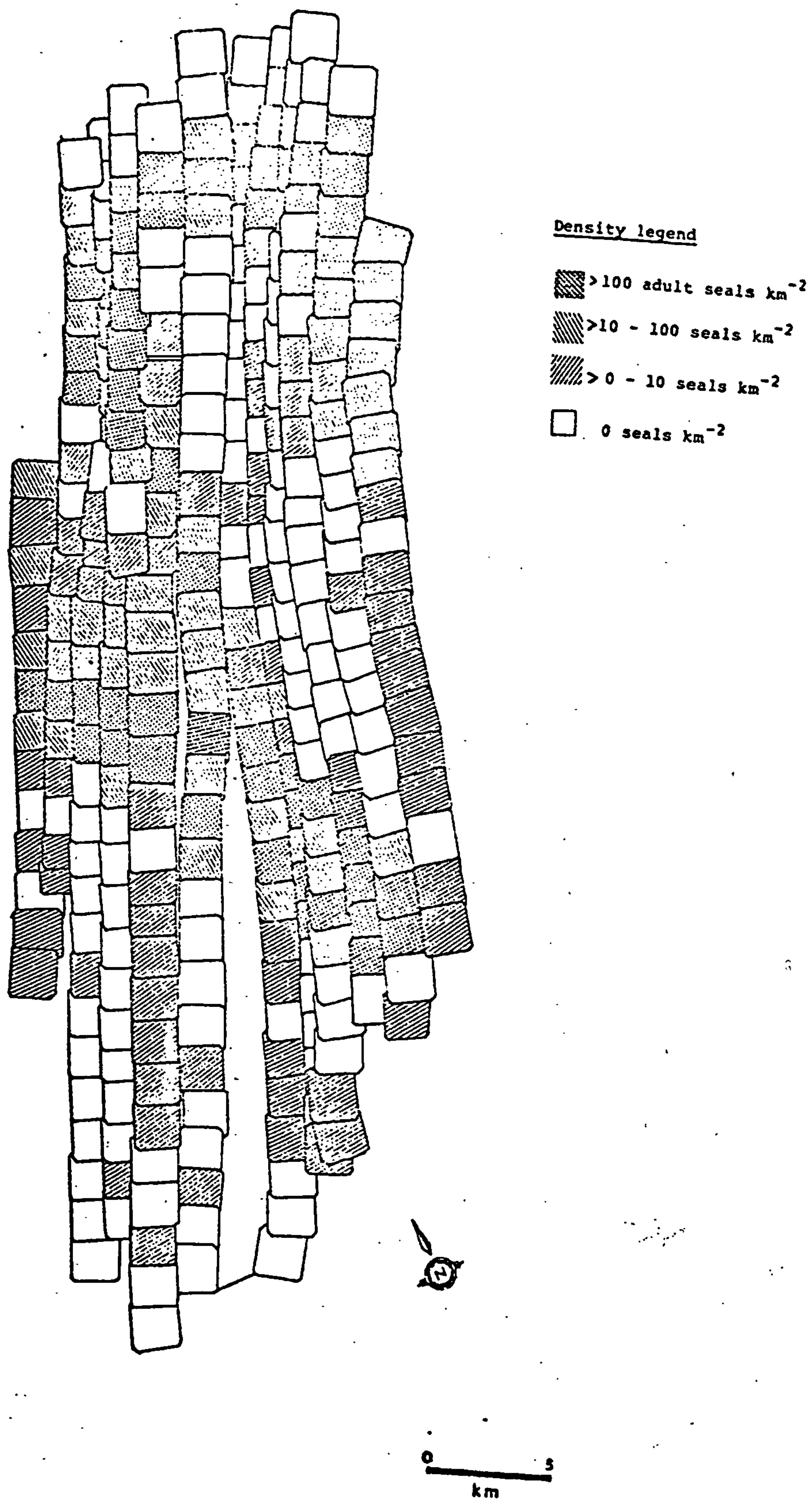


Fig. 13. Mosaic of 1220 m imagery obtained on 15 March 1977 on the Front off Newfoundland.

