Summary of Physical, Biological, Socio-Economic and other factors relevant to potential oil spills in the Passamaquoddy Region of the Bay of Fundy

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TECHNICAL REPORT NO. 428

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Environment Canada

SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

FISHERIES RESEARCH BOARD OF CANADA

TECHNICAL REPORT NO. 428

SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

Department of the Environment

Halifax, N.S. Dartmouth, N.S. St. Andrews, N.B.

Ottawa, Ont.

Canada

March 1974

FOREWORD

The rapidly growing demand for oil in North America has resulted in the development of major oil terminals serviced by tankers in ever increasing size and number. Despite increased awareness of the hazards involved, improved safety standards, etc., accidents do and will continue to take place resulting in oil spilled into the sea. To those faced with the task of deciding where oil terminals are to be built and how they are to be operated, it is essential to have knowledge not only of the potential benefits to be derived from such developments but also the potential risks associated with the endeavour. The risk of accidents, and the subsequent escape of oil poses threats to many of the coastal resources, activities, and amenities in the immediate vicinity of a terminal or grounding. Moreover, because of the mobility of oil in the sea, even those several hundred miles from the scene may be placed in jeopardy.

Earlier this year the Pittston Company submitted to the Maine Board of Environmental Protection a proposal to locate a major oil refinery and marine terminal development on Moose Island, Eastport, Maine. This proposal has brought clearly into focus the need for both Americans and Canadians to recognize the potential benefits and liabilities associated with such a development. This report has been assembled by a team within the Department of Environment in order to provide a concise summary of a number of the physical, biological and Canadian socio-economic factors relevant to potential oil spills in the Passamaquoddy Region of the Bay of Fundy. By outlining and identifying these factors, it is our hope that those persons and agencies who have collective responsibility for presentation and consideration of a full and comprehensive view relating to the proposed developments at Eastport will be in a better position to do so. Additionally, some aspects of this report can be used more broadly since they are applicable to the considerations of tanker terminal siting in general.

R. W. Trites

12 December 1973

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SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS OF THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

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PHYSICAL OCEANOGRAPHIC CHARACTERISTICS

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SUMMARY

As noted by Forgeron (1959) the large magnitude of the tides within the Quoddy Region, including Passamaquoddy and Cobscook Bays plus their outer channels, play an important role in the distribution and circulation of the waters within the area. Current meter data and drift bottle analysis reveal that water can travel throughout the entire Quoddy Region within a period of days. Chevrier's (1959) surface residual currents show a counterclockwise motion in Passamaquoddy Bay and, in general, outflows from Western Passage, Cobscook Bay and the Campobello Island side of Head Harbour Passage. Bumpus and Lauzier (1965) found the surface residual circulation in the Bay of Fundy to be inward along the north coast of Nova Scotia and outward along the coast of New Brunswick. They also observed the existence during the winter of a southeasterly flow across the mouth of the bay thus creating a closed circulation. This feature is not observed during the summer and is intermediate between the two during the spring.

Current meter data collected in Head Harbour Passage during 1973 provide additional, although not significantly different, information from that of earlier surveys (Forrester, 1959). In the narrowest section of the passage (Stations 2 and 3; 5 metres depth) an outflow residual current is observed. At the southern end of the passage (Station 4; 5 and 15 metres depth) the residual current is westward towards Passamaquoddy Bay. This flow may result from topographical effects upon the tidal currents and hence may not be entirely nontidal in origin. Statistically estimated maximums of the residual currents are predicted to be 1.3 ±0.3 knots and 1.4 ±0.2 knots for Stations 2 and 4 respectively. The maximum current observed in the channel was 4.5 ±0.5 knots. This occurred on an ebbing tide. Investigation of the periods during which currents are less than 0.5 or 1.0 knot shows large variability from one tide to the next. Consequently, any one prediction, calculated from harmonic constituents, of the time duration of currents below a given rate, may not be reliable. Differences in the time durations occur from station to station as well as at different depths at the same station.

1. INTRODUCTION

Over the past half-century there have been numerous studies of parts or aspects of the Bay of Fundy system. These studies, which arose for a variety of different purposes, have varied immensely in size, scope, complexity, and duration. One of the more intensive studies was undertaken in 1957-58 under the auspices of the International Passamaquoddy Fisheries Board, one of two boards appointed by the International Joint Commission to investigate the feasibility and impact of a proposed tidal hydroelectric power development using Passamaquoddy and Cobscook Bays.

Bound together in Appendix I, Oceanography, of the Report to the International Joint Commission, the papers of Bumpus (1959), Chevrier (1959), Forgeron (1959), Forrester (1959), and Trites (1959) together provide a good summary of the physical oceanographic work undertaken up to 1959. The subsequent work of Bumpus and Lauzier (1965) and Neu (1972) provide useful additional information. The results of a recent survey by the Atlantic Oceanographic Laboratory of the currents in Head Harbour Passage constitute new material and is presented and discussed here.

For convenience the area will be divided into two parts: the Quoddy Region, which includes that area shoreward of a line connecting Point Lepreau, North Head, Grand Manan, and West Quoddy Head (Fig. 1); and the Bay of Fundy, including in part the Gulf of Maine and southwestern Scotian Shelf. This study discusses the oceanographic, meteorological and topographical features of these two areas which could affect oil dispersion or ship navigation.

2. THE QUODDY REGION

2.1 Tides and Tidal Currents

Forgeron (1959) writes:

> "In the Quoddy Region tides and their associated currents are relatively important oceanographically because of their considerable magnitude. The tides of the Bay of Fundy are an anomolistic type, that is '... the change in the moon's distance has more influence upon the tide than the change of the moon's phases. The difference in the range of the tide, at perigee and apogee, is thus greater than the difference in range at the average spring and neap tides...' (Bay of Fundy Tide and Current Tables, 1958). Tides in the Bay of Fundy range from 15 ft at the mouth to 60 ft at the head and are among the highest in the world. In the Quoddy Region, the maximum range is approximately 30 ft. Mean tidal ranges vary from 20 ft at the head of the St. Croix estuary to 17 ft at North Head, Grand Manan. Spring tidal ranges are 24 ft at North Head, Grand Manan, and 28 ft at St. Stephen (Bay of Fundy Tide and Current Tables, 1948).

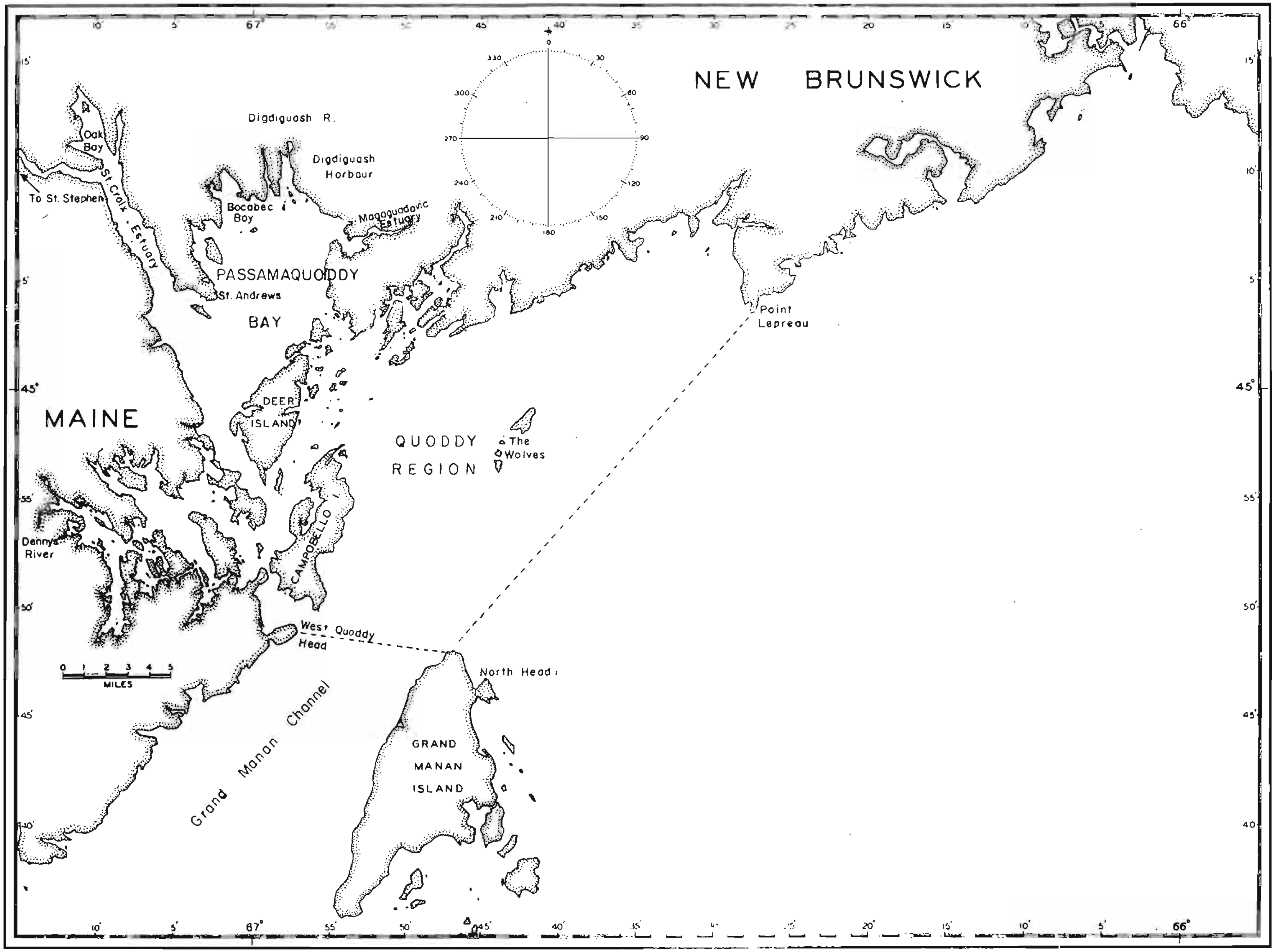


FIGURE 1: Map of Passamaquoddy Bay and Quoddy Region.

"During the summer months of 1957 and 1958 an extensive direct current measurement program was undertaken in the Bay of Fundy jointly by the Canadian Hydrographic Service of the Department of Mines and Technical Surveys and the Atlantic Oceanographic Group of the Fisheries Research Board of Canada. Currents were measured for periods of 13 or 25 hours at 60 locations in the Quoddy Region (Forrester, 1959).

"The amount of water moving northward in Grand Manan Channel during the flooding tide is far greater than the intertidal volume of the Quoddy Region. The relatively large intertidal volumes which pass through the Passages to Passamaquoddy and Cobscook Bays result in high velocity tidal currents and thorough vertical mixing. Tidal currents in Letite Passage have mean maximum values of 8.1 ft/sec for the flood tide and 7.9 ft/sec for the ebb tide. In Western Passage, a mean maximum of 5.3 ft/sec was recorded for both flood and ebb tides (Forrester, 1959). The intense mixing of the waters profoundly influences temperature and salinity distribution in the Inner Quoddy Region. Except for areas near the Passages, currents in Passamaquoddy Bay are usually less than 1 ft/sec. Tidal currents, calculated for 5 sections in northeast Passamaquoddy Bay, show a decrease in velocity toward the head of the Bay...."

To provide more detailed information for Head Harbour Passage, a current survey was undertaken within this region during August and September of 1973. The currents were measured at four locations (Fig. 2) using self-buoyant German Hydrowerkstaaten current meters. At Stations 1 and 4 readings were taken at 5 and 15 metres depth while at Stations 2 and 3 only a 5 metre reading was taken. Station 3 was located in close proximity to Station 2 for comparison purposes. In order to detect if irregular events were being observed during the survey period, Station 3 was maintained for an additional 80 days. The time between successive measurements was 5 minutes except at Station 3 where a 10-minute interval was used.

After the survey the instruments were calibrated from towing experiments. The bearings had been replaced, a standard practice due to their corrosion through contact with air while in transit. Over-all performance of the instruments was found to be good and the factory calibrated response was verified. The persistence of the data throughout the actual survey suggests little or no change in the instrument's response during that time.

Time series plots of the rate and direction of the currents for all stations and depths are shown in Figures 3 through 8. The first 20 days (beginning August 23) are represented except at 15 metres at Station 4 where instrument failure resulted in only a 17-day record.

At Station 1 (Fig. 3 and 4) currents during flood tide conditions flow in a general direction of 340° and reach a maximum rate of 2 knots. Lack of a defined ebb current is most noticeable. The location of Station 1 appears from the irregular directional data during ebb tides to be in the lee of East Quoddy Head on Campobello Island.

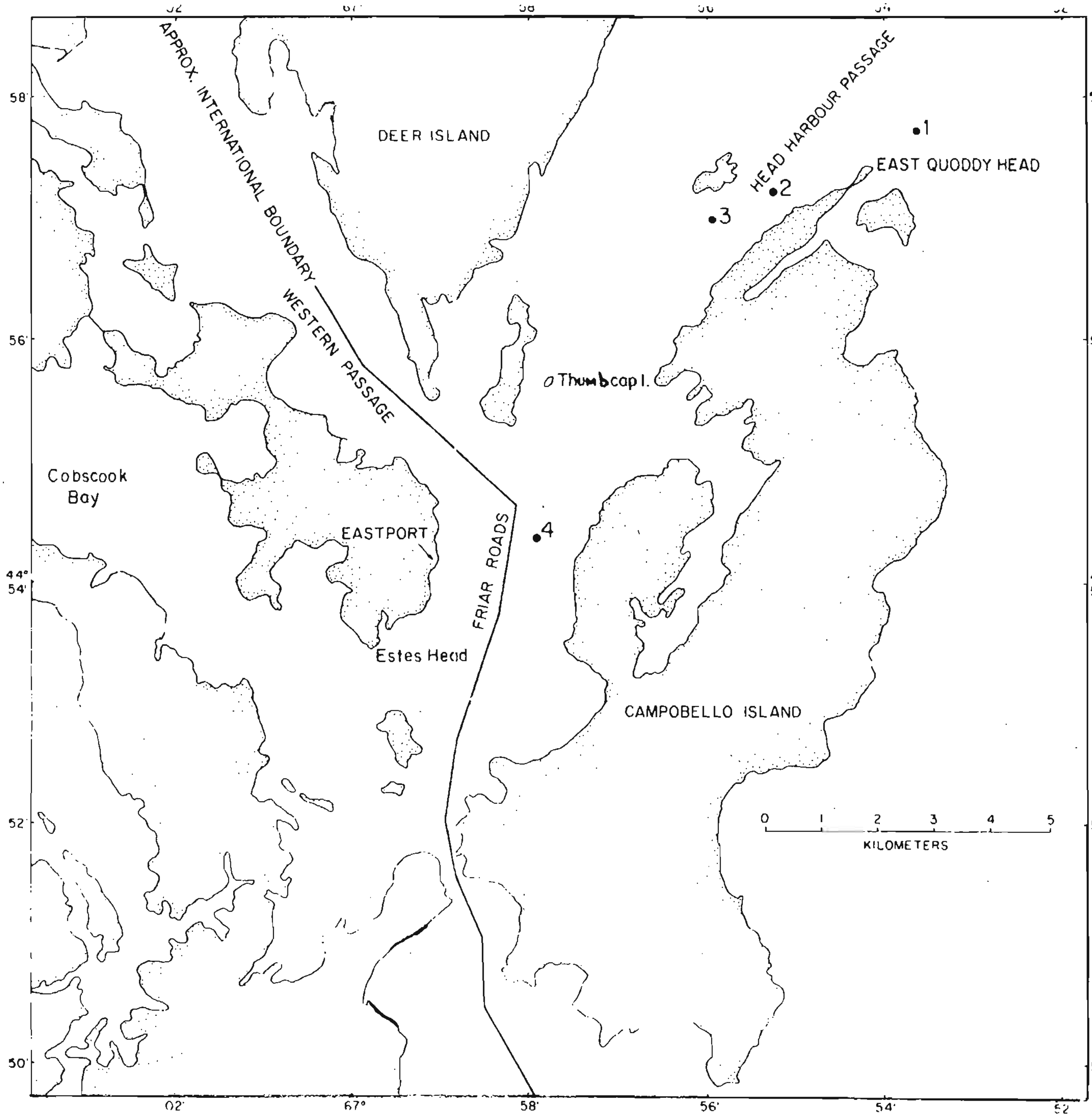


FIGURE 2: Map showing the current meter stations in Head Harbour Passage

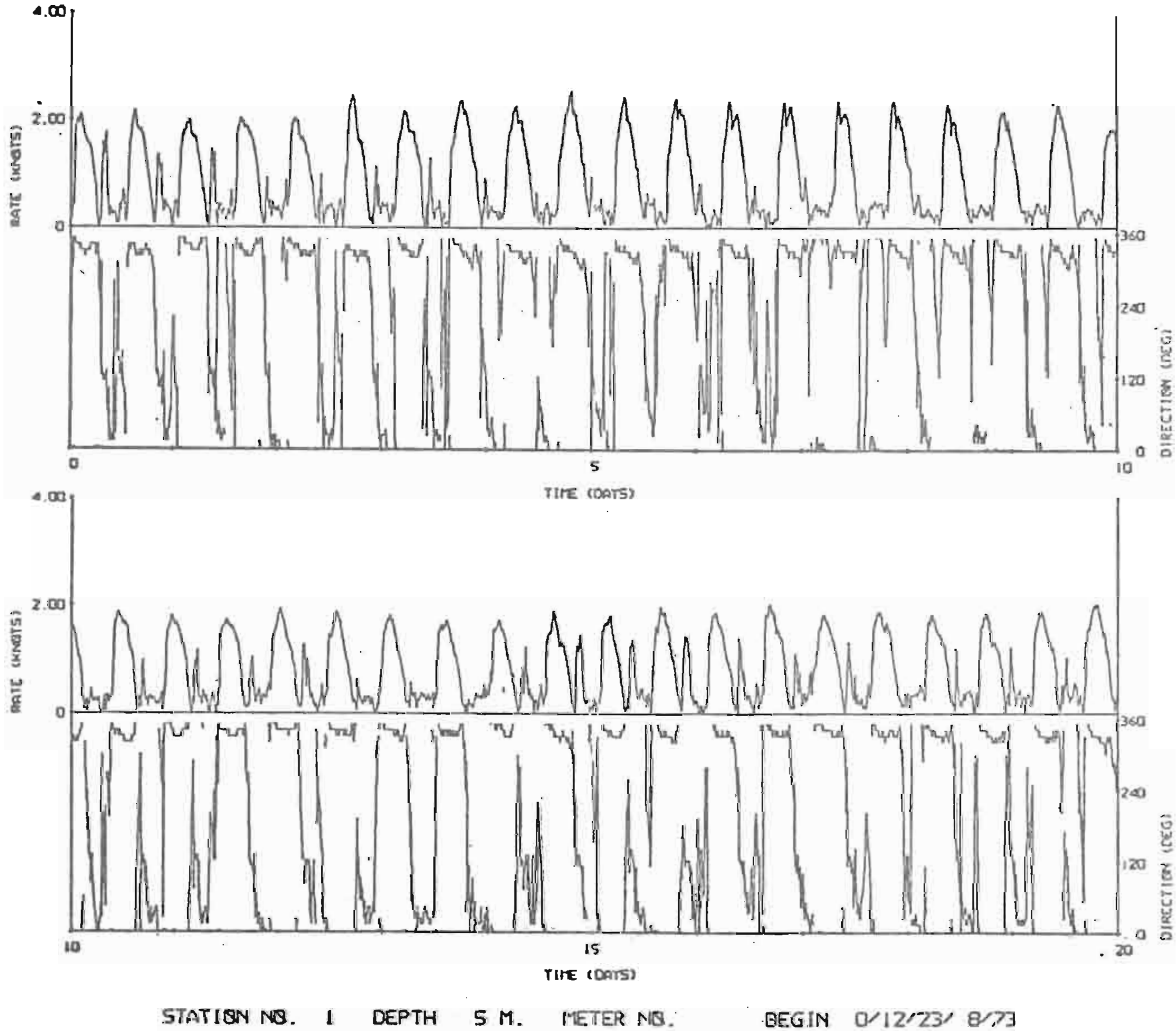
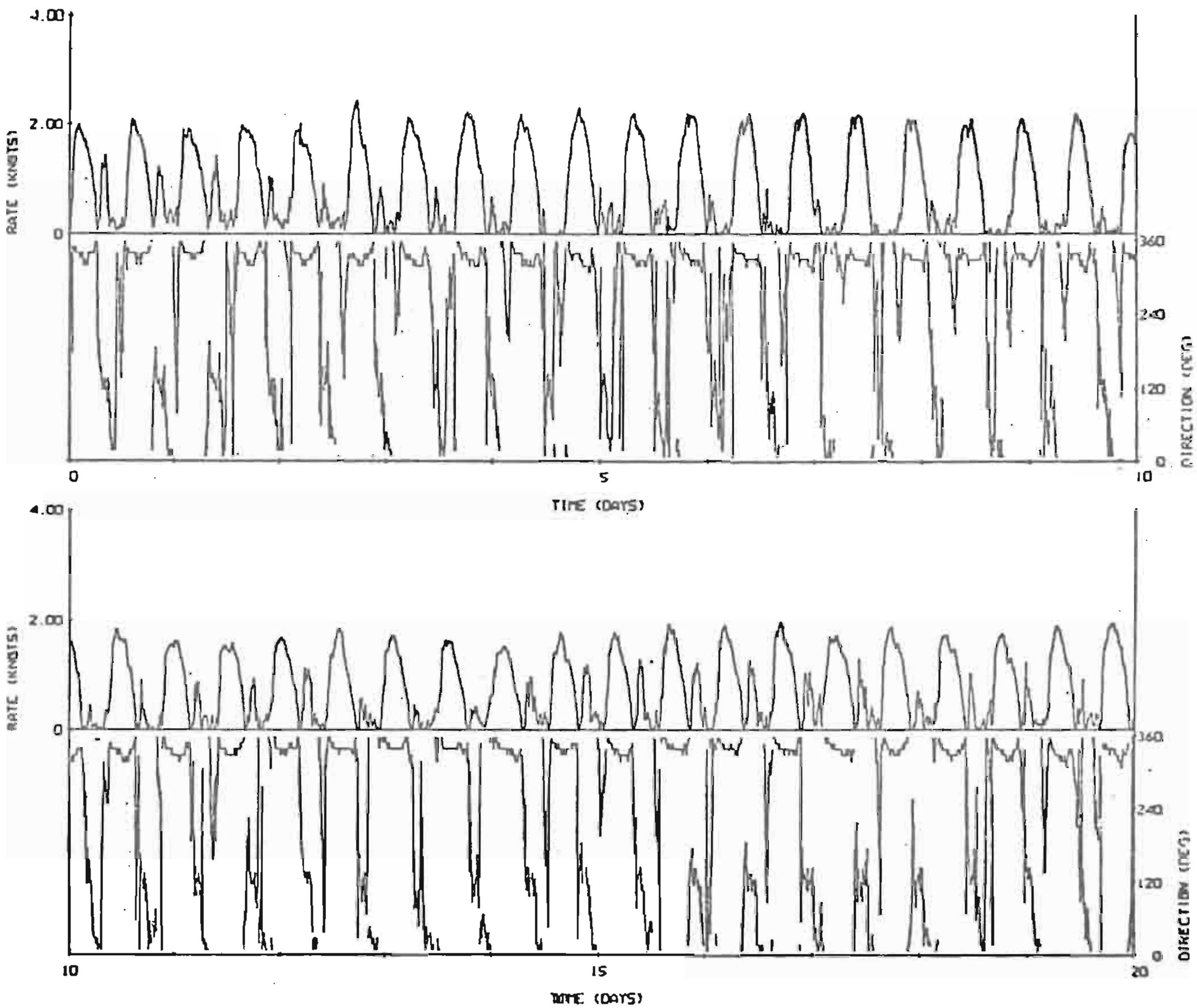
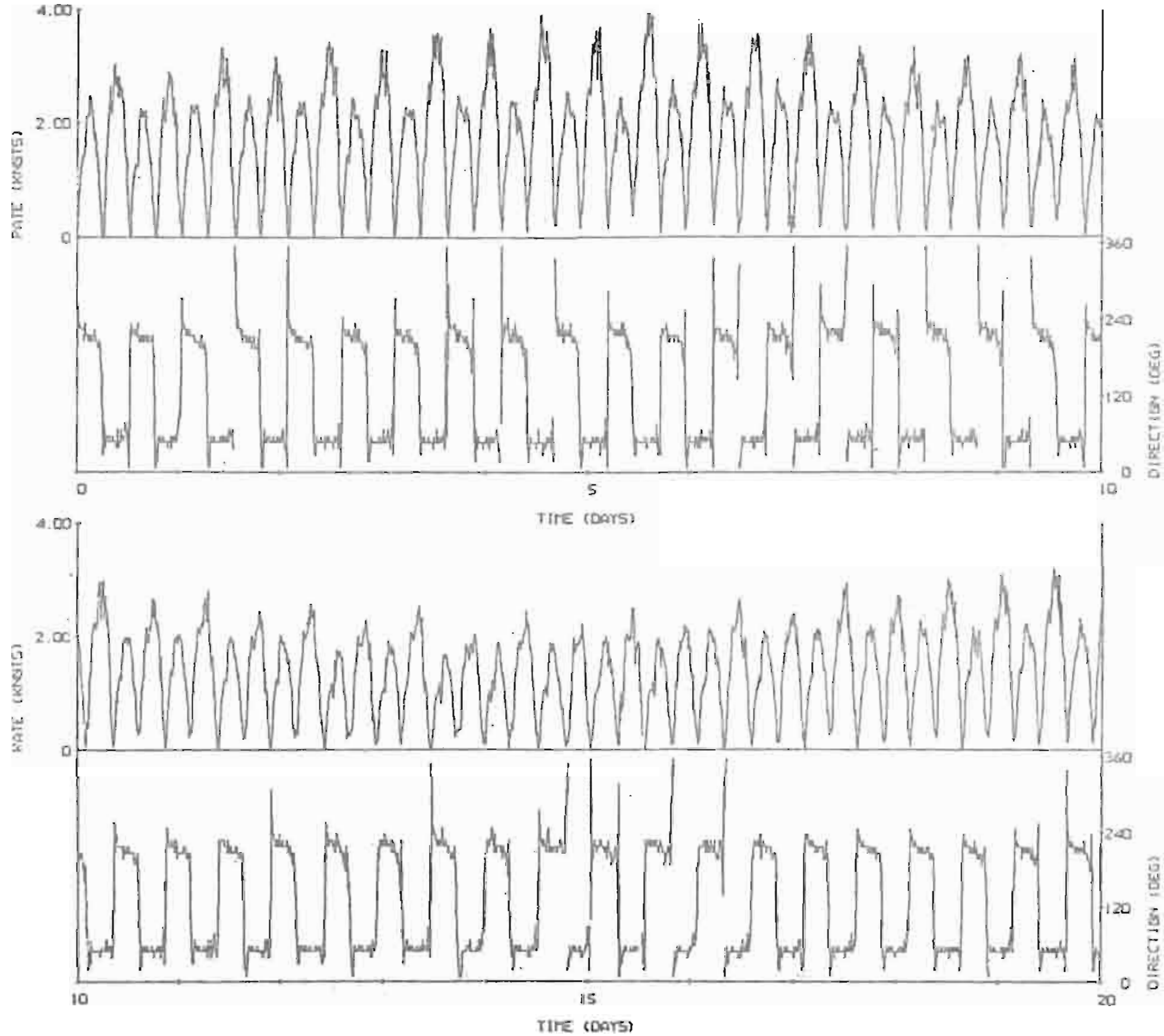


FIGURE 3: Time series plot of the rate and direction of the current at 5 metres depth at Station 1 between August 23 and September 13, 1973.



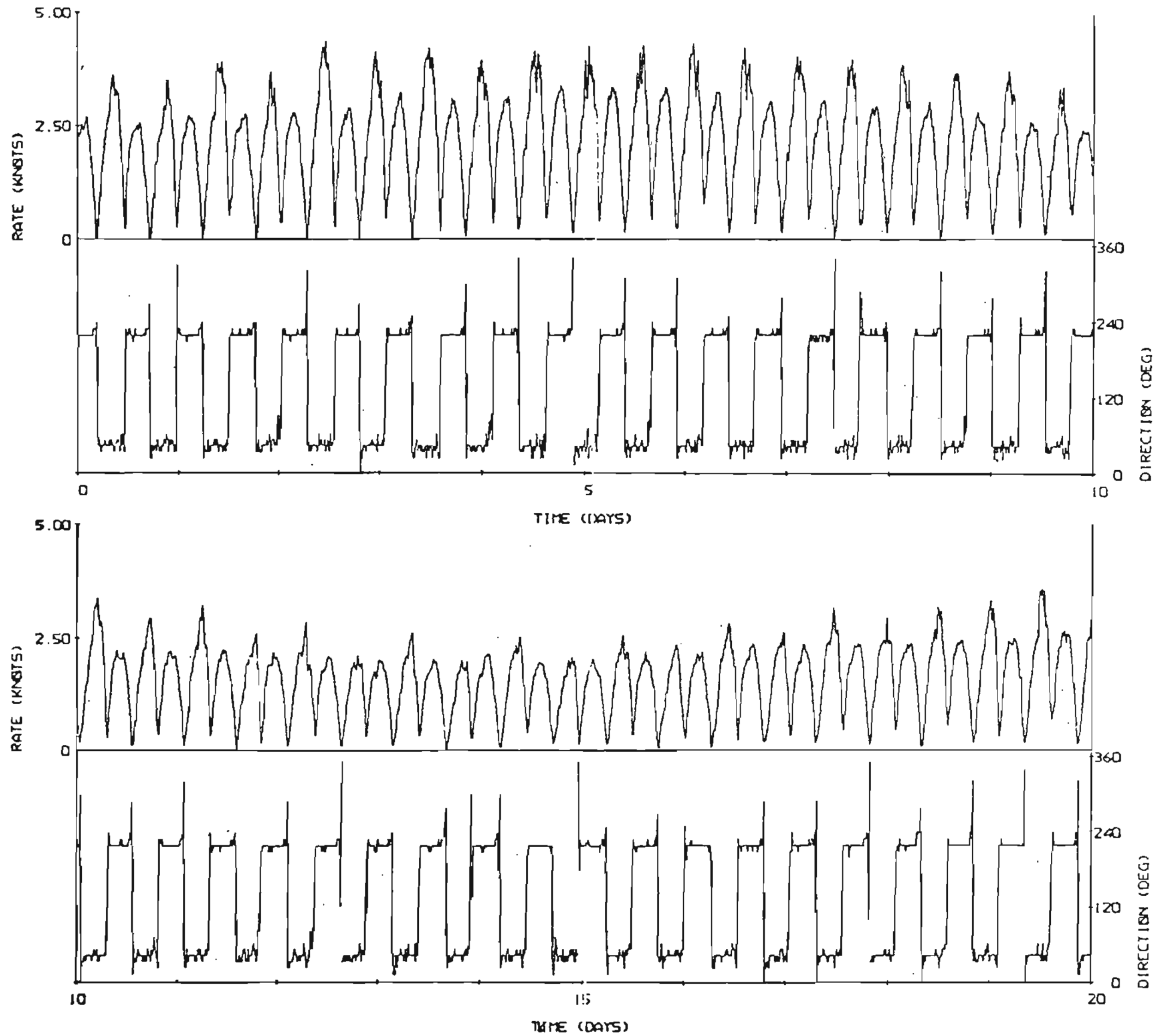
STATION NO. 1 DEPTH 15 M. METER NO. BEGIN 0/12/23/ 8/73

FIGURE 4: Time series plot of the rate and direction of the current at 15 metres depth at Station 1 between August 23 and September 13, 1973.



STATION NO. 2 DEPTH 5 M. METER NO. BEGIN 55/12/23/ 8/73

FIGURE 5: Time series plot of the rate and direction of the current at 5 metres depth at Station 2 between August 23 and September 13, 1973.



STATION NO. 3 DEPTH 5 M. METER NO. BEGIN 0/14/23/ 8/73

FIGURE 6: Time series plot of the rate and direction of the current at 5 metres depth at Station 3 between August 23 and September 13, 1973.

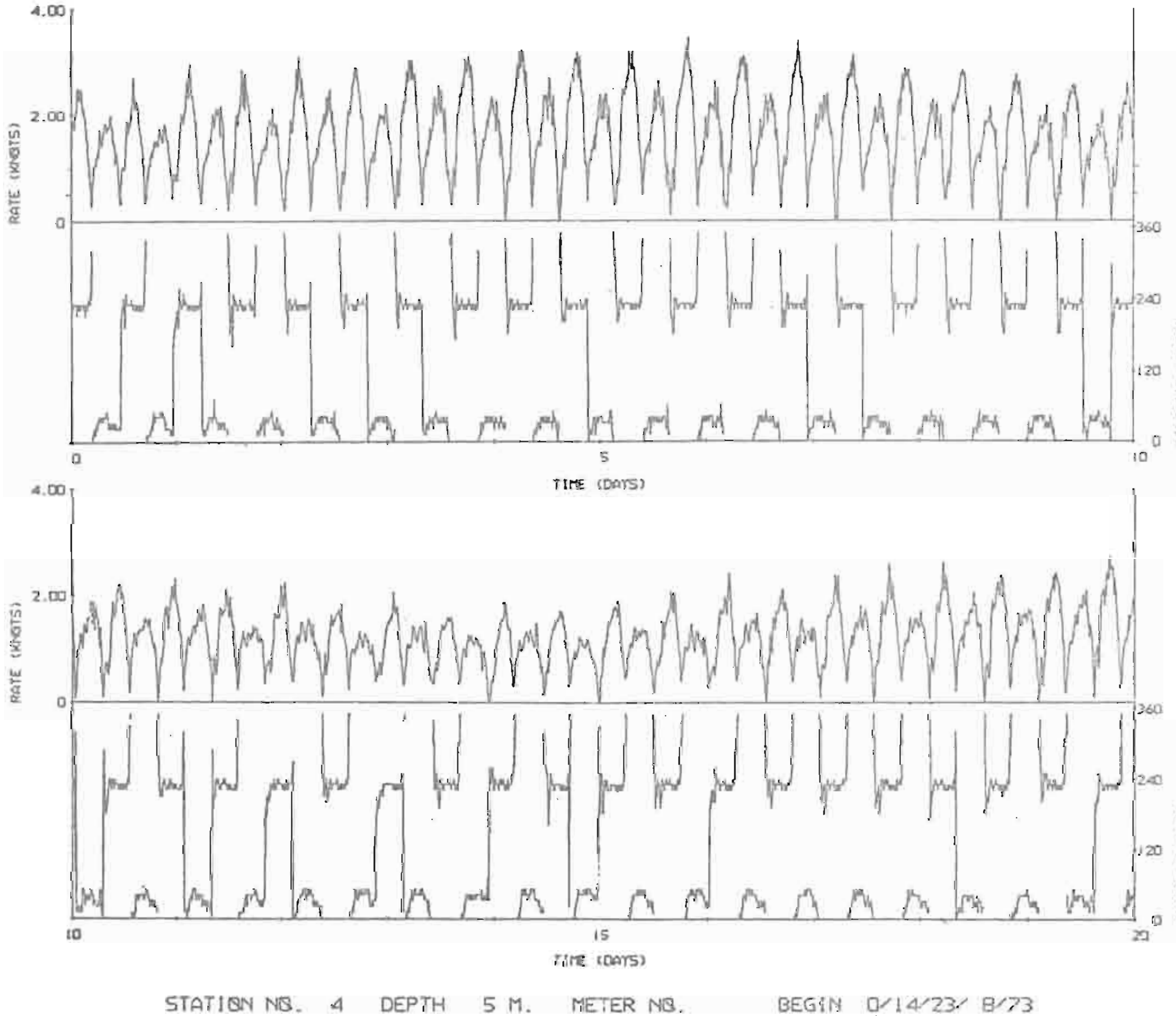
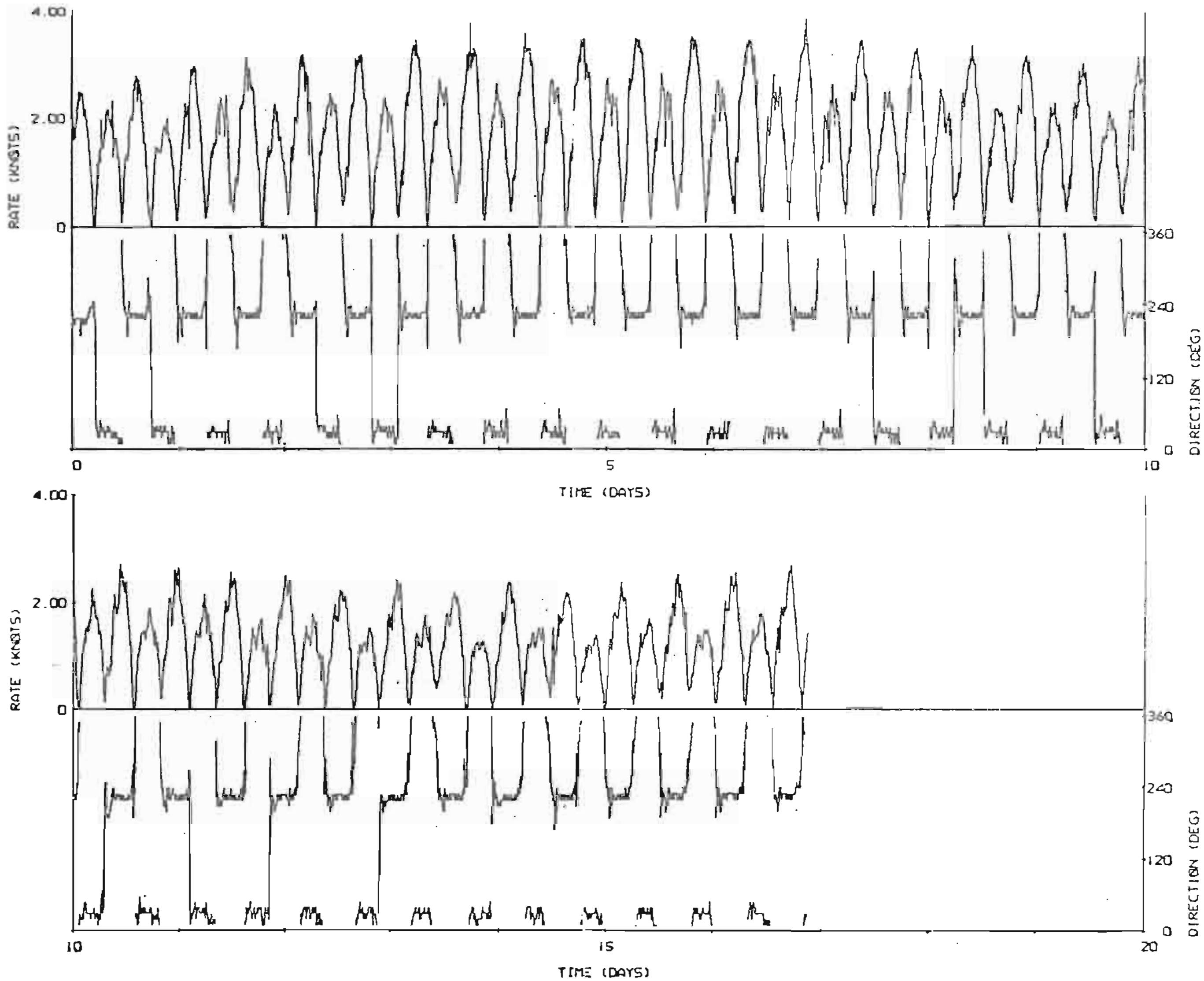


FIGURE 7: Time series plot of the rate and direction of the current at 5 metres depth at Station 4 between August 23 and September 13, 1973.



STATION NO. 4 DEPTH 15 M. METER NO. BEGIN 0/14/23/ 8/73

FIGURE 8: Time series plot of the rate and direction of the current at 15 metres depth at Station 4 between August 23 and September 10, 1973.

At Station 2 (Fig. 5) higher speed currents are observed during ebb tides (at a direction of approximately 50°) than during flood tides. This difference in speed decreases from spring to neap conditions. A gradual shift of the directional signal is found during flood tides while for an ebbing tide it is relatively constant.

Differences are observed in the currents between Stations 2 and 3 (Fig. 5 and 6). At Station 3, currents during an ebb tide flow in a more northerly direction by approximately 10°. During a flood tide the direction of flow is relatively constant at approximately 220°. The maximum rates attained for both flood and ebb tides appear slightly higher at Station 3. Topographical effects may cause these differences as Station 2 was moored near the centre of the deepest channel in Head Harbour Passage at a depth of 112 metres, while Station 3 was to the west of the channel over shallows in a depth of 44 metres. As at Station 2, the highest speed current at Station 3 is found during an ebb tide. No major differences were detected in the overall data recorded at Station 3 during the survey and the additional 80 days for which it was moored. However the spikes observed in the current's rate on an ebb tide (see Fig. 6) were found to be more numerous during the last 60 days of the record.

At Station 4 stronger currents were observed on the flooding tide than on an ebbing tide, a feature opposite to that of Stations 2 and 3. The current vectors show a tendency to shift towards a more easterly direction at the beginning of an ebb tide and back again during the ebb's latter stages. Less fluctuation in the directional signal is observed during a flood tide.

Statistical representation of the data is presented in dialplots, a pictorial diagram in the form of a histogram for each 30° of direction (Fig. 9-14). The mooring information is given at the centre of the dial and includes station number, depth, start time, length of record and the percentage of near-zero currents. The histograms display the percentage of the total number of observations found within increments of 0.5 knot for each 30° section. These sections are chosen with reference to true north. The arrows on each histogram denote the largest observed current for that direction. The area under the bar graphs denotes the frequency of occurrence of currents and hence the histogram containing the largest area is the predominant direction.

Figures 9 through 14 are the dialplots for Stations 1 to 4. Those features discussed from the time series plots are further illustrated and emphasized. For Station 1 the predominant flow is in one direction, corresponding to flood tides. At Station 2, two predominant directions which are aligned approximately with the channel's axis are observed but are not directly opposing. Southwesterly currents are associated with flood tides and northeasterlies with ebb tides. Maximum rates occur during ebb tides. Cross stream currents reach values as high as one knot. At Station 3 the currents are stronger during an ebb tide. Unlike Station 2, however, the two predominant directions are observed to be directly opposing. At Station 4 the major direction of the currents during flood and ebb conditions are not found to be directly opposite. The strongest currents appear during flood tides.

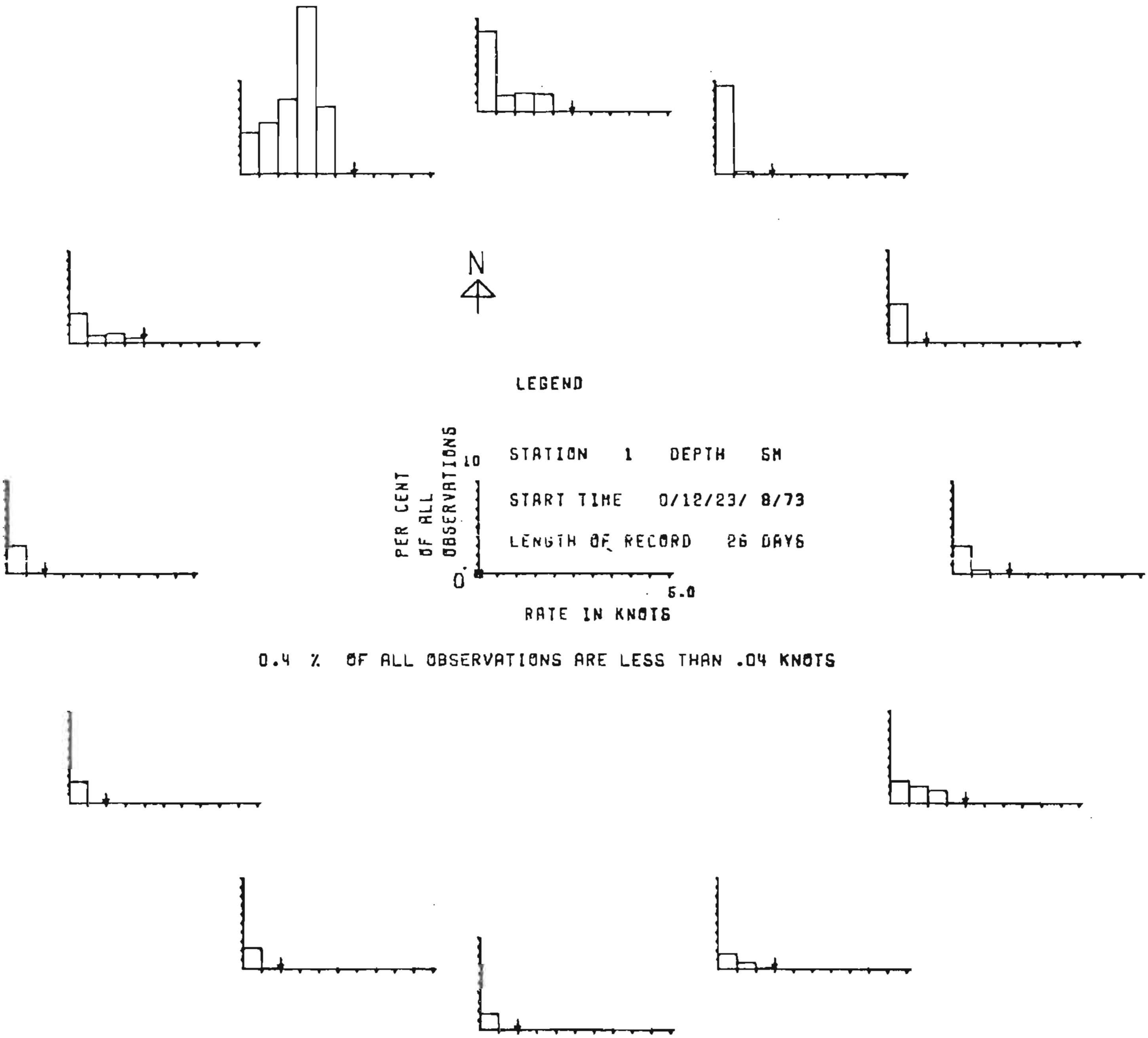


FIGURE 9: Dialplot for 5 metres depth at Station 1.

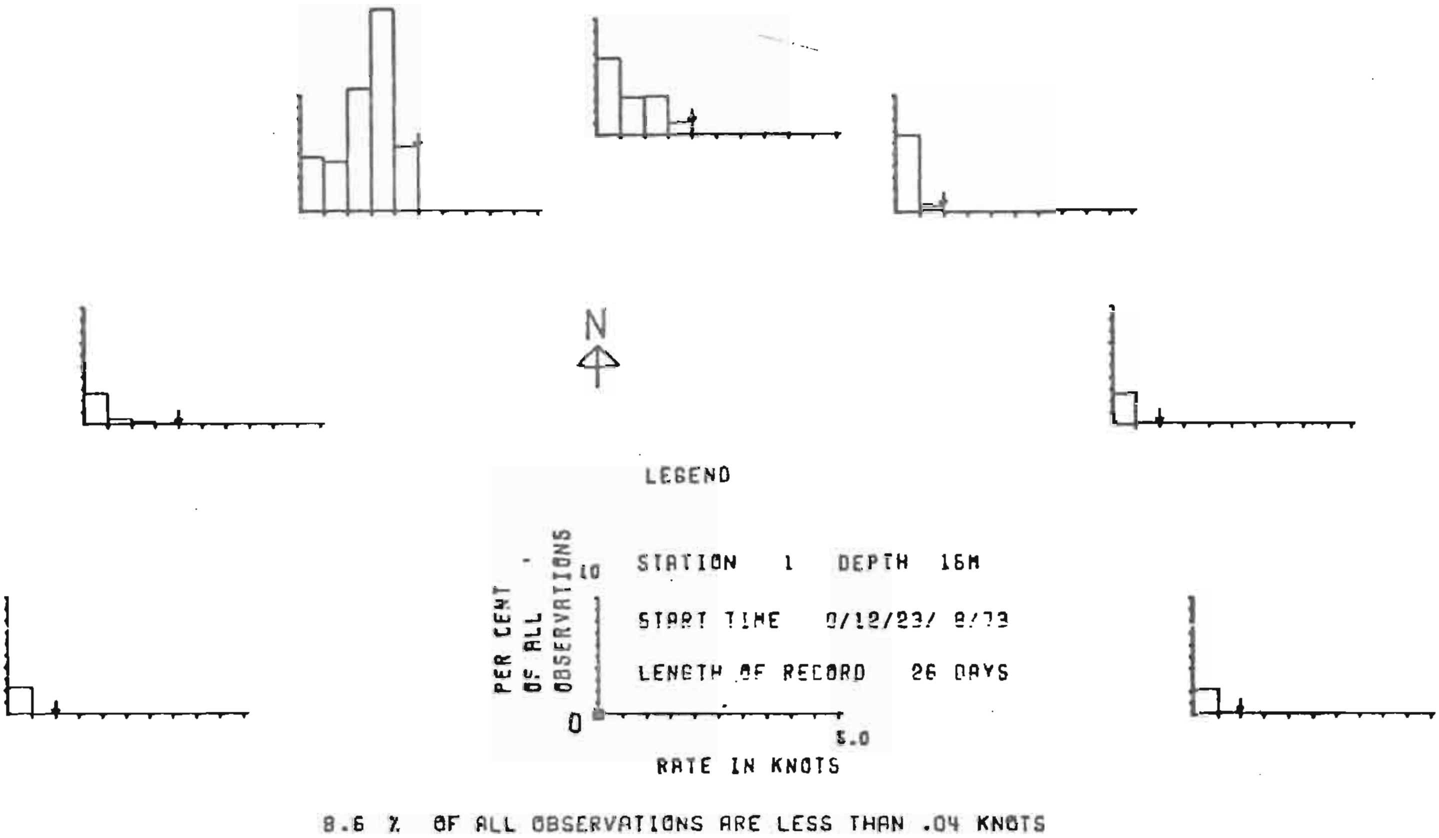


FIGURE 10: Dialplot for 15 metres depth at Station 1.

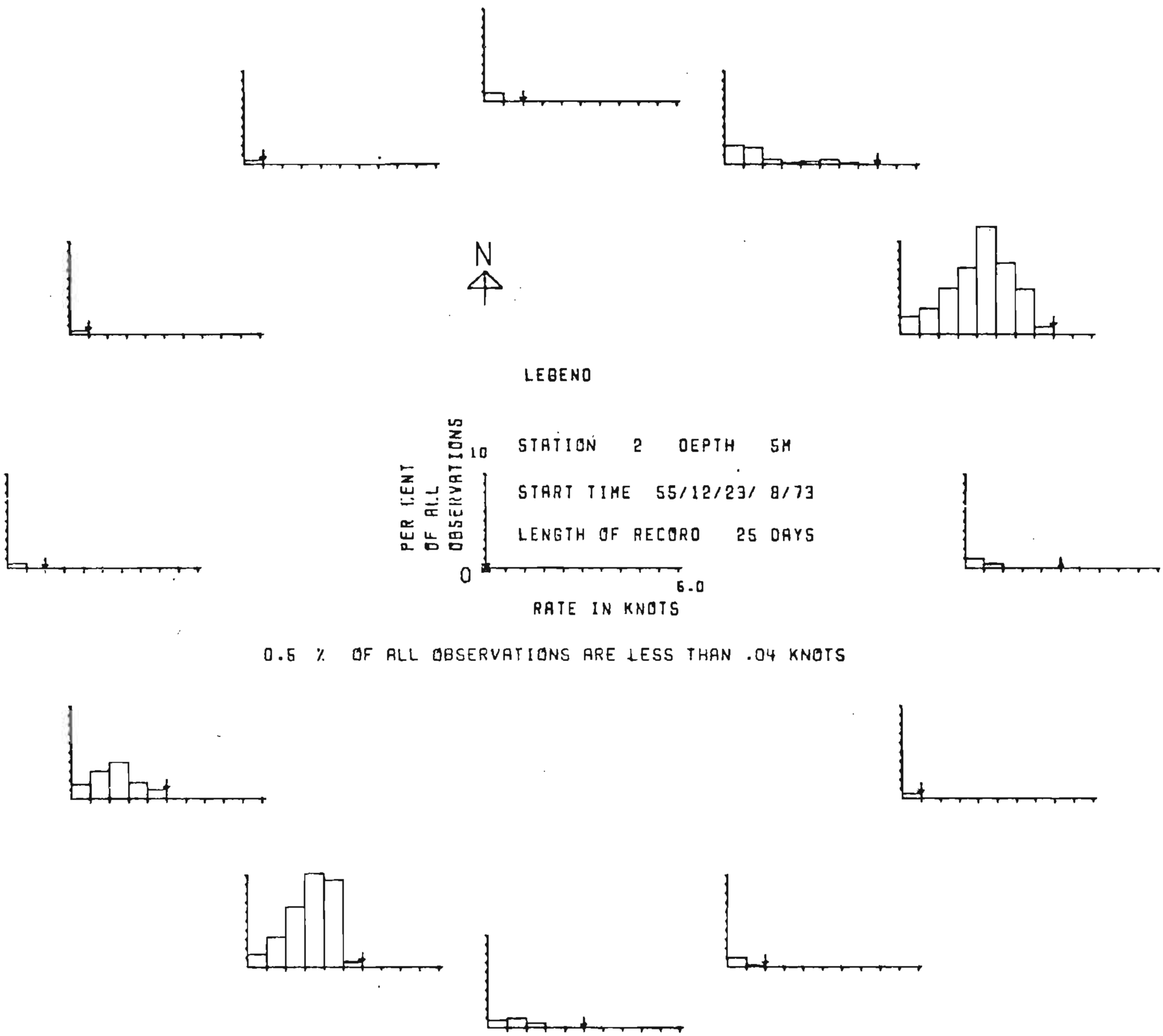


FIGURE 11: Dialplot for 5 metres depth at Station 2.

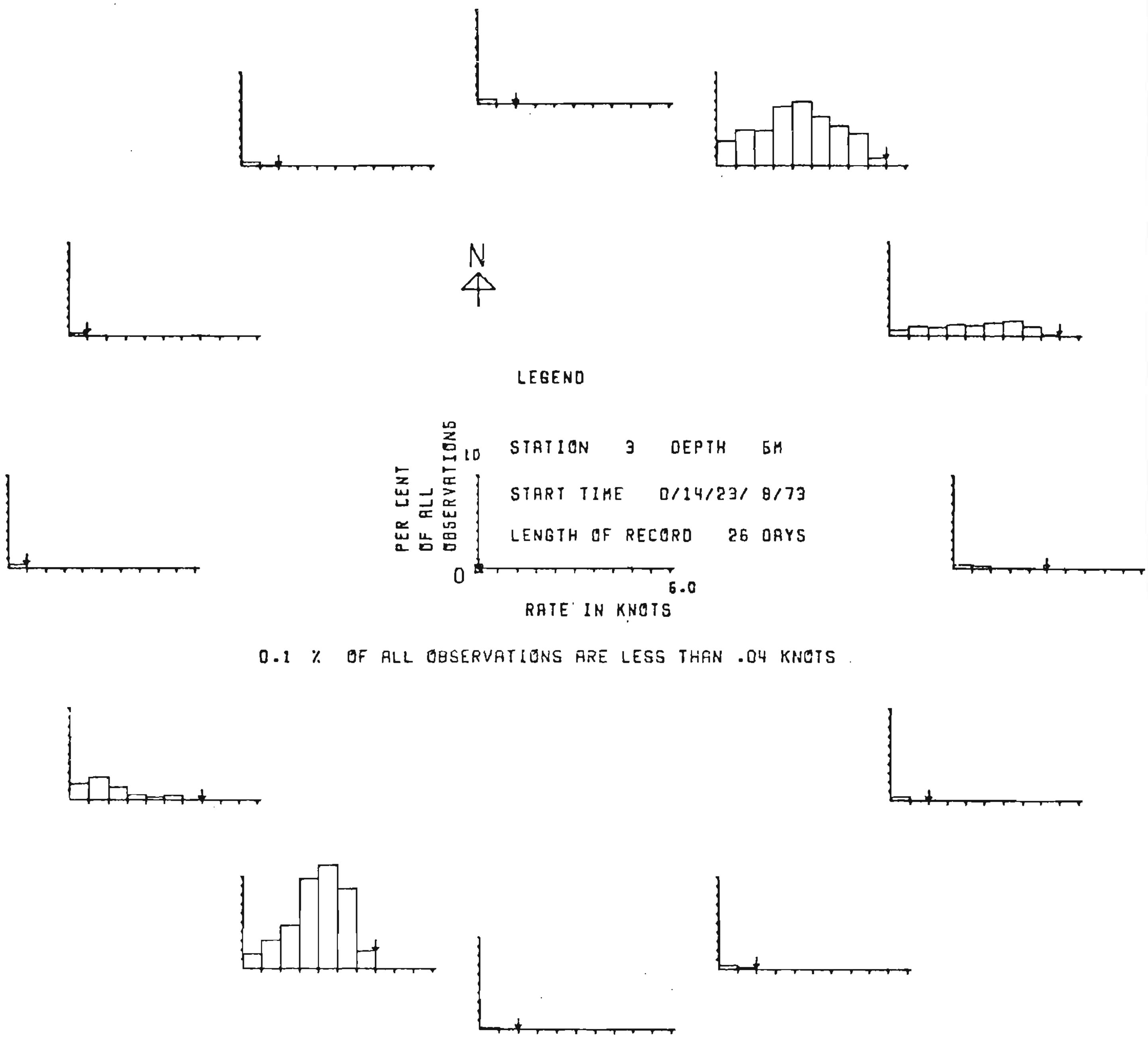


FIGURE 12: Dialplot for 5 metres depth at Station 3.

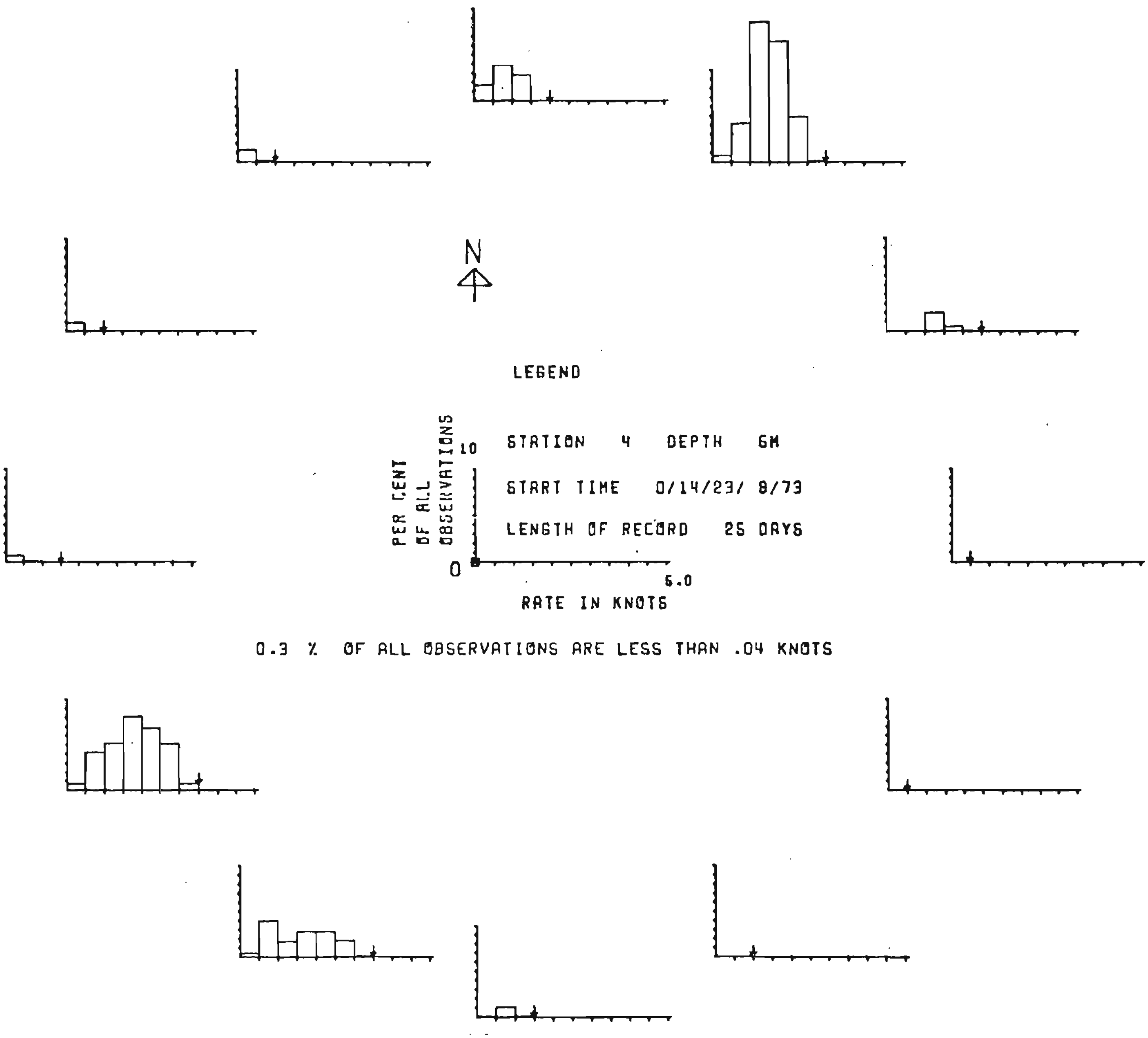


FIGURE 13: Dialplot for 5 metres depth at Station 4.

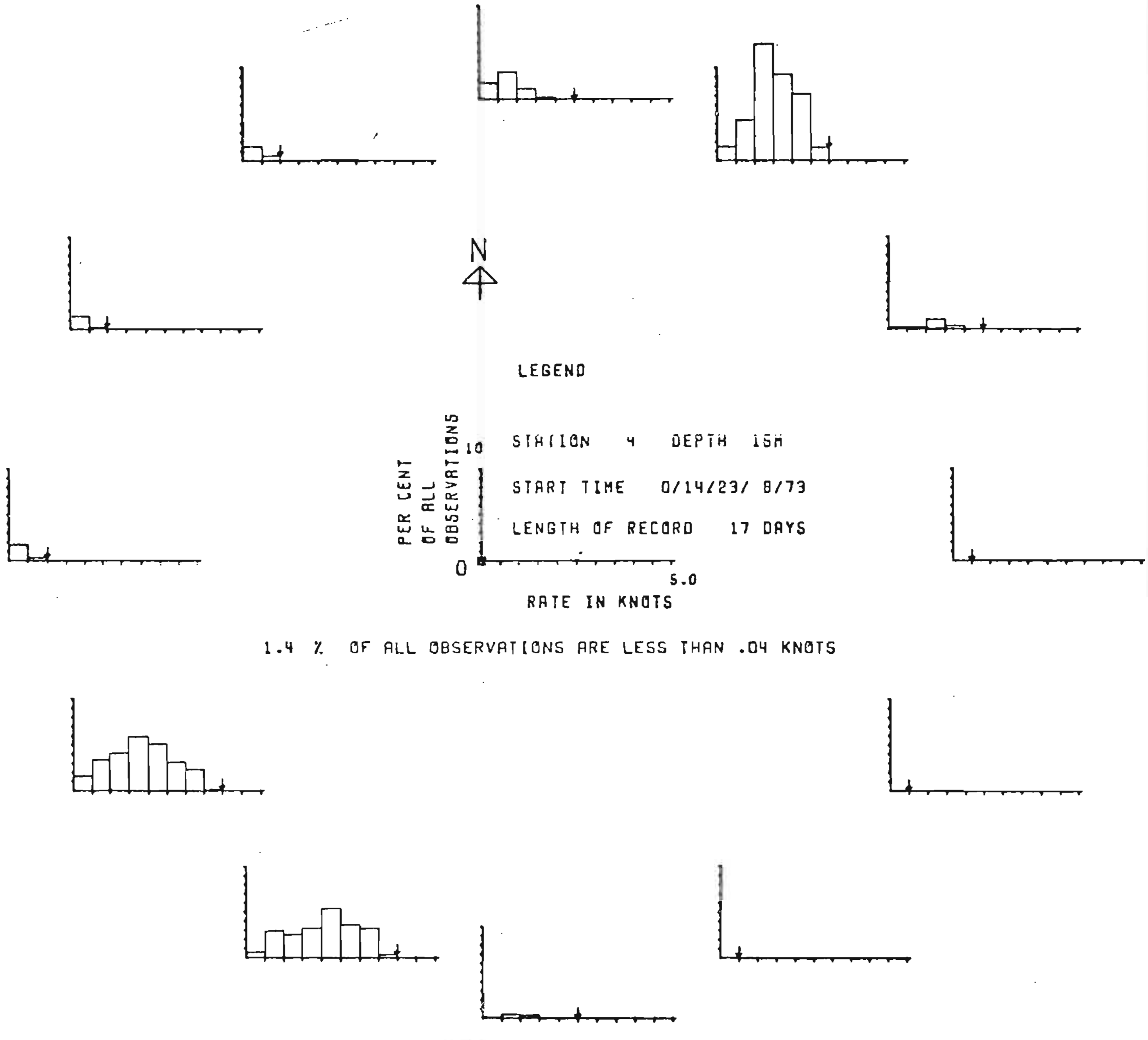


FIGURE 14: Dialplot for 15 metres depth at Station 4.

The periods of the important tidal harmonic constituents within Head Harbour Passage are given in Table 1. The amplitude and phase for each of these constituents in both the minor (cross channel) and major (along channel) directions are given in Tables 2 to 7. These values are the vector averages taken from 15-day analyses. Residual currents are also listed. The minor and major directions vary from station to station due to topographical differences. Station 2 residuals are observed to be larger than those of Station 3. Station 4 residuals differ by 0.2 knots in the major direction between 5 and 15 metres. Little difference is observed in the minor direction.

The relative size between the amplitudes in the minor and major directions for the tidal constituents as well as the residuals reveal that the direction of the residual current at Stations 2 and 3 is more easterly than that of the tidal current. At Station 4 the residual appears to be directed further to the west than the tidal current. This explains the non-opposing current vectors for ebb and flood tides at Stations 2 and 4. Station 3 has the weakest residual current, hence its effect upon the tidal currents is the least. This may account for the fact that the dialplots show oppositely directed currents on ebb and flood tides for this station. It must be remembered, however, that these residuals may be in part tidally induced via interaction with the topography. Station 4 is most affected as it lies near the point of intersection of two channels. Therefore, generalization of the above residual flows to an area much beyond the station in question (especially at Station 4) is not recommended.

TABLE 1

The Major Tidal Potential Constituents
within Head Harbour Passage

Constituent	Name	Period (hr)
Z_0	Residual Current	
O_1	Principal Lunar Diurnal	25.82
K_1	Luni-Solar Diurnal	23.93
M_2	Principal Lunar	12.42
S_2	Principal Solar	12.00
M_4	Lunar Quarter Diurnal	6.21
MS_4	Lunar Shallow Water Distortion	6.10
N_2	Larger Lunar Elliptic	12.66
P_1	Principal Solar Diurnal	24.07
K_2	Luni-Solar Semi-Diurnal	11.97

TABLE 2
Tidal Constituents for Station 1 at 5 Metres

Constituent	Major Direction (325°) Amplitude (kt)	Phase	Minor Direction (55°) Amplitude (kt)	Phase
Z_0	0.636	000.0	0.185	000.0
O_1	0.028	13.8	0.032	102.3
K_1	0.055	20.9	0.025	84.6
M_2	1.070	226.6	0.130	172.1
S_2	0.072	221.7	0.028	125.5
M_4	0.269	111.6	0.150	57.6
MS_4	0.071	101.2	0.029	17.3
N_2	0.219	203.6	0.016	205.5
P_1	0.018	20.9	0.008	84.6
K_2	0.020	221.7	0.008	125.5

TABLE 3
Tidal Constituents for Station 1 at 15 Metres

Constituent	Major Direction (325°) Amplitude (kt)	Phase	Minor Direction (55°) Amplitude (kn)	Phase
Z_0	0.624	000.0	0.147	000.0
O_1	0.016	359.8	0.007	56.2
K_1	0.025	16.6	0.019	47.9
M_2	1.091	225.4	0.115	195.6
S_2	0.052	232.0	0.019	147.6
M_4	0.26	113.7	0.095	38.8
MS_4	0.078	115.9	0.036	5.4
N_2	0.224	202.4	0.023	172.6
P_1	0.008	16.6	0.006	48.0
K_2	0.014	232.0	0.005	147.6

TABLE 4
Tidal Constituents for Station 2 at 5 Metres

Constituent	Major Direction (220°) Amplitude (kt)	Phase	Minor Direction (310°) Amplitude (kt)	Phase
Z_0	-0.269	000.0	-0.245	000.0
O_1	0.055	18.6	0.014	356.6
K_1	0.100	52.0	0.025	8.7
M_2	2.453	246.1	0.181	225.6
S_2	0.315	256.8	0.029	264.0
M_4	0.079	336.1	0.177	4.2
MS_4	0.018	358.4	0.040	12.3
N_2	0.503	223.1	0.037	202.6
P_1	0.032	52.0	0.008	8.7
K_2	0.086	256.8	0.008	264.0

TABLE 5
Tidal Constituents for Station 3 at 5 Metres

Constituent	Major Direction (225°) Amplitude (kt)	Phase	Minor Direction (315°) Amplitude (kt)	Phase
Z_0	-0.127	000.0	-0.031	000.0
O_1	0.098	25.9	0.020	70.4
K_1	0.133	34.4	0.026	13.1
M_2	2.597	240.8	0.151	35.6
S_2	0.412	274.0	0.022	46.1
M_4	0.320	21.6	0.024	331.0
MS_4	0.084	50.7	0.006	338.0
N_2	0.567	217.9	0.031	12.6
P_1	0.043	34.4	0.008	13.5
K_2	0.112	274.0	0.006	46.1

TABLE 6
Tidal Constituents for Station 4 at 5 Metres

Constituent	Major Direction (215°) Amplitude (kt)	Phase	Minor Direction (305°) Amplitude (kt)	Phase
Z_0	0.069	000.0	0.205	000.0
O_1	0.032	30.0	0.006	261.1
K_1	0.057	56.8	0.011	257.2
M_2	2.131	247.4	0.301	258.9
S_2	0.277	270.1	0.080	248.3
M_4	0.225	161.8	0.049	212.3
MS_4	0.033	181.8	0.043	214.6
N_2	0.437	224.4	0.062	235.9
P_1	0.018	57.3	0.003	257.2
K_2	0.075	270.1	0.008	248.3

TABLE 7
Tidal Constituents for Station 4 at 15 Metres

Constituent	Major Direction (215°) Amplitude (kt)	Phase	Minor Direction (305°) Amplitude (kt)	Phase
Z_0	0.270	000.0	0.238	000.0
O_1	0.054	25.5	0.017	260.4
K_1	0.062	57.1	0.009	307.2
M_2	2.387	250.9	0.104	244.4
S_2	0.293	274.5	0.016	246.8
M_4	0.156	185.4	0.109	194.7
MS_4	0.036	220.2	0.028	224.9
N_2	0.489	227.9	0.012	175.5
P_1	0.020	57.1	0.003	307.2
K_2	0.080	274.5	0.004	246.8

2.2 Tidal Excursions

The tidal excursion is the distance travelled by a water particle during half of a tidal cycle. Forgeron (1959) calculated tidal excursions from intertidal volumes for the Passamaquoddy Region. The results are given in Figure 15.

Tidal excursions during flooding conditions for Head Harbour Passage calculated from integrated values of Forrester's (1959) current measurements are shown in Figure 13, Section 2 of this report.

2.3 Duration of Slack Water in Head Harbour Passage

Slack water is theoretically defined as the time at which currents cease to exist due to changing tidal conditions. In actual fact currents in some areas never fall to zero over a tidal cycle. Thus for this study, time durations for currents less than 1.0 knot and less than 0.5 knot have been examined. For several days during spring and neap tides these durations have been plotted and are shown in Figures 16 to 19. Distinction between low and high water period has also been made. Two spring tides and one neap tide were contained within the time span of the survey except at 15 metres at Station 4. Station 1 was not included due to the siting problem previously mentioned. Of particular note are (1) the variability in the time durations, (2) the differences between spring and neap tides as well as between low and high water slack, and (3) the differences between stations. The time durations range from 20 minutes minimum to 85 minutes maximum for currents below 0.5 knot and from 30 minutes minimum to 95 minutes maximum for currents below 1.0 knot.

The average time durations plus twice their standard deviations for currents less than 0.5 and 1.0 knot are given in Tables 8 and 9 respectively. Predicted values are also displayed. These were calculated from the equation

$$V = \sum_i A_i \cos (\omega_i t + \phi)$$

where for the i^{th} component, A is the amplitude, ω is the frequency, and ϕ is the phase angle. All of the tidal constituents considered were taken to be in phase with the M_2 tide during spring conditions and out of phase with the M_2 tide during neap tides. Only those tidal constituents having amplitudes greater than 0.15 knot in the major direction (see Tables 4 through 7) were used.

An increase in the average values occurs from spring to neap tides, all other conditions being equal. At Stations 2 and 3, the averages are higher during high water slack while at Station 4 the opposite is found. At Station 2 and Station 4 at 15 metres average

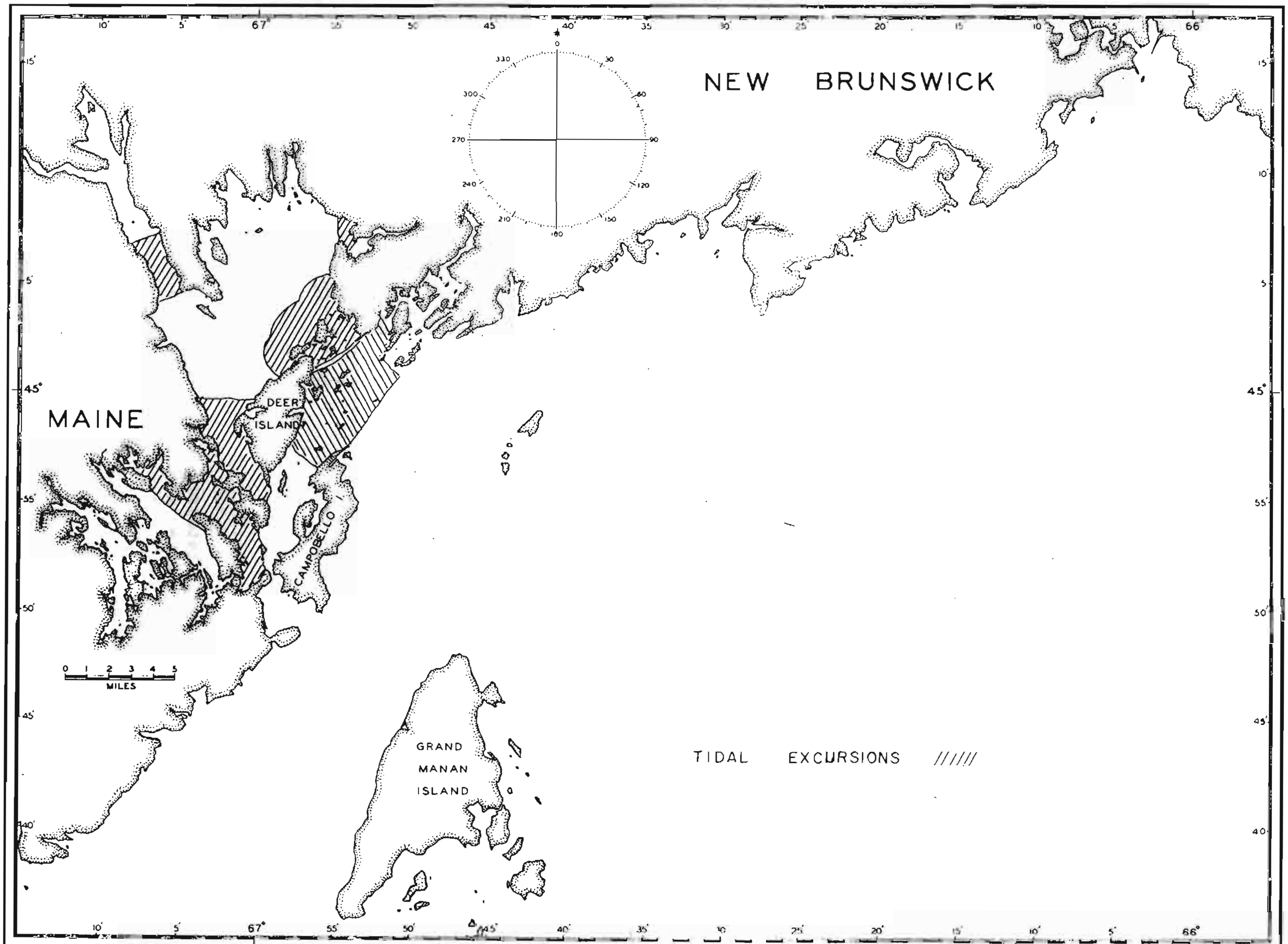


FIGURE 15: Tidal excursions in the Quoddy Region (from Forgeron, 1954).

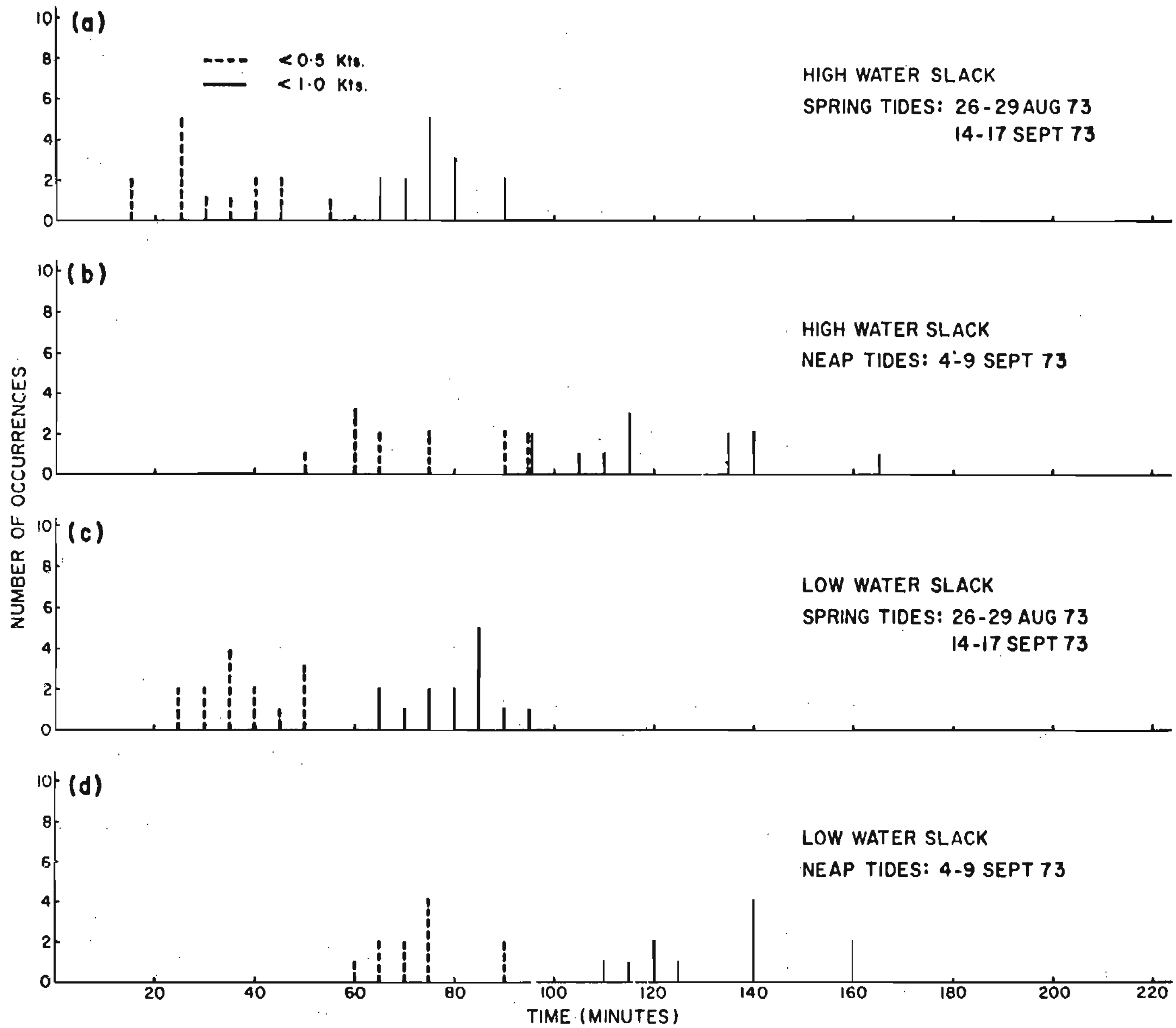


FIGURE 16: Histogram of the time duration during slack water at 5 metres depth at Station 2.

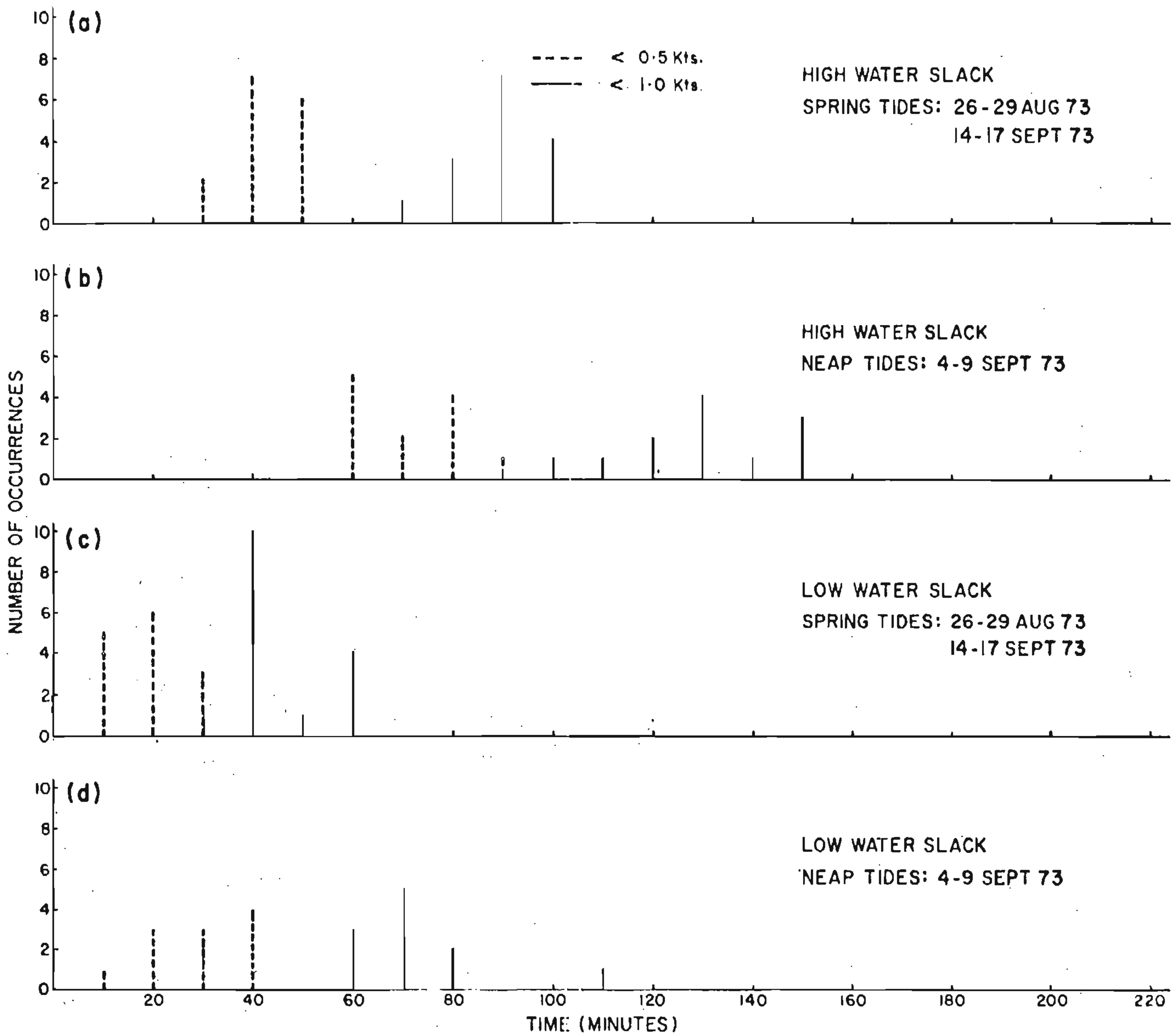


FIGURE 17: Histogram of the time duration during slack water at 5 metres depth at Station 3.

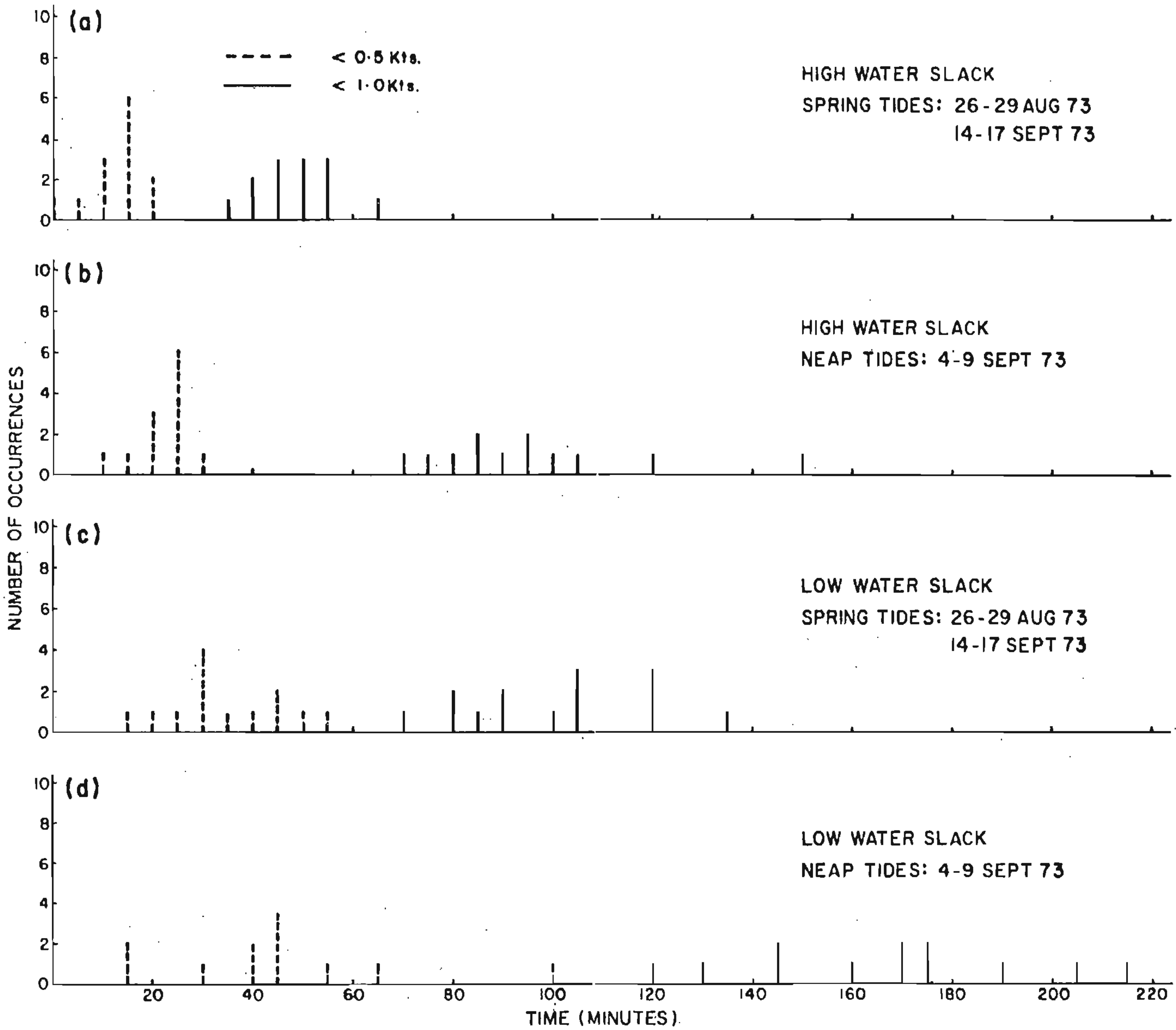


FIGURE 18: Histogram of the time duration during slack water at 5 metres depth at Station 4.

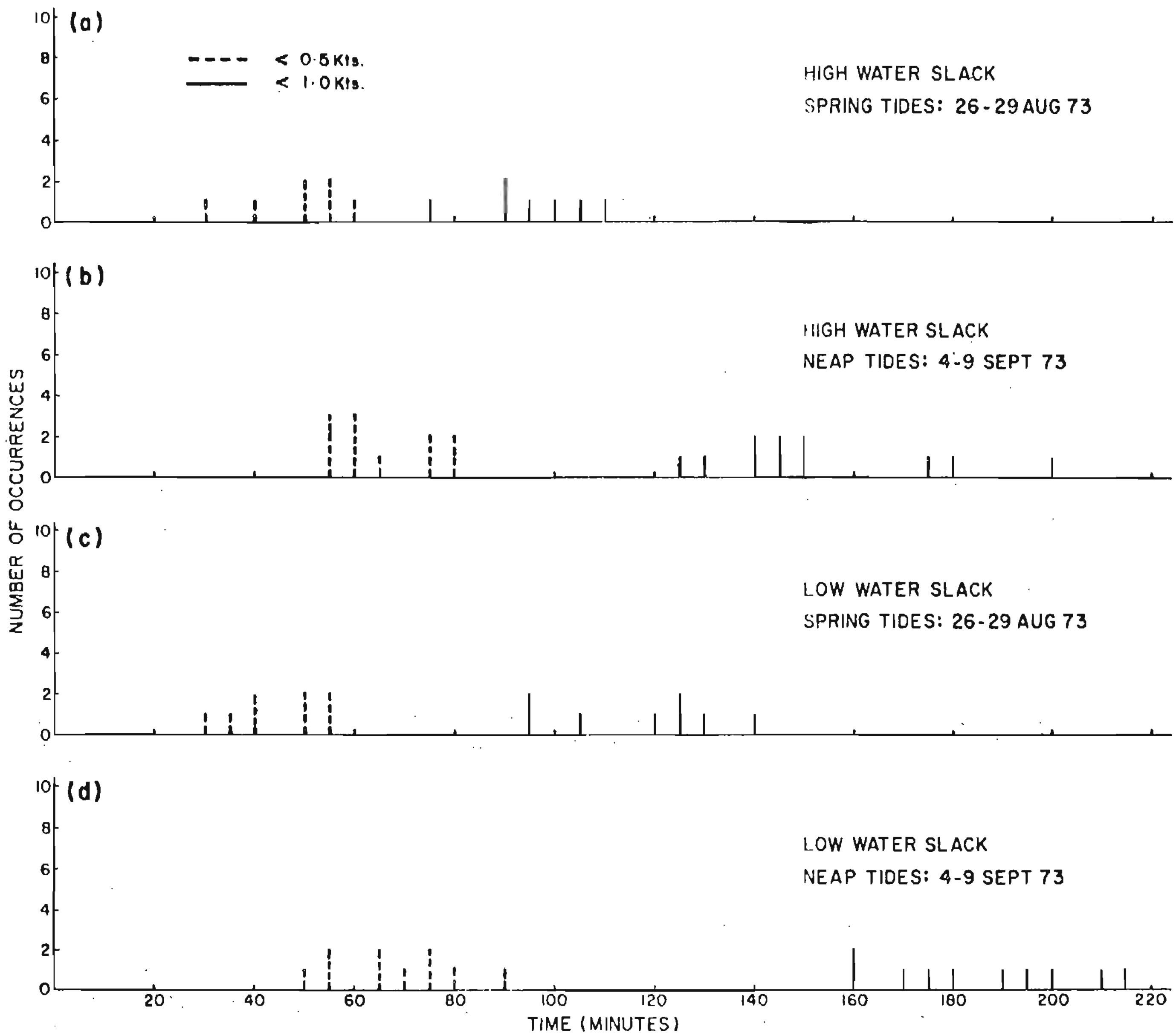


FIGURE 19: Histogram of the time duration at slack water at 15 metres depth at Station 4.

values correspond closely to predicted values. Station 3 exhibits predictable averages during high water times but much lower values during low water slack. Station 4 at 5 metres has generally lower average values than predicted. It should be noted that even if good agreement exists between predicted and average values of the time duration, individual values may deviate largely from this value as indicated by the large standard deviations. For this reason use of the average values for purposes other than gross comparisons is dubious and suspect to large errors.