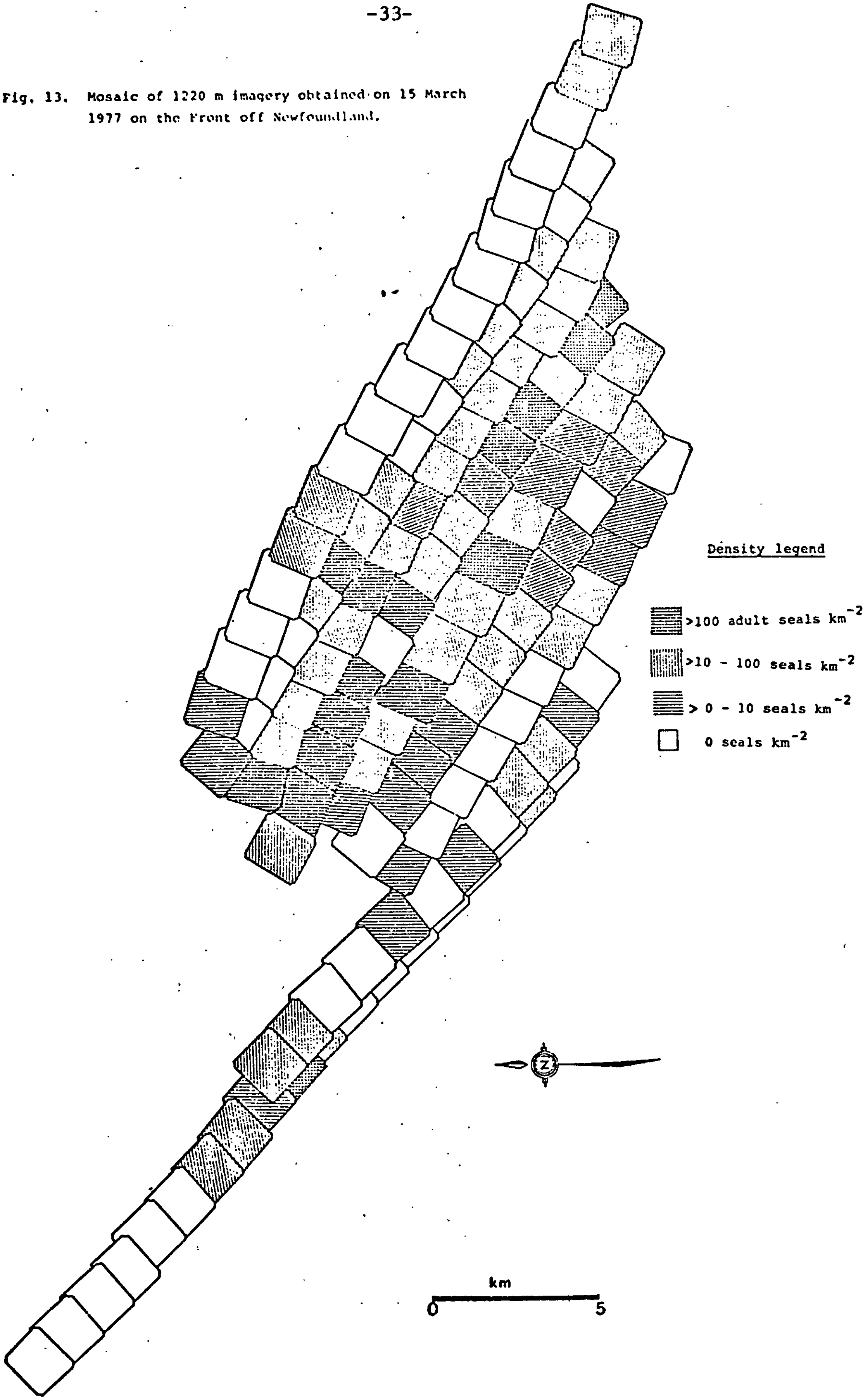


Fig. 14. Mosaic of 1220 m imagery obtained on 14 March 1977 indicating major "landmarks".