TABLE 8

Period for Which Currents are < 0.5 knot

Station	Depth	Sampling Interval (min)	Spring Tides High Water $T \pm 2\sigma_t$	Spring Tides Low Water $T \pm 2\sigma_t$	Spring Tides Predicted	Neap Tides High Water $T \pm 2\sigma_t$	Neap Tides Low Water $T \pm 2\sigma_t$	Neap Tides Predicted
2	5	5*	32 ±23	38 ±17	40	73 ±31	74 ±19	80
3	5	10	43 ±14	16±19	35	71 ±22	29 ±21	75
4	5	5	13 ±11	35 ±24	40	22 ±11	45 ±47	85
4	15	5	49 ±20	44 ±19	40	65 ±20	68 ±25	75

TABLE 9

Period for which Currents are < 1.0 knot

Station	Depth	Sampling Interval (min)	Spring Tides High Water $T \pm 2\sigma_t$	Spring Tides Low Water $T \pm 2\sigma_t$	Spring Tides Predicted	Neap Tides High Water $T \pm 2\sigma_t$	Neap Tides Low Water $T \pm 2\sigma_t$	Neap Tides Predicted
2	5	5*	76 ±15	80 ±18	80	122 ±42	134 ±34	165
3	5	10	89 ±17	45 ±19	75	130 ±32	45 ±19	160
4	5	5	48 ±16	100 ±29	85	96 ±44	166 ±57	185
4	15	5	95 ±23	117 ±33	75	153 ±45	185 ±39	160

* On Station 2, 10-minute running averages were used.

2.4 Current Variability and Extremes in Head Harbour Passage

To examine current variability, Tables 10 to 14 have been produced showing the changes in major and minor speed components over 5-minute intervals versus, in all cases, the concurrent speed in the major direction. This information, fed as input to a pilot and a pilotage model, would lead to estimates of the degree of ship control needed in order to successfully compensate for surges in currents.

Examination of the tables shows that large changes occur more frequently in the transverse (Tables 11, 13 and 14) than in the axial component (Tables 10 and 12). Moreover, these changes are more frequent at Station 2 (Table 11) than at Station 4 (Table 13) at 5 metres depth while at Station 4 large changes are more frequent at 15 metres depth (Table 14) than at 5 metres depth (Table 13).

To examine extreme current speeds, both the current observations and a predictive statistical model have been used. The extreme currents observed in each record in flood and ebb directions are presented in Table 15. These speeds are the resultant of the tidal currents and the residual currents. The observed extremes are largest (4 to 4.5 knots) at Stations 2 and 3.

The residual currents have variability which may be modelled statistically to yield an estimate of the extreme residual surge to recur once in, say, 500 days of the same season. This surge could be added to the mean residual and to the maximum tidal current to estimate the 500-day grand extreme current. The technique is described in Loucks et al. (1973). The results (50 percentile 500-day extreme residual surge) are 1.3 ±0.3 and 1.4 ±0.2 knots for Station 2 and 4 (at 5 metres) respectively. The corresponding 500-day grand extreme currents are 5.2 and 4.8 knots for Stations 2 and 4 respectively. The important characteristic of extreme residual surges is that they are practically unpredictable; therefore the current may differ from one's expectations as derived from the stage of the tide by 1.3 knots at any time.

TABLE 10

Current Variability in the Axial Direction for Station 2

STA 02 DEPTH 005 55 MN 12 HR 23 DY 08 MO 73 YR

		NEGATIVE CHANGE OF RATE										RATE						POSITIVE CHANGE OF RATE						
RATE	TOTAL	100 OR OVER	090 TO 099	080 TO 089	070 TO 079	060 TO 069	050 TO 059	040 TO 049	030 TO 039	020 TO 029	010 TO 019	000 TO 009	000 TO 009	010 TO 019	020 TO 029	030 TO 039	040 TO 049	050 TO 059	060 TO 069	070 TO 079	080 TO 089	090 TO 099	100 OR OVER	TOTAL	RATE
000-009	94							001	005	009	026	053	114	028	005	001								148	000-009
010-019	97								003	011	031	052	075	033	012	002								122	010-019
020-029	90							001	002	005	029	053	052	037	005	002	001							97	020-029
030-039	103	001							005	016	030	051	064	049	006									119	030-039
040-049	75							002		009	039	025	032	039	007	001								79	040-049
050-059	80							002	006	013	034	025	042	036	010		001	001						90	050-059
060-069	78							002	006	011	030	029	029	042	010	004								85	060-069
070-079	70						001		004	017	015	033	049	038	011	002								100	070-079
080-089	70								008	014	025	023	053	028	004		001						001	87	080-089
090-099	86							001	002	011	038	034	086	023	009	003	002							123	090-099
100-109	99							001	004	013	025	056	097	027	008	002								134	100-109
110-119	101							002		006	039	054	086	019	012	009	001							127	110-119
120-129	128							002	003	008	044	071	102	028	012	004	001	002	001					150	120-129
130-139	102							001	001	009	037	054	072	030	010	006	002							120	130-139
140-149	125								003	010	055	057	086	031	022	007	003	001						150	140-149
150-159	123								002	007	049	065	052	028	014	004	002							100	150-159
160-169	132							001		010	051	070	079	032	015	002	001							129	160-169
170-179	128								002	013	051	062	069	037	016	006	003							131	170-179
180-189	153								002	010	069	072	100	037	015	005		001						158	180-189
190-199	167							001	001	018	047	100	093	041	016	004	002	002						158	190-199
200-209	164					001		001	002	012	051	097	115	030	019	003	001							168	200-209
210-219	175								001	007	056	111	100	034	007	004	001	001						147	210-219
220-229	152							002	001	007	041	101	103	038	011	006								158	220-229
230-239	185							001	004	011	069	100	107	037	007	005	001		001					158	230-239
240-249	110						001	001	002	013	033	060	069	024	015	001	002							111	240-249
250-259	70							001	001	010	029	029	036	020	005	004	001	001	001					68	250-259
260-269	62							002	005	005	029	021	033	015	005	004	001		001					59	260-269
270-279	74						001	002	003	015	031	022	023	019	016	002	001	001						62	270-279
280-289	51						001		004	008	018	020	035	018	013	005	004	001	001					77	280-289
290-299	42							001	002	005	017	017	020	019	008	003	001							51	290-299
300-309	46					001			006	005	022	012	015	017	011	002	001	002						48	300-309
310-319	27							001	001	008	009	008	022	012	009	002	001							46	310-319
320-329	20						001		001	001	010	007	011	008	009	003	002	002						35	320-329
330-339	17							001		003	007	006	009	010	005									24	330-339
340-349	14									002	005	007	003	006	005	003	002	002						21	340-349
350-359	4										001	003	004	006		002	001	002						15	350-359
360-369	6									001		005	002	003	003		001	001	001					11	360-369
370-379	2										001	001	005											5	370-379
380-389	0														001	001								2	380-389
390-399	0												001											1	390-399
	3322	1	0	0	0	2	5	30	92	333	1193	1666	2145	979	368	114	41	20	6	0	0	0	1	3674	

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TABLE 11

Current Variability in the Transverse Direction for Station 2

STA 02 DEPTH 005 55 MN 12 HR 23 DY 08 MO 73 YR

NEGATIVE CHANGE OF MINOR RATE — KNOTS*100 — POSITIVE CHANGE OF MINOR RATE

RATE	TOTAL	100 OR OVER	090 TO 099	080 TO 089	070 TO 079	060 TO 069	050 TO 059	040 TO 049	030 TO 039	020 TO 029	010 TO 019	000 TO 009	000 TO 009	010 TO 019	020 TO 029	030 TO 039	040 TO 049	050 TO 059	060 TO 069	070 TO 079	080 TO 089	090 TO 099	100 OR OVER	TOTAL	RATE
000-009	74									002	013	059	141	026	001									168	000-009
010-019	76								001	005	009	061	104	034	005									143	010-019
020-029	70									003	014	053	086	021	008	001	001							117	020-029
030-039	84								001	003	010	070	066	038	009	003		001		001				138	030-039
040-049	58								002	004	013	039	057	029	007	003								96	040-049
050-059	65						001		005	007	016	036	061	034	005	003	001	001						105	050-059
060-069	55								002	008	025	020	054	039	009	004	001		001					108	060-069
070-079	66								003	007	035	021	057	034	008	003	001	001						104	070-079
080-089	57					001			007	009	025	015	055	033	007	005								100	080-089
090-099	72						003	002	005	010	033	019	085	036	008	005	002	001						137	090-099
100-109	88					002		007	003	008	035	033	100	022	017	004		001	001					145	100-109
110-119	81							007		030	017	027	087	014	034	001	007	001	003					147	110-119
120-129	99							010		032	017	040	111	016	044	002	004	002						179	120-129
130-139	87			001	002		003	008	004	027	007	035	096	004	028	001	003	001		002				135	130-139
140-149	118			001			003	004	003	054	010	043	096	003	054		001	002		001				157	140-149
150-159	103					001	009	001	002	040	005	045	076		037	001		005			001			120	150-159
160-169	103					002	006		011	037	002	045	097	001	027	022		004	005		002			158	160-169
170-179	128		002			005	002	001	027	023	002	066	073	004	015	031	001		006		001			131	170-179
180-189	143	001	001			003	001	001	033	027	001	075	109	001	010	037	002		008	001				168	180-189
190-199	143		001		001	004		001	045	014	002	075	128	002	004	045	002		001					182	190-199
200-209	140	001			004	003		001	059	011	001	060	119	001		065	002		001	004				192	200-209
210-219	140				004	003		006	044	002		031	108	002		064	002			006				182	210-219
220-229	121				004			017	031	003	001	065	136	001		026	020			005	001			189	220-229
230-239	160			001	002	001		025	030	002		039	136			013	029				005			183	230-239
240-249	95		001				001	021	017	001		054	084	001		007	033	001						126	240-249
250-259	61					001		016	006			038	062		001	003	010					001		77	250-259
260-269	57		002	001	001			009	005	001		038	038			004	019					003		64	260-269
270-279	66		001	001	001		003	019	002		001	038	038	001		002	027	001				001		70	270-279
280-289	64	001	001	001			003	019	004	001	001	033	045	001			007	010				001		64	280-289
290-299	43	001					008	011				023	028				010	011					001	50	290-299
300-309	44	002				001	012	011	001		001	016	032				009	006	001				002	50	300-309
310-319	32					001	009	004				018	027	001			002	010					001	41	310-319
320-329	22						003	005	001			013	022	001				007	002				001	33	320-329
330-339	21	001					007	003				010	013					007						20	330-339
340-349	16	001					005	003				007	012					004	003					19	340-349
350-359	10						003	003				004	009											9	350-359
360-369	10	001				002	001	001				005	006						001					7	360-369
370-379	3					002						001	002						002					4	370-379
380-389	1					001							001											1	380-389
390-399	0																		001					1	390-399
	2876	9	9	6	19	33	83	216	354	371	296	1480	2677	400	338	355	196	77	36	20	10	6	5	4120	

<u>TABLE 12</u>

Current Variability in the Axial Direction for Station 4 at 5 metres

STA 04 DEPTH 005 00 MN 14 HR 23 DY 08 MO 73 YR

		NEGATIVE CHANGE OF RATE										RATE						POSITIVE CHANGE OF RATE							
RATE	TOTAL	100 OR OVER	090 TO 099	080 TO 089	070 TO 079	060 TO 069	050 TO 059	040 TO 049	030 TO 039	020 TO 029	010 TO 019	000 TO 009	000 TO 009	010 TO 019	020 TO 029	030 TO 039	040 TO 049	050 TO 059	060 TO 069	070 TO 079	080 TO 089	090 TO 099	100 OR OVER	TOTAL	RATE
000-009	31							003	002	006	008	012	069	022	007	004	004	002						108	000-009
010-019	35					001	001	004	006	003	011	009	019	029	013	004	002	001	001					69	010-019
020-029	39					002	002	002	002	006	013	012	026	025	011	005	001	001						69	020-029
030-039	54		001			004	003	002	002	010	016	016	023	031	012	003			002	003				74	030-039
040-049	64				001		004	002	001	012	028	016	038	026	012	001	002							79	040-049
050-059	72	001			002	002	001	001	002	007	022	034	050	039	012	004	001							106	050-059
060-069	115	001		002	001	001	001	002	002	006	042	057	083	045	011	002	001							142	060-069
070-079	123							002	004	007	047	063	075	040	009	002								126	070-079
080-089	142				001		001	001	002	006	043	088	074	046	012	002								134	080-089
090-099	174								005	008	037	124	106	039	012	003		002						162	090-099
100-109	198									010	048	140	139	039	008	003	001							190	100-109
110-119	201						001		001	006	063	130	155	046	005	004								210	110-119
120-129	183						001			011	070	101	135	055	012	007	001							210	120-129
130-139	150								001	010	042	097	121	038	012	001	001	002						175	130-139
140-149	181							001	001	014	047	118	152	043	017	006								218	140-149
150-159	176								001	016	062	097	145	045	012	006	002							210	150-159
160-169	143									011	033	099	113	049	010	005	002							179	160-169
170-179	156								001	012	051	092	112	037	017	005	001							172	170-179
180-189	165							001	007	011	068	078	108	043	014	002								167	180-189
190-199	137								001	011	041	084	106	049	011	001	001							168	190-199
200-209	133								004	012	050	067	098	050	010	005								163	200-209
210-219	101									006	040	055	085	053	008	001								147	210-219
220-229	88									005	034	049	061	038	011	001								111	220-229
230-239	75								002	008	021	044	054	029	010	004	001							98	230-239
240-249	53									003	017	033	036	021	007	001								65	240-249
250-259	41						001		001	002	025	012	038	011	008	006								63	250-259
260-269	65									007	014	044	041	013	004	002								60	260-269
270-279	62								003	006	020	033	020	009	004									33	270-279
280-289	29									003	011	015	021	009	001									31	280-289
290-299	27									002	011	014	009	003	002									14	290-299
300-309	13									004	006	003	005											5	300-309
310-319	6								001	001	002	002	001	001										2	310-319
320-329	1										001		001	001										2	320-329
330-339	1										001													0	330-339
	3234	2	1	2	5	10	16	21	52	242	1045	1838	2319	1024	294	90	21	8	3	3	0	0	0	3762	

TABLE 13

Current Variability in the Transverse Direction for Station 4 at 5 metres

STA 04 DEPTH 005 00 MN 14 HR 23 DY 08 MO 73 YR

NEGATIVE CHANGE OF MINOR RATE — KNOTS*100 — POSITIVE CHANGE OF MINOR RATE

RATE	TOTAL	100 OR OVER	090 TO 099	080 TO 089	070 TO 079	060 TO 069	050 TO 059	040 TO 049	030 TO 039	020 TO 029	010 TO 019	000 TO 009	000 TO 009	010 TO 019	020 TO 029	030 TO 039	040 TO 049	050 TO 059	060 TO 069	070 TO 079	080 TO 089	090 TO 099	100 OR OVER	TOTAL	RATE
000-009	57							001		004	012	040	067	014		001								82	000-009
010-019	66					001	001			005	016	043	033	005										38	010-019
020-029	61					001		001	002	004	015	038	037	010										47	020-029
030-039	62					001	001	001	001	007	015	036	039	022	003	001		001						66	030-039
040-049	66							002		005	013	046	050	018	009									77	040-049
050-059	82					001		002	002	004	021	052	063	021	005	003	002	001		001				96	050-059
060-069	108								003	007	041	057	083	048	014	003	001							149	060-069
070-079	98							003	003	014	034	044	080	050	014	004	003							151	070-079
080-089	123			001					006	004	052	060	073	048	023	005	004							153	080-089
090-099	146							002	007	003	064	070	102	064	013	007	002	002						190	090-099
100-109	157						001	001	009	021	058	067	156	045	017	008	002		002	001				231	100-109
110-119	172					001		004	002	060	029	076	146	042	043	004	002		001	001				239	110-119
120-129	169				001			006	002	070	011	079	143	026	046	003	005			001				224	120-129
130-139	138				001		001	008		053	001	074	132	013	037	001	003		001					187	130-139
140-149	155						001	002	001	059	003	089	174	007	057	001	002	002	001					244	140-149
150-159	155						002		002	069	005	077	157	002	060	006	002	002		001		001		231	150-159
160-169	144						005		021	035	001	032	119		045	009	001	002	001			001		178	160-169
170-179	133					001	002	001	051	013		005	112	001	036	044	001		001					195	170-179
180-189	152					003	001		064	005		079	116		014	048		001		001				180	180-189
190-199	114				001				054	001		058	132		005	052	001			001				191	190-199
200-209	135							001	065	001		068	098	002	002	059								161	200-209
210-219	91							003	038			050	112		001	038	004			002				157	210-219
220-229	74							009	014			051	090			026	009							125	220-229
230-239	77							025	005			047	074			009	012	001						96	230-239
240-249	60							017				043	044			004	010							58	240-249
250-259	48							020			001	027	043			003	010							56	250-259
260-269	62		001				001	017	001			042	039				020	004						63	260-269
270-279	32						004	007				021	035			001	024	001			002			63	270-279
280-289	31						008	005				018	021				007	001						29	280-289
290-299	20						003					017	010				008	003						21	290-299
300-309	11											011	004				002	001						7	300-309
310-319	4											004	001				001	002						4	310-319
320-329	1											001	002											2	320-329
330-339	1											001												0	330-339
	3005	0	1	1	3	9	31	138	353	444	392	1633	2587	438	444	340	138	24	7	9	2	2	0	3991	

<u>TABLE 14</u>

Current Variability in the Transverse Direction for Station 4 at 15 metres

STA 04 DEPTH 015 00 MN 14 HR 23 DY 08 MO 73 YR

RATE	TOTAL	NEGATIVE CHANGE OF MINOR RATE										KNOTS*100					POSITIVE CHANGE OF MINOR RATE							TOTAL	RATE
		100 OR OVER	090 TO 099	080 TO 089	070 TO 079	060 TO 069	050 TO 059	040 TO 049	030 TO 039	020 TO 029	010 TO 019	000 TO 009	000 TO 009	010 TO 019	020 TO 029	030 TO 039	040 TO 049	050 TO 059	060 TO 069	070 TO 079	080 TO 089	090 TO 099	100 OR OVER		
000-009	83					001				004	012	066	128	013										141	000-009
010-019	72								001	008	014	049	057	013		001								71	010-019
020-029	59									003	012	044	040	013	002	001								56	020-029
030-039	59								003	007	014	035	034	011	002									47	030-039
040-049	43						002	001	003	004	007	026	044	015	004	001								64	040-049
050-059	55					002			003	005	015	000	037	016	001	002	001							57	050-059
060-069	63							002	002	008	026	025	036	026	003	001	001	001	001					69	060-069
070-079	56						001	002		010	028	015	036	017	003				001					57	070-079
080-089	83							001	003	003	046	030	035	028	007	007	004		001					82	080-089
090-099	84							001	005	005	045	028	050	024	005	004	004	001	001					89	090-099
100-109	83	001		001			001		003	007	035	035	061	037	012	007	001	001	001		001			121	100-109
110-119	87						001	001	002	040	012	031	058	024	024	001	005	001	002					115	110-119
120-129	104						001	006		051	006	040	064	022	037		009	001	001					134	120-129
130-139	80							002	001	034	003	040	074	012	024	002	005	001		001				119	130-139
140-149	76				001		002	002		033	005	033	073	004	038	002	002	004	001				001	125	140-149
150-159	78						002	001	001	034	001	039	094	002	031	006	006	002			001			142	150-159
160-169	83					002			015	028		038	067	002	020	004	001			001	001			96	160-169
170-179	77					001		001	025	005	001	044	073	001	022	022			001					119	170-179
180-189	76	001	001			003	001		027	002		041	075	001	012	028			001					117	180-189
190-199	77				002				036			039	059	001	005	020	001	001					001	88	190-199
200-209	70	001			001	001		002	037			028	081		004	045	001			004				135	200-209
210-219	73				002		001	001	037			032	084			028	008			001				121	210-219
220-229	64			001				018	007			036	061		001	012	008			002				84	220-229
230-239	73	001						031	003			038	069		001	014	020							104	230-239
240-249	40							018				022	056			002	018	003		001				80	240-249
250-259	36		001					017				018	036			002	017				001			56	250-259
260-269	27							011				016	037		001	001	012							51	260-269
270-279	38						005	014				019	030			001	014	001				001		47	270-279
280-289	20						002	006				012	014				004	003						21	280-289
290-299	30						022	001				007	022				010	008						40	290-299
300-309	29						014					015	031				001	011						43	300-309
310-319	28						013				001	014	016				001	006						23	310-319
320-329	11						005					006	021					018	001					40	320-329
330-339	22					005	006					011	019					008	003					30	330-339
340-349	7					002						005	008					006	002					16	340-349
350-359	2					001						001	002					003	003					8	350-359
360-369	1					001																		0	360-369
370-379	0												001											1	370-379
380-389	1											001	001											1	380-389
		4		2		19		139		291		1011		282		214		80		10		1			
	2050		2		6		79		214		283		1784		259		154		20		4		2	2810	

TABLE 15

Eastport Observed Extreme Current Ranges

Station	Depth (m)	Extreme Currents (kt)	Direction	Extreme Currents (kt)	Direction	Dates Between Which the Extremes were Observed
1	5	3.5 ±0.5	NNW	2.0 ±0.5	SE	Aug. 23-Sept. 17/73
1	15	2.5 ±0.5	NNW	1.5 ±0.5	SE	Aug. 23-Sept. 17/73
2	5	4.0 ±0.5	NE	3.0 ±0.5	SW	Aug. 23-Sept. 17/73
3	5	4.5 ±0.5	NE	3.5 ±0.5	SW	Aug. 23-Oct. 3/73
4	5	3.0 ±0.5	NE	3.5 ±0.5	SW	Aug. 23-Sept. 17/73
4	15	3.0 ±0.5	NE	4.0 ±0.5	SW	Aug. 23-Sept. 9/73

2.5 River Discharge

Forgeron (1959) writes:

"Most of the fresh water inflow to the Inner Quoddy Region comes from three rivers, St. Croix, Magaguadavic and Digdeguash, which discharge into Passamaquoddy Bay at a mean annual rate of approximately 4000 cfs. The St. Croix River is largest and discharges about as much as the Magaguadavic and Digdeguash Rivers combined.

"Fresh water discharge varies widely both seasonally and annually. In general, peak periods of river discharge occur twice each year. A curve constructed from average monthly values during the past 34 years ... shows that the St. Croix River discharge reaches a monthly maximum of 4461 cfs in April during the spring freshet and a monthly minimum of 1539 cfs in September. A second but much smaller peak appears in November or December ....

"In Cobscook Bay, the main fresh water source is the Dennys River. The average annual discharge for 1956 and 1957 was 136 cfs. The total freshwater discharge into Cobscook Bay is estimated at approximatly 300 cfs annually."

2.6 Bottom Topography

Forgeron (1959) writes:

"The principal features of the geology of the Passamaquoddy region have been summarized ... from reports of the Canadian Geological Survey. From a consideration of the rock structure, together with charts of the area, general conclusions can be drawn concerning the bottom configuration and the physiographic development of the region.

"Bottom configuration: The St. Croix estuary above St. Andrews has an average depth below low water of 38 ft. The low water area is 10 sq mi (square nautical miles) exposing 3 sq mi of intertidal mud flats. A channel 100-130 ft in depth runs from the mouth of the estuary to within one-half mile of Oak Bay .... The bottom profile is irregular throughout.

"Passamaquoddy Bay, excluding the St. Croix estuary above St. Andrews, has a low water area of 51 sq mi leaving exposed 6 sq mi of intertidal mud flats. The average low water depth is 78 ft. The deepest waters in the Bay (200-250 ft) are found immediately inside Western and Letite Passages. The bottom of the Bay is assymetrical in a north-south section. It is steeply sloping and deep in the south and gently sloping and shallow in the north.

"Western Passage has a mean low water depth of 172 ft and a low water area of 4 sq mi and an intertidal zone of less than 1 sq mi. The bottom is irregular. Maximum cross-sectional depth at one location is only 165 ft whereas at another it is 390 ft. Although Western Passage is similar to Head Harbour Passage in depth the cross-sectional appearances are different. Western Passage is 'U'-shaped in cross-section, whereas Head Harbour Passage is shallow and very irregular on the north side with a deep narrow channel cutting through on the south side. Repeated cross-sections and longitudinal sections of soundings in Letite Passage revealed a narrow sinuous channel with a very irregular bottom profile and shallow water zones on both sides of the channel. The effective minimum depth is about 60 ft.

"Cobscook Bay has a low water area of 21 sq mi. with 7 sq mi. of exposed intertidal mud flats. The average depth is 26 ft. There is a narrow channel 70-100 ft deep in the lower half of the Bay. The bottom is regular and slopes gently towards this channel.

"The southern part of the Outer Quoddy Region has a channel approximately 480 ft deep running from off Head Harbour into the Bay of Fundy between The Wolves and Grand Manan. The remainder of the region slopes irregularly toward the Letite-Lepreau coast.

"Physiographic Development: The main features of the bottom of Passamaquoddy Bay were probably shaped by ice. The St. Croix estuary undoubtedly held a valley glacier. The ice sheet moving in from the north resulted in the shallow, gently sloping, northern part of the Bay and the steeply sloping, deeper zone along the Precambrian contact from the northern side of Deer Island to Midjik Bluff.

"The valley glacier of the St. Croix estuary probably extended into Western and Head Harbour Passages and gave rise to the irregular bottom profiles.

"As opposed to Passamaquoddy Bay, Cobscook Bay is characterized by little submarine relief. It is an example of a submerged valley."

2.7 Selected Meteorological Variables

2.7.1 Wind

Quoting from Forgeron (1959):

"Winds play an important role in moving the surface waters. The effect depends on strength, direction and fetch. The predominant winds in the Quoddy Region are from the southwest in the summer and from the northwest in the winter. During the summer southwest winds tend to retain the warmer waters in the northeast part of Passamaquoddy Bay. During the winter northwest winds tend to remove the surface waters from the Bay."

A summary of winds at Point Lepreau, N.B., is given in Figure 20 from Chevrier (1959).

2.7.2 Low Visibility

Low visibility due to fog is much more prevalent over the water and on the headlands than it is further inland. Consequently, the statistics may vary considerably between stations in the same region. The statistics given in Table 16 are for an exposed coastal station

TABLE 16

Percentage of the time during which the thick weather alarm was activated - Head Harbour Light and Alarm Log Sheets

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1972	25.4	20.6	29.1	11.5	18.9	54.6	29.9	21.3	23.3	10.6	9.0	23.1
1973	12.3	25.3	11.2	15.1	27.9	42.1	41.1	-	-	-	-	-

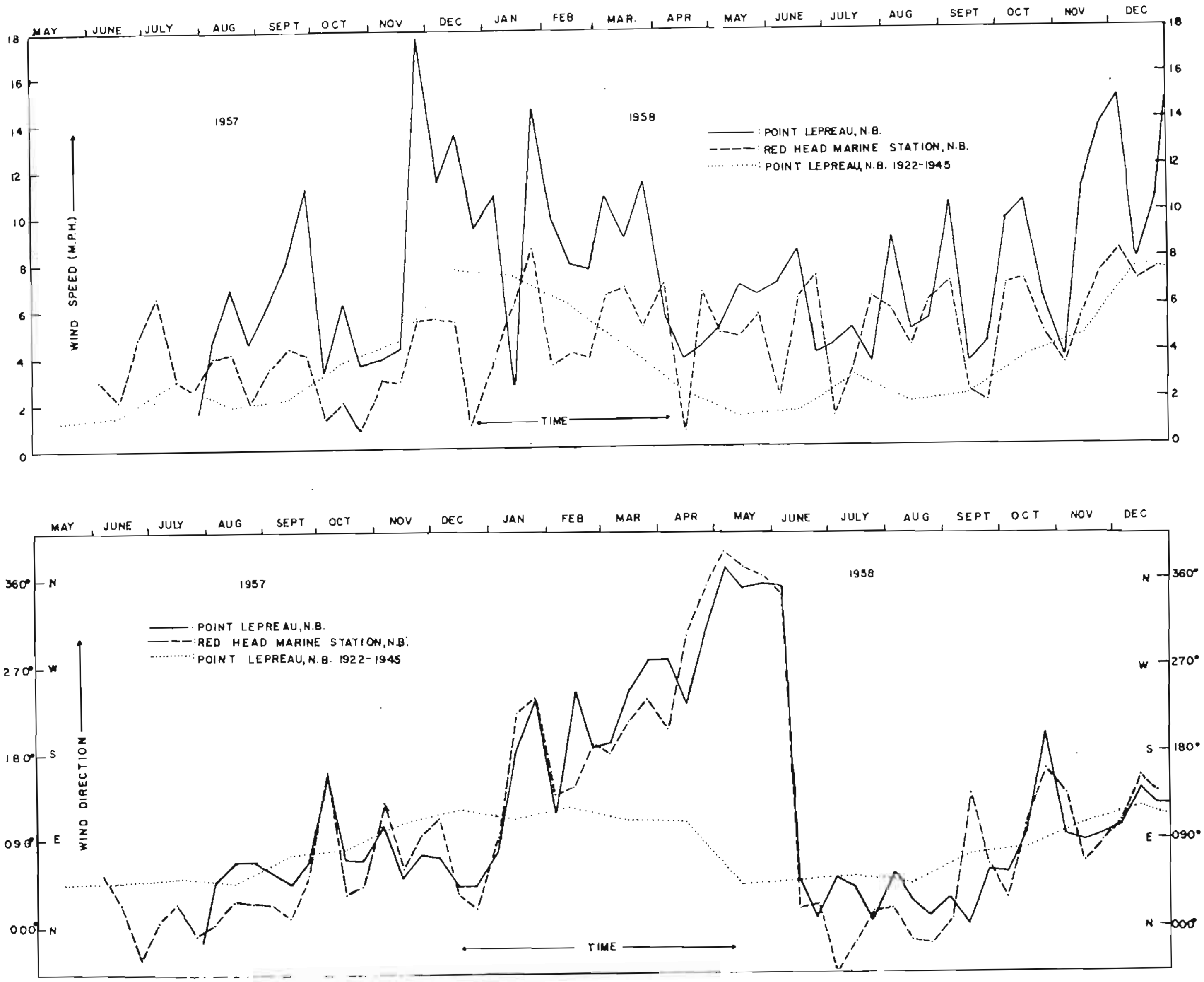


FIGURE 20: Average resultant of wind speed and direction for 10-day intervals at Point Lepreau, N.B., from July 1957 to December 1958, at Red Head Marine Station, N.B., from June 1957 to December 1958, and at Point Lepreau, N.B., on a monthly average basis, from January 1922 to December 1945 (from Chevrier, 1959).

2.8 Surface Circulation (Residual Currents)

The drift bottle experiments reported by Chevrier (1959) provide useful information on the residual currents in the region. Drift bottles were released at a network of stations throughout the area at fortnightly intervals over a two-year period. From these Chevrier calculated monthly and seasonal plots of drift incorporating the dominant features. These are shown in Figures 21 to 24.

> "During 1957-1958, 8,430 drift bottles were released in the Quoddy Region and approximately 25% were recovered. The returns were higher in enclosed areas, such as in Passamaquoddy where over 36% of the bottles launches were returned, while in Grand Manan Channel, a relatively open area, only 11% of the bottles released were recovered. Approximately 29% of the recovered bottles stranded in Head Harbour and Western Passages, 20% in Letite Passage, 18% in Outer Quoddy Region, 17.5% in Passamaquoddy Bay, 5% in Nova Scotia, 5% in Cobscook Bay, 3% in New England, 2% in Grand Manan, and 0.4% in St. Croix estuary .... The total number of bottles released in Passamaquoddy Bay represented 28% while the returns represented 42%. In Outer Quoddy Region, the total number of bottles released represented 36% while only 16% were returned. Except for a few bottles found afloat off Cape Spencer, N.B., no recoveries were reported along the northwestern shore of the Bay of Fundy, east of Point Lepreau. No bottles were recovered on the Atlantic coast of Nova Scotia.
>
> "The drift bottle recoveries suggest that, on the average, there is a counter-clockwise surface circulation in Passamaquoddy Bay, a variable flow through Letite Passage, and an outflow through Western Passage. In Head Harbour Passage the flow is inward along the Deer Island side and outward along the Campobello Island side.
>
> "On the whole, wind action is very effective in determining the course of drift of the bottles. In general, it is considered that winds from the south (summer) tend to confine surface waters to Passamaquoddy Bay, while winds from the north and west (winter) remove the surface waters from the Bay.
>
> "In Cobscook Bay the general pattern of drift was outward although it was not uncommon to find that bottles had penetrated well up to the head of the Bay.
>
> "In the Outer Quoddy Region, the non-tidal drift is usually southerly along the coasts of Campobello Island and Maine. This drift was particularly evident during the winter, 1958, when a large number of drift bottles were found along the New England coast. There is evidence, on the average, that

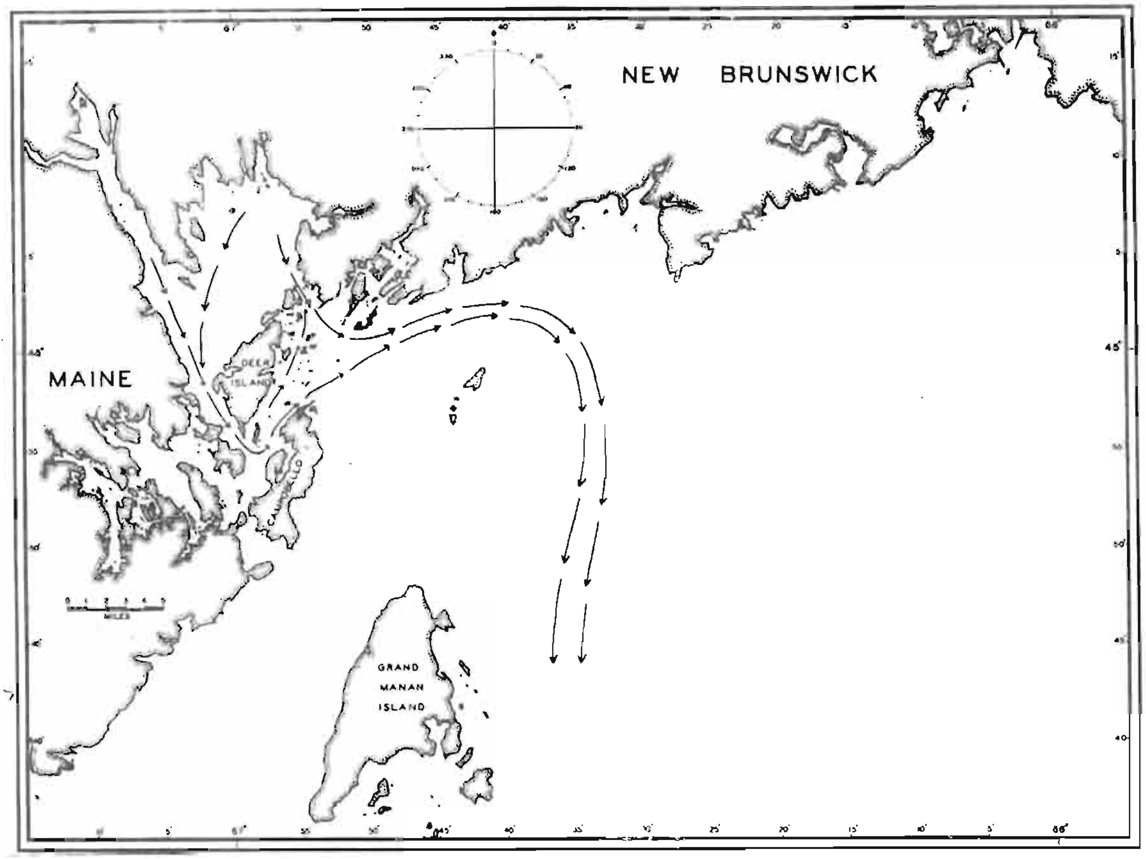


FIGURE 21: a. Seasonal pattern of surface circulation as indicated by drift bottles, winter, 1957 (from Chevrier, 1959).

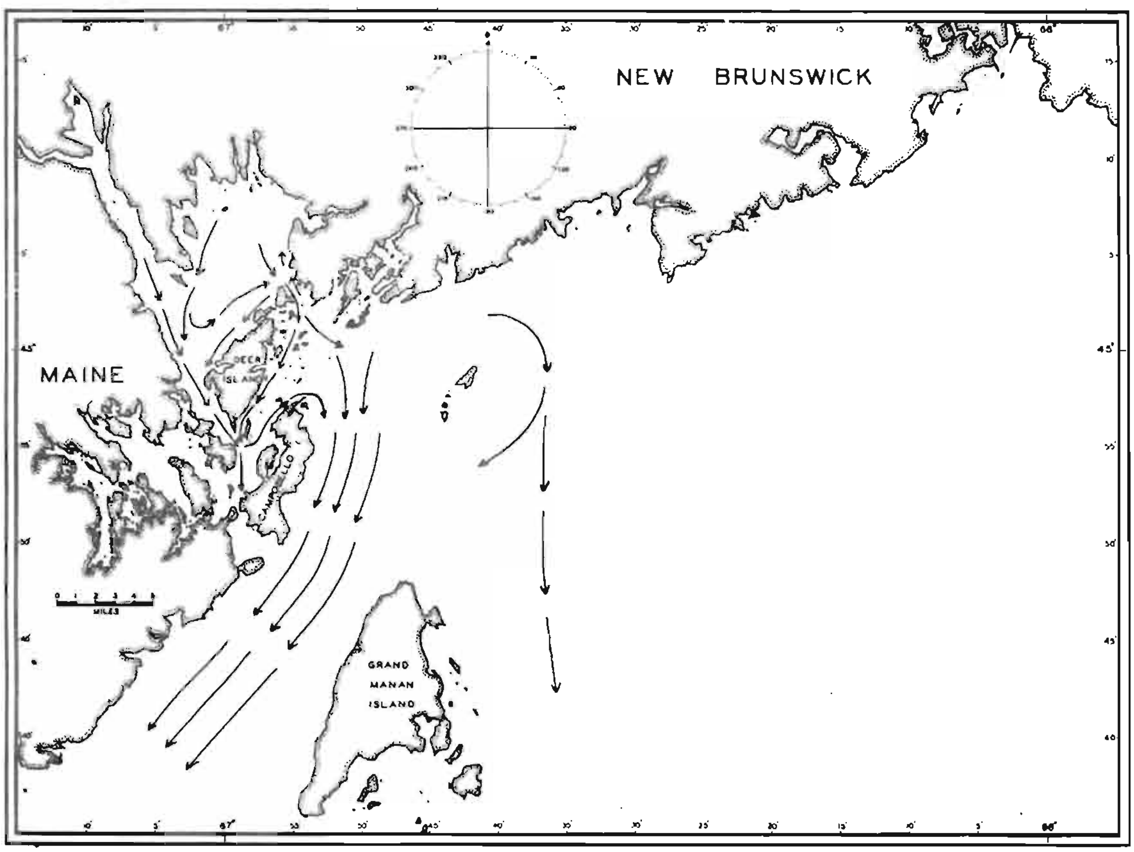


FIGURE 21: b. Seasonal pattern of surface circulation as indicated by drift bottles, winter, 1958 (from Chevrier, 1959).

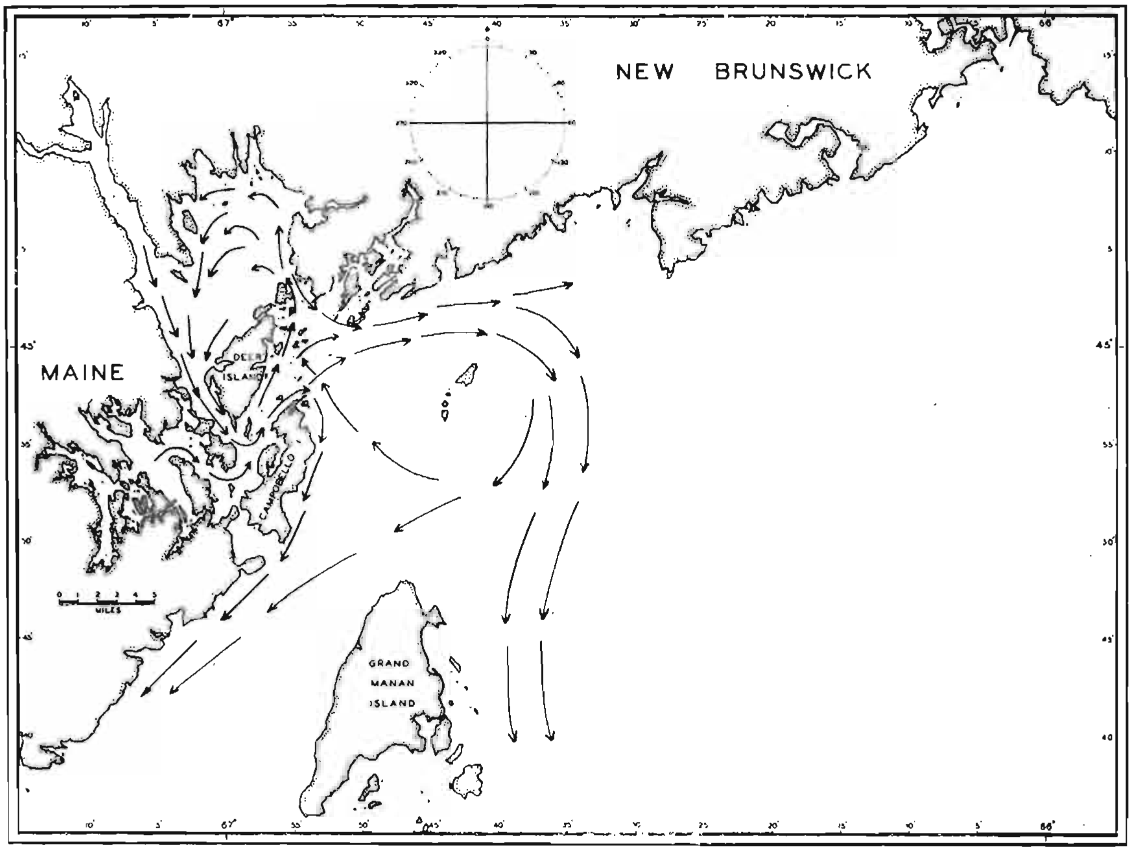


FIGURE 22: a. Seasonal pattern of surface circulation as indicated by drift bottles, spring, 1957 (from Chevrier, 1959).