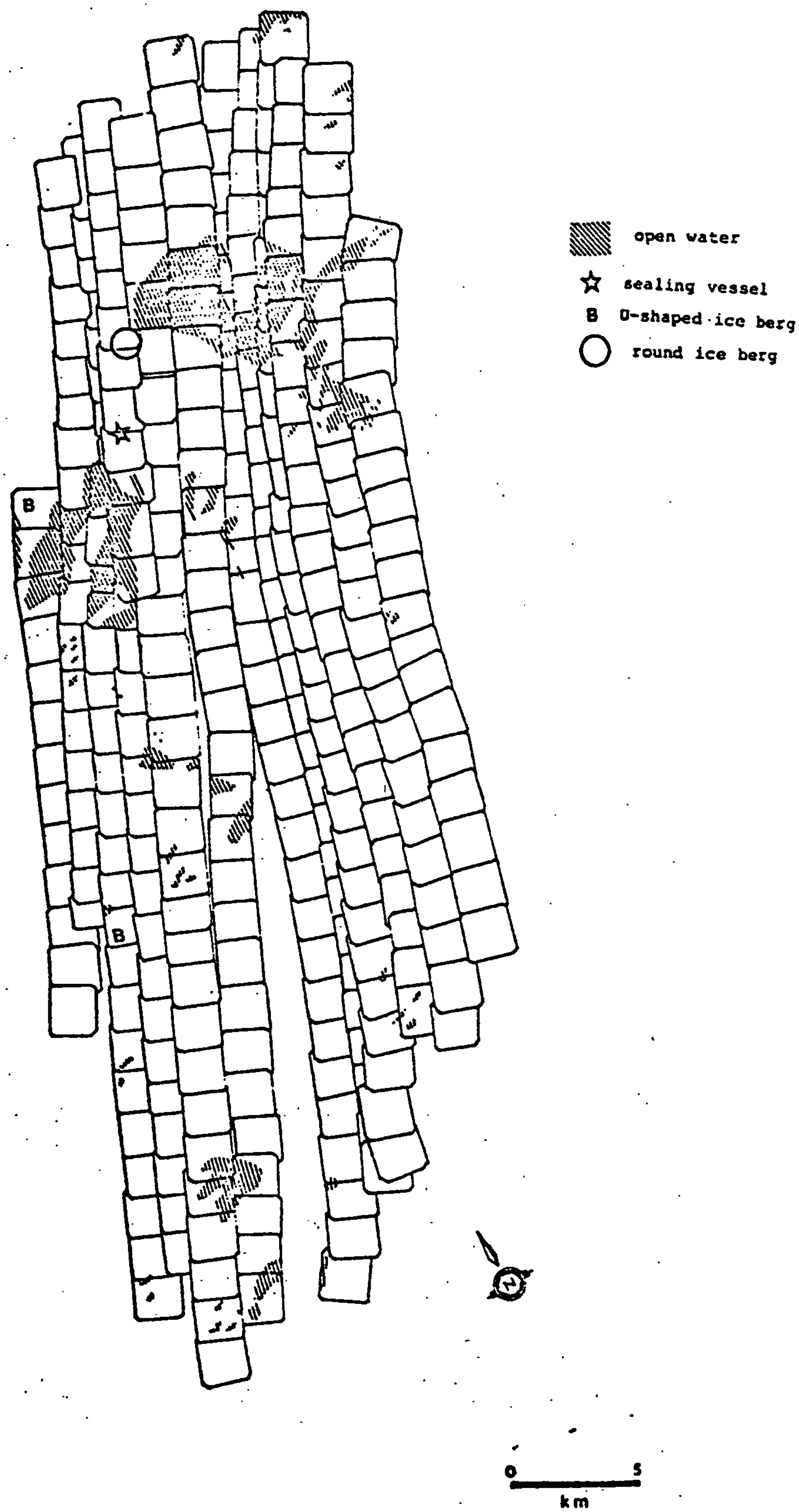