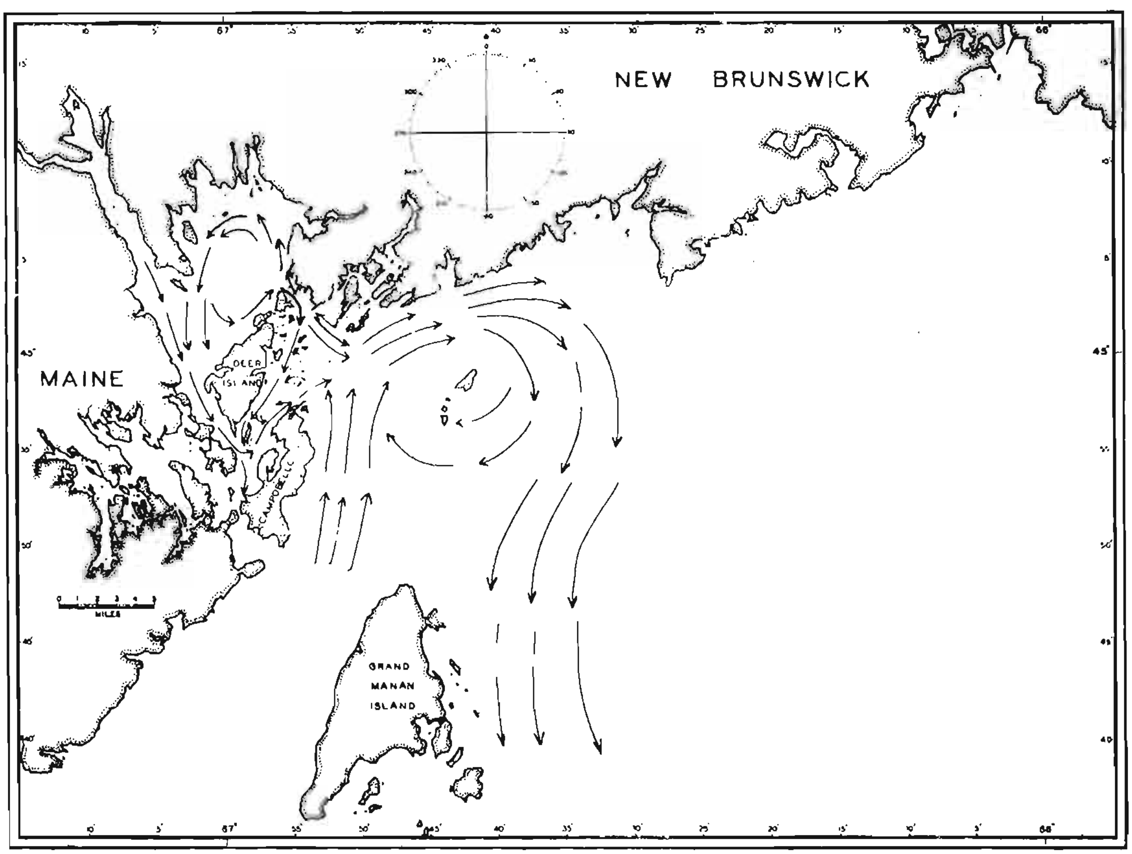


FIGURE 22: b. Seasonal pattern of surface circulation as indicated by drift bottles, spring, 1958 (from Chevrier, 1959).

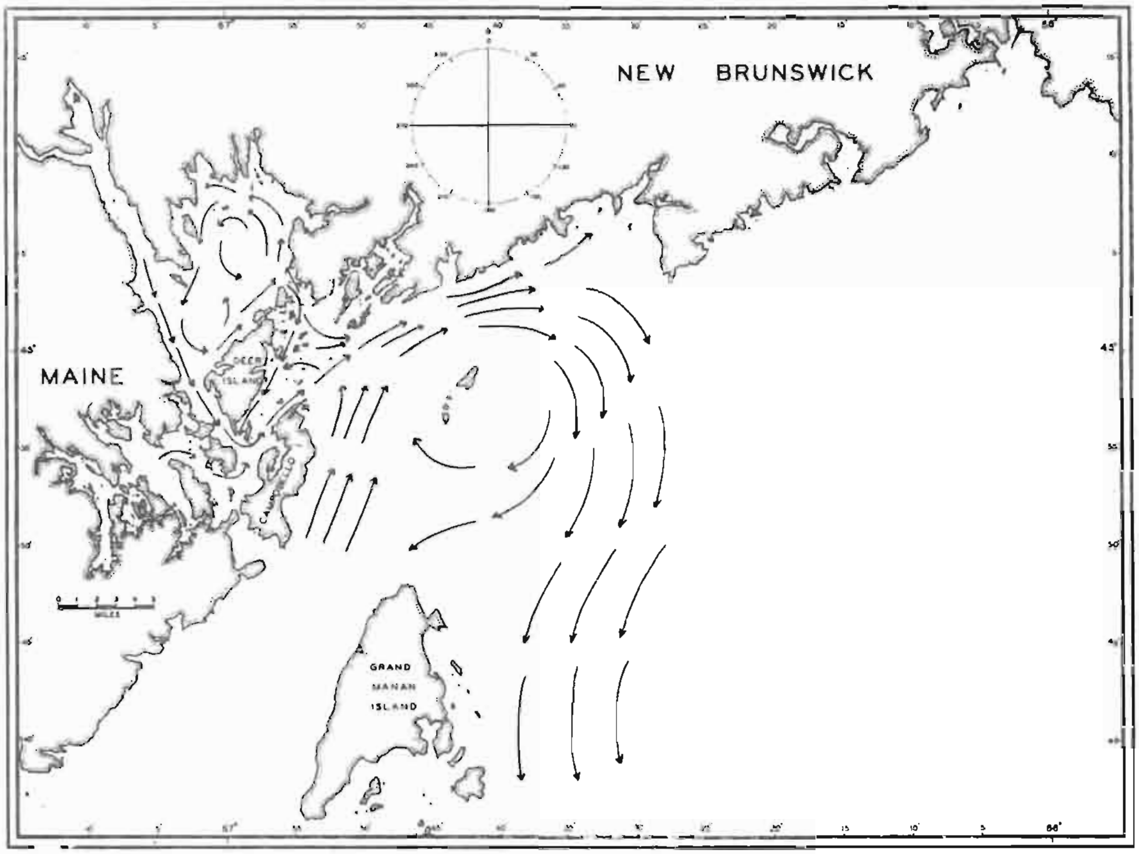


FIGURE 23: a. Seasonal pattern of surface circulation as indicated by drift bottles, summer, 1957 (from Chevrier, 1959).

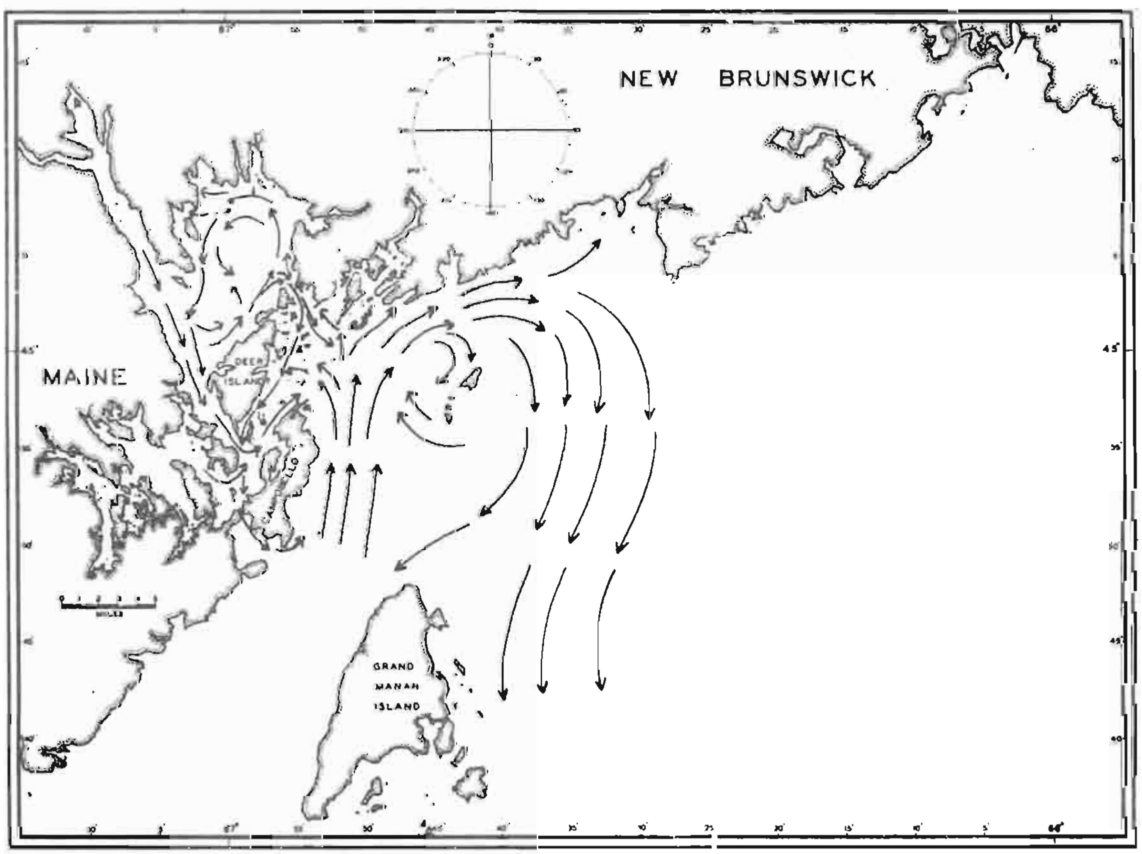


FIGURE 23: b. Seasonal pattern of surface circulation as indicated by drift bottles, summer, 1958 (from Chevrier, 1959).

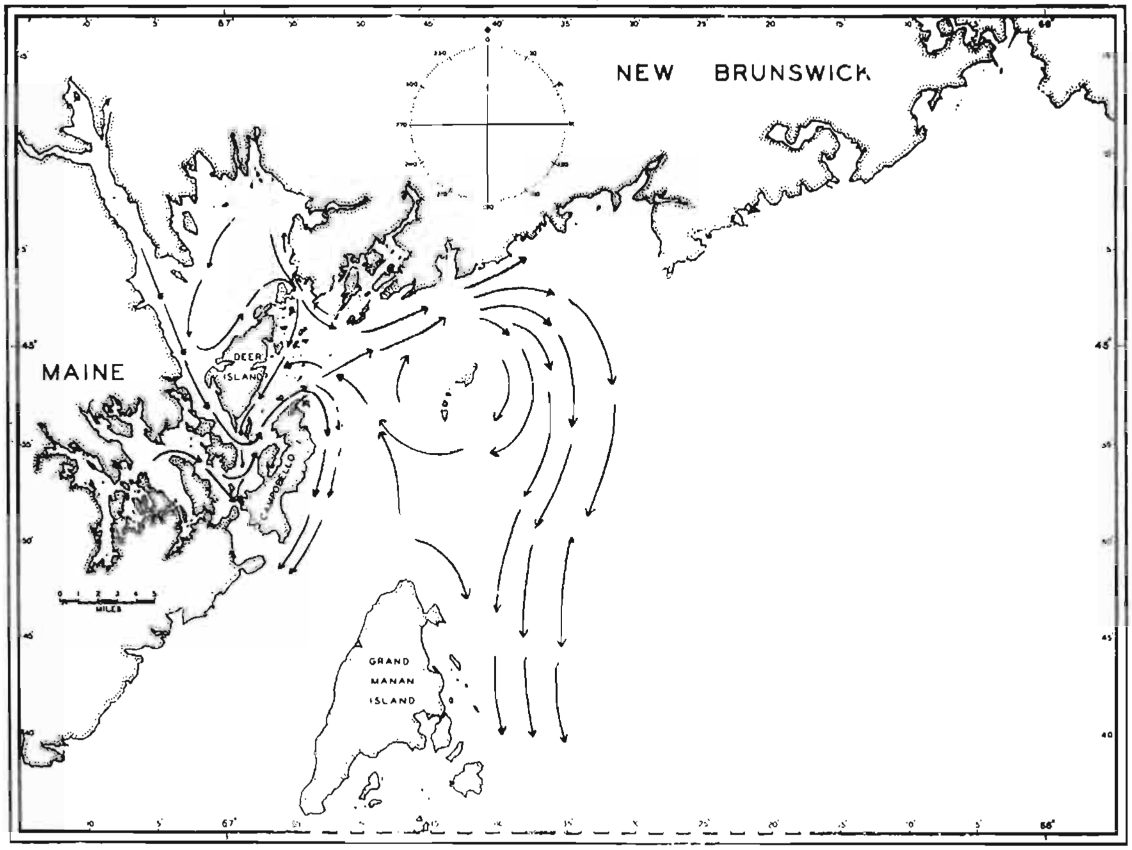


FIGURE 24: a. Seasonal pattern of surface circulation as indicated by drift bottles, autumn, 1957. (from Chevrier, 1959).

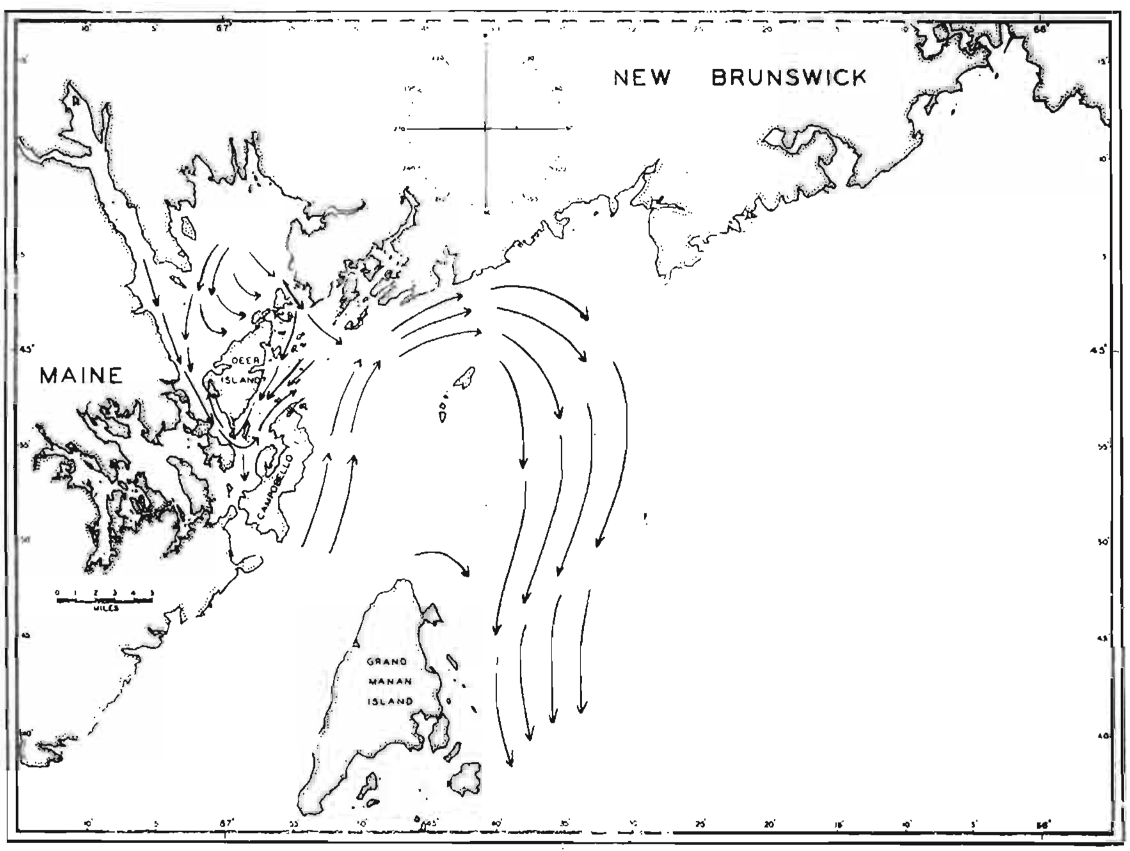


FIGURE 24: b. Seasonal pattern of surface circulation as indicated by drift bottles, autumn, 1958 (from Chevrier, 1959).

a clockwise rotation around The Wolves occurs. However, there are insufficient data to prove or disprove this for the winter months. In general, it is concluded that the surface waters leaving the Quoddy Region move outward between The Wolves and Point Lepreau, southward off the eastern side of Grand Manan Island, and thence either across the mouth of the Bay of Fundy to Nova Scotia or along the coast of Maine."

3. BAY OF FUNDY REGION

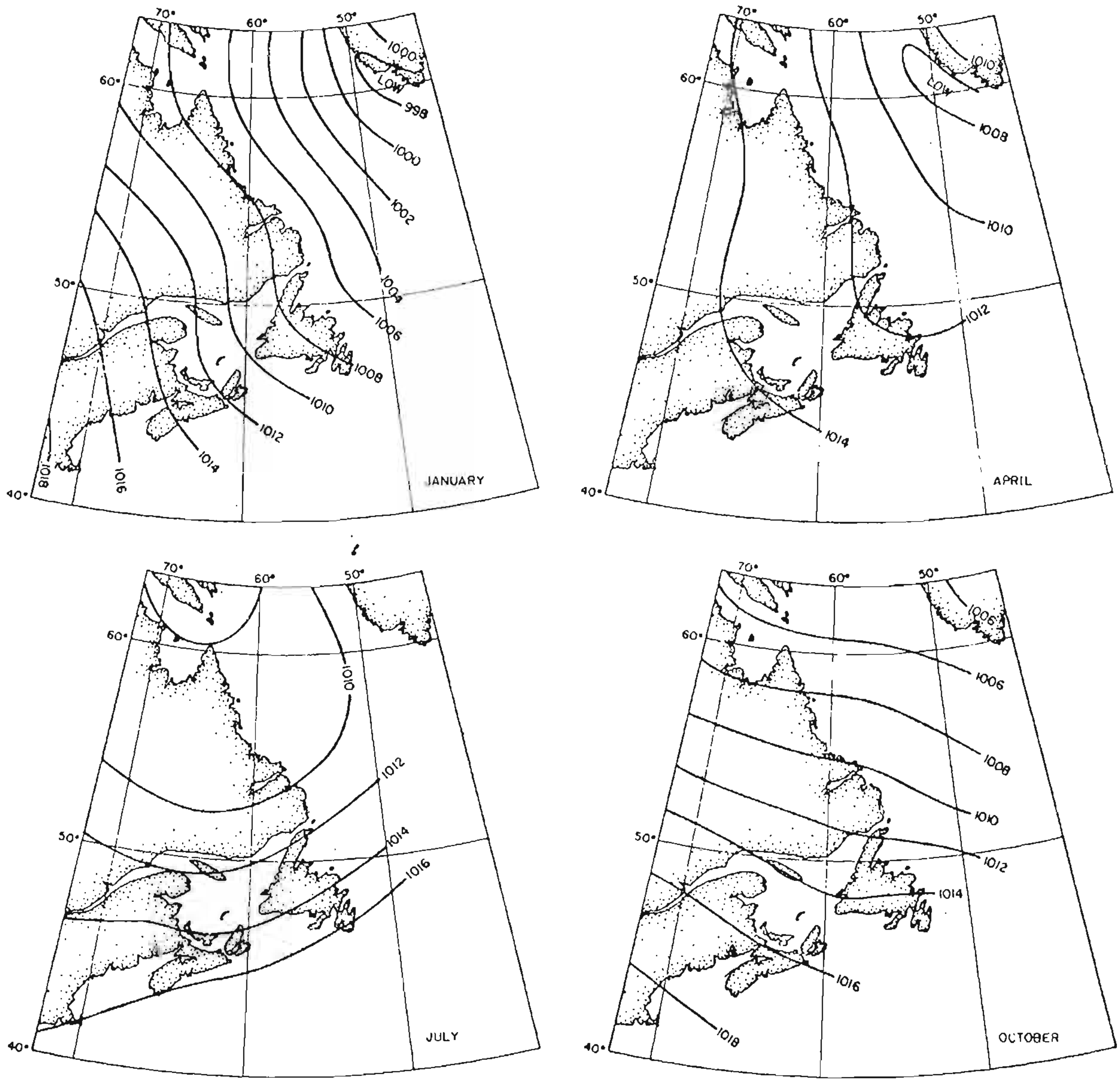
3.1 Selected Meteorological Variables

3.1.1 Wind

The work of Chevrier (1959) indicates a close similarity between winds at Pointe Lepreau and at Saint John. From the mean atmospheric pressure charts illustrated by Neu (1972) and reproduced in Figure 25, it seems evident that the gross features of the Lepreau or Saint John statistics will probably be applicable over much of the Bay of Fundy-Gulf of Maine area. Neu (1972) analyzed data from the Saint John Airport and U.S. Naval Oceanographic Office Monthly Pilot Charts and writes:

> "Westerly winds prevail throughout most of the seasons, however they are more northwesterly during the winter and more southwesterly during the summer. This feature is demonstrated in Figure 5 where the large-scale or geostrophic wind can be derived from the barometric pressure distribution. As indicated by the direction of the isobars and the strong pressure gradient, the two basic winds differ greatly in strength and character. During the winter, there is generally a strong outflow of cold continental Arctic air, which, on encountering the moist warm air of the Gulf Stream and mid-Atlantic, frequently forms storms of gale magnitude in which rain often changes to snow. The centres of these cyclones usually pass south of the Bay of Fundy, but nevertheless strongly affect this region. In the summer, winds are moderate except for storms of tropical origin. These storms occur in the period from June to November and frequently reach hurricane force, and gusts in excess of 35 m/sec may occur. However, their centres usually pass outside of our region of interest and travel offshore of Nova Scotia. For the Fundy Tidal-Power study, it was estimated that winds in excess of 40 m/sec (80 mph) have a frequency of occurrence of once in 20 years."

Mean monthly directional wind spectrum of Saint John Airport are shown in Figures 26 and 27 (Neu, 1972).



NOTE : ATMOSPHERIC PRESSURE IN MILLIBARS
MEAN SEA LEVEL PRESSURE OF PERIOD 1940 TO 1953
FROM ATLAS OF CANADA, DPT. OF MINES AND TECH. SURVEYS, 1957

FIGURE 25: Mean seasonal atmospheric pressure (from Neu, 1972).

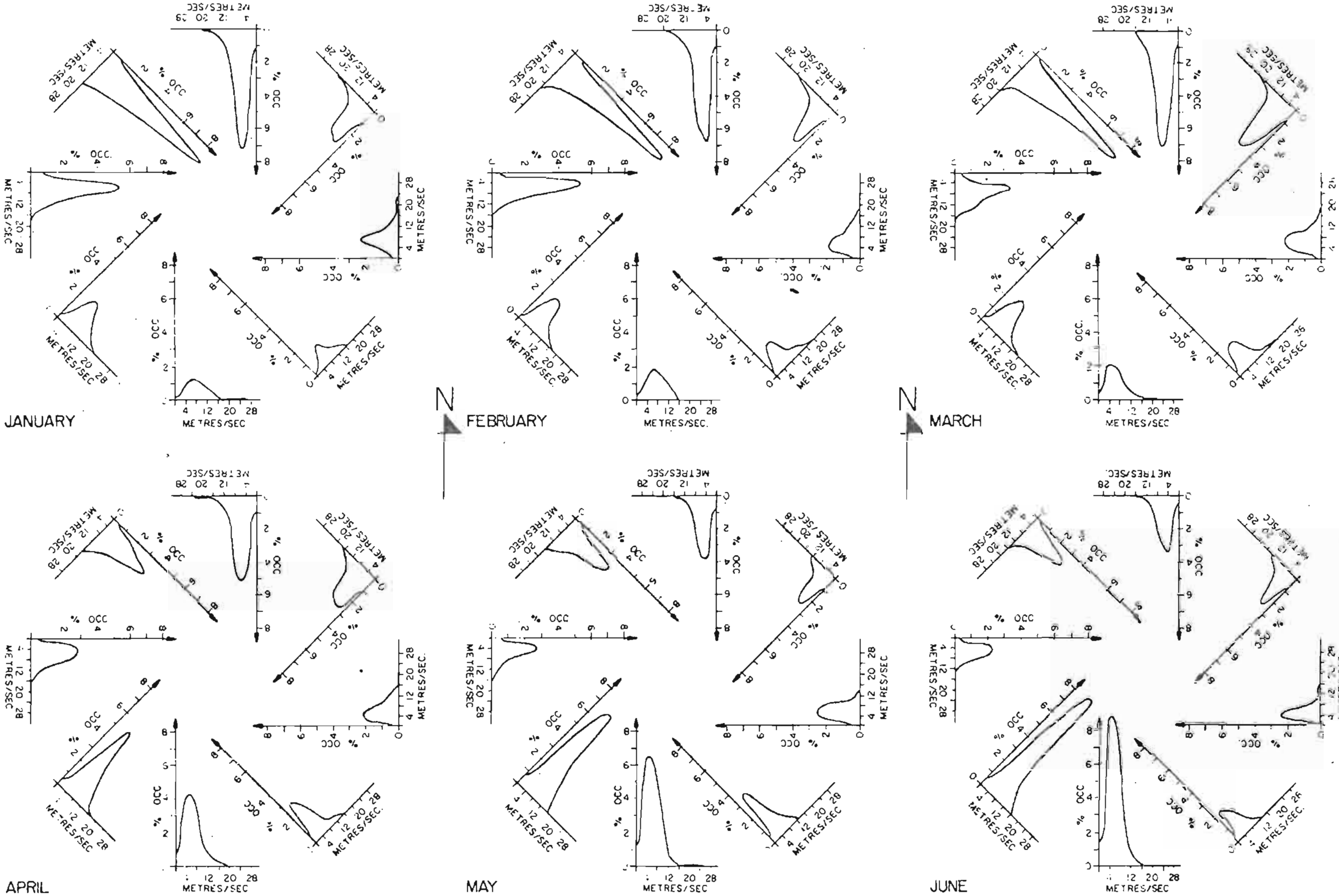


FIGURE 26: Mean monthly directional wind spectrum of Saint John Airport - January to June (from Neu, 1972).

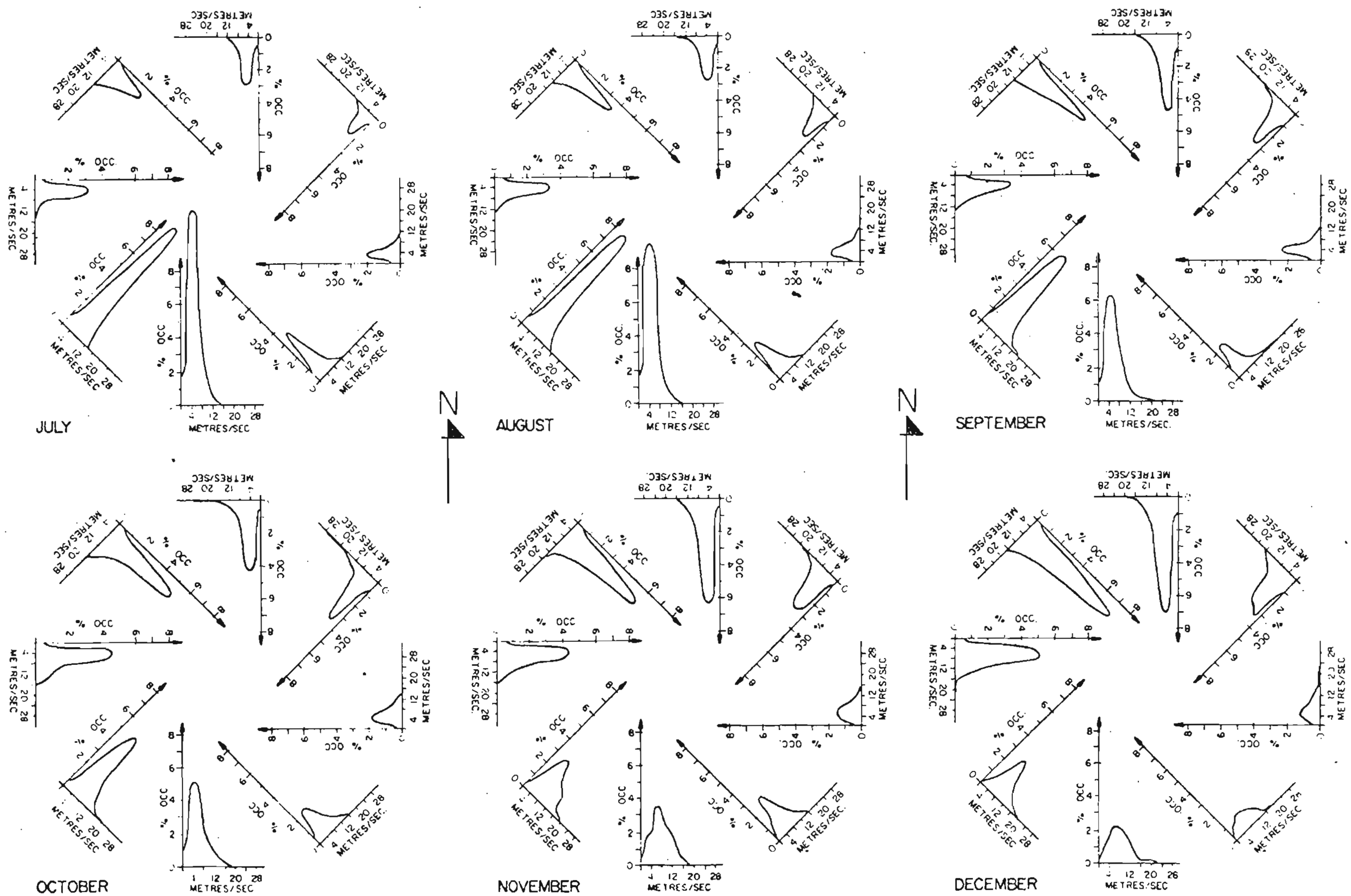


FIGURE 27: Mean monthly directional wind spectrum of Saint John Airport - July to December (from Neu, 1972).

3.1.2 Visibility

Ship reports have been used by the U.S. Climatological Centre, Asheville, to produce estimates of the occurrence of thick weather in the Bay of Fundy region. The results are contained in Table 17.

TABLE 17

The percentage of time during which visibility in the Bay of Fundy is 0.5 miles or less (from compiled ship reports).

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
4	5	7	6	-	20	34	28	14	8	7	7

3.2 Waves

Neu (1972) writes:

"In the Bay of Fundy, there are two types of waves which have to be considered: the deep ocean wave which propagates into the Bay from the open Atlantic and the locally wind-generated wave in the Bay itself. These two types of waves are superimposed on each other.

"... preliminary results indicate that significant waves in excess of 2 metres occur more than 20 percent of the year. The height of the one-year maximum wave appears to be 10 metres and that of the 'design-wave' (100-year wave) 14 to 15 metres."

3.3 Surface Circulation

Bumpus (1959) writes:

"Circulation in the Bay of Fundy

"Mavor (1922 and 1923) examined Dawson's (1908) current meter data and his own drift-bottle experiments (June, August, and September 1919) together with the findings of Bigelow and concluded, '... that there is a movement of water into the Bay of Fundy from the Gulf of Maine and the southern end of the Nova Scotia coast and along the eastern side of the Bay of Fundy.' This has been surmised by Craigie and Chase (1918). 'This movement is most marked at a depth of 50 meters but can be recognized from the surface to a depth of 100 meters. It extends into the Bay of Fundy on the Nova Scotian side at least 12 miles below the Gulf of Digby. A portion of this water probably moves across the bay towards St. John Harbour.' He also mentioned that there was a flow out of the Bay to the east of Grand Manan and an inward movement in the Grand Manan Channel.

"Returns from bottles set out by Huntsman in a line off Yarmouth, N.S. in July, August, September, and October 1926 (A.O.G. 1958) and summarized by Bigelow (1927) 'demonstrate the northerly drift along western Nova Scotia into the southern side of the Bay of Fundy, and up it. The New Brunswick recoveries show the anticlockwise movement brought out by Mavor's experiments.'

"Fish and Johnson (1937) set out several series of drift bottles in May and June 1932 in the northwestern part of the Gulf of Maine and in the southern part of the Bay of Fundy. They reported that numerous bottles from the northern part of the Gulf of Maine entered the Bay of Fundy, many proceeded toward Minas Basin, others appeared to have followed the route suggested by Mavor and stranded in the Quoddy Region or on Grand Manan. Those released in the Bay of Fundy gave similar results. There was also evidence that bottles released in the southwest portion of the Bay of Fundy proceeded across the mouth of the Bay to the eastern side, suggesting a closed circulation at the surface at this time of the year.

"Watson (1936) has described in detail the oceanographic observations made during 1932 and presents some dynamical evidence for the residual current systems mentioned above.

"Hachey and Bailey (1952) report several drift-bottle experiments commenced in May 1930. They summarized their results as follows:

> 'All of the drift bottles indicated a tendency of the water to circulate the island of Grand Manan in a clockwise direction.
>
> 'The movements of the bottles suggest a cyclonic circulation about the basin determined by the 50 fathom contour in the Bay of Fundy.
>
> 'An intense movement toward the mouth of Passamaquoddy Bay is definitely illustrated, while it will be noted that the water movement along the coast of Campobello Island is outward.
>
> 'An inward movement in the main waters between Grand Manan and the mainland is noted in keeping with the clockwise circulation about Grand Manan. However, the waters in contact with the coast of Maine have an outward movement.'

"Bumpus et al (1957) launched radio drift buoys in the Trinity Ledge area off Yarmouth in Grand Manan Channel and off Cape Spencer in the autumn of 1956. These experiments added some detail to the earlier descriptions of the circulation in the Bay of Fundy and confirmed the existence of the same general pattern for the autumn period. There were no previous drift experiments at this time of the year in that region. The inflowing drift, restricted to the southeasterly side of the bay, averaged about 10 miles per day, and the outflowing drift was restricted to the northwest side at comparable speeds. The inflowing drift was about 10 miles wide off Digby and the outflowing drift was about 6 miles off Cape Spencer. While some of the water from the Lurcher Shoal-Trinity Ledge region may penetrate well up into the Bay, perhaps even to its head, cyclonic rotations with speeds of 2 to 4 miles per day between the two drifts may shorten the route and allow transfer of water from one side of the Bay to the other. Higher speeds were postulated along the periphery and slower ones in the central eddying motions than the mean speeds concluded by the earlier writers, and possibly deeper penetration into the Bay along the southeast side prior to drifting over to the New Brunswick shore. Mavor and Fish and Johnson have tended to restrict the routes of drift bottles reaching New Brunswick to the vicinity of the 50 fathom curve. We believe that the transfer from the inflowing to the outflowing drift can take place all along the center portion well up into the Bay.

"The residual current in the Grand Manan Channel may be variable depending on the tidal range and meteorological conditions (MacGregor and McLellan, 1952).

"Circulation on the southwestern Scotian Shelf

"The circulation on the Nova Scotian shelf appears to be complex and variable. The efforts of the Canadian Fisheries Expedition of 1914-15, Bjerkan (1919), Huntsman (1924), Beigelow (1927), and Hachey (1947), reveal how complex the circulation may be.

"A southwesterly flow along the Nova Scotia coast may prevail during the spring months, fed by the icy waters and ice flows debouched from the Gulf of St. Lawrence. This water may regularly be traced to the offing of Shelburne, and some years on into the Gulf of Maine. This drift appears to cease by June at the latest. With the retrogression of the Nova Scotian current an eddy pattern may set up with cyclonic eddies about the basins and anticyclonic eddies about the banks. Hence inflow into the northern Gulf of Maine and the Bay of Fundy during the summer appears to be, not from the Nova Scotian current, which by this time has turned off-shore and eastward off Shelburne, but from across Browns Bank. The area between Cape Sable and Shelburne evidently becomes a 'dead area'.

"Only three of the 800 drift bottles released by Trites and Banks (1958) during August 1954 over the Scotian shelf reached the Bay of Fundy. The circulation deduced from the bottle returns and distribution of salinity indicated a cyclonic circulation centered northeast of Sable Island. Only a narrow filament of the southwesterly drift, close to the shore, rounded Cape Sable into the Bay of Fundy.

"Circulation in the Gulf of Maine

"Bigelow (1927) has documented his many years of work in the Gulf of Maine in his extensive monograph on the 'Physical Oceanography of the Gulf of Maine'. The dominant non-tidal circulation comprises a cylconic circulation in the Gulf of Maine and an anticyclonic circulation around Georges Bank and other shoals with seasonal and annual variations. Redfield (1939 and 1941) has examined the time variation in the concentration of the pteropod, Limacina retroversa and the crustacean plankton throughout the Gulf of Maine together with concurrent oceanographic data. He ascribed the principal factor influencing the distribution of these population densities to the inflow of barren water from over the Nova Scotian banks in winter. The inflow is compensated for by the escape of water to the south and east across the end of Georges Bank. The populations are able to grow and maintain themselves in the recurrent cyclonic eddy which commences in the spring. Unfortunately Redfield's field work did not extend into the Bay of Fundy where the application of his theory would have been fruitful.

"Day (1958) has examined the drift-bottle experiments conducted in the Gulf of Maine from 1931 to 1956 (Bumpus and Day, 1957) consisting of releases from late February through June.

"Commencing in the autumn of 1956 drift-bottle experiments have been conducted in the Gulf of Maine on a nearly year-round basis. The results of Day's report and the still more recent experiments are summarized as follows:

"Bigelow's July-August circulation pattern, ..., a relatively closed circulation and hence a highly conservative one, seems to be the climax of a seasonal evolution, possibly the result of vernal warming and river runoff and the consequent build-up of a dynamic structure conducive to produce these motions.

"In February and March, the Gulf eddy is ill defined on the south as water from Massachusetts Bay moves southward out South Channel. The Georges eddy is not apparent at this time, the net movement across Georges Bank being southwest. By late April, the two counter-rotating eddies are taking from with the appearance of a northeasterly movement along the northern edge of Georges Bank where the two eddies become confluent. A branch of the Gulf eddy develops, penetrating into the eastern side of the Bay of Fundy. This dual eddy system continues throughout the summer. Beginning in September the Georges eddy breaks down as does the southern side of the Gulf eddy. The indraft into the Bay of Fundy is limited to north of 43°, i.e. from over Eastern Channel and Browns Bank but not from Georges Bank. The western side of the Gulf eddy weakens as winter sets in and the Georges eddy gives way by December to an easterly offshore drift. Just when this reverses to the southwesterly drift previously noted in February or March remains to be determined.

"At any time during the year, the prevailing circulation may be modified by winds or river runoff. Offshore winds from the northwest quadrant have a pronounced effect on the Georges region tending to destroy the Georges eddy. Northeasterly winds, even of short duration, speed up the northern segment of the Gulf eddy and increase the flow out South Channel. Winds from the west and southwest seem to give a strong onshore component to the waters south of Cape Cod and to accentuate the northward flow from Browns Bank to the Bay of Fundy. A prolonged drought may weaken the western side of the Gulf eddy restricting the eddy to the northern half of the Gulf of Maine. Abundant river runoff will strengthen the western side of the Gulf eddy."

A concise summary of surface circulation pattern in the Bay of Fundy-Gulf of Maine are contained in the Serial Atlas of the Marine Environment, Folio 7 (Bumpus and Lauzier, 1965). The material presented in this atlas is based on the results of many drift bottle releases in the area. As stated in this publication:

"The circulation in the Bay of Fundy is related to that of the eastern half of the Gulf of Maine. At all times, there is an inflow along the southern entrance of the Bay. This inflow reaches a minimum during the winter months and a maximum during summer and autumn. The outflow from the Bay to the northern Gulf of Maine also exhibits a seasonal variation, being minimal during the winter and maximal during the spring and early summer.

"In the Bay itself, the winter surface drift is composed of one large or a few small eddies that retain within the Bay what has been released there or what has previously drifted into it. At that time a definite movement from the northwest to the southeast side of the Bay is observed. During the spring there is an increase in the average speed of the westerly component along the northwest side of the Bay. This is accompanied by a more or less straightforward inflow along the southeast side of the Bay. This 'U turn' type of circulation is continued during the summer. The autumn circulation is an intermediate one between the 'open' circulation of the summer months and the 'closed' circulation of the winter months.

"Gulf of Maine

"The indraft from off Cape Sable, from across Browns Bank and the eastern Gulf of Maine into the Bay of Fundy, is the chief characteristic during the winter season. A southerly flow develops along the western side of the Gulf of Maine and continues past Cape Cod through Great South Channel. Between the indraft into the Bay and the southerly flow along the western side of the Gulf, several irregular eddies develop by February. An area of divergence north of Georges Bank is well developed by February.

"The Gulf of Maine eddy develops rapidly during the spring months so that one large cyclonic gyre encompasses the whole of the Gulf of Maine by the end of May. There is an indraft on the eastern side of this gyre from the Scotian Shelf and Browns Bank. Abreast of Lurcher Shoals the drift may continue on northward into the Bay of Fundy or it may turn westward toward the coast of southern Maine, continue southward across Massachusetts Bay where it may divert into Cape Cod Bay or turn toward the east, north of Georges Bank.

"The Maine eddy, which reached its climax in May, begins to slow down in June. By autumn and winter the southern side breaks down into a drift across Georges Bank."

Figure 28 displays the seasonal current patterns for the Bay of Fundy/Gulf of Maine Region as found by Bumpus and Lauzier (1965).

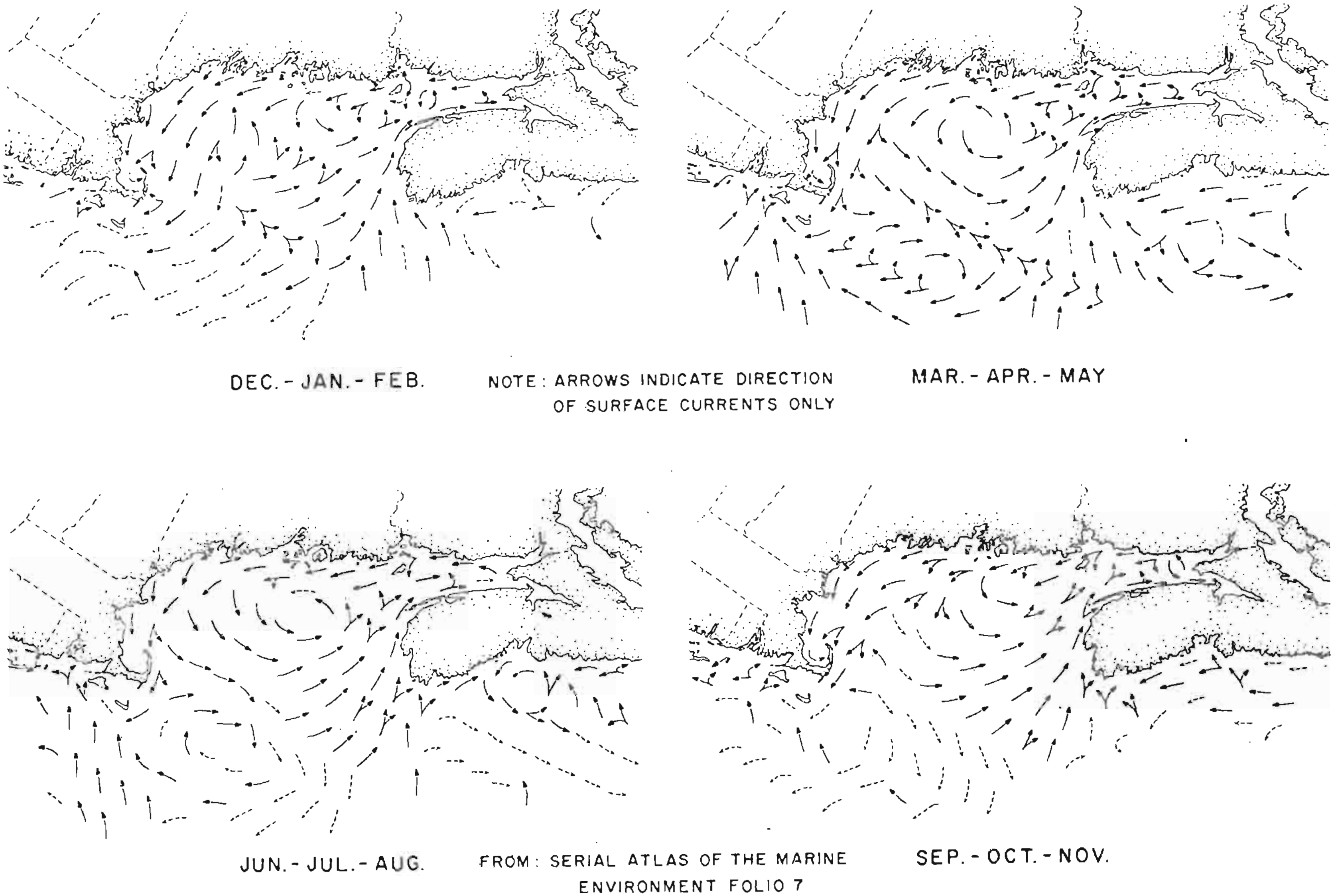


FIGURE 28: Mean seasonal surface currents for Bay of Fundy and the Gulf of Maine (from Bumpus and Lauzier, 1965).

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SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

SECTION 2

DISPERSION OF SPILLED OIL

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Bedford Institute of Oceanography
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SUMMARY

Dispersion of spilled oil would be rapid and extensive in the Head Harbour Passage. The risk of contamination seems to be general rather than concentrated in a few 'collector-sites.' Thus all the waters and shores of the Passage would be vulnerable to contamination within 12 hours of a spill there. Waters and shores of Passamaquoddy Bay, Campobello and Grand Manan would be vulnerable to contamination within a week. Waters and shores of the Bay of Fundy and Gulf of Maine would be vulnerable to contamination with longer delays. Concentrations of oil particles in the water column would be expected to be on the order of 10^{-8} cm^3/cm^3.

1. INTRODUCTION

The purpose of this chapter is to synthesize existing information so that gross estimates may readily be made for the areal extent of an oil slick, the geographical area likely to be exposed to contamination from spilled oil given the time, location and size of the spill, and the concentration of oil particles likely to be found diffused down into the water column.

2. DISPERSION OF OIL DURING THE FIRST 12 HOURS

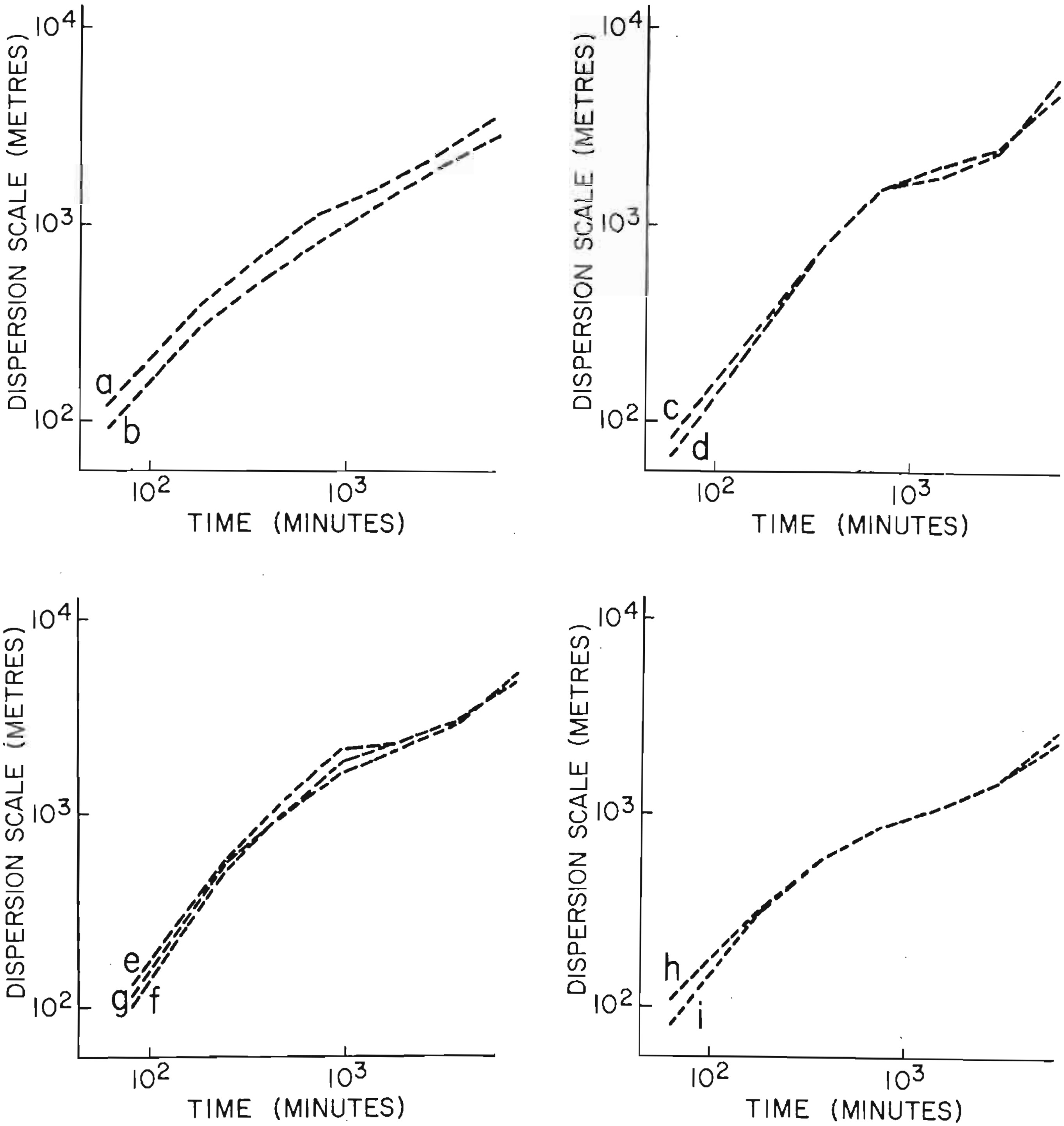
The term dispersion is being used to include advection (bodily transport), spreading due to inertial forces and diffusion due to turbulence. Thus to know the dispersion of an oil slick is to know the distribution of spilled oil. The recent current-meter data has been used to estimate the rate of horizontal diffusion of oil due to water turbulence. The technique is described in a note (Loucks et al, 1974) being readied for publication. The results are given in Figures 1 to 4 for current meter stations #2 and #4 (Chapter 1). These represent the growth of patch diameter with time.

Spreading of oil slicks by mechanisms other than turbulent diffusion have been summarized by Moore et al, (1973). Their results are reproduced in Figure 5 and show patch area dependent on spill size. A representative turbulent patch characteristic has been superimposed on Figure 5 in Figure 6. This characteristic is appropriate to a patch of initial size equal to the distance constant of the current meter. If a larger patch is somehow established, then the turbulence characteristic should be matched to that size and subsequent growth include the turbulence contribution.

It is noted that the turbulence characteristic has slope steeper than the other mechanisms and so may be expected to dominate eventually. It is noted that the turbulence characteristic has slope steeper than the other mechanisms and so may be expected to dominate eventually.

In order to estimate a lower bound for the area of a spill during the first twelve hours assuming winds were calm, we have used the turbulent patch characteristic together with the sinusoidal M2 velocities of amplitude 1.5 m/sec as defining width and length respectively for a series of patches making up the spill. This growth curve is also included in Figure 6 although it has cumulative character.

Forrester (1959) has published tidal current diagrams for the Quoddy Region. His results for Head Harbour Passage are borne out by the tidal constants derived from current meters moored in August/September, 1973 (Section 1). Although his diagrams exclude residual current, this does not introduce serious errors in estimating the drift of a slick over one tidal cycle.


DISPERSION SCALE (METRES)
10^4
10^3
10^2
TIME (MINUTES)
a
b
c
d
e
f
g
h
i

FIGURES 1 to 4: Characteristics of a patch spreading due to turbulence calculated on residual (tides removed) data (5 minute intervals) for the period starting August 23, 1973.

Station 2, 5m depth (below low water).

1. Transverse (minor) component.

   a) Data points 1 to 2376, August 23 to 31.
   b) Date points 2377 to 4765, August 31 to Sept. 8.

2. Longitudinal (major) component.

   c) August 23 to 31.
   d) August 31 to Sept. 8.

Station 4, 5m depth (below low water).

3. Major.

   e) August 23 to 31.
   f) August 31 to Sept. 8.
   g) Sept. 8 to Sept. 16.

4. Minor.

   h) August 23 to 31.
   i) August 31 to Sept. 8.

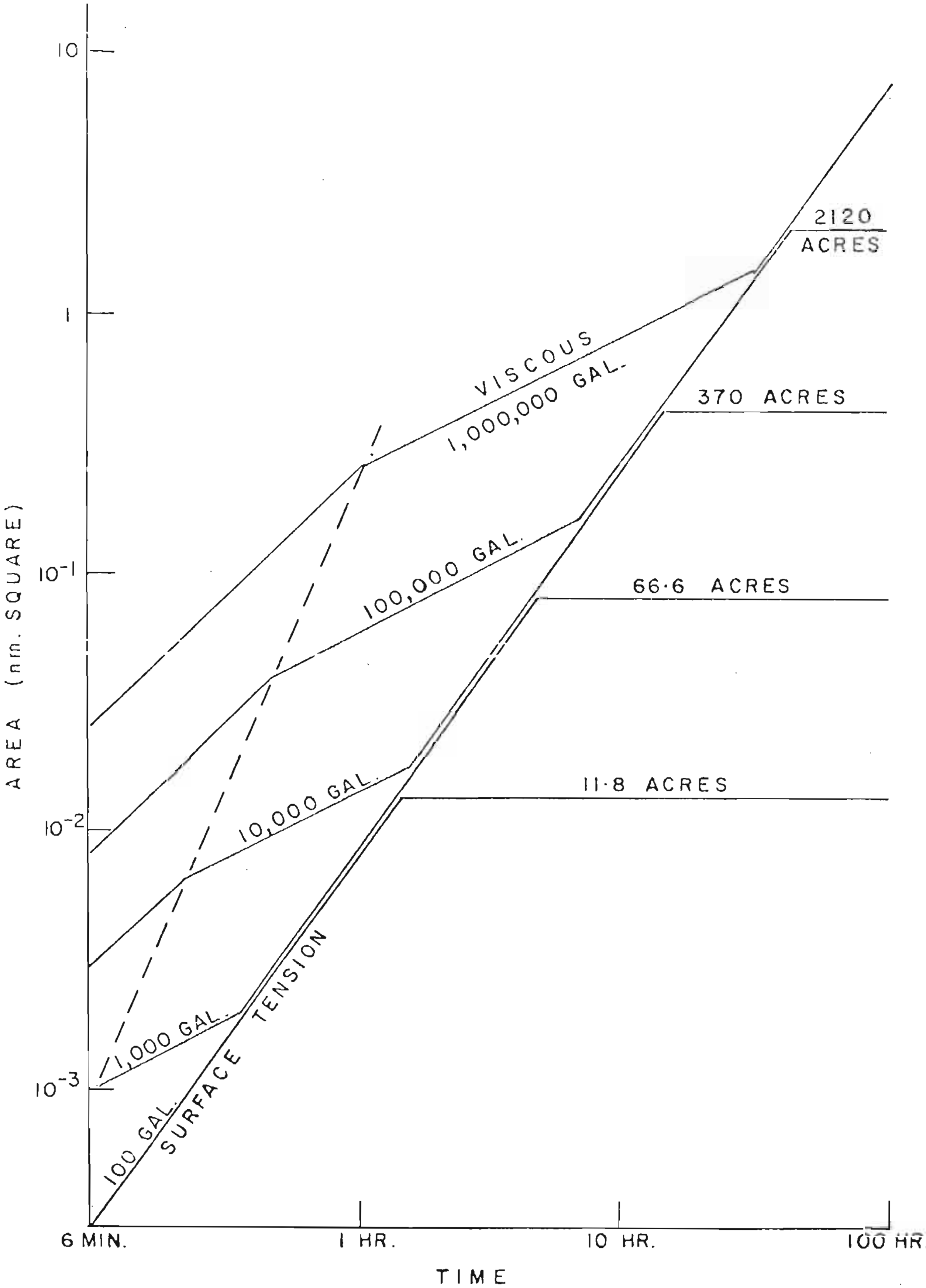


FIGURE 5: Representative spreading histories for five spill volumes, area covered versus time from spill. Typical crude oil characteristics (from Moore et al., 1973).

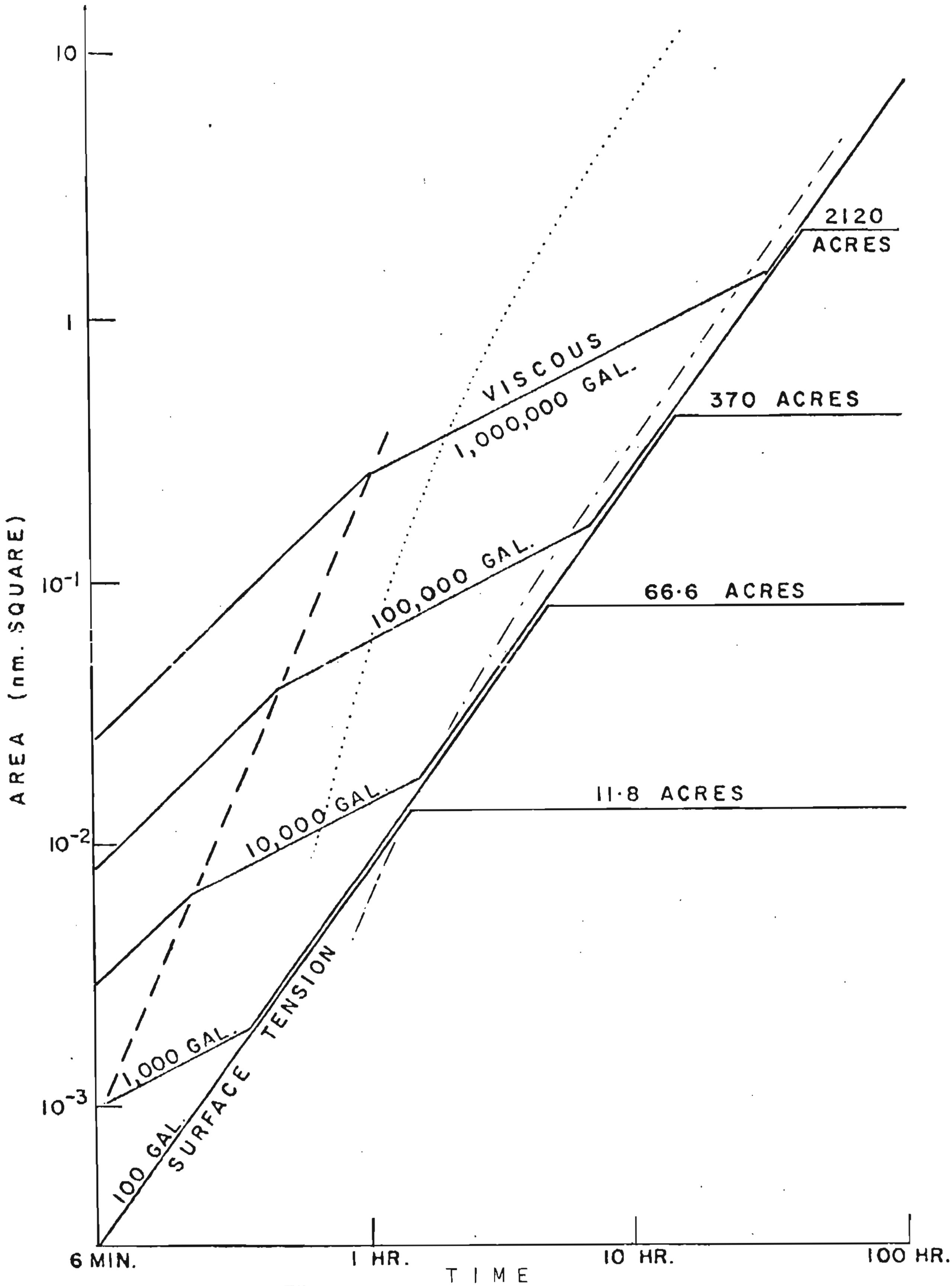
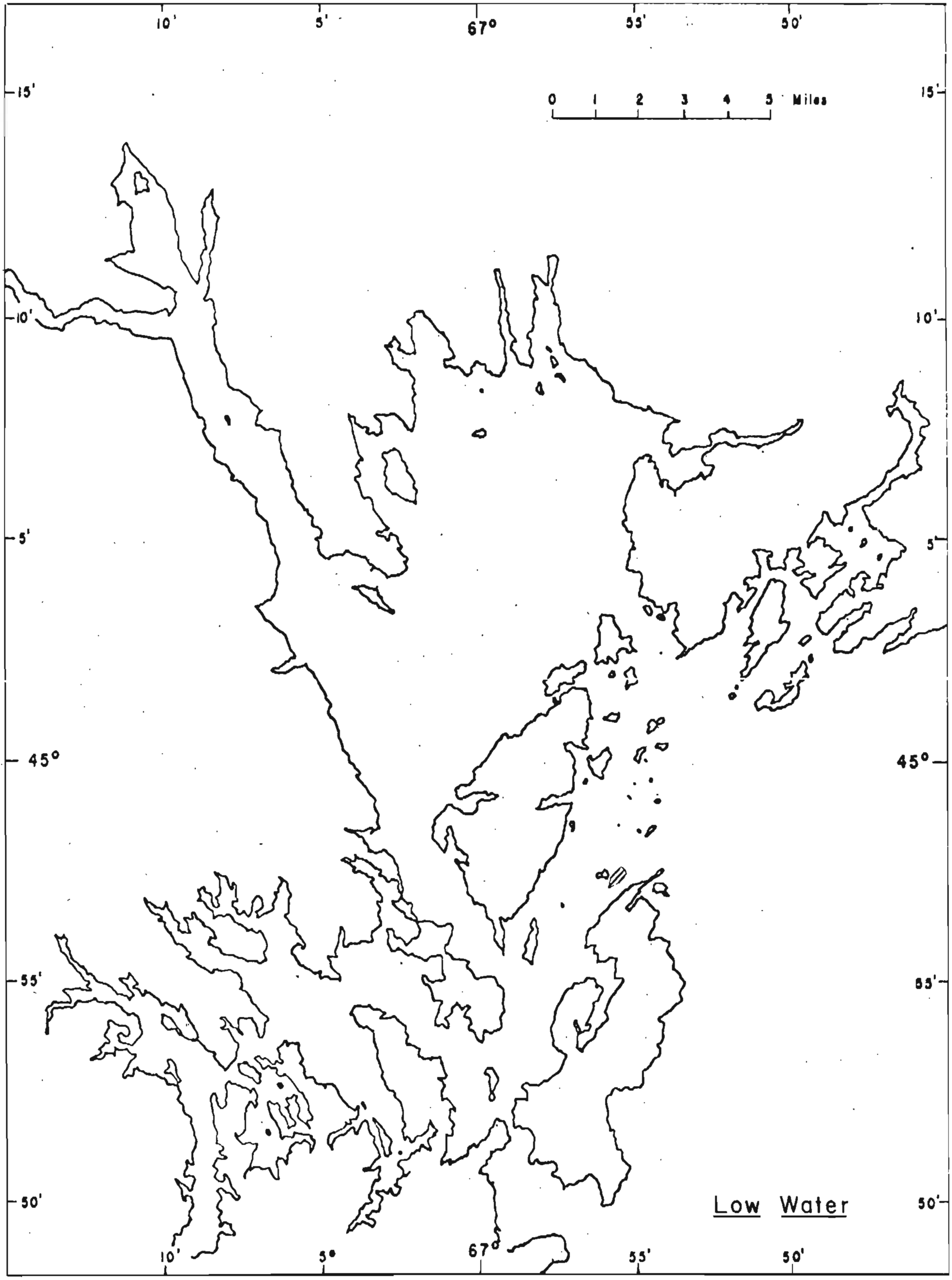


FIGURE 6: A reproduction of Figure 5 with the addition of a) the square of a turbulent patch characteristic (-·-·-·) and b) the cumulative turbulent characteristic for a spill taken as a series of patches in a tidal seaway (·····).



FIGURES 7-18: Hourly estimates of the spread of a 50,000-ton spill imagined to occur in Head Harbour Passage at low water.

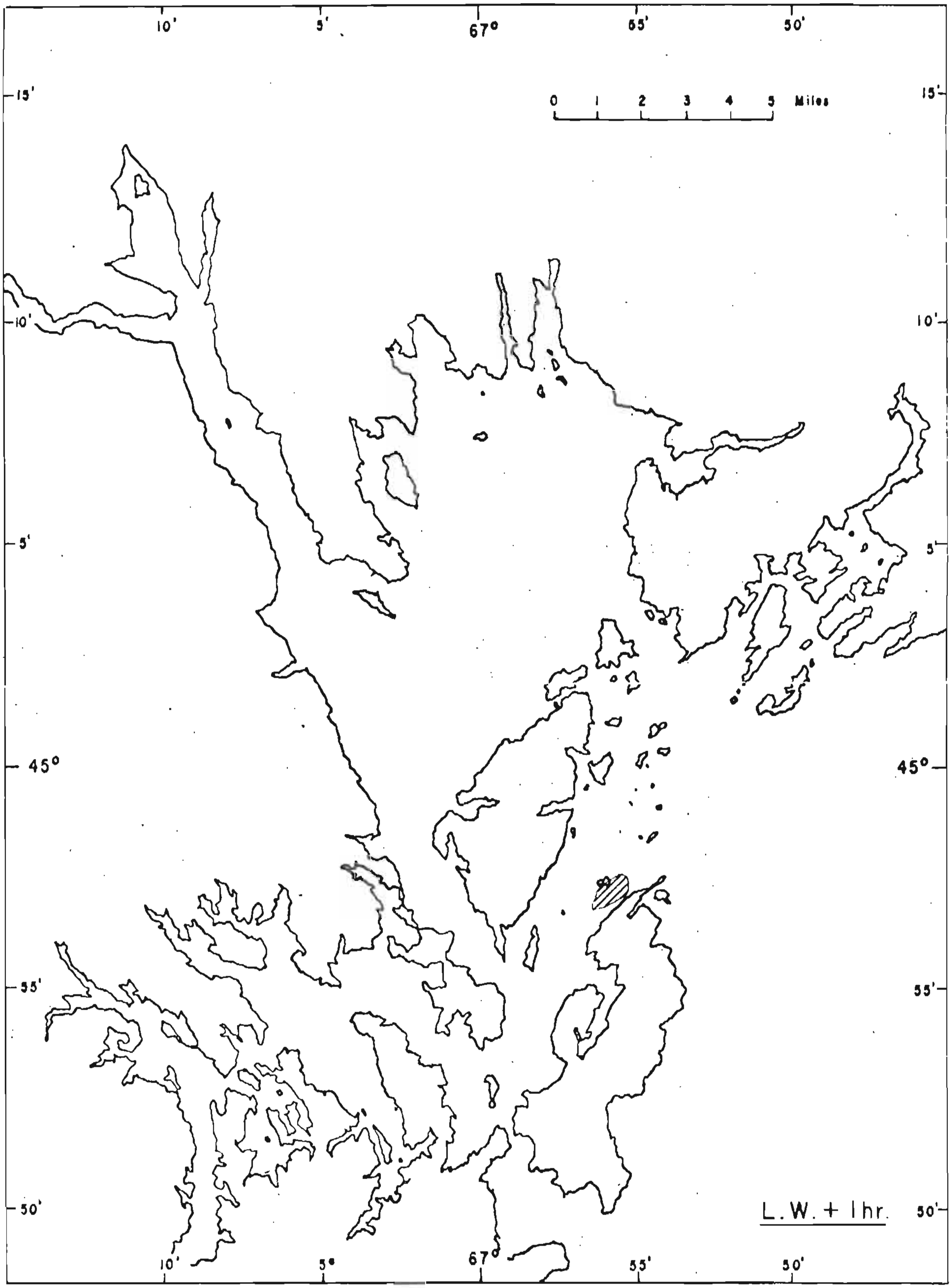


FIGURE 8

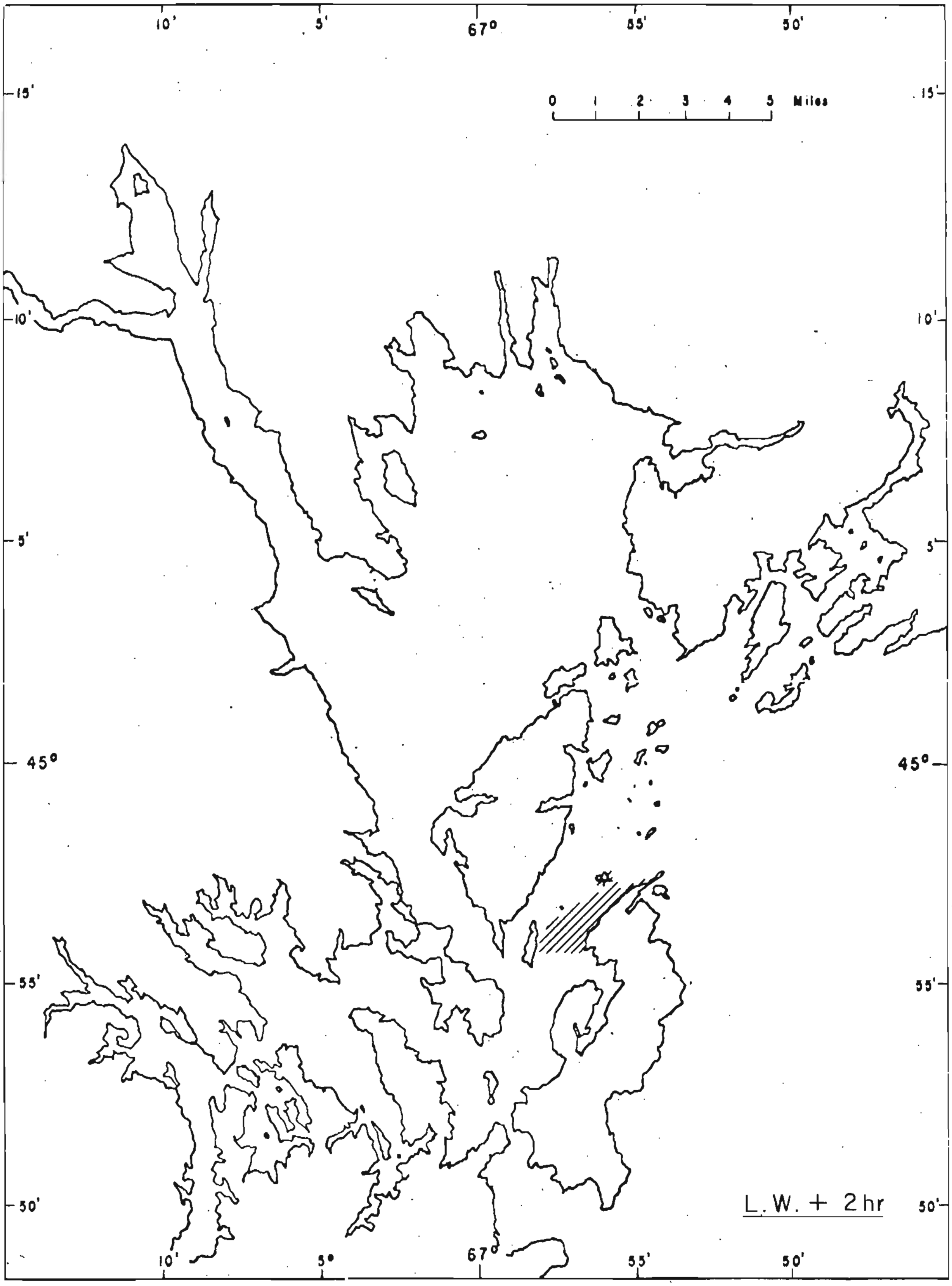


FIGURE 9

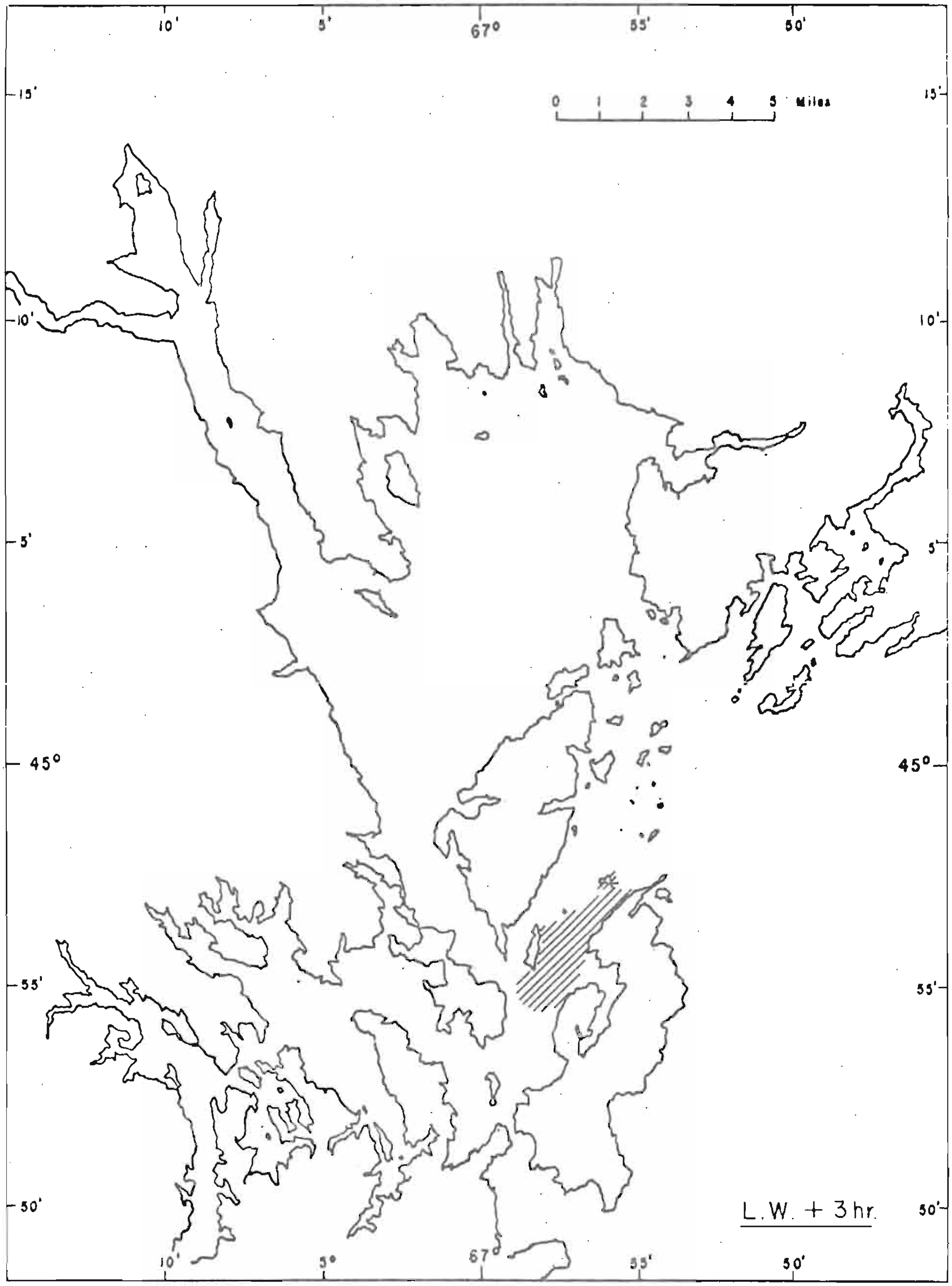

10'
5'
67°
55'
50'
15'
0
1
2
3
4
5
Miles
15'
10'
10'
5'
5'
45°
45°
55'
55'
50'
50'
L.W. + 3 hr.
10'
5°
67°
55'
50'