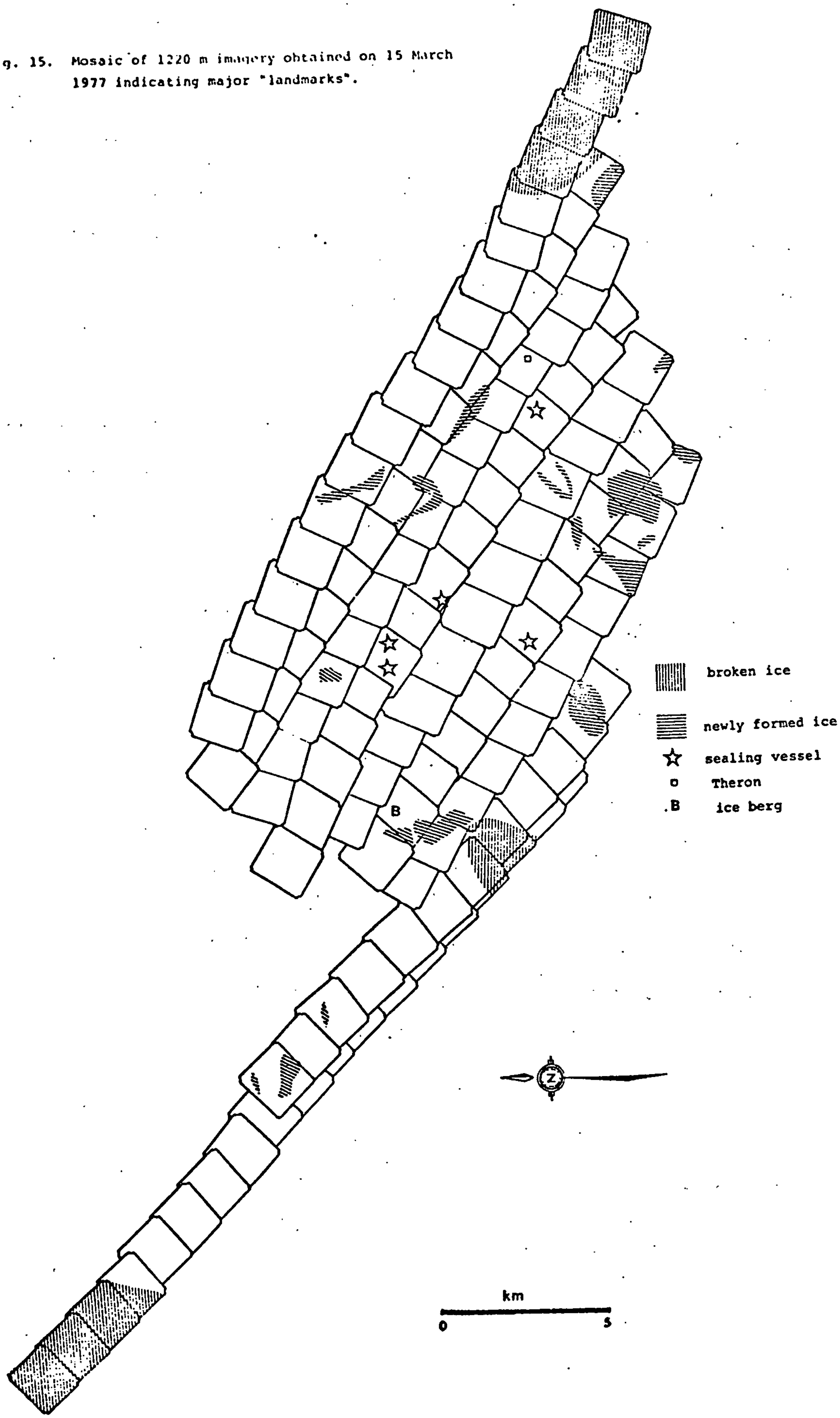