FIGURE 10

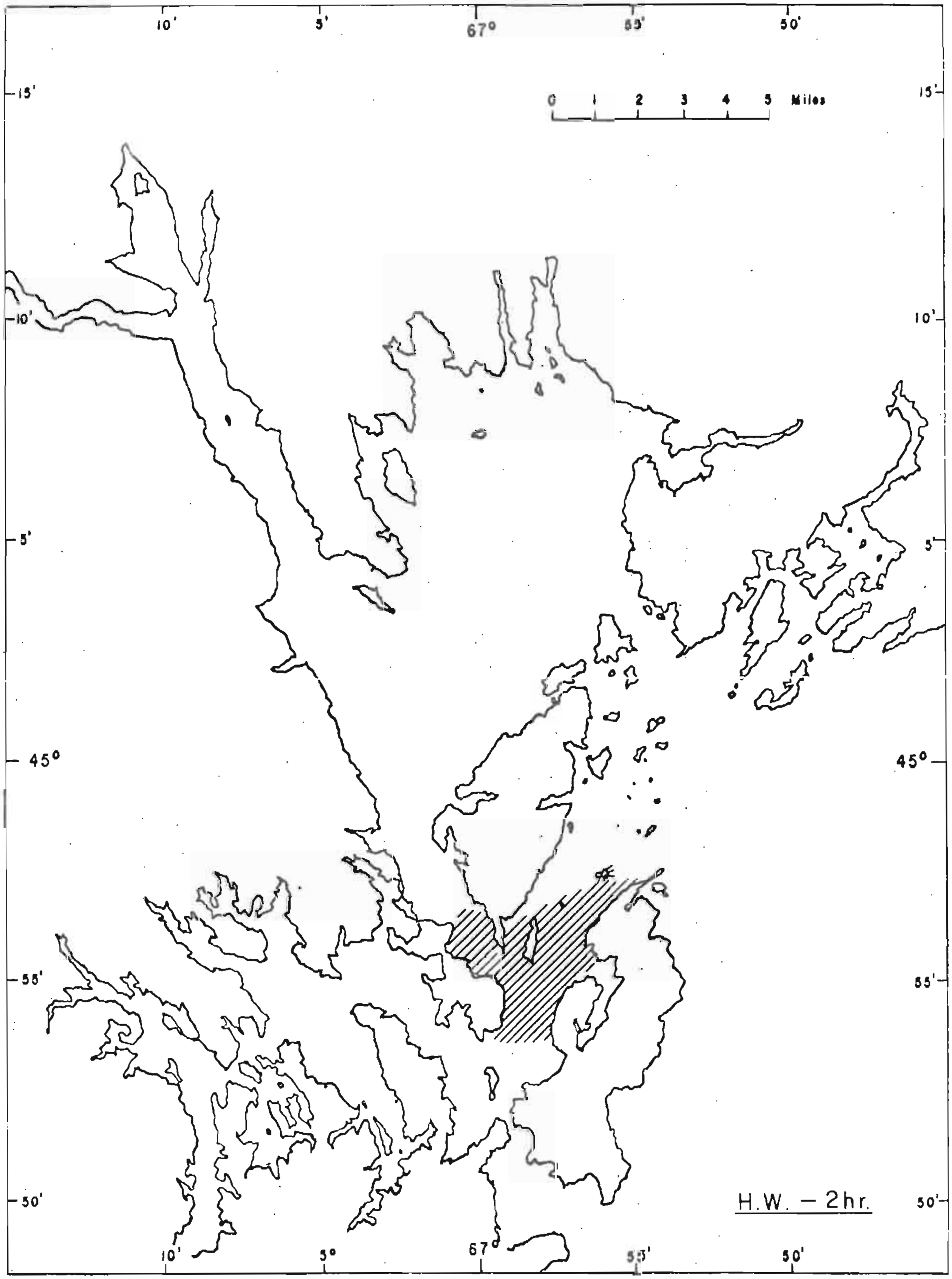


FIGURE 11

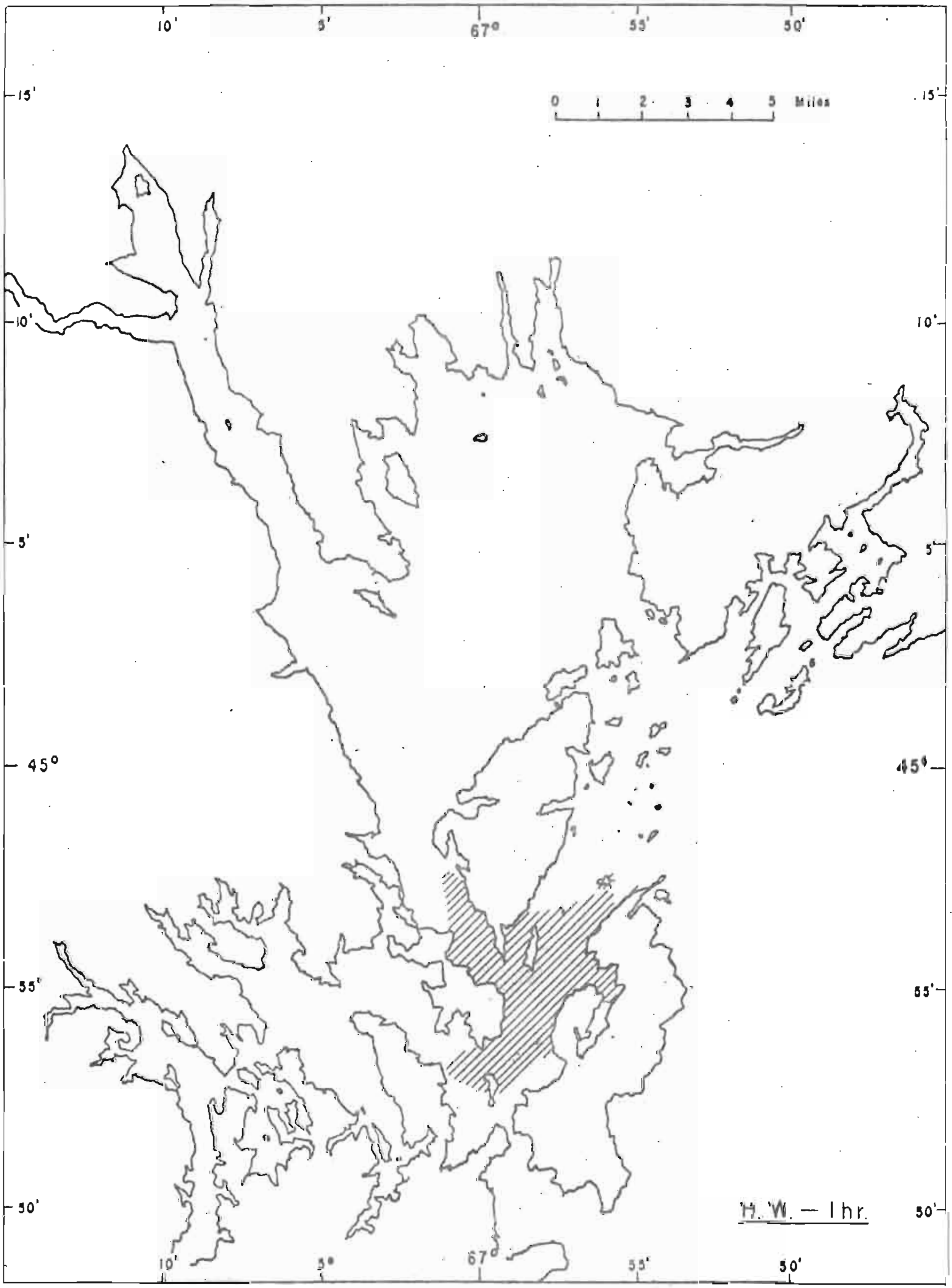


FIGURE 12

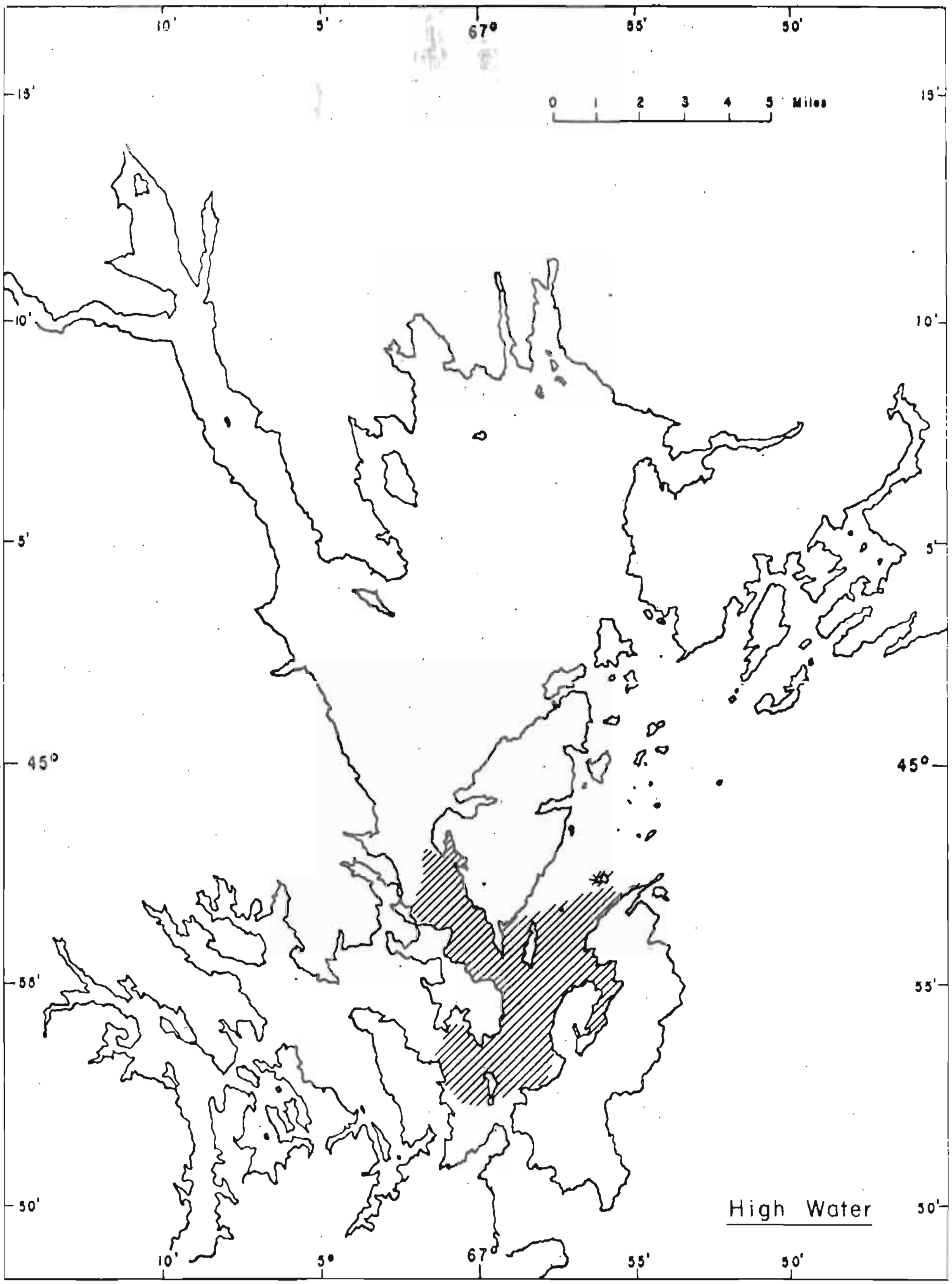


FIGURE 13

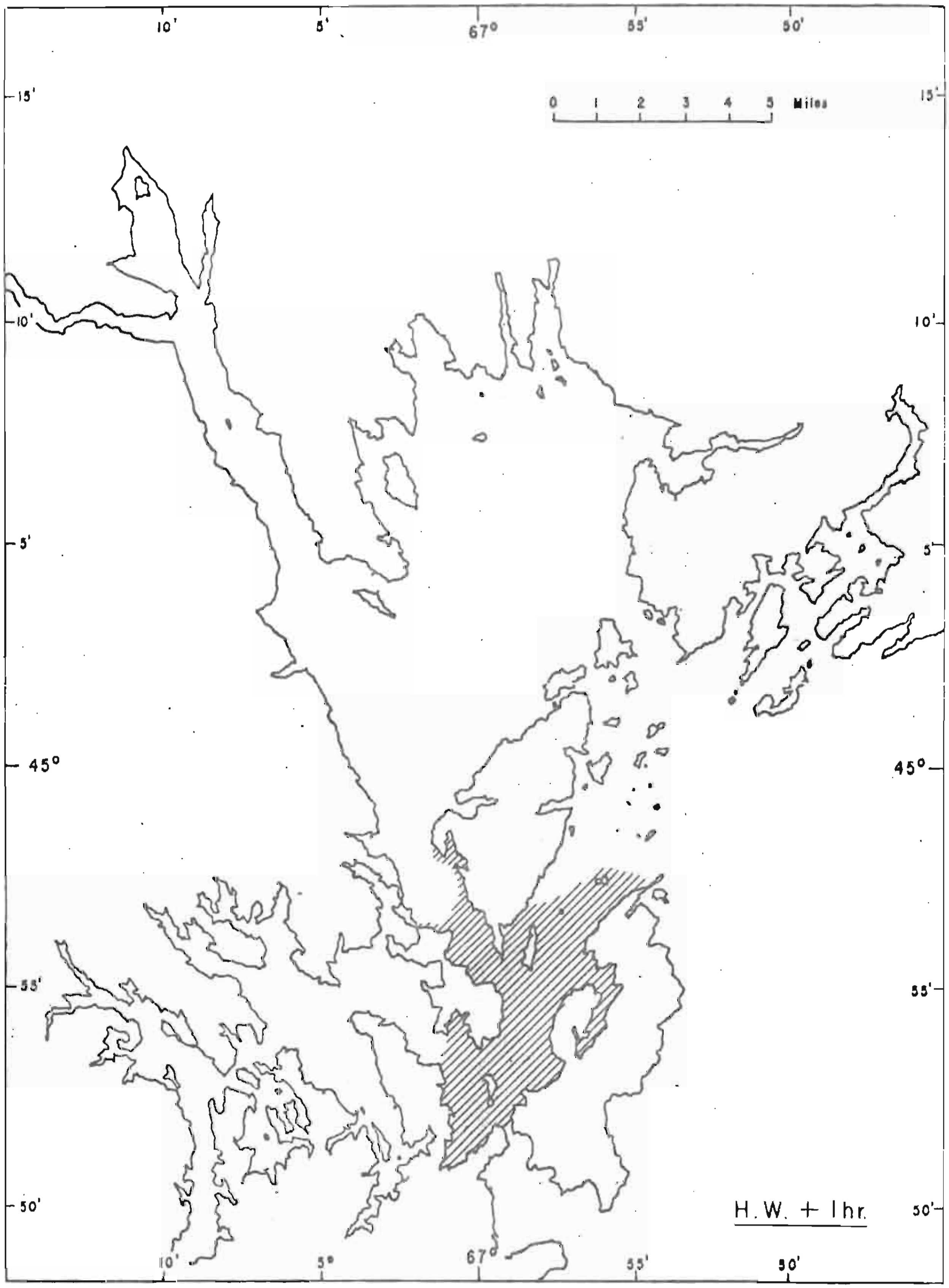


FIGURE 14

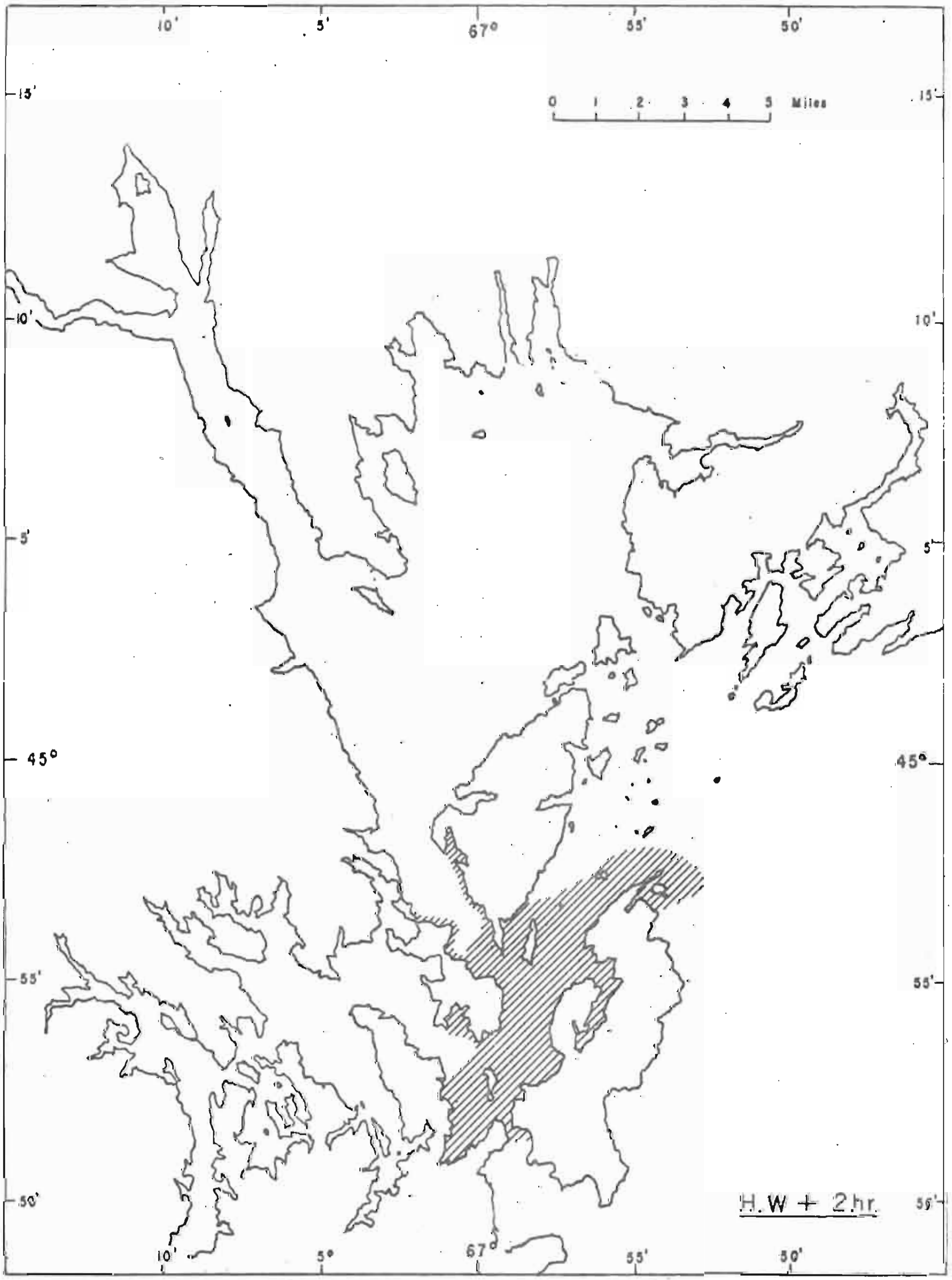


FIGURE 15

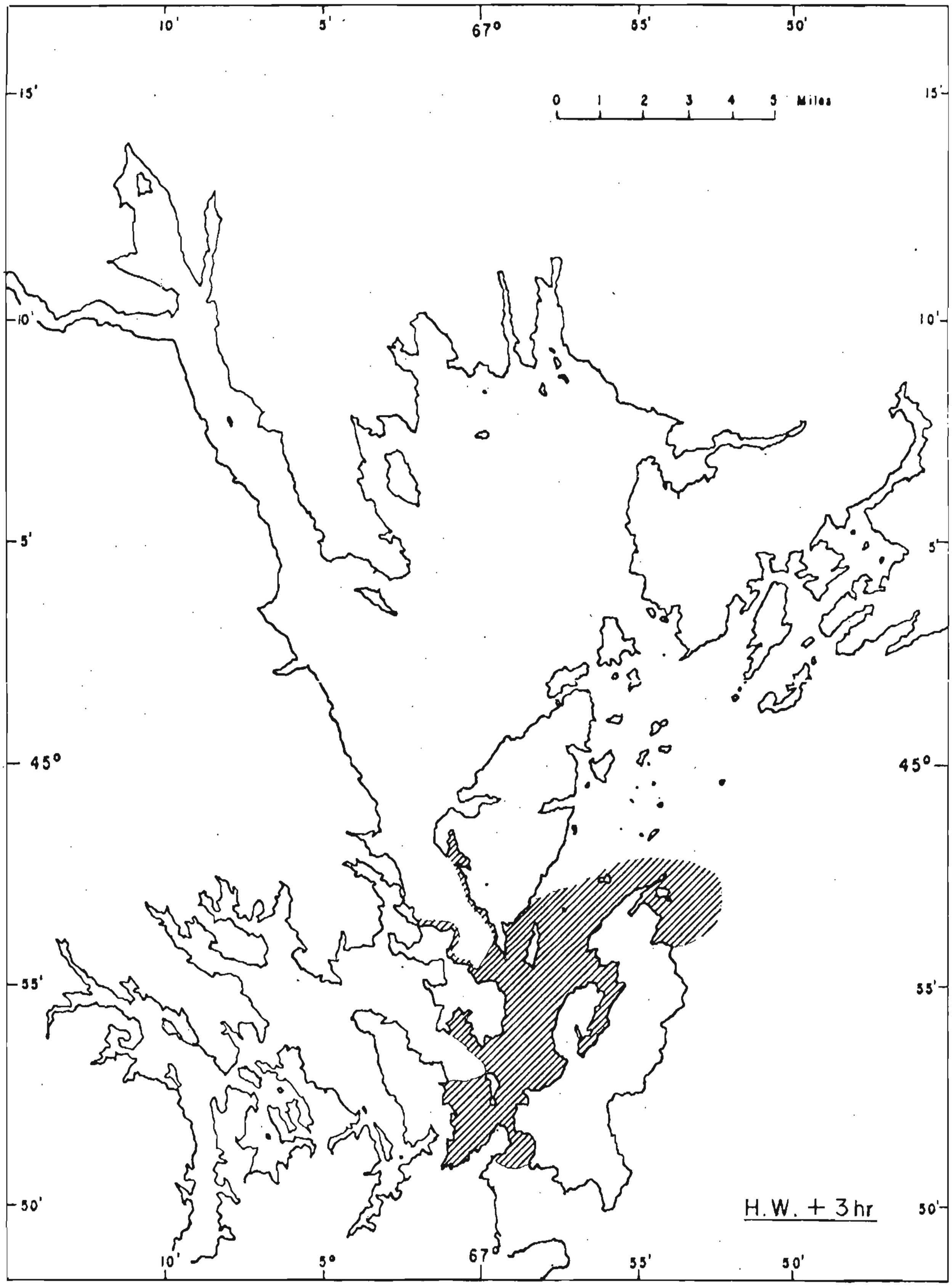


FIGURE 16

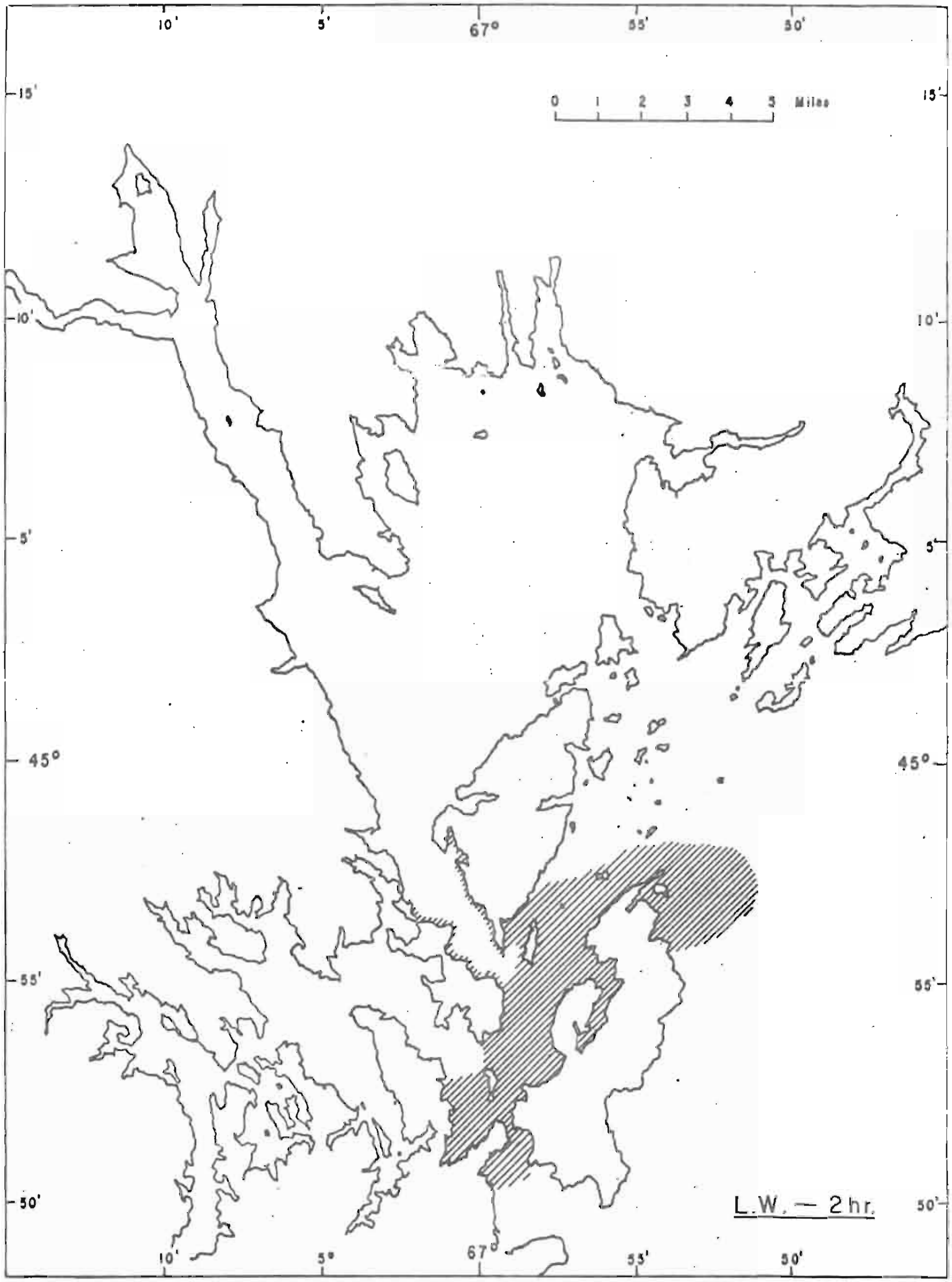


FIGURE 17

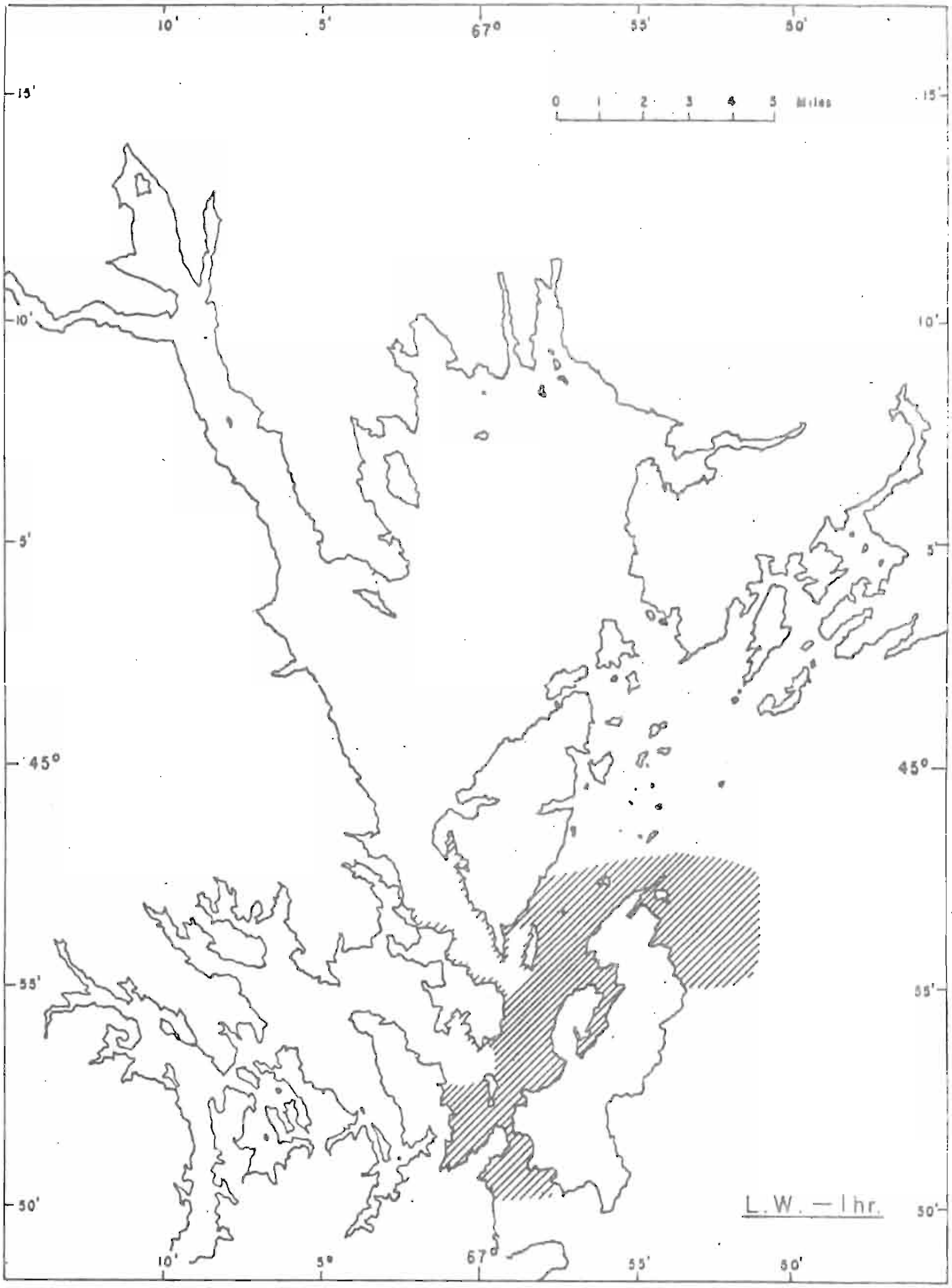


FIGURE 18

FIGURE 19-31: Hourly estimates of the spread of a 50,000-ton spill imagined to occur off Estes Head one hour before high water.

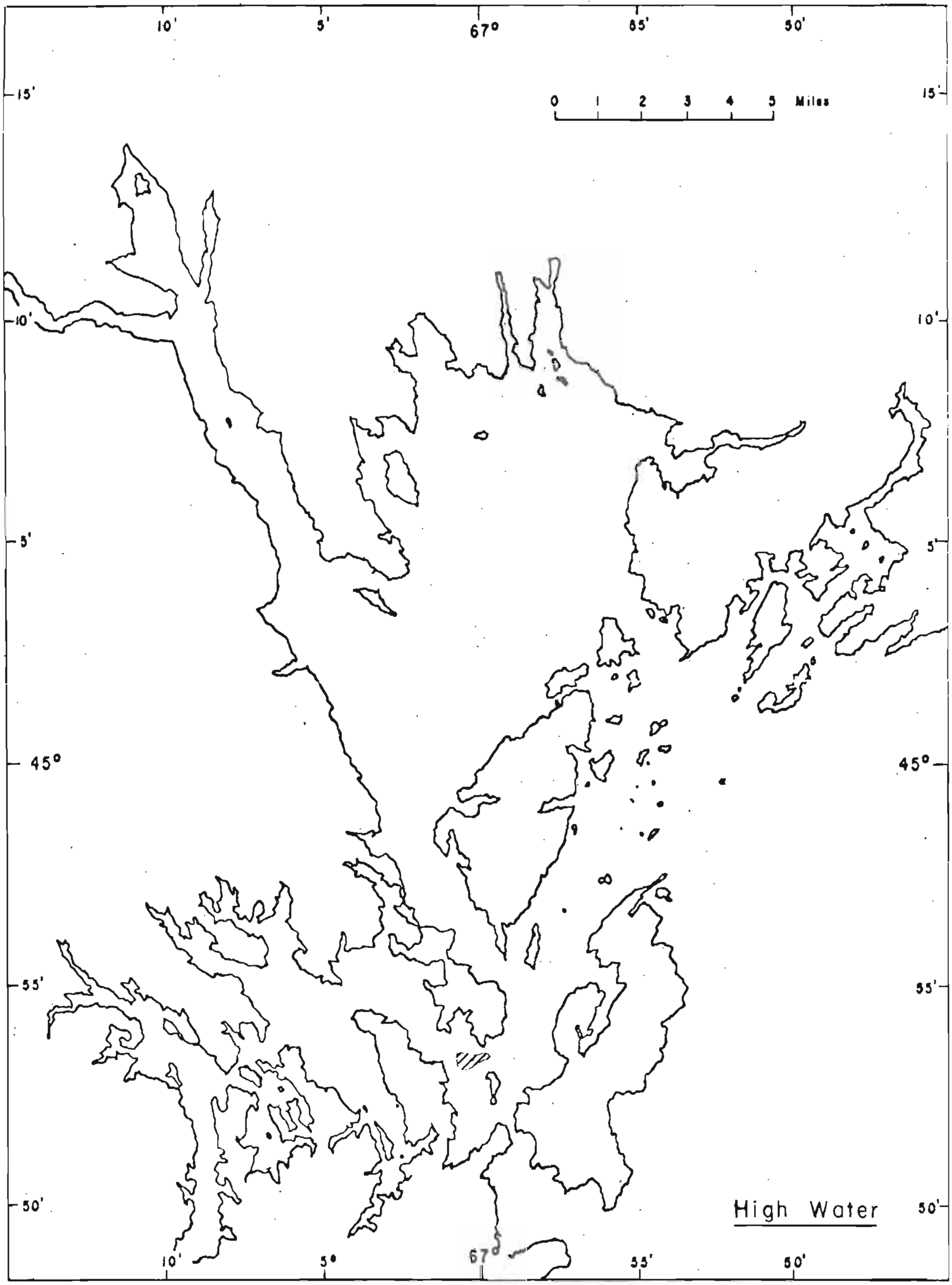


FIGURE 20

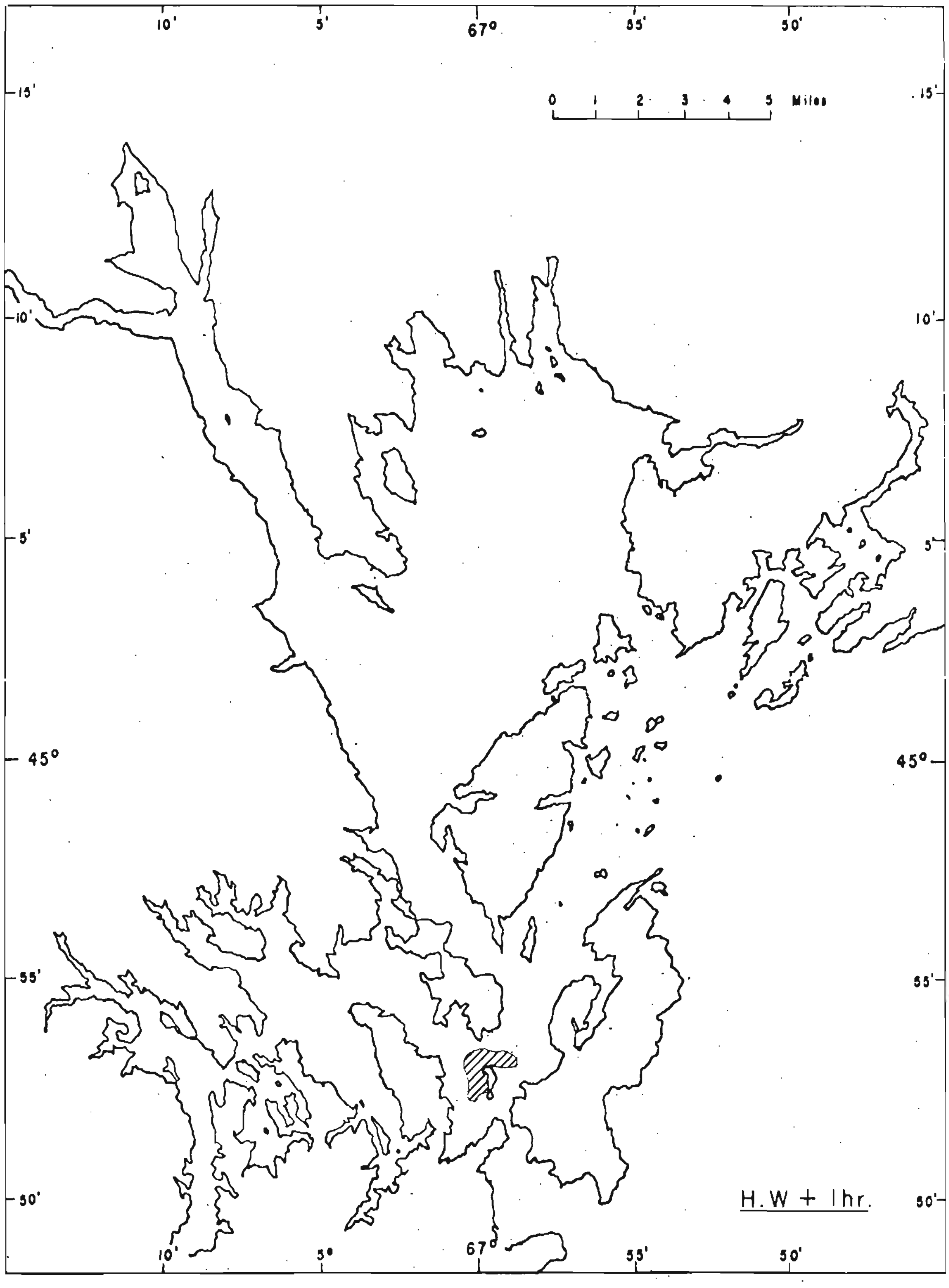


FIGURE 21

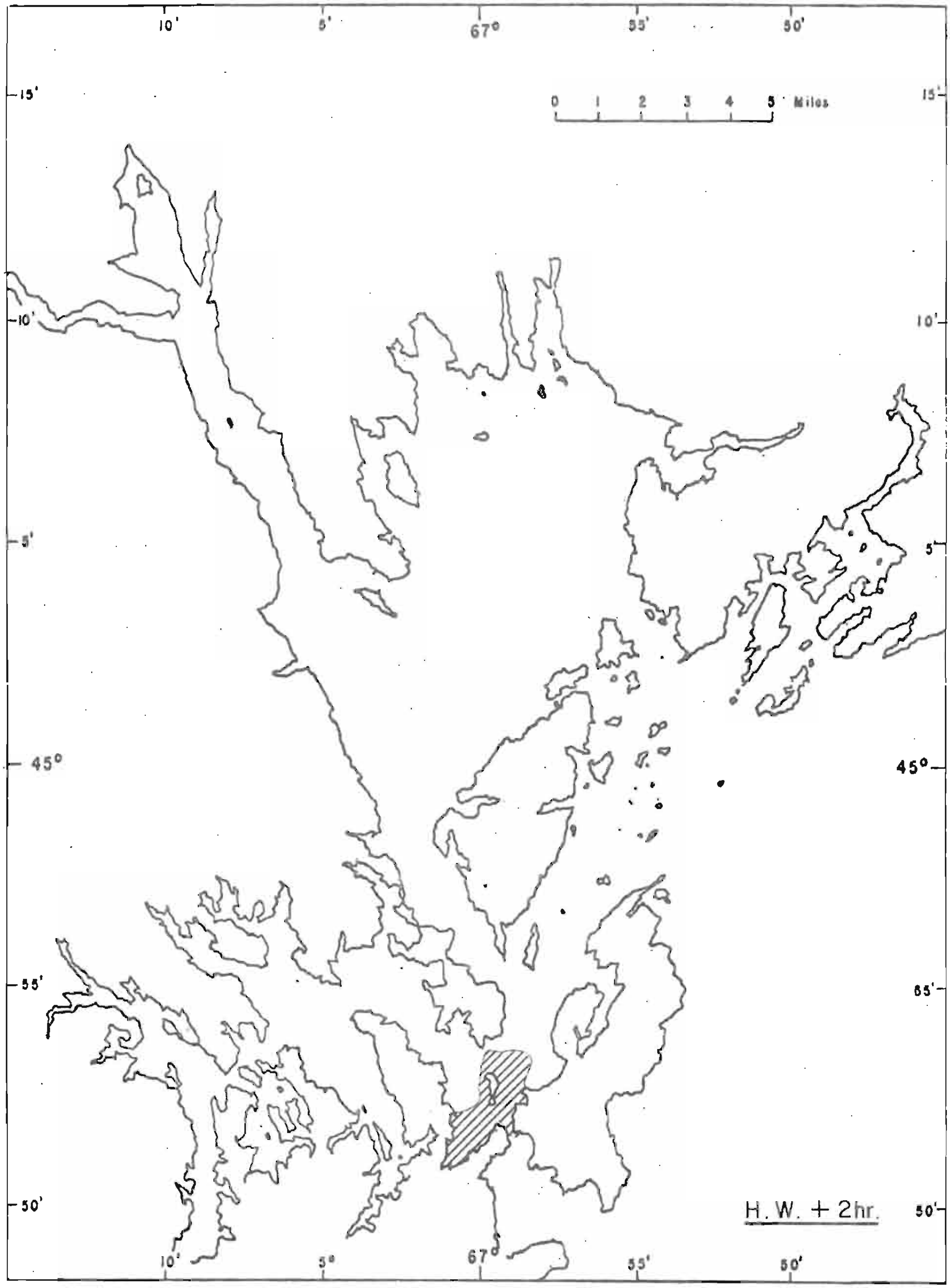


FIGURE 22

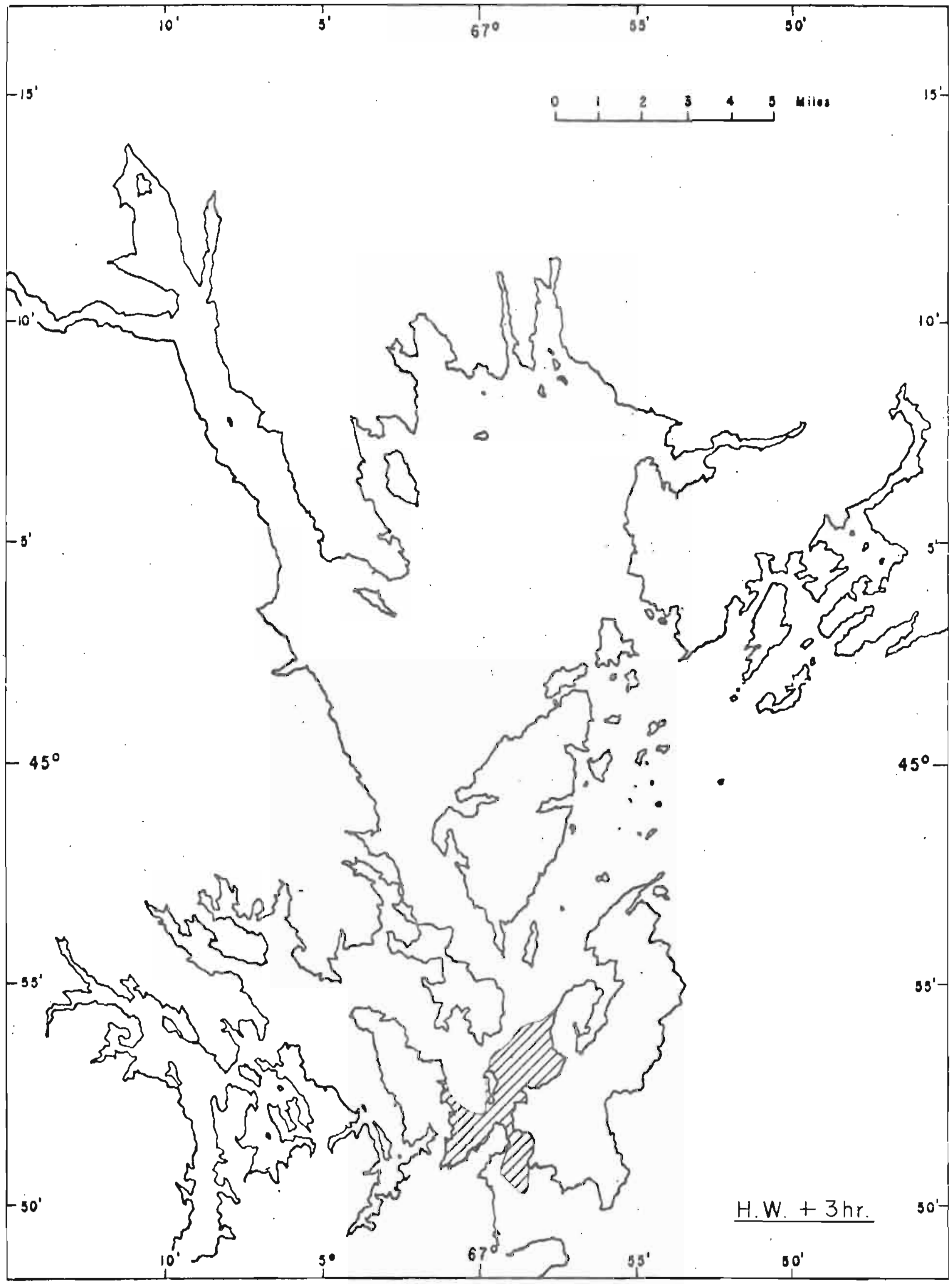


FIGURE 23

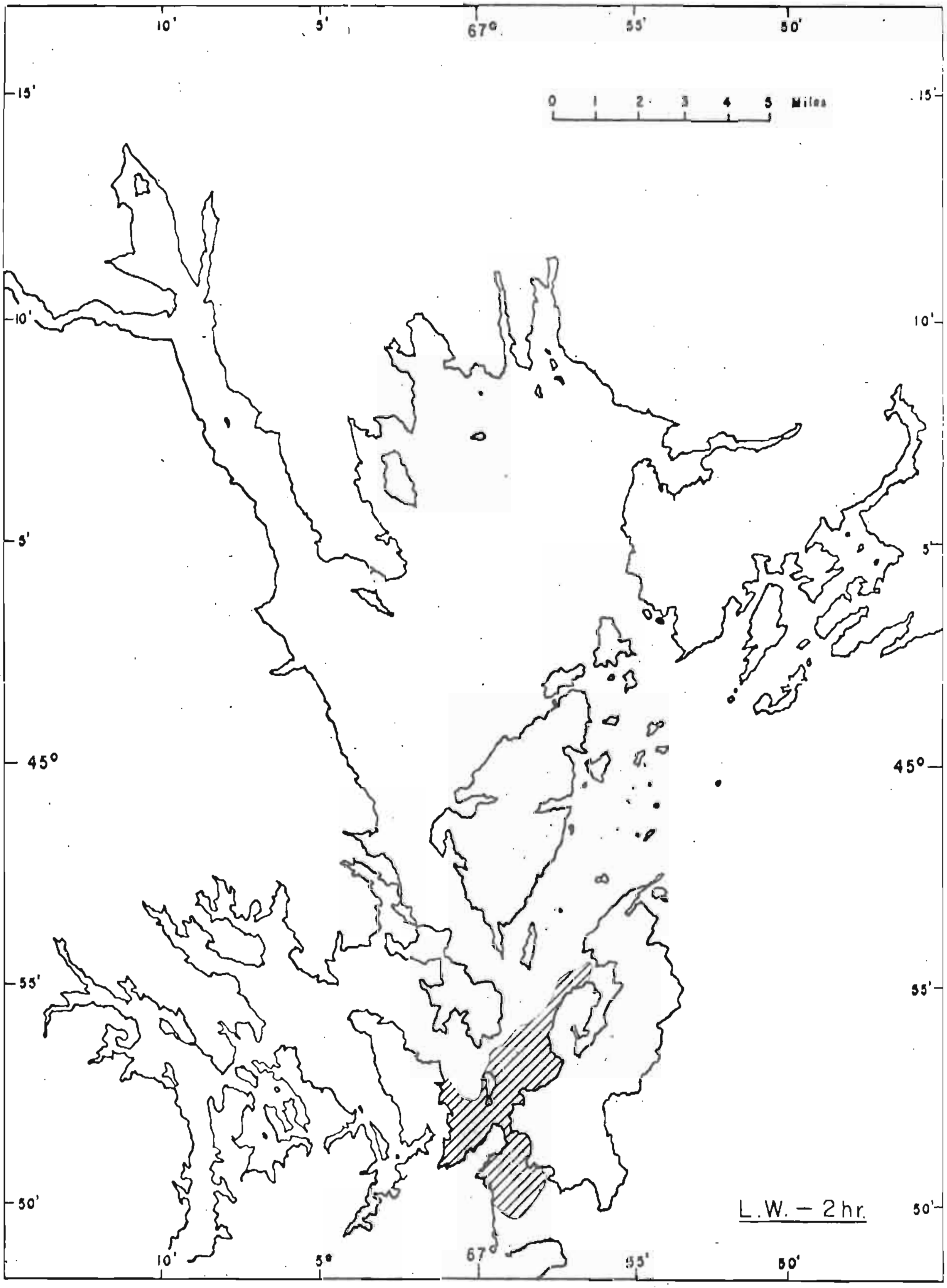


FIGURE 24

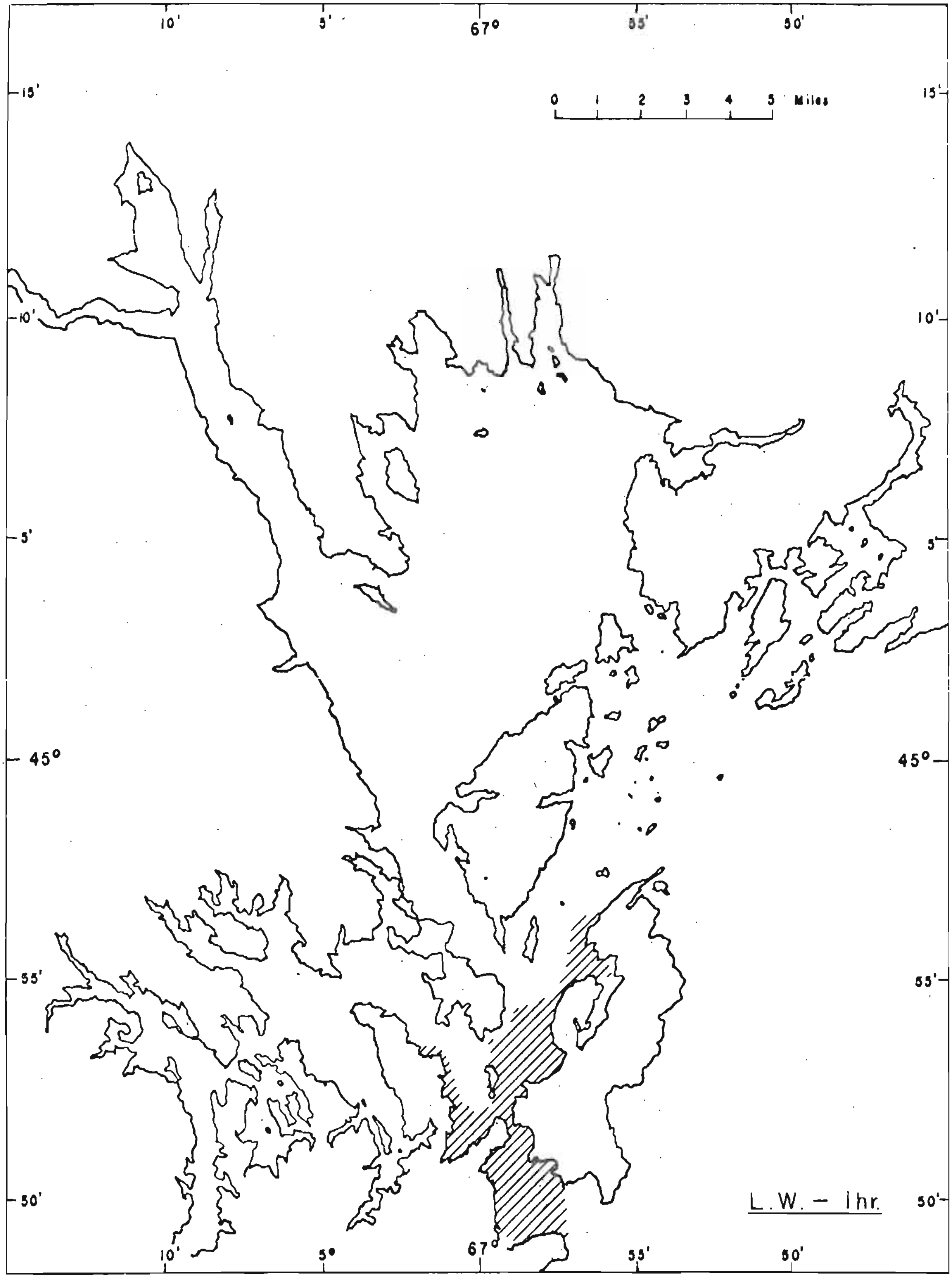


FIGURE 25

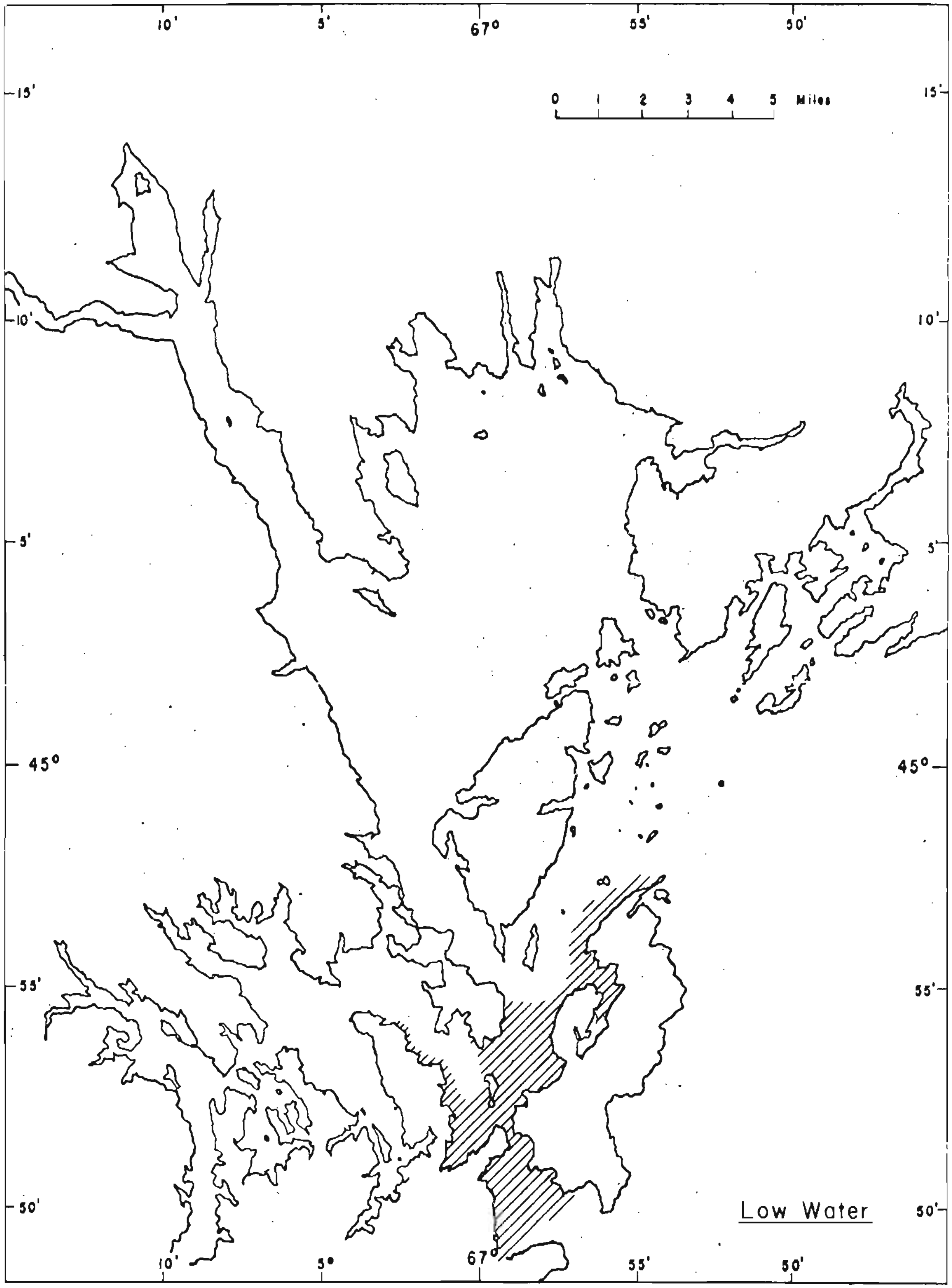


FIGURE 26

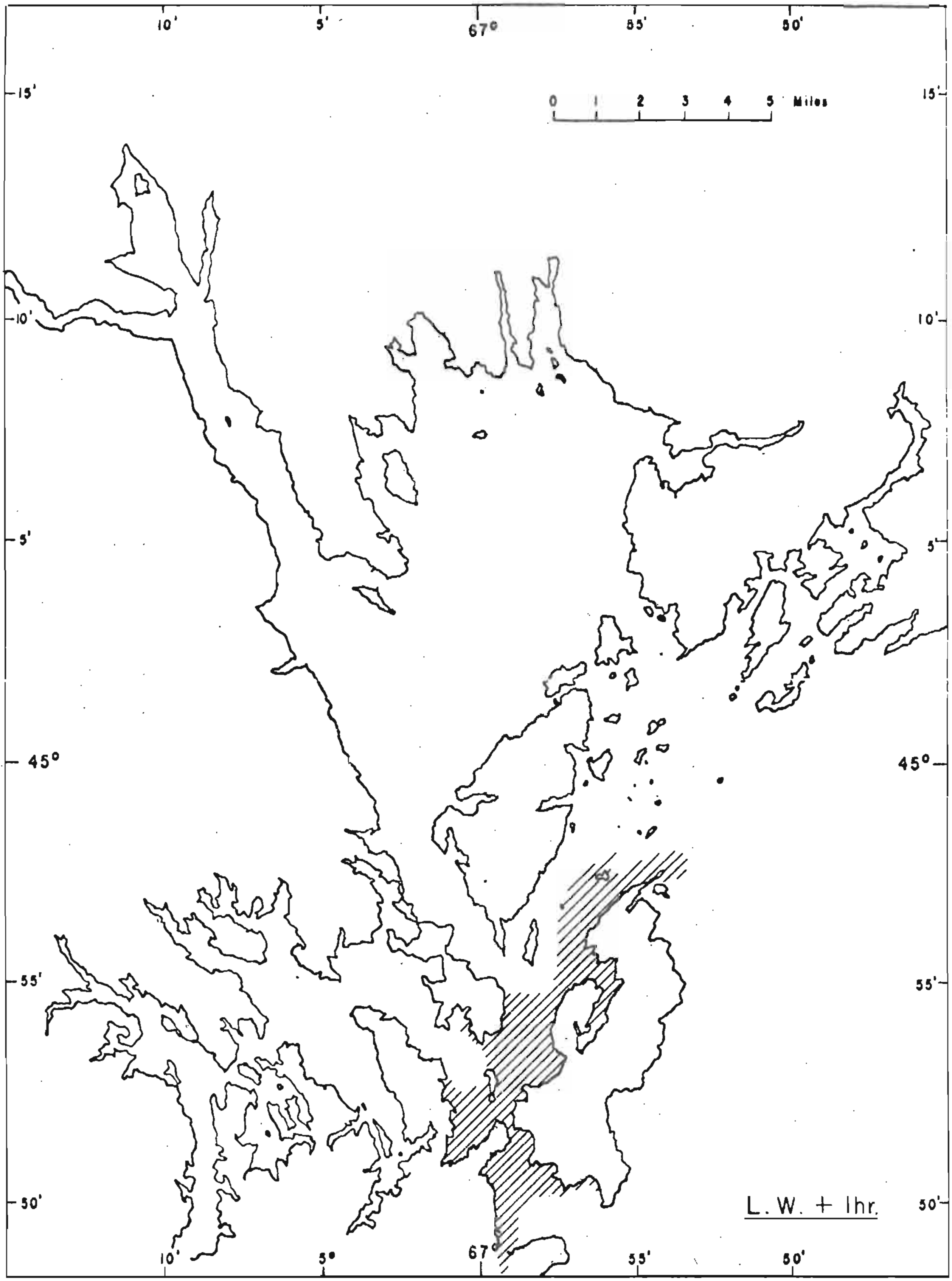


FIGURE 27

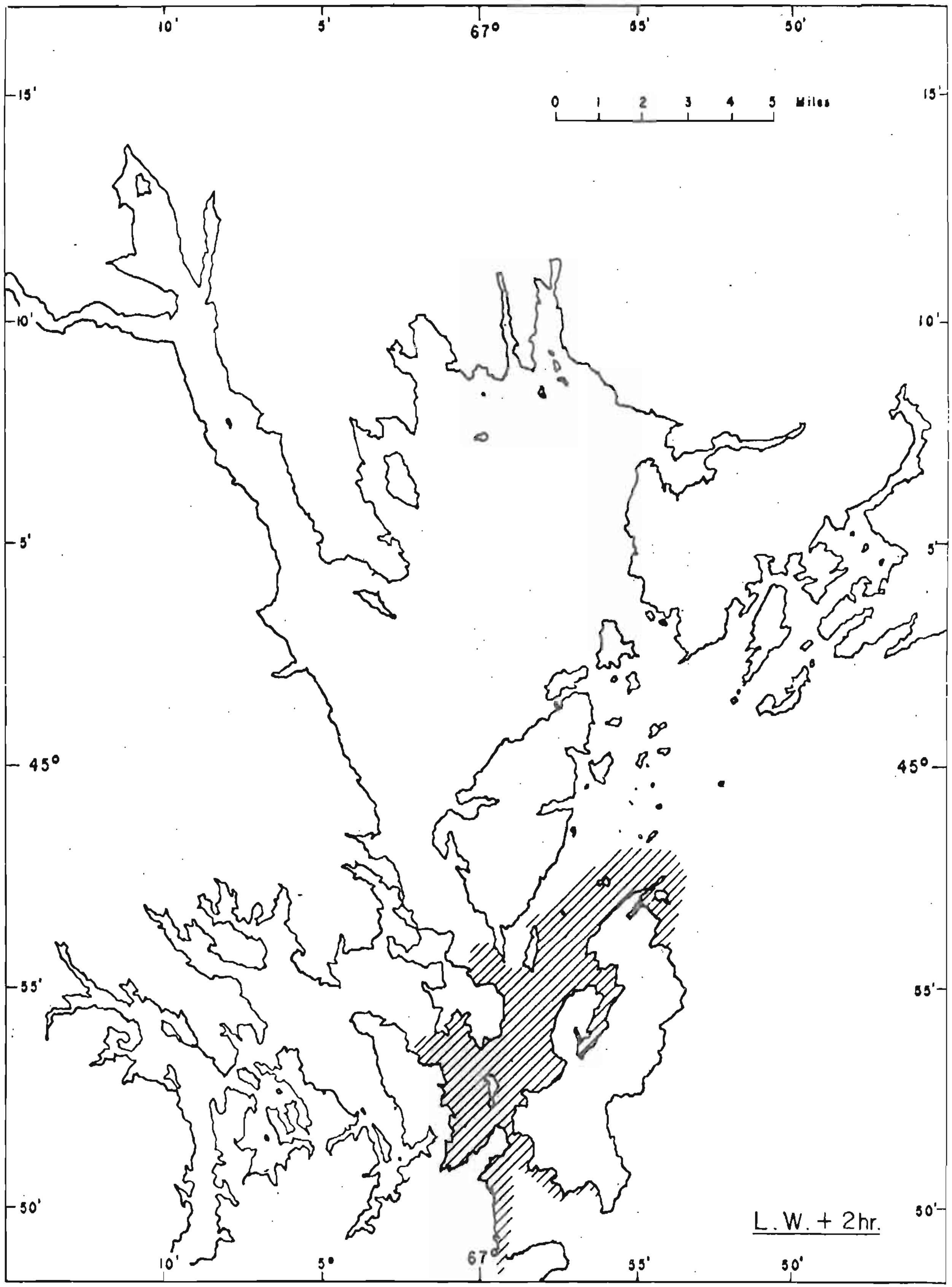


FIGURE 28

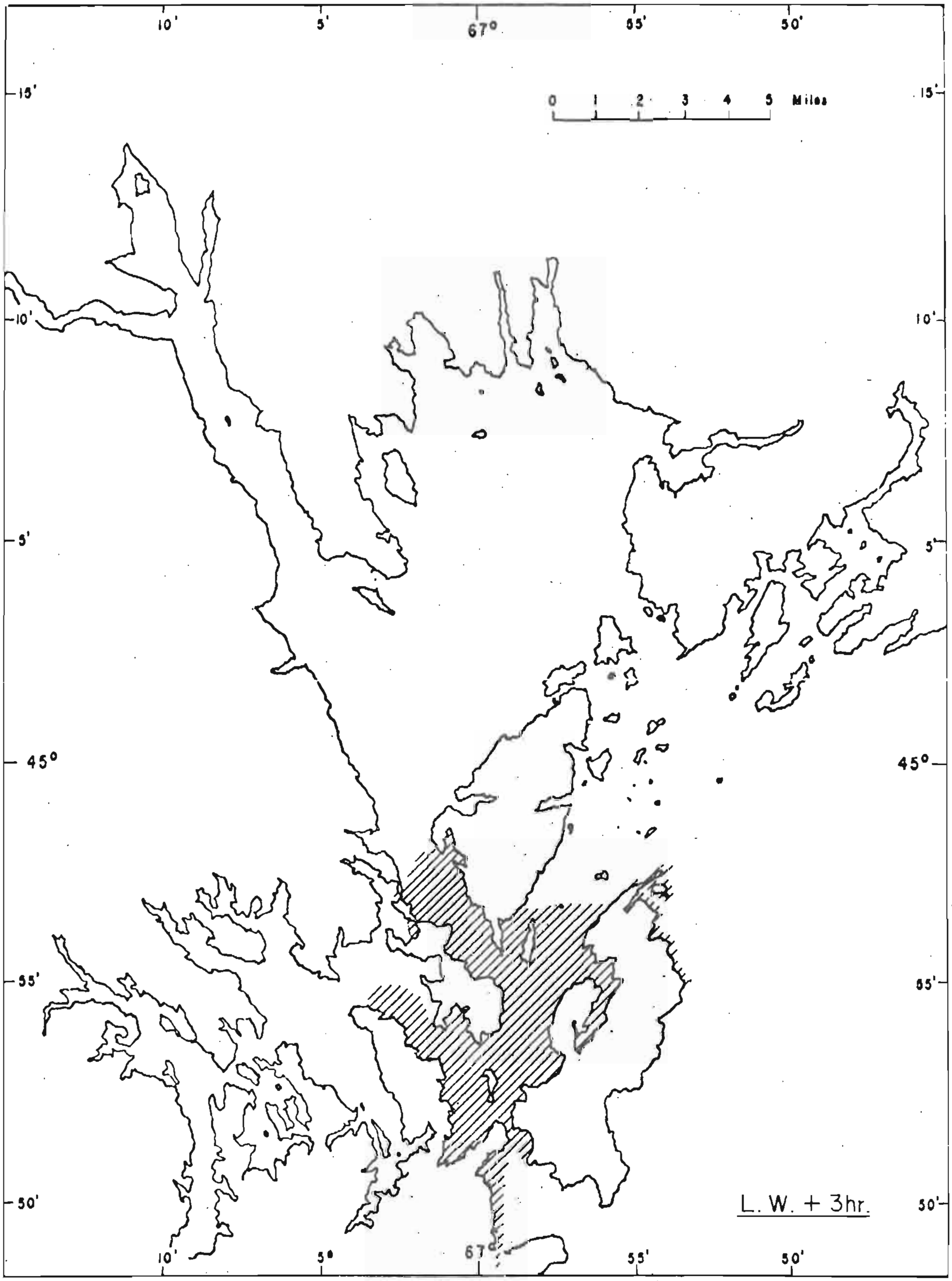


FIGURE 29

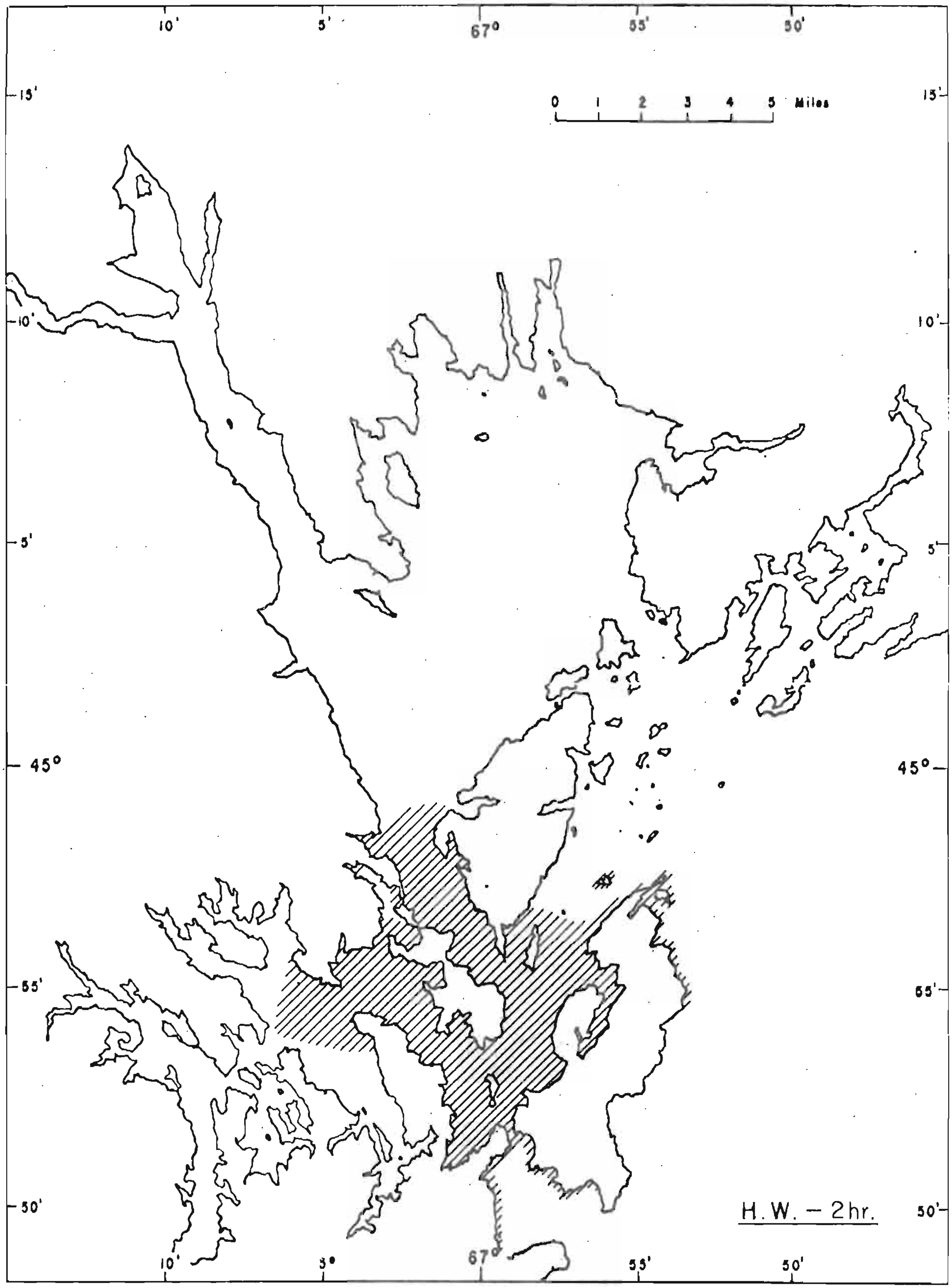


FIGURE 30

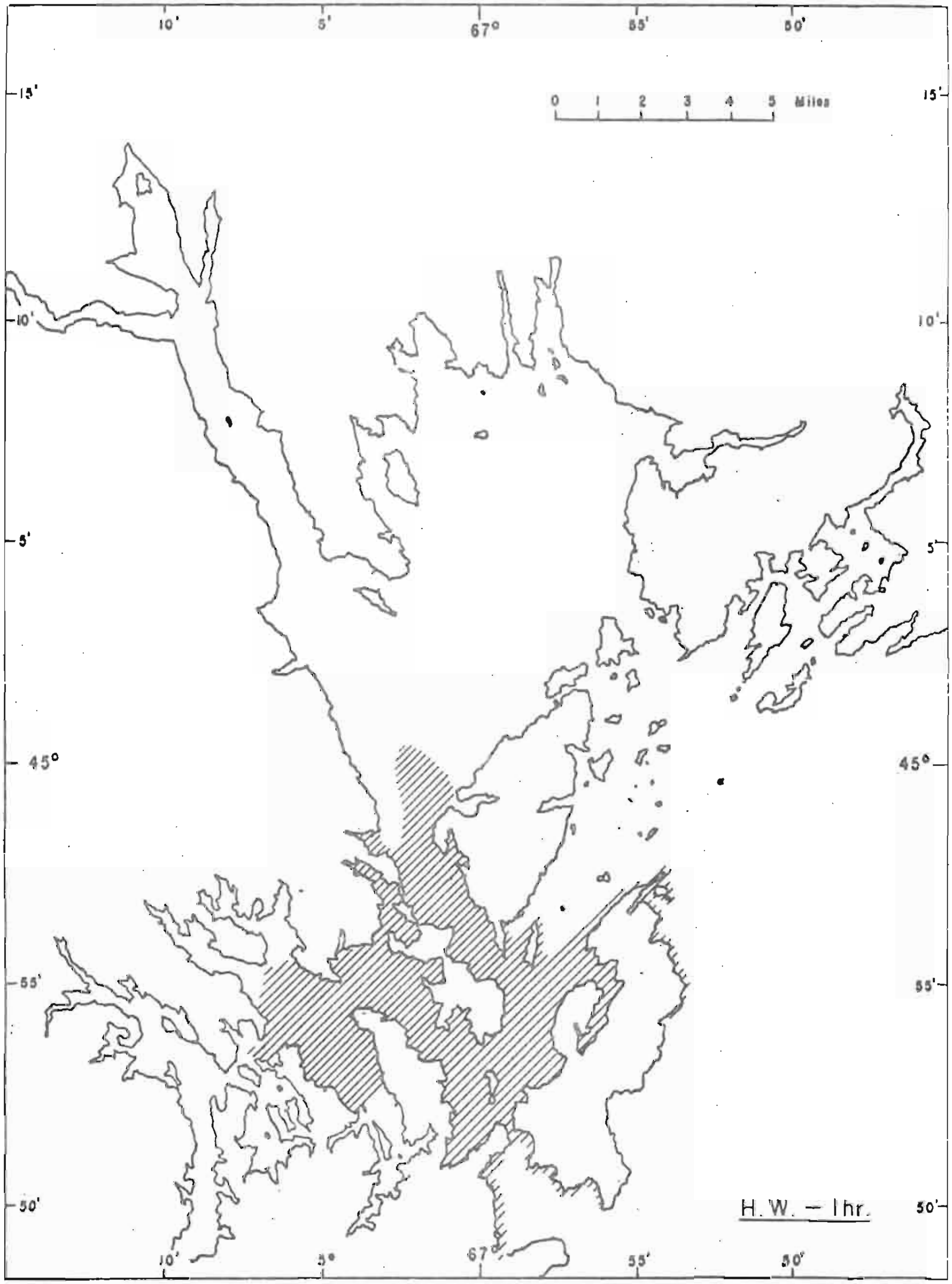


FIGURE 31

Using Forrester's diagrams for the drift and the cumulative growth curve of Figure 6 for the spreading and (minor/minor) diffusion, two scenarios have been prepared. Figures 7 to 18 show the simulated spread of a spill occurring in Head Harbour Passage at low water; Figures 19 to 31 are for a spill occurring off Estes Head one hour before high water. (One may assume the slick is torn into fragments when it becomes very thin so that turbulent diffusion of the fragments continues.) Figure 18 shows that, from a spill in Head Harbour Passage at low water, waters and shores of that Passage as well as Western Passage and Cobscook Bay would be vulnerable to contamination within 12 hours. Figure 31 shows that, from a spill off Estes Head near high water, waters and shores of the above areas would again be vulnerable and that penetration farther into Cobscook Bay and through Western Passage would be likely.

3. DISPERSION OF OIL OVER TIMES GREATER THAN 12 HOURS

The medium term implications of an oil spill which has eluded efforts at containment can be inferred from knowledge of the residual circulation of the area surrounding the spill. Such information can be obtained from drift bottle experiments. Chevrier (1959) has published results of the 1957-1958 drift bottle project (which involved 10,000 releases) in the Quoddy region. (Certain of these have been re-analyzed for present purposes.) Bumpus and Lauzier (1965) have also published surface circulation patterns in the Bay of Fundy and Gulf of Maine from drift bottle release (Section 1).

Three release areas (chosen as likely oil spill locations) in Head Harbour Passage and approaches were examined anew in order to delineate the areas affected by an oil spill, assuming that the original spill (regardless of initial size) became fragmented into tar lumps each being advected by the local currents and so simulated by a drift-bottle. The results for all seasons were lumped. The three areas of interest are: (i) off East Quoddy Head, at the entrance to Head Harbour Passage (Fig. 32); (ii) between Thumbcap Island and Campobello Island, in the middle of Head Harbour Passage (Fig. 33); and (iii) off Estes Head at dockside (Fig. 34). The figures show quite uniform scatter of drift bottle recoveries; no outstanding clear areas are identified.

Partition by seasons and years (Fig. 28, Section 1) shows the varying residual current systems. Thus (Fig. 35), oil can be expected to drift through the whole Gulf of Maine/Bay of Fundy system.

4. ESTIMATED CONCENTRATION OF OIL IN THE WATER COLUMN

Forrester (1971) reported finding oil particles from the wrecked tanker *Arrow* diffused into the water column to depths of 80 metres. This prompts one to ask what concentrations of oil might be expected to be diffused into the column from a spill in Head Harbour Passage.

The turbulent energy levels in the water column are perhaps 100-fold greater in Head Harbour Passage than in Chedabucto Bay, the site of the *Arrow* wreck of section 2 above. Consequently, diffusion of particles to depth--even particles larger than the 1 mm maximum size observed in Chedabucto Bay--would be easily accomplished. The limiting process would likely be the production of such particles. In Chedabucto Bay production of particles was believed to have occurred mainly as a result of wave and surf action (Forrester, *loc. cit.*). In Head Harbour Passage, only the northern approaches are exposed to ocean surf; however, the strong currents do contribute energy to choppy wave action, intense surface turbulence and whirlpools at certain stages of the tide. Moreover, dispersants may be used. Taking all the foregoing into account, one might guess that the maximum size of particles produced in Head Harbour Passage might equal that in Chedabucto Bay and might even exceed the latter value of 1 mm.

Forrester finds that over two decades from 1 to 100 and from 100 to 1000 microns the log-diameter volume distribution for oil particles averaged 2.17×10^{-10} and 4.68×10^{-9} cm^3/cm^3 per decade respectively. Arguing by analogy with atmospheric aerosols where log-diameter volume distributions are constant up to the large particle cut-off (Junge, 1963), then if the maximum sized particle produced in Head Harbour Passage were tenfold higher than in Chedabucto Bay, the average concentration would be doubled to 10^{-8} cm^3/cm^3.

In summary, given similar thermal conditions, concentrations of oil in the water column are anticipated to perhaps exceed those found in Chedabucto Bay. For a discussion of the ecological significance of these concentrations, the reader is referred to Section 4.

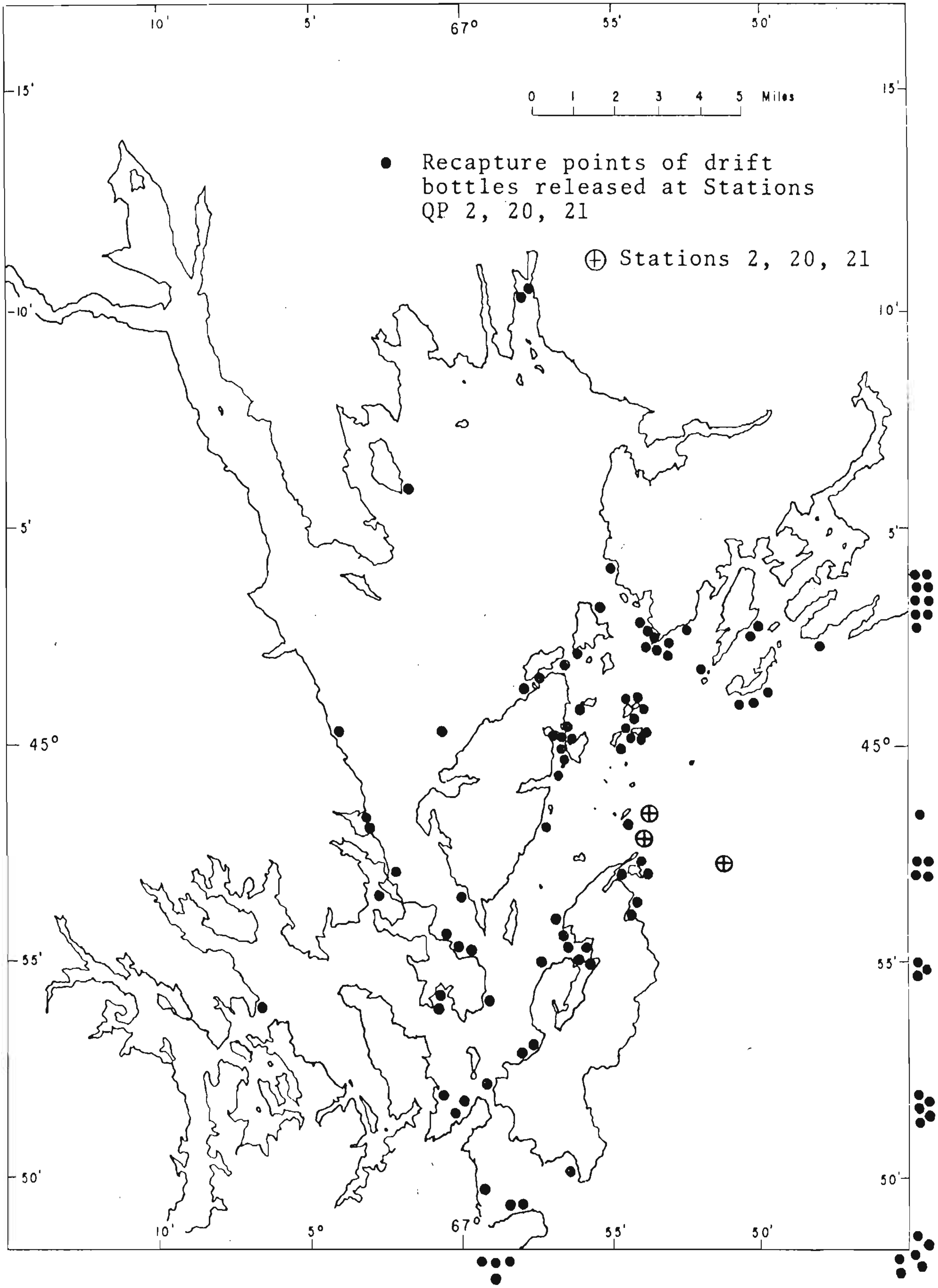


FIGURE 32: Recapture points of drift bottles released at Stations QP2, 20, 21 during the International Passamaquoddy Fisheries Investigation.

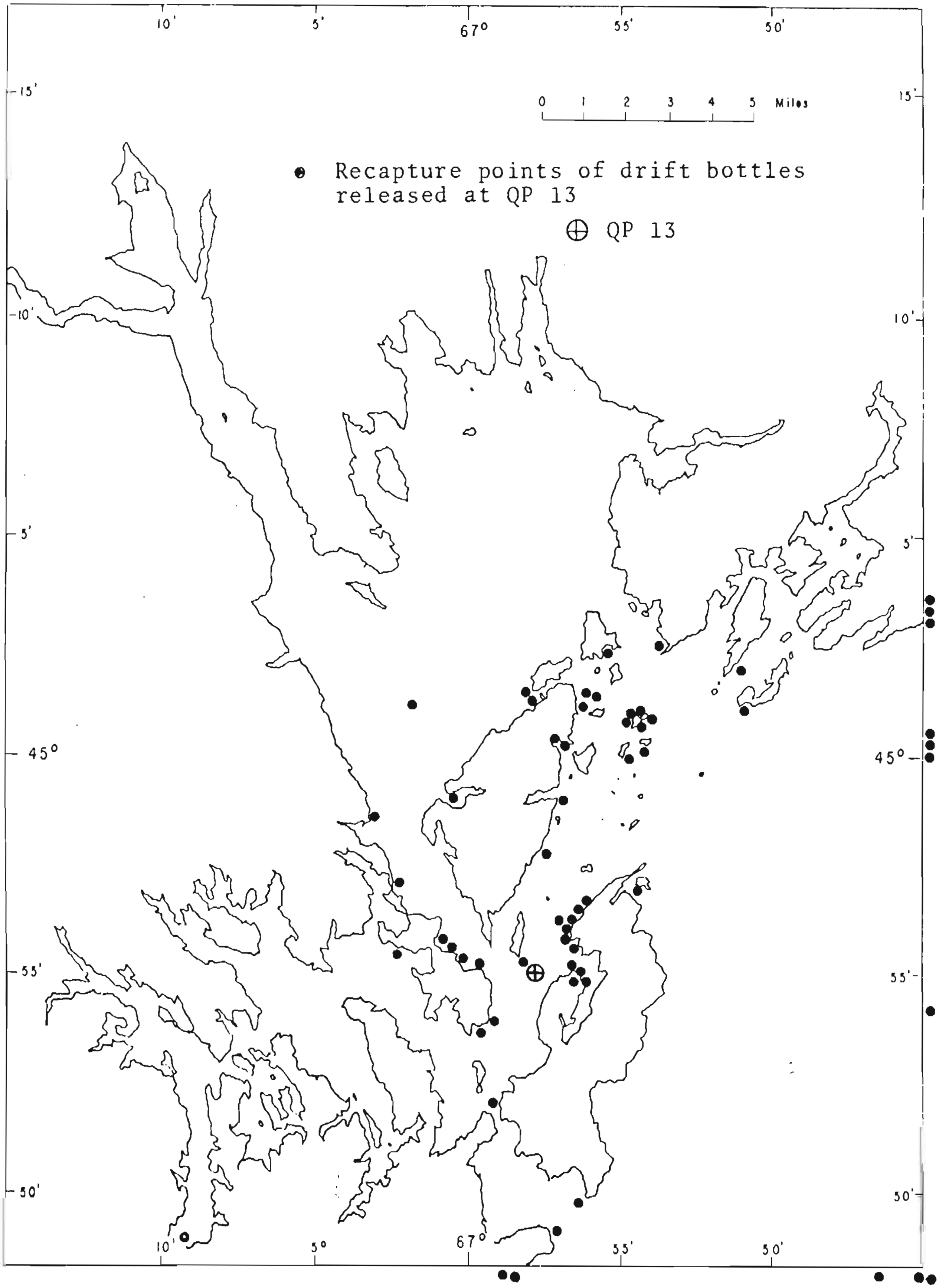


FIGURE 33: Recapture points of drift bottles released at QP13 in Head Harbour Passage

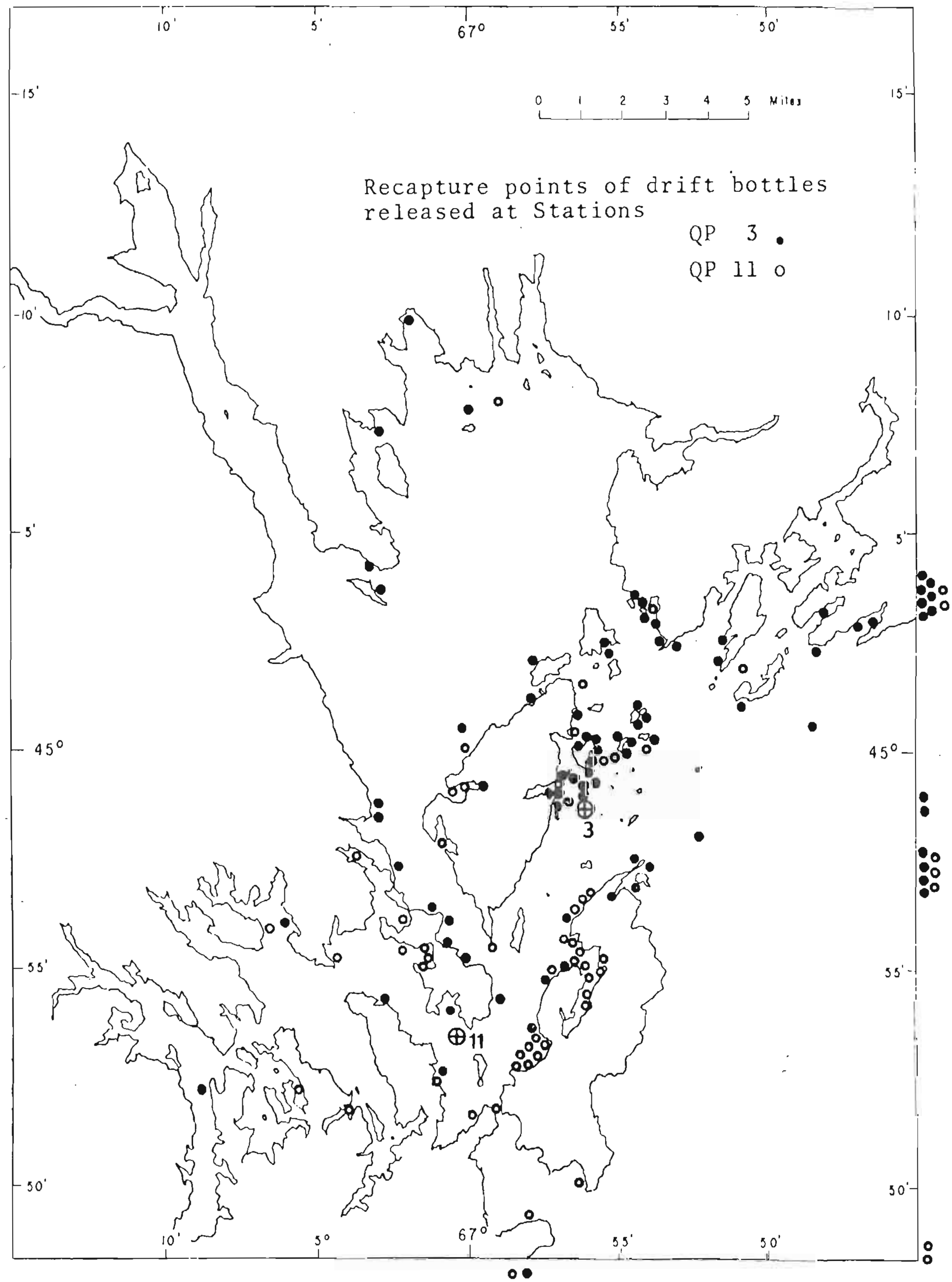


FIGURE 34: Recapture points of drift bottles released at Station QP3 in Head Harbour Passage and Station QP11 off Estes Head.

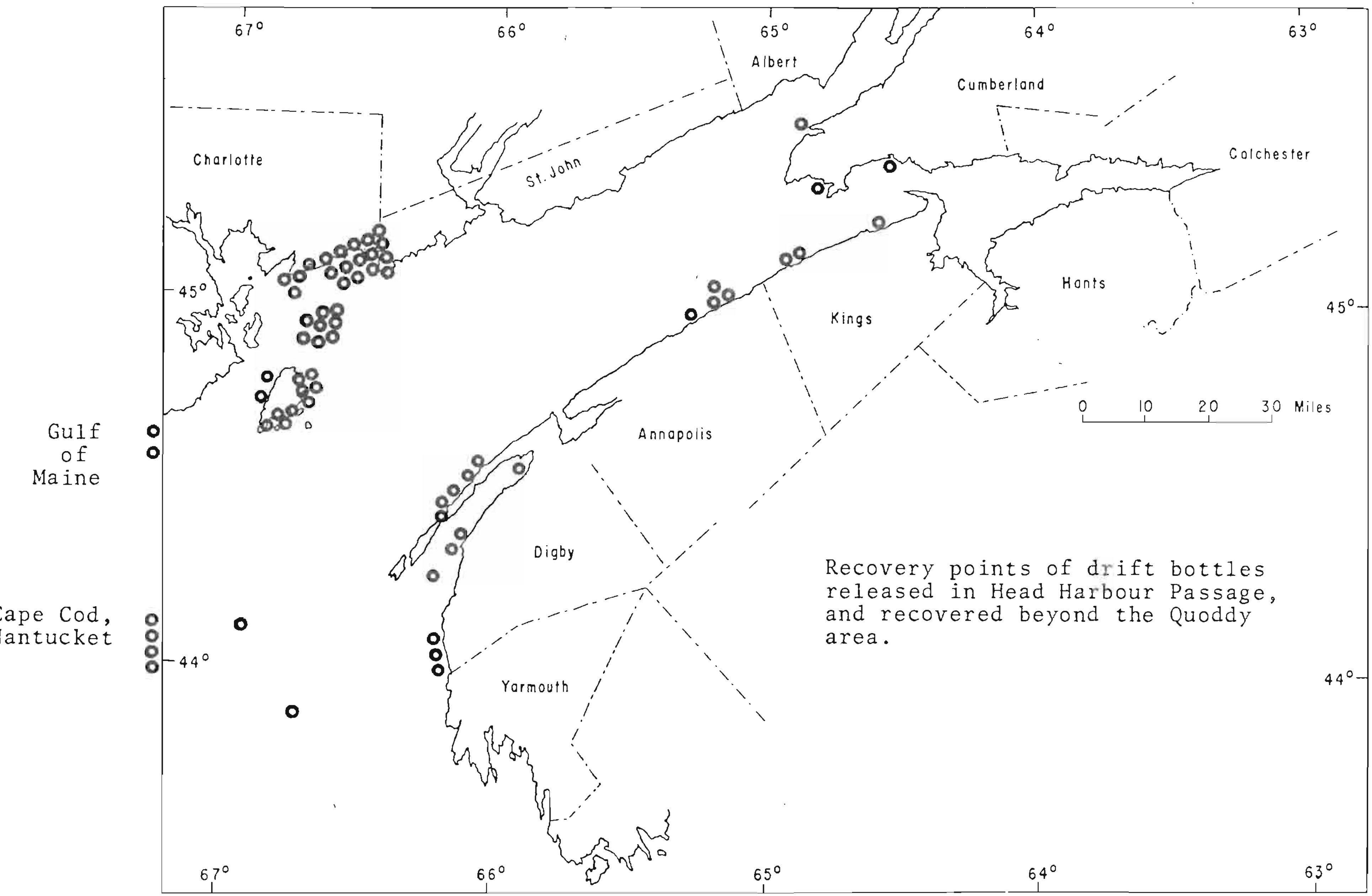


FIGURE 35: Recapture points of drift bottles recovered beyond the Quoddy area.

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SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMQUODDY REGION OF THE BAY OF FUNDY

SECTION 3

RENEWABLE MARINE RESOURCES

D.G. Wilder, P.F. Elson, D.E. Gaskin,
A.C. Kohler, W.T. Stobo and S.N. Tibbo

Fisheries Research Board
Department of the Environment
Biological Station, St. Andrews, N.B.

CONTENTS

SUMMARY

Much of our information regarding the abundance and distribution of our renewable marine resources is derived from commercial fishing operations. In the following account, annual and average landings and landed values for the years 1968-1972 are considered by species or species groups for Charlotte County, N.B., and for the whole Bay of Fundy, including Yarmouth County, N.S. Unfortunately, landing points do not accurately represent areas of capture of migratory species fished by larger, more mobile vessels. However, the quantities and values presented are reasonably good indices of the risk of oil spills to our marine renewable resources. Since the distribution of the relatively sedentary invertebrates is well represented by landings statistics, the Charlotte County data for these species have been given separately for the four statistical areas.

In *Charlotte County*, annual landings have averaged 164 million pounds with a landed value of $4.4 million (table following). Percentage contributions of the more important species or species groups by weight and value were as follows:

	Weight %	Value %
Herring	93	57
Invertebrates	2	31
Groundfish	4	11

Bay of Fundy landings averaged 435 million pounds, valued at $17.6 million (table following). Percentage contributions by the more important species or species groups by weight and value were as follows:

	Weight %	Value %
Invertebrates	3	48
Herring	80	28
Groundfish	10	19
Seaweeds	4	3
Diadromous	2	2

Average (1968-72) landings (millions of pounds) and landed values (millions of dollars) of renewable resources in Charlotte County, N.B., and in the Bay of Fundy.

	Charlotte County				Total Bay of Fundy			
		(millions of lb)		(millions of $)		(millions of lb)		(millions of $)
Herring (incl. scales)		152.4		2.5		346.9		5.0
Mackerel		1.6		-		2.4		0.1
Cod	2.4		0.2		12.4		0.9	
Haddock	1.4		0.2		11.8		1.3	
Redfish	0.1		-		1.7		-	
Hake	0.2	6.3	-	0.5	2.0	45.6	0.1	3.3
Cusk	0		0		0.5		-	
Pollock	1.7		0.1		12.4		0.6	
Wolffish	-		-		0.8		-	
Flounders	0.5		-		3.4		0.2	
Other	-		-		0.4		-	
Lobsters	1.0		1.0		7.1		7.0	
S.S. Clams	2.0		0.2		5.4		0.5	
Shrimp	0.7	3.8	0.1	1.4	0.8	14.1	0.1	8.4
Scallops	-		-		0.6		0.7	
Winkles	-		-		0.1		-	
Dulse	0.1		-		-		-	
Irish moss	0	0.1	0		14.9	18.1	0.5	0.5
Rockweed	0		0		3.1		-	
Alewives	-		-		6.9		0.1	
Shad	0		0		0.2		-	
Smelt	0		0		0.2	7.4	-	0.3
Eels	-		-		0.1		-	
Salmon	0		0		0.1		0.1	
Totals		164.3		4.4		434.5		17.6

1. HERRING

Two major Canadian herring fisheries occur in or near the entrance to the Bay of Fundy (Huntsman, A.G., 1953; McKenzie, R.A., and Tibbo, S.N., 1960). There is evidence that these fisheries, operating on opposite sides of the Bay, exploit two distinct herring stocks (Scattergood, L.W., and Tibbo, S.N., 1959).

The New Brunswick 'sardine' fisheries are the oldest large-scale herring fishery on the Atlantic coast and apparently exploit a portion of the Georges Bank herring stock. Based at Black's Harbour, the sardine industry has been a major factor in the economy of much of the New Brunswick shore (including the islands of Campobello and Grand Manan) for the last 80 years or more. The fishery takes place from spring to fall and on average 40% of the landings are from shoreline weirs. Each year there is a spring influx of 'sardines' into the Bay of Fundy near the New Brunswick coast from the south and west with a reverse movement in the fall.

The Nova Scotia herring fisheries exploit herring of a separate and distinct stock (Scattergood, L.W., and Tibbo, S.N., 1959). The fishery has two components, exploiting both juveniles and adults. The juvenile fishery based on weirs occurs along the inshore Nova Scotian side of the Bay of Fundy, and has become increasingly important in recent years as New Brunswick 'sardines' have declined in abundance. In addition, a major fishery for adults of this 'Nova Scotia' stock developed in the 1960s in the Trinity-Lurcher area in summer. The principal herring fishing areas in the Bay of Fundy are illustrated in Figure 1. Increased exploitation of this stock began in the late 1960s with the development of a foreign fishery on adults overwintering on the Scotian Shelf. To prevent increased fishing effort on the adult portion of this stock, in 1972 an internationally agreed quota of 65,000 metric tons (143 million pounds) was set for the adult stages and a 90,000 metric tons (198 million pounds) quota was set for 1973.

The Canadian Bay of Fundy herring fisheries represent a multi-million dollar industry. The quantities and values presented were obtained from the Canadian Fisheries Statistics published data. The figures refer to landed quantities and values and not necessarily to herring caught solely in the Bay of Fundy, although over 80% are caught in the Bay of Fundy environs.

During the period 1968-72, Bay of Fundy landings ranged from 191 to 596 million pounds (Table 1). Landings throughout the Bay are heaviest in the second half of the year, and since 1969 over 80% of the landings have been made during this period. Charlotte County plays an extremely important part in this fishery, with landings averaging 44% of the Bay of Fundy totals and representing 51% of the $4.6 million average yearly economic return to fishermen.

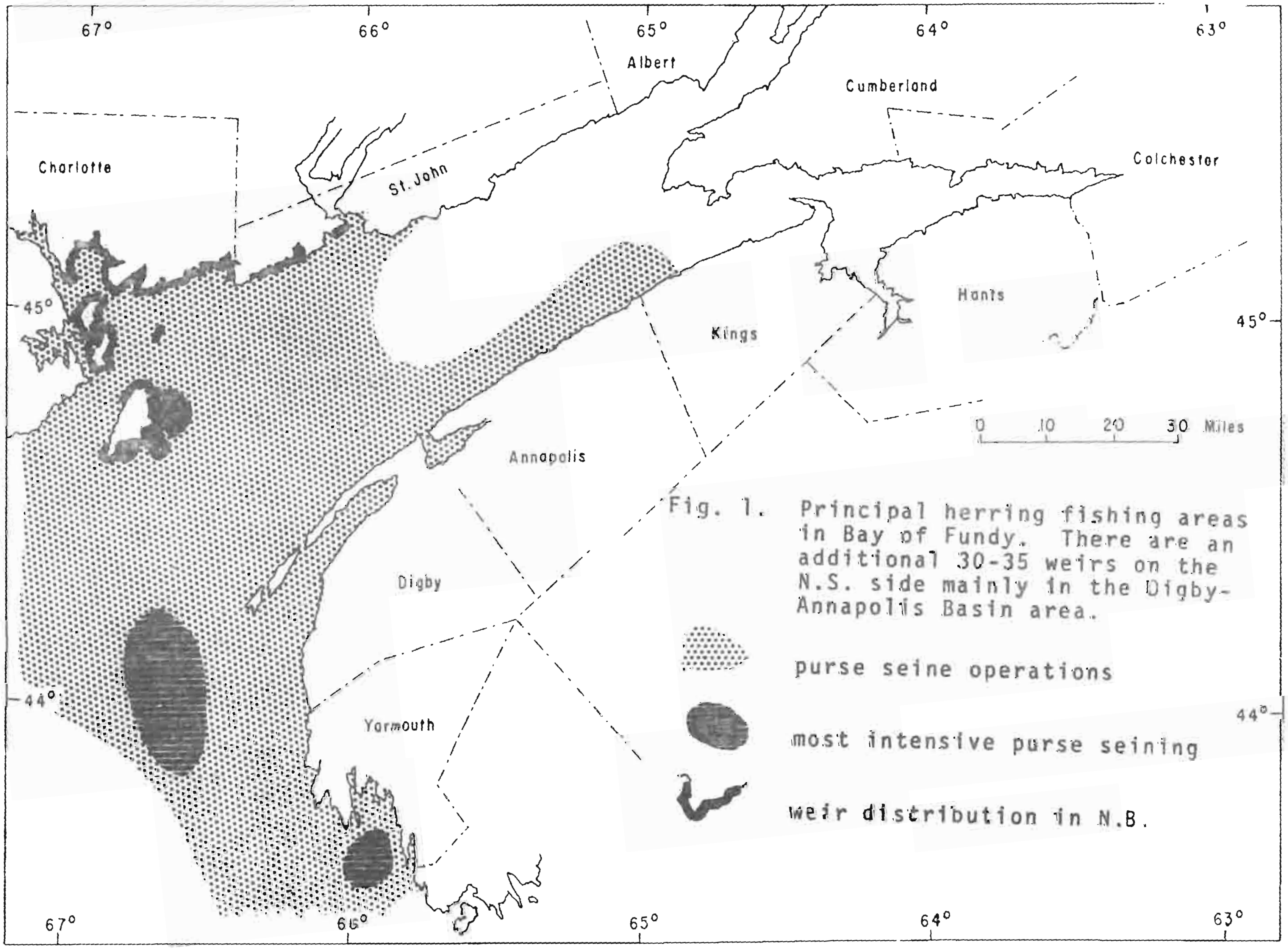

Fig. 1. Principal herring fishing areas in Bay of Fundy. There are an additional 30-35 weirs on the N.S. side mainly in the Digby-Annapolis Basin area.

Table 1. Landings and landed values of herring for Charlotte County and the Bay of Fundy, 1968-72.

	Charlotte County		Bay of Fundy	
Years	Landings (lbx1000)	Landed Values ($x1000)	Landings	Landed Values
1968	263,039	3235	596,294	6443
1969	154,136	2024	352,502	3983
1970	108,672	1658	271,971	3664
1971	78,709	1409	191,565	3122
1972	147,774	3525	303,404	5989
Mean	150,466	2370	343,147	4640

The Charlotte County fishery is based largely on fixed gear with 42% of the landings being caught in weirs (Table 2). The Nova Scotia fishery, however, is largely a mobile fleet fishery. As can be seen from Table 2, only 6% of herring landed outside of Charlotte County are caught by weirs; the remaining 94% is mainly taken by purse seiners, the majority to be processed as fish meal.

Table 2. Landings of herring by stationary gear (weirs) and mobile gear (purse seines, gill nets, mid-water trawls) for Charlotte County and the Bay of Fundy, 1968-72.

	Charlotte County		Bay of Fundy	
Years	Weirs (lbx1000)	Total	Weirs (lbx1000)	Total
1968	83,793	263,039	98,474	596,294
1969	72,463	154,136	80,240	352,502
1970	47,093	108,672	59,035	271,971
1971	34,535	78,709	44,575	191,565
1972	81,223	147,774	91,344	303,404
Mean	63,821	150,466	74,734	343,147

The product value for herring is generally accepted as being about three to four times the landed value, thus the Bay of Fundy herring resource is worth about $14 to $18 million yearly. As the demand for herring has increased, the landed price has also increased. In 1968 the 600 million pounds of herring landed in the Bay of Fundy were worth $6.4 million ($0.01/lb). By 1972 the value per pound had doubled, the 300 million pounds of landed herring being worth $6.0 million or $0.02/lb (Table 1).

The price increase is largely due to the trend to process an increasing proportion of herring as food rather than meal. Although the Charlotte County fishery has always been a predominantly food fishery, most of the Nova Scotia herring have been processed as meal. The decline of Atlantic herring stocks along with the increased world demand for this species as food would seem to guarantee no future reduction in price and should encourage, and enable, fishermen to sell more of their catch for food. This should result in an additional increase in landed value. Currently Nova Scotia fishermen are receiving $0.04/lb ($90/m.t.) for food herring and $0.10 ($220/m.t.) would seem to be a reasonable value for the future.

A valuable by-product of this fishery, but not reflected in the landed values, is herring scales. The value of herring scales has remained fairly stable over the last five years producing revenues on the average of $313,000 (Table 3).

Table 3. Quantities and value of herring scales landed in Charlotte County and the Bay of Fundy, 1968-72.