Fig. 15. Mosaic of 1220 m imagery obtained on 15 March 1977 indicating major "landmarks".



ANALYSIS OF DATA

Preliminary estimates of the number of harp seal pups accounted for by the 1977 survey based on a simple random sampling procedure were discussed at a meeting of participants on 17 August. These results, for both the Gulf and the Front, were included in a preliminary interim report submitted to the Committee on Seals and Sealing on 21 and 22 August (Appendix 1).

For these calculations each flight line at 305 m was treated as a sample. Since all flight lines were not of equal length, the samples were effectively weighted in inverse proportion to the area within the herd they represented (Som, 1973).

The results of these calculations were characterized by wide confidence intervals commonly encountered in harp seal census results for various reasons (Lavigne _et al._, 1975 a). Since simple random sampling does not make the most efficient use of the available data, a variety of other estimates were subsequently investigated using data from the Front surveys only.

The original plan to use ratio estimation (Lavigne _et al._, 1975 a; Lavigne and Ronald, 1975) was not carried out immediately. It was thought that poor quality 1220 m black and white imagery and resulting variation in counts of adult seals obtained would not permit an efficient estimate using this method of analysis.

At the time of writing, only the results of the stratified random sampling procedure are complete. Other analyses may be appended to this report if completed in time for the meeting.

Post stratification was carried out with respect to the apparent density of adult seals on the 1220 m imagery (Fig. 12 and 13). Four strata were identified: >100 seals km^{-2}, >10 to 100 seals km^{-2}, >0 to 10 seals km^{-2}, and 0 seals km^{-2}. Ultraviolet frames were then matched to the 1220 m imagery and separated into samples. All ultraviolet imagery from one flight line within a single 1220 m frame was considered a sample. The number of pups in the area covered by the survey were then estimated using varying probability, stratified sampling estimators (Som, 1973).

For 14 March, an additional stratum was added to account for an area within the patch not photographed on the 1220 m imagery, yet sampled at 305 m with ultraviolet photography. These ultraviolet frames were separated into samples in units of 10 frames for analysis.

The results of these analyses on data obtained on the Front in March 1977 are summarized in Table 7.

DISCUSSION

It would appear that reasonably complete photographic coverage was obtained for the main whelping concentration of harp seals on the Front off Newfoundland in March 1977. The most efficient estimator of the number of pups accounted for by the census presented above was obtained from simple random sampling (Table 7). More efficient estimators from ratio and regression analysis are presently being computed. These techniques should reduce the variance in the estimated number of pups. On the basis of preliminary calculations no great change in the mean estimate is expected.

For the present, the best estimate of pups obtained from the census on the Front is thus 185,159 ± 45,279 (95% CI) (Table 8). Qualitative assessment of the detectability of pups on the Front suggested that about

TABLE 7

Estimates of the number of harp seal pups ($\hat{P}$) accounted for by the 1977 aerial census on the Front off Newfoundland, 14 and 15 March 1977

Method of Estimation	$\hat{P}$	95% C.I.
14 March		
Simple Random Sampling	115,818	58,433
Stratified Random Sampling	131,865	59,500
15 March		
Simple Random Sampling	69,341	48,394
Stratified Random Sampling	50,412	12,686
Total, Front 1977		
Simple Random Sampling	185,159	45,279
Stratified Random Sampling	182,278	60,837

10 per cent would not be photographed by the sensor (Capstick et al., 1977). Application of this correction factor results in an estimate of pup production in the area censused on the Front of 203,675.

The census in the Gulf of St. Lawrence was incomplete and the survey accounted for less than 30,000 seals (Appendix 1). It is not reasonable to speculate on the percentage of coverage obtained and thus no estimate of pup production was made for harp seals whelping in the Gulf in 1977.

It is of some importance to obtain an estimate of pup production in the western Atlantic from aerial census techniques to compare with independent estimates made using other techniques (e.g. Sergeant, 1975; Benjaminsen and Lett, 1976; Capstick et al., 1976). In 1975, pup production in the Gulf was estimated to be 46,300 ± 5,158 (Lavigne et al., 1975b, Lavigne, 1976). If it is assumed that two whelping stocks of harp seals are present in the western north Atlantic, an approximation of pup production in recent years can be made. Evidence supporting this assumption includes the difference in whelping dates (Sergeant, 1976), apparent differences in age at maturation (Sergeant, 1966, 1973), and some evidence of fidelity to place of birth by whelping harp seals (Sergeant, 1976). Using the corrected estimate for the Front in 1977 (203,675) and the estimate from the Gulf of St. Lawrence in 1975 (46,300) suggests that pup production estimated by aerial census techniques in recent years may be in the order of 250,000 seals for western Atlantic harp seals.

All of the above estimates do not include seals which were not covered by the 1220 m aerial survey flights. Minor concentrations of seals not surveyed in 1977 have been noted in this report. In addition some seals between the areas photographed on 14 and 15 March 1977 on the Front, have not been accounted for. Further speculation on the completeness of the survey is, however, futile.

TABLE 8

Summary of estimates of pup production on the Front in March 1977 and in the Gulf of St. Lawrence in March 1975

Front (1977)	185,159[1] ± 45,279
Gulf (1975)	46,300 ± 5,158

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1 with a 10 per cent correction factor for seals not detected by the census the estimate for the Front becomes:

	203,675
Gulf (1975)	46,300
TOTAL	249,975

ACKNOWLEDGEMENTS

This report represents the culmination of four years of research involving many individuals and a number of organizations. The 1977 census was undertaken as a cooperative project between participants from the University of Guelph and the Fisheries and Marine Service in conjunction with the Canada Centre for Remote Sensing.

Various individuals contributed to the development of the survey design. These include P.F. Lett, M.C. Mercer, R. Stewart, K. Ronald, and C.K. Capstick.

The field work was accomplished through the cooperation and expertise of the Canada Centre for Remote Sensing, the flight crew from Innoted Aviation Ltd., Ottawa, and sensor operators from Intera Environmental Consultants, Ottawa.

Other individuals provided assistance in the field. These include S. Dudka, T. Curran, B. Beck, P. Brodie, and W. King. The imagery was analysed in the lab primarily by D. Leishman, L. Sleeth, S. Smith, with additional assistance from A. Hamilton, M. Hammill and G. Nancekivell.

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Appendix 1

University of Guelph

COLLEGE OF BIOLOGICAL SCIENCE
DEPARTMENT OF ZOOLOGY

September 12, 1977

To whom it may concern:

Preliminary results of the 1977 harp seal census were discussed at a meeting of scientists from the University of Guelph and the Fisheries and Marine Service, Environment Canada on 17 August 1977. A confidential interim report was then presented to the Committee on Seals and Sealing on 21 and 22 August 1977.

These results were not made public because of their preliminary nature. To avoid later confusion and misunderstanding it seemed prudent to release only the final figures when these became available.

Subsequently, the results were released by persons unknown, and this resulted in a number of phone calls and one letter regarding these results. Since the quoted figure is incorrect, and confidentiality has been breached, the interim report to COSS (attached) is being made available to anyone who asks for it. I can only ask you to be more responsible than some (one) of my colleague(s). These results are not final, and they refer ONLY TO THE SEALS COUNTED ON THE IMAGERY, they do not provide an estimate of pup production for the Northwest Atlantic in March 1977.

The final report should be ready by 22-23 September 1977 and tabled at a CAFSAC (Canadian Atlantic Fisheries Scientific Advisory Committee - Marine Mammals) meeting at that time.

Your cooperation in not contributing to further confusion and controversy about the status of the harp seal will be appreciated.

Sincerely,

D.M. Lavigne
Assistant Professor

DML:mf

P.S. The CAFSAC meeting has now been rescheduled for 20, 21 October.

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RESTRICTED

The 1977 Census of western Atlantic harp seals

A confidential interim report to
the Committee on Seals and Sealing

21-22 August 1977

by

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In March 1977, an aerial census of harp seal whelping patches off eastern Canada was conducted by the University of Guelph and the Fisheries and Marine Service, Environment Canada, in conjunction with the Canada Centre for Remote Sensing, Innotech Aviation Ltd., and Intera Environmental Consultants Ltd.

Three flights were made over whelping patches in the Gulf of St. Lawrence on 9, 10 and 11 March; two flights were carried out on the Front off Newfoundland on 14 and 15 March.

Post-survey evaluations were made by the Guelph-FMS participants in March and April, primarily to outline the apparent extent of the aerial coverage. A meeting was subsequently held in early June to discuss all aspects of the aerial survey. Analysis of the imagery began in April[a] and is still in progress. A second meeting to discuss the initial results, and to plan further analyses was held on 17 August.

Plans are now being made to obtain a duplicate set of imagery for the Marine Fish Division, Fisheries and Marine Service, Environment Canada, Dartmouth, N.S. to completely repeat the analyses of the survey data. Data analysis continues at the University of Guelph with the participation of Dr. W.G. Doubleday, Environment Canada, Ottawa.

At the 17 August meeting preliminary results of the aerial census were discussed, and we have been asked to present these results to COSS. It must be stressed that these results are PRELIMINARY. The estimates given are based on the simplest type of sample survey design - simple random sampling, and refer only to the seals on the ice in the areas covered by the census.

For these calculations, each flight line at 305 m was considered to be a random sample of the herd. Adults and pups counted on the resulting ultraviolet imagery were then extrapolated to the area surveyed at 1220 m and a mean estimate of the number of pups on the ice was obtained. No correction factors have been applied for areas not covered by the survey. Further analyses, incorporating more of the available information are in progress. The clumped or aggregated distribution of both adult seals and pups (typical of harp seals) implies that the best estimates of pup production in the areas surveyed may be somewhat different from the preliminary results tabled below.

The extent of the aerial coverage over all whelping patches is the subject of considerable debate at this time. Coverage of the principal whelping patches on the Front appears in our opinion, to be reasonably complete. Coverage of all known whelping patches in the Gulf of St. Lawrence was not obtained.

A draft report outlining the results of the 1977 aerial census is being prepared and will be forwarded to participating groups for evaluation and comment as soon as possible. A final report will be issued in time for the various stock assessment meetings later in 1977.

TABLE 1

Aerial survey coverage of harp seal whelping patches in March 1977

	Area Surveyed km^2	Area Sampled km^2 (%)
9 March[a]	453.5	24.4 (5.4)
10 March[b]	188.8	9.3 (4.9)
11 March[c]	252.0	14.8 (5.9)
14 March	571.7	11.7 (2.0)
15 March	261.1	16.3 (6.2)

a Lines 1-5 (209.0 km^2) not included in area sampled because of absence of seals, i.e. total area flown - 662.5 km^2.

b Much of the imagery from 10 March overlaps with imagery from 9 March.

c Line 5 (3.29 km^2) was not included in area sampled as it was not randomly selected, and overlapped to some extent with sample line 3.

TABLE 2

Preliminary estimates of the number of harp seal pups in whelping patches surveyed during March 1977[a]

	$\overline{X}$	S.E.
Gulf of St. Lawrence		
9 March	19,421	7,709
11 March (Bird Rocks)	6,909	2,769
Front		
14 March[b]	115,818	4,601
15 March[b]	69,341	18,823
TOTAL	211,489	

[a] These estimates were made using a simple random sampling procedure. The best estimates of pup production in the areas surveyed may be somewhat different from these preliminary estimates.

[b] There is some quantitative evidence that as many as 10% of the pups would not be detected on the Front this year, primarily because of deep snow and overhanging ledges. Using this correction factor the pup estimate for the area sampled on the Front becomes 203,675, and the estimated total number of pups accounted for by the survey becomes 230,005.

APPENDIX II

As an alternative to the estimates in the text, the use of a ratio of pup counts on u.v. imagery to the corresponding adult counts on 9x9 imagery in combination with the total 9x9 adult count was examined.

As a first approximation, the relationship between adult counts and pup counts is a straigt line through the origin with variance increasing with mean count. Cochran (1963) indicates that in this situation with the variance proportional to the mean, the ratio estimator is the best linear unbiased estimator of the total adult count.

Using mean u.v. pup count of 4.2378, mean 9x9 adult count of 1.33592 and total adult count of 29,950, the estimate of total pups is 95007.

If the variance of the estimated total adult count is estimated from repeated counting, the coefficient of variation of the estimator is approximately 0.095. This value was obtained by substituting sample estimates of covariances in equation 6.7 p 158 of Cochran, ignoring the finite population correction factor and adding the relative variances of the ratio and the estimated total adult count.

Since the relationship between pup and adult counts is not precisely linear, the ratio estimator is biased. According to formula 6.14 of Cochran this bias is approximately 1.17% with the total pup count underestimated. Formula 6.17 of Cochran indicates that the bias is less than 1.41%.

This estimate does not allow for the area not covered in the 9x9 mosaic and does not adjust for the percentage of pups not seen from the air.

In view of the increase of variance with mean in the relation between pup and adult counts, the more exact equation 6.18 of Cochran is likely to lead to a smaller estimated variance for the ratio. This formula was not used due to shortage of time.

A regression estimator was also calculated for these variables with an estimated total pup count of 103386 before allowance for area not mosaiced and pups not seen from the air. This estimator also has a small bias due to nonlinearity of the regression and has a similar coefficient of variation provided there is no uncertainty in the area estimates for u.v. comparisons and for 9x9 coverage. These areas do no appear in the ratio estimator. Bounds for the bias were not estimated.