	Charlotte County		Bay of Fundy	
Years	Landings (lbx1000)	Landed Values ($x1000)	Landings (lbx1000)	Landed Values ($x1000)
1968	2982	230.7	5170	409.3
1969	2700	202.4	4446	342.1
1970	1031	78.6	2721	220.6
1971	671	50.9	2420	202.5
1972	2116	185.3	4205	391.4
Mean	1900	149.6	3792	313.2

The Bay of Fundy is also important since it appears to serve as an overwintering area for the larval and post-larval stages of a majority of the Nova Scotia stock (Stobo, W.T., and Iles, T.D., 1973). This Nova Scotia stock spawns mainly in the Trinity-Lurcher area at the entrance to the Bay. Dense concentrations of the newly hatched larvae quickly disperse within the Bay and remain there over winter (Fig. 2). Potential recruitment to later life history stages within the Bay is in a lowered condition due to reduced food availability. They are therefore highly susceptible to environmental disruption. The result of a major oil spill could be catastrophic to the stock wherever it is fished.

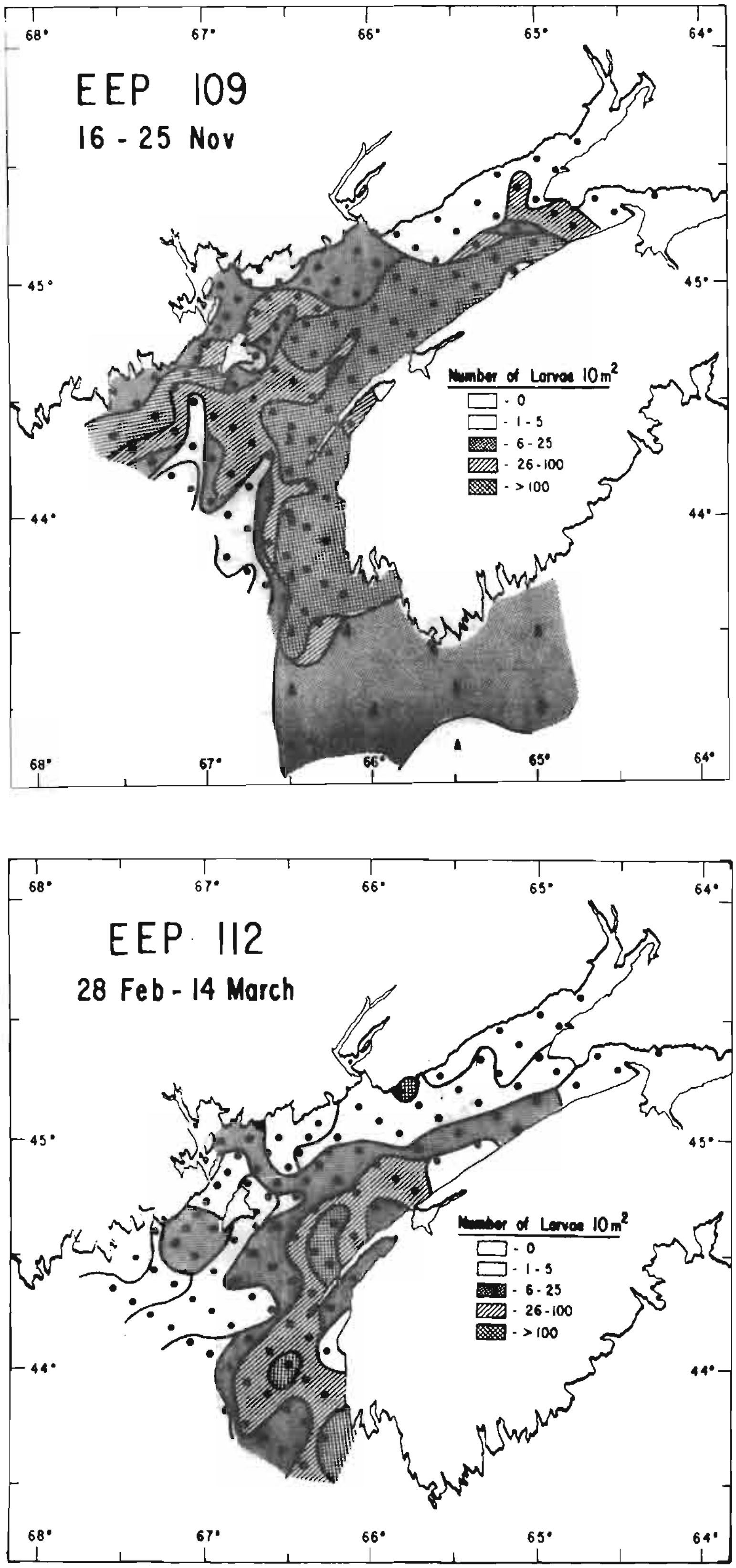

Fig. 2. The distribution of herring larvae in the Bay of Fundy are presented for survey cruises conducted in November 1972, and February-March 1973. The closed circles and triangles indicate sampling stations.

2. MACKEREL

Little is known about the potential of the mackerel resource in the Bay of Fundy. To date most of fishing effort has been directed toward herring since it is more desirable for food or meal.

The quantities and value of mackerel landed in the Bay of Fundy are presented in Table 4 for the period 1968-72. Total landings range from 0.4 to 5.2 million pounds and values from $21.1 to $85.5 thousand.

However, the decline in herring stocks along the Atlantic coast and the resultant quotas to limit the quantity of herring taken yearly will necessitate a diversion of effort to other species if the purse seine fleet is to maintain its size. Mackerel is the most likely species to absorb this effort diversion. If this occurs, a much greater effort will be directed to developing processing techniques and mackerel could become important to both purse seine and weir fisheries.

Table 4. Landings and landed values of mackerel in Charlotte County and the Bay of Fundy, 1968-72.

	Charlotte County		Bay of Fundy	
Years	Landings (lbx1000)	Landed Values ($x1000)	Landings (lbx1000)	Landed Values ($x1000)
1968	72	1.1	411	21.1
1969	803	6.8	1125	25.4
1970	4174	43.1	5193	85.5
1971	2224	20.7	2667	52.0
1972	961	8.0	2433	74.4
Mean	1647	15.9	2366	51.7

3. GROUNDFISH

Groundfish landings in Charlotte County are made up principally of cod, haddock, redfish, hake, pollock, and a mixture of flounders. Landings and landed values for Charlotte County are listed in Table 5. Landings averaged 6.3 million pounds valued at $500 thousand. Most of these fish are caught outside Passamaquoddy Bay, in the area roughly bounded by lines from Deer Island to Saint John, to Digby, to Yarmouth, to Deer Island as indicated in Figure 3.

Turning to Canadian landings and values from the whole Bay of Fundy (Table 6) we find that, in addition to the species mentioned above, cusk and wolffish are important, particularly on the Nova Scotia

Table 5. Landings (round weight) and landed values of groundfish in Charlotte County, N.B., 1968-72.

Species	Landings (lbx1000)	Value ($x1000)	Landings (lbx1000)	Value ($x1000)	Landings (lbx1000)	Value ($x1000)
	1968		1969		1970	
Cod	4088	238	2453	145	1848	124
Haddock	3428	337	1439	169	988	145
Redfish	68	3	95	4	55	2
Halibut	4	1	4	2	11	4
Hake	198	9	114	6	123	6
Cusk	2	-	-	-	-	-
Pollock	1789	73	2429	122	1960	108
Wolffish	53	2	42	3	29	1
Plaice	-	-	-	-	4	-
Witch	-	-	7	-	20	2
Yellowtail	-	-	2	-	22	1
Winter Flounder	-	-	2	-	4	-
Mixed Flounder	702	60	664	51	282	23
Others	48	2	48	3	15	1
Total	10,380	725	7299	505	5361	417
	1971		1972		Average	
Cod	1654	156	2147	211	2438	175
Haddock	741	126	389	93	1397	174
Redfish	224	7	163	5	121	4
Halibut	13	6	9	5	9	4
Hake	196	12	242	14	174	9
Cusk	-	-	-	-	-	-
Pollock	1080	76	1038	80	1659	92
Wolffish	20	1	18	1	33	2
Plaice	4	-	4	-	2	-
Witch	35	5	29	4	18	2
Yellowtail	-	-	33	5	11	1
Winter Flounder	-	-	66	7	15	1
Mixed Flounder	304	24	284	30	447	38
Others	7	-	-	-	24	1
Total	4278	413	4422	455	6348	503

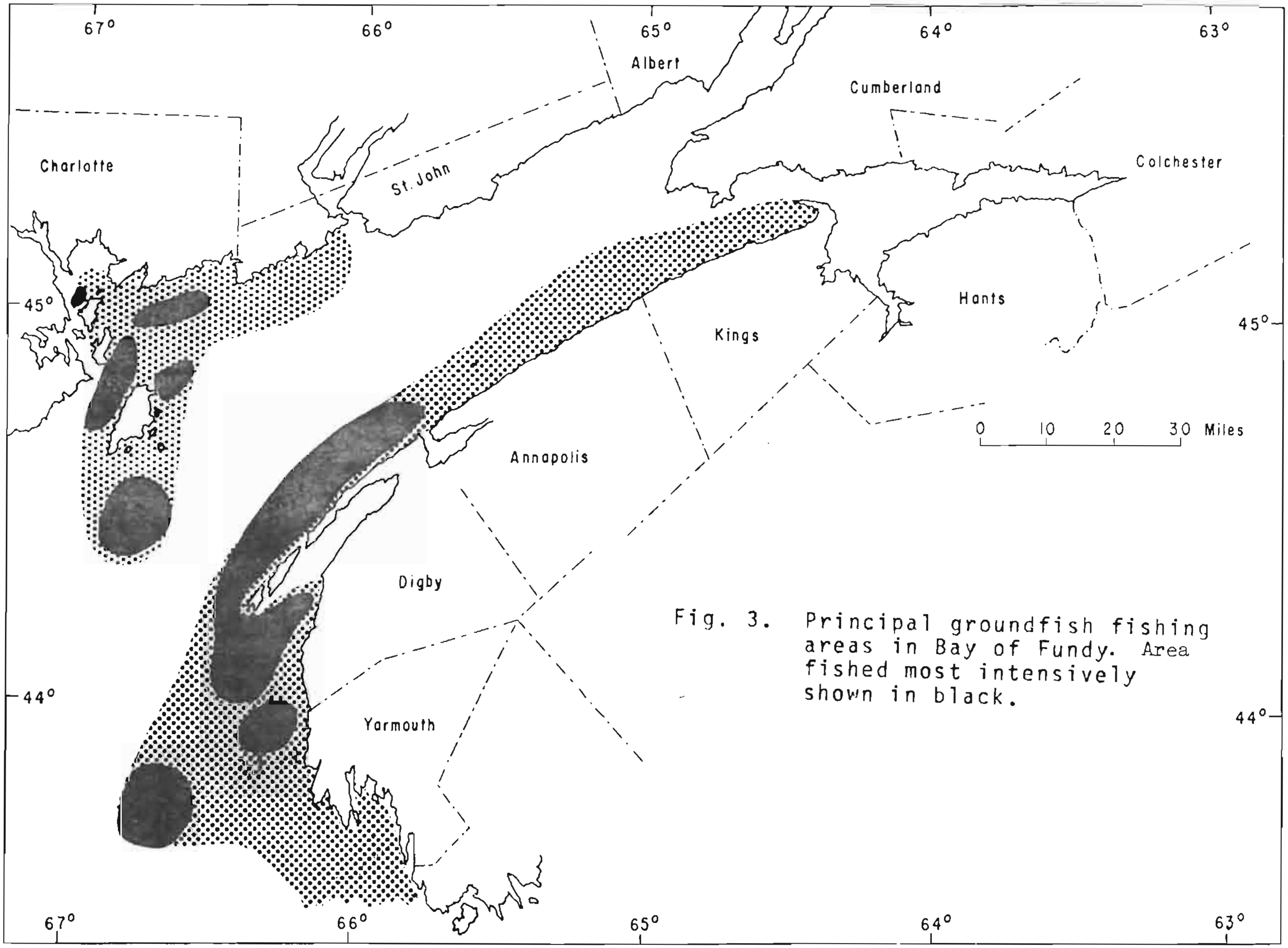

Fig. 3. Principal groundfish fishing areas in Bay of Fundy. Area fished most intensively shown in black.

Table 6. Landings (round weight) and landed values of groundfish in Bay of Fundy, 1968-72.

Species	Landings (lbx1000)	Value ($x1000)	Landings (lbx1000)	Value ($x1000)	Landings (lbx1000)	Value ($x1000)
	1968		1969		1970	
Cod	17,514	913	12,736	766	9,962	819
Haddock	22,922	1746	13,501	1394	8,349	1146
Redfish	614	16	1,870	56	1,322	45
Halibut	101	47	75	40	77	39
Hake	1,406	69	1,540	51	1,503	63
Cusk	367	16	167	6	266	11
Pollock	12,573	454	11,598	453	9,097	429
Wolffish	634	20	755	28	783	32
Plaice	-	-	59	2	62	3
Witch	-	-	97	4	108	6
Yellowtail	-	-	40	2	62	4
Winter Flounder	-	-	2	-	1,709	75
Mixed Flounder	3,021	115	3,524	180	1,520	87
Others	356	14	836	33	491	20
Total	59,508	3410	46,800	2015	35,311	2779
	1971		1972		Average	
Cod	9,878	921	11,953	1174	12,408	919
Haddock	7,421	1011	6,943	1287	11,827	1317
Redfish	2,477	107	1,982	75	1,652	60
Halibut	108	55	112	66	95	49
Hake	2,009	105	3,667	221	2,024	102
Cusk	486	23	1,124	61	482	23
Pollock	10,019	582	18,810	1131	12,419	616
Wolffish	906	41	911	47	799	34
Plaice	33	2	84	5	48	2
Witch	145	8	130	8	97	5
Yellowtail	99	6	99	7	59	4
Winter Flounder	1,954	92	1,654	95	1,065	52
Mixed Flounder	1,366	77	1,437	98	2,174	111
Others	249	10	273	14	440	18
Total	37,150	2040	49,179	4289	45,589	3312

side of the Bay. For the past five years, cod, haddock, and pollock have been the most important species landed both in weight and in value. However, haddock landings have decreased regularly from 1968 to 1972 due to overfishing. Landings from the Bay of Fundy averaged 45.6 million pounds valued at $3.3 million.

In addition to the species landed by Canadians, dogfish, silver hake, and skates are abundant. These are used by other countries fishing in the northwest Atlantic and could become of value to Canadian fishermen.

3.1 Effects of An Oil Spill on Groundfish Stocks

In the event of a major oil spill in the Bay of Fundy area, the species most likely to be affected would be those that spend some time in the intertidal zone. The main commercial groundfish species affected would be winter flounder (Tyler, A.V., 1973). To quote Tyler, "during the warmer months, winter flounders make extensive use of the intertidal zone for feeding. Large numbers swim in with the rising tide. It is this shoreline zone that would be most heavily damaged by oil. Most of the food organisms that live on the rocks or in the sediments would be killed due to smothering. Without the food supply from the intertidal zone, natural production of flounders would fall off. It is not known exactly what portion of flounder production is dependent on the intertidal zone but it is fair to say that the cutback would be substantial."

Another risk to the fishery would be minute suspended particles of oil found at depth after a spill. These are not only ingested by adult fish but would likely affect egg and larval stages, particularly during the spring and summer spawning periods. These early stages could suffer fairly large mortalities from a major spill. It is likely that if oil particles were eaten by adult fish, the fillets would have a tainted taste. Tyler has cited several studies where fish flesh has been tainted from oil pollution.

There is little doubt that the groundfish fisheries of the area would be affected by a major oil spill.

4. INVERTEBRATES

4.1 Charlotte County, N.B.

Only five species of invertebrates make appreciable contributions to the fishery. These are the lobster *(Homarus americanus)*, the soft-shelled clam *(Mya arenaria)*, the shrimp *(Pandalus borealis)*, the scallop *(Placopecten magellanicus)*, and the winkle *(Littorina littorea)*. Annual and average commercial landings and landed values of these in Charlotte County for 1968 to 1972 by statistical districts are given in Table 7. Invertebrate landings averaged 3.8 million pounds valued at $1.4 million.

The *lobster* is by far the most valuable invertebrate with an average landed value of $1 million. This inshore fishery extends from low tide level to depths of 30 fathoms or more. Landings vary seasonally because of weather, water temperature, and the lobster fishing season which is open from November 15 to June 24. Thus there is no lobster fishing from June 25 to November 14; about 5% of the catch is landed from January 1 to April 30, about 25% from May 1 to June 24, and about 70% from November 15 to December 31. The immediate effects of an oil spill would depend to a considerable extent on when the spill occurred.

Lobster larvae are free-swimming from mid-June to mid-September and are normally found in greatest numbers in the surface layers where they would be most susceptible to oil pollution. In the Bay of Fundy, plankton towing at the surface and at various depths has yielded extremely few larvae. This undoubtedly reflects a general scarcity, but the large tidal amplitude and general turbulence may distribute the larvae in the water column and so reduce surface catches. In any case, it would be virtually impossible to demonstrate directly the effects of an oil spill on the abundance or distribution of larvae in this area.

Because of its excellent hydrographic conditions and proximity to U.S. markets, Charlotte County is Canada's major area for the long-term storage of live lobsters (McLeese, D.W., and Wilder, D.G., 1964). Lobsters purchased from all Atlantic provinces in the spring and fall when catches are good are held for three to four months in large tidal pounds for marketing in summer and winter. There are ten such pounds on Grand Manan which stocked an average of 2.5 million pounds a year from 1968 to 1972. Seven similar pounds on Deer Island also stocked an average of 2.5 million pounds and a single pound on Campobello Island stocked 0.2 million pounds. The location of these pounds are shown in Figure 4. Thus, although the 18 Charlotte County pounds on the average stock 5.2 million pounds a year, the operations are seasonal and stocking patterns differ. Consequently, much less than 5.2 million pounds are at risk at any particular time. Average total stocks in storage reach a peak of 1.6 million pounds by January 1 and remain high through January, February, and early March. Stocks are negligible during April and May, climb to 1.1 million pounds by June 1, reach a peak of 1.6 million pounds by July 1, and remain high through July and early August. Less than 1/4 million pounds are impounded during September, October, and early November. By December 1, the average stock increases to 0.6 million pounds. Thus the maximum risk occurs in early January and early July when 1.6 million pounds with a market value of $3 to $3.5 million are impounded. In addition, up to 300,000 pounds may be stored in floating crates and cars and land-based tanks. In the event of a spill, the stock on hand may be killed or rendered unfit for human consumption (Wilder, D.G., 1970). The pounds themselves are unlikely to be a total

Table 7. Charlotte County invertebrates. Commercial landings and landed value, 1968-72, by statistical districts.

	Grand	Manan	West	Isles	Mainland W.		Mainland E.		Totals	
	(lbx 1000)	($x 1000)	(lbx 1000)	($x 1000)	(lbx 1000)	($x 1000)	(lbx 1000)	($x 1000)	(lbx 1000)	($x 1000)
1968										
Lobsters	617	460	97	69	46	34	95	66	856	628
S.S. Clams	0	0	14	1	506	33	353	27	869	61
Shrimp	240	26	807	81	0	0	178	43	1225	150
Scallops	33	32	8	7	1	1	4	4	45	45
Winkles	18	2	2	-	7	1	17	2	44	4
Totals	908	520	928	158	556	69	647	142	3039	889
1969										
Lobsters	944	815	141	118	64	57	146	122	1295	1112
S.S. Clams	0	0	26	2	875	48	391	35	1292	85
Shrimp	32	4	0	0	107	30	1346	337	1485	371
Scallops	1	1	0	0	0	0	2	2	3	3
Winkles	42	4	39	3	0	0	26	2	107	10
Totals	1019	824	206	123	1046	135	1911	498	4182	1580
1970										
Lobsters	828	759	130	120	80	74	102	97	1140	1050
S.S. Clams	0	0	43	3	1087	82	787	88	1917	173
Shrimp	94	18	31	5	0	0	198	43	323	65
Scallops	18	21	0	0	3	4	3	4	25	20
Winkles	46	4	10	1	2	-	37	3	95	8
Totals	986	802	214	129	1172	160	1127	235	3499	1326
1971										
Lobsters	796	839	111	117	67	73	73	76	1047	1104
S.S. Clams	30	2	37	3	1783	142	1600	183	3450	331
Shrimp	0	0	34	9	0	0	201	40	235	49
Scallops	4	4	1	1	4	5	10	13	18	23
Winkles	52	5	13	2	0	0	19	1	84	17
Totals	882	850	196	132	1854	220	1903	313	4835	1515
1972										
Lobsters	653	878	88	118	58	75	59	76	857	1146
S.S. Clams	1	-	5	1	1140	105	1279	218	2424	325
Shrimp	0	0	1	-	0	0	140	22	142	22
Scallops	7	11	1	1	1	1	14	23	22	35
Winkles	52	5	13	2	1	-	7	1	73	8
Totals	713	894	108	122	1200	181	1499	340	3520	1537
Av. 1968-72										
Lobsters	768	750	113	108	63	63	95	87	1039	1008
S.S. Clams	6	-	25	2	1077	82	882	110	1990	195
Shrimps	73	10	175	19	22	6	413	97	682	131
Scallops	13	14	2	2	2	2	7	9	23	27
Winkles	42	4	15	2	2	-	21	2	81	7
Totals	902	778	330	133	1166	153	1418	305	3816	1369

loss but might require costly, time-consuming cleaning. This would involve loss of revenue while they were out of commission.

Soft-shelled clam landings averaged about 2 million pounds valued at $200,000. Stocks are primarily intertidal and are extremely vulnerable to damage from oil spills. Clam flats in Chedabucto Bay have remained closed for almost 4 years following the spill of Bunker C oil from the *Arrow* (Thomas, M.L.H., 1973). Virtually all landings are from the Charlotte County mainland where considerable areas are closed to clam digging because of pollution or paralytic shellfish poisoning. If pollution could be reduced or the clams cleansed and if fuller use could be made of clams from Class III toxic areas, production might be up to one-third greater than at present. There is no consistent seasonal pattern in the landings.

The relatively new *shrimp* fishery centred around Grand Manan reached peak landings of 1.5 million pounds in 1969 valued at $370,000. The fishery declined rapidly to about 140,000 pounds valued at $20,000 in 1972. Fisheries for this species in other parts of the world have fluctuated markedly. Similar and possibly greater fluctuations are to be expected in the Charlotte County stock, a northern extension of the much larger Gulf of Maine population. The fishery is conducted primarily with bottom trawls at depths of 20 to 60 fathoms from January to May.

Scallop landings averaged 23,000 pounds valued at $27,000. In some years, production is considerably higher than indicated by the landings. In the fall of 1971, for example, Digby boats caught at least 24,000 pounds of scallops in Passamaquoddy Bay which were landed and reported at Digby, N.S. In Charlotte County scallops are fished at depths of 10 to 50 fathoms or more. There is no clear, consistent seasonal pattern to the landings.

The common *periwinkle* which occurs in the intertidal zone supports a small but stable fishery with an average production of 80,000 pounds valued at $7500. They are harvested most actively during summer and early fall but some are taken throughout the year.

Other Charlotte County invertebrate species that are not yet used commercially but hold some promise for development are the sea urchin *Strongylocentrotus droebachiensis)*, the Jonah Crab *(Cancer borealis)*, the blue mussel *(Mytilus edulis)* and the striped shrimp *(Pandalus montagui)*. Neish has estimated the total biomass of sea urchins *(S. droebachiensis)* in Charlotte County at 51 million pounds live weight of which about 5.5 million pounds were roe (Neish, I.C., 1973a).

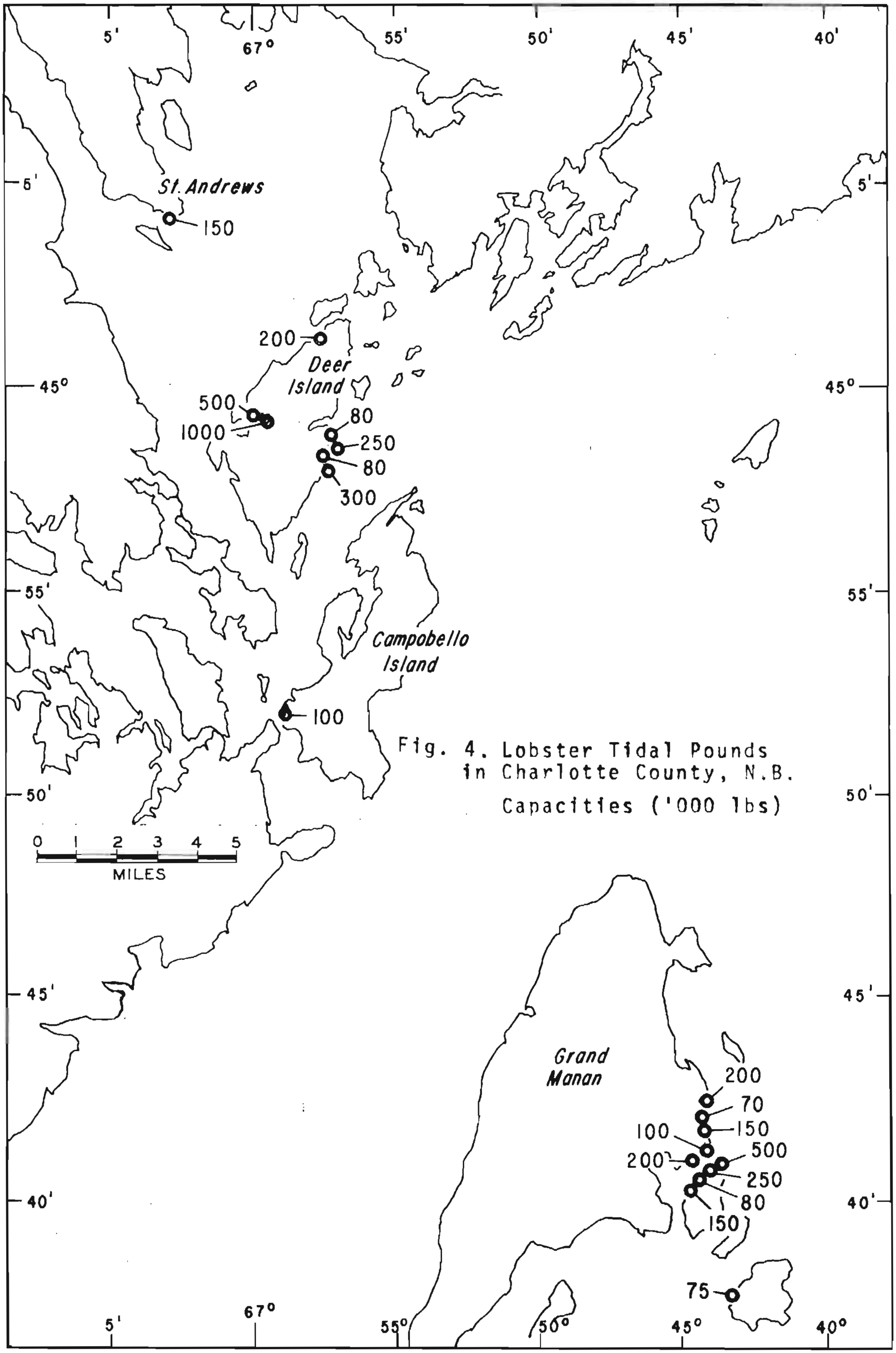

Fig. 4. Lobster Tidal Pounds in Charlotte County, N.B.

Capacities ('000 lbs)

4.2 Bay of Fundy

Eight species of invertebrates contribute to the fishery. Average annual landings and landed values for each species for the period 1968-72 are listed in Table 9 for the Bay as a whole. Landings of all species averaged 14.1 million pounds valued at $8.4 million. Over 80% of the landed value was from the Nova Scotia side of the Bay. About 88% of the landed value on the New Brunswick side was from Charlotte County.

The *lobster* is by far the most important invertebrate contributing 83% of the invertebrate landed value. The seasonal pattern of landings in Nova Scotia differs from New Brunswick primarily because of differences in the lobster fishing seasons. About 50% of the N.S. catch is landed in December and 37% from April 1 to June 30. The remainder (13%) is landed in January, February, March, July, October and November. There is no fishing on the N.S. side from July 21 to October 15. On the N.S. side, 72% of the lobsters are landed in Yarmouth County and 24% in Digby County. The distribution of Bay of Fundy landings in 1972 is shown in Figure 5. There are four tidal pounds in Yarmouth County with a total capacity of 0.5 million pounds. These N.S. tidal pounds probably handle in the vicinity of 750,000 pounds per year but the quantity at risk during peak storage periods in early January and early June would be less than 500,000 pounds. In N.S. there is additional storage capacity for 350,000 pounds in cars and tanks.

Nova Scotia *scallop* landings represent essentially the Digby scallop fishery. Landings by larger vessels at Saulnierville and Yarmouth being largely from Georges Bank outside the Bay of Fundy have not been included. The distribution of landings in 1972 is shown in Figure 6.

About 87% of the *soft-shelled clams* reported from the N.S. side of the Bay are landed in Digby County and the southern half of Annapolis County. The remainder are landed in Colchester County from flats in Minas Basin and Cobequid Bay (Fig. 7).

Shrimp landings on the N.S. side of the Bay have declined from 430,000 pounds in 1970 to virtually nothing in 1972. Over 90% of the catch has been landed in Digby County.

The fishery for *winkles* on the N.S. side of the Bay has been extremely variable with peak landings of 80,000 pounds in 1969 and no fishery in 1971. The entire crop is landed in Digby County.

The entire *baitworm* production was from the northern half of Yarmouth County and the fishery was prosecuted in the summers of 1968 and 1969 only. Average production for these two years was 21,000 pounds with a landed value of $16,000, considerably higher than the 5-year average given in Table 9. The principal species is the bloodworm *(Glycera dibranchiata)*.

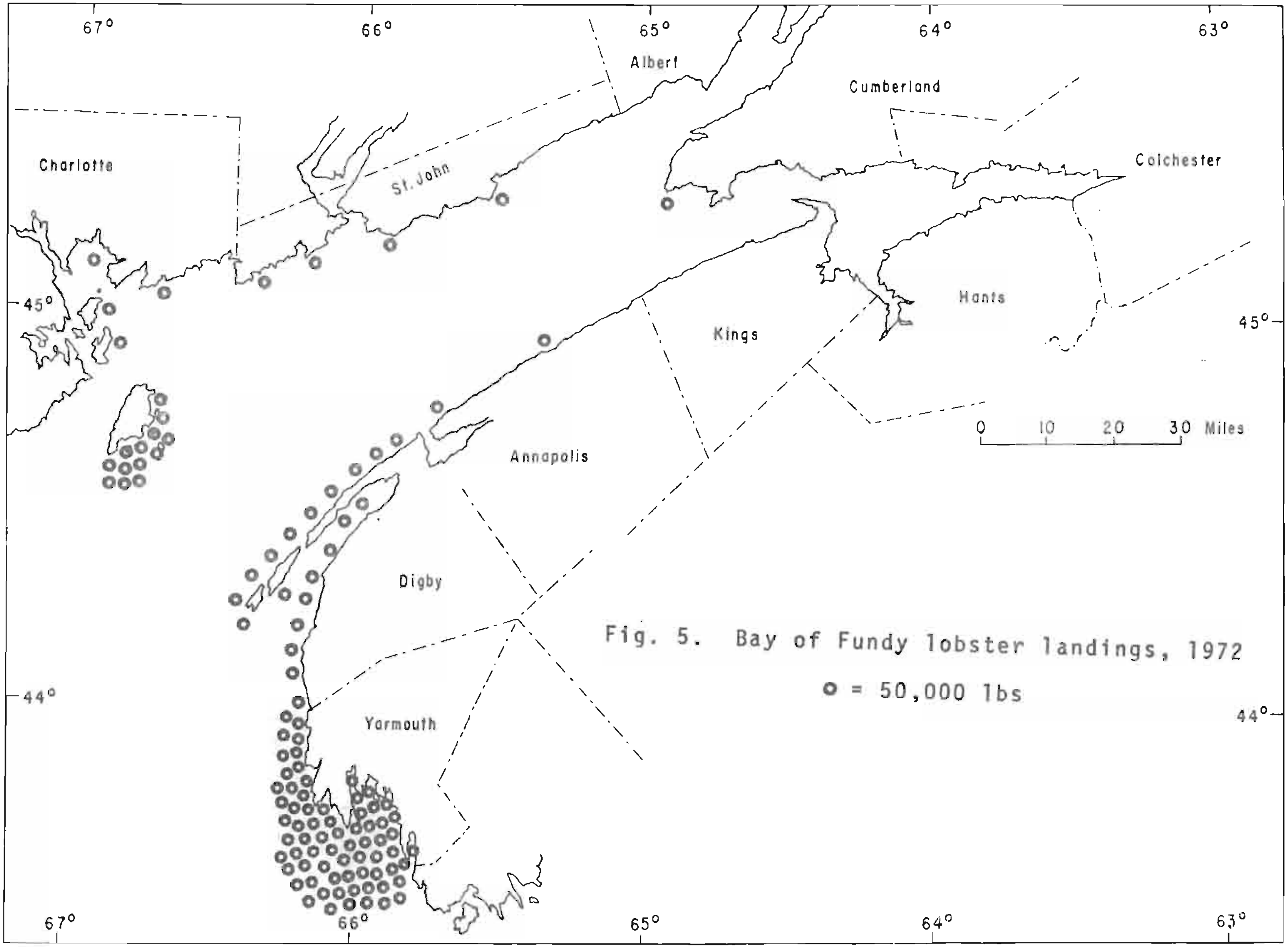

Fig. 5. Bay of Fundy lobster landings, 1972

○ = 50,000 lbs

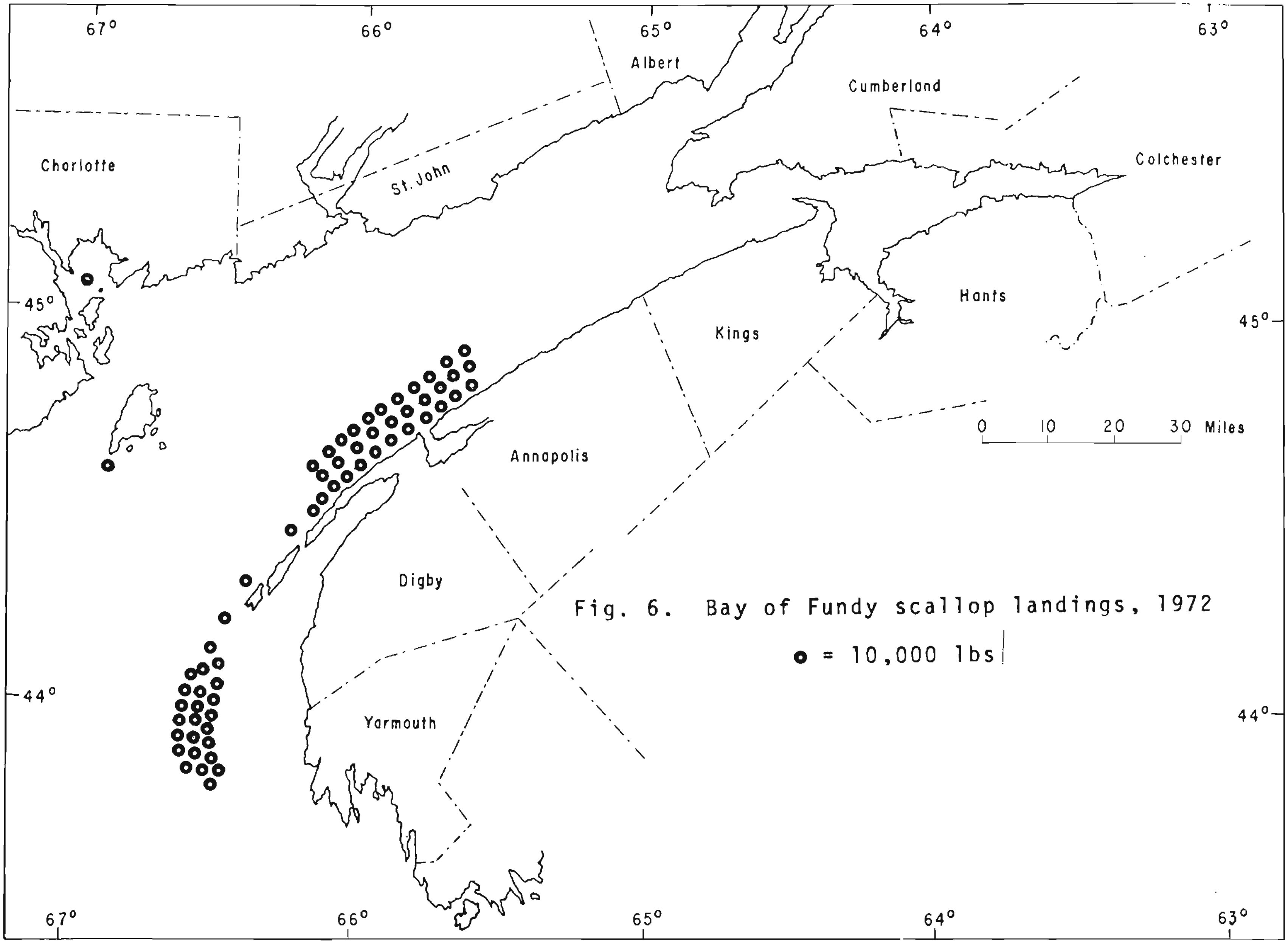

Fig. 6. Bay of Fundy scallop landings, 1972

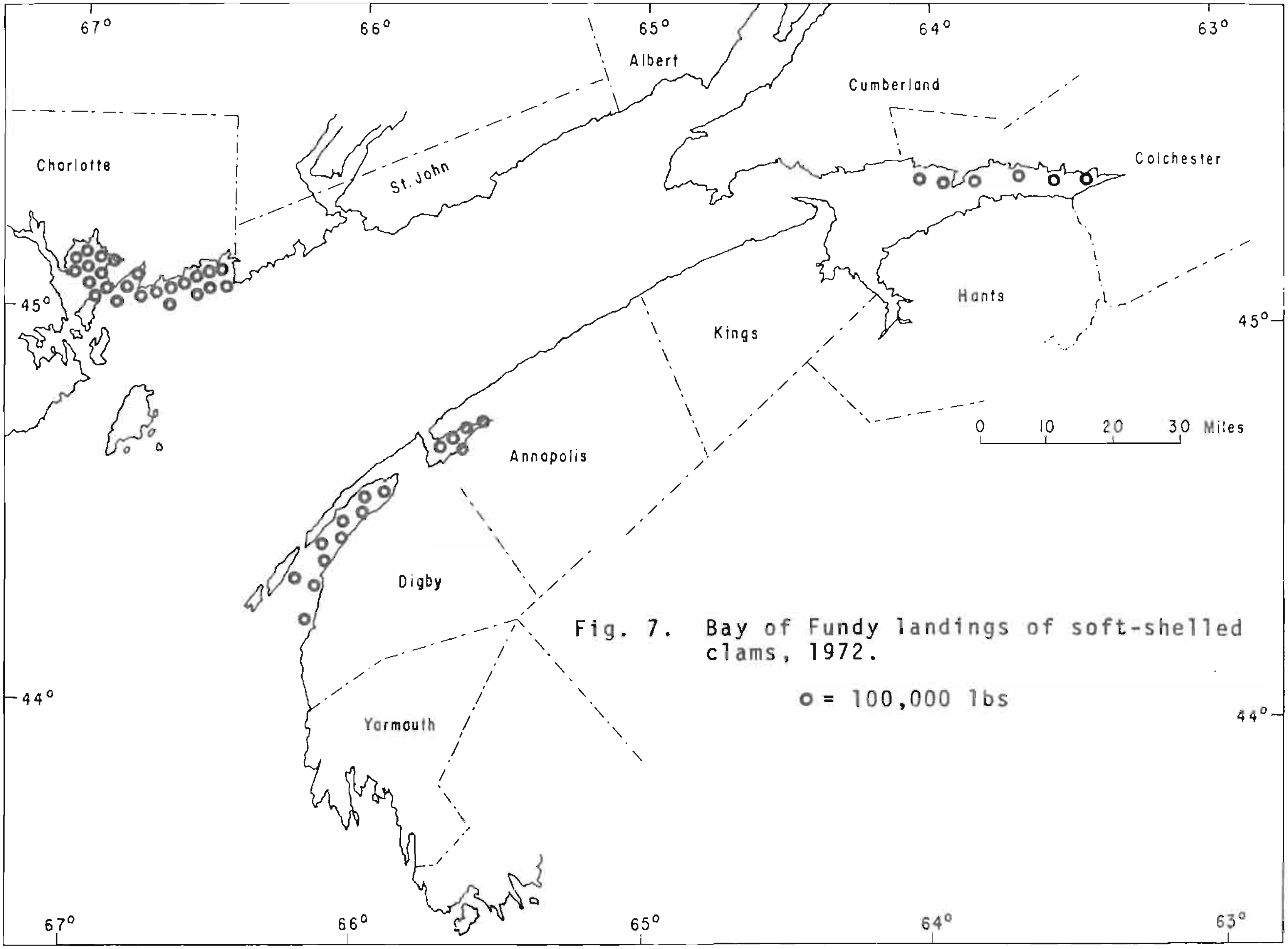

Fig. 7. Bay of Fundy landings of soft-shelled clams, 1972.

o = 100,000 lbs

Table 9. Bay of Fundy invertebrates. Average landings and landed value, 1968-72.

Species	Total Bay of Fundy (lbx1000)	($x1000)
Lobsters	7121	7018
Scallops	637	730
S.S. Clams	5423	486
Shrimp	773	149
Winkles	118	10
Baitworms	8	6
Bar Clams	52	5
Crabs (unspecified)	14	1
Totals	14,146	8405

The *bar clam (Spisula solidissima)* fishery is restricted to the southern half of Digby County.

The unspecified crabs were all landed in the northern half of Digby County and are almost certainly the Jonah crab *(Cancer borealis)*.

In addition to the invertebrates listed above, the *ocean quahog (Arctica islandica)*, although not yet used commercially, may occur in commercial quantities in the Bay of Fundy.

5. DIADROMOUS

Diadromous species which spend part of their lives in marine areas near shore and frequently near surface are likely candidates for damage by oil spills. All species range widely and hence are likely to reach a spill which did not occur in their immediate vicinity.

Species contributing to the commercial fisheries of the area are the anadromous Atlantic salmon *(Salmo salar)*, alewives *(Alosa pseudoharengus)*, shad *(Alosa sapidissima)*, and smelt *(Osmerus mordax)* and the catadromous eel *(Anguilla rostrata)*. Salmon in particular also have high recreational value, probably much higher than their commercial value. It has been estimated, for example, that salmon angled in New Brunswick contribute possibly 5 to 10 times as much as the commercial fishery despite the fact that 5 to 10 times more fish are taken in the commercial fishery. The striped bass *(Roccus saxatilis)* of the Saint John and other rivers is drawing increasing attention from anglers. Anadromous speckled trout *(Salvelinus fontinalis)* occur in some streams in the area.

5.1 Commercial Fisheries

There are no significant, consistent fisheries for diadromous species in Charlotte County. A few thousand pounds of alewives, eels and sturgeon are taken some years but the combined average landed value is less than $1000.

Table 10 shows landings and landed values of diadromous species for the Bay of Fundy as a whole for the years 1968 to 1972.

Salmon landings declined so drastically in 1969 that commercial fishing in New Brunswick was closed in 1972 to permit recovery of the stock. Salmon landings from 1968 to 1971 averaged 84,000 pounds valued at $72,000. The distribution of the Bay of Fundy commercial and angled catch in 1971 is shown in Figure 8. Some post-smolt salmon of the Saint John system and other rivers do reach Charlotte County in late summer and autumn and would be exposed to oil spills in the Eastport area and approaches.

Landings of *alewives* have varied from 1.0 to 15.8 million pounds valued at $38,000 to $295,000. The distribution of landings in 1971 is shown in Figure 9. *Shad* landings have ranged from 70,000 to 251,000 pounds worth $14,000 to $37,000. The migratory habits of alewives and shad have received little study but it is reasonable to suppose that their coastwise movements would somewhat resemble those of salmon, particularly as affected by marine currents.

Landings from the small but relatively stable *smelt* fishery have averaged 175,000 pounds valued at $25,000.

Eel landings have varied from 40,000 to 217,000 pounds worth $5000 to $49,000. Eels are abundant in all Bay of Fundy streams. The juveniles approach shore probably in late winter and certainly in spring, swimming in the upper water layers. It has been noted that in streams where the young had to pass through polluted waters, eels tended to decrease in numbers. For the most part, eels have not been heavily exploited but in the past few years export demand has increased and prices have doubled.

Landings of all diadromous species in the Bay of Fundy have averaged 7.4 million pounds valued at $279,000.

Table 10. Landings and landed value of diadromous species in Bay of Fundy, 1968-72.

Year	Species	lbx1000	$x1000
1968	Alewives	5645	104
	Shad	102	17
	Smelt	192	30
	Eels	40	5
	Sturgeon	9	1
	Salmon	152	118
Total		6140	275
1969	alewives	1035	38
	Shad	70	14
	Smelt	258	28
	Eels	79	9
	Sturgeon	2	-
	Salmon	55	49
Total		1499	138
1970	Alewives	1385	46
	Shad	181	20
	Smelt	178	28
	Eels	56	11
	Sturgeon	1	-
	Salmon	81	70
Total		1882	175
1971	Alewives		295
	Shad	251	33
	Smelt	156	26
	Eels	217	49
	Sturgeon	8	3
	Salmon	49	50
Total		16,453	456
1972	Alewives	10,478	244
	Shad	216	37
	Smelt	90	14
	Eels	129	34
	Sturgeon	18	7
	Salmon	12	16
Total		10,943	352
5-year average	Alewives	6863	145
	Shad	164	24
	Smelt	175	25
	Eels	104	22
	Sturgeon	8	2
	Salmon	84*	72*
All Species		7383	279

* 4-year average for salmon since commercial fishery in New Brunswick closed in 1972.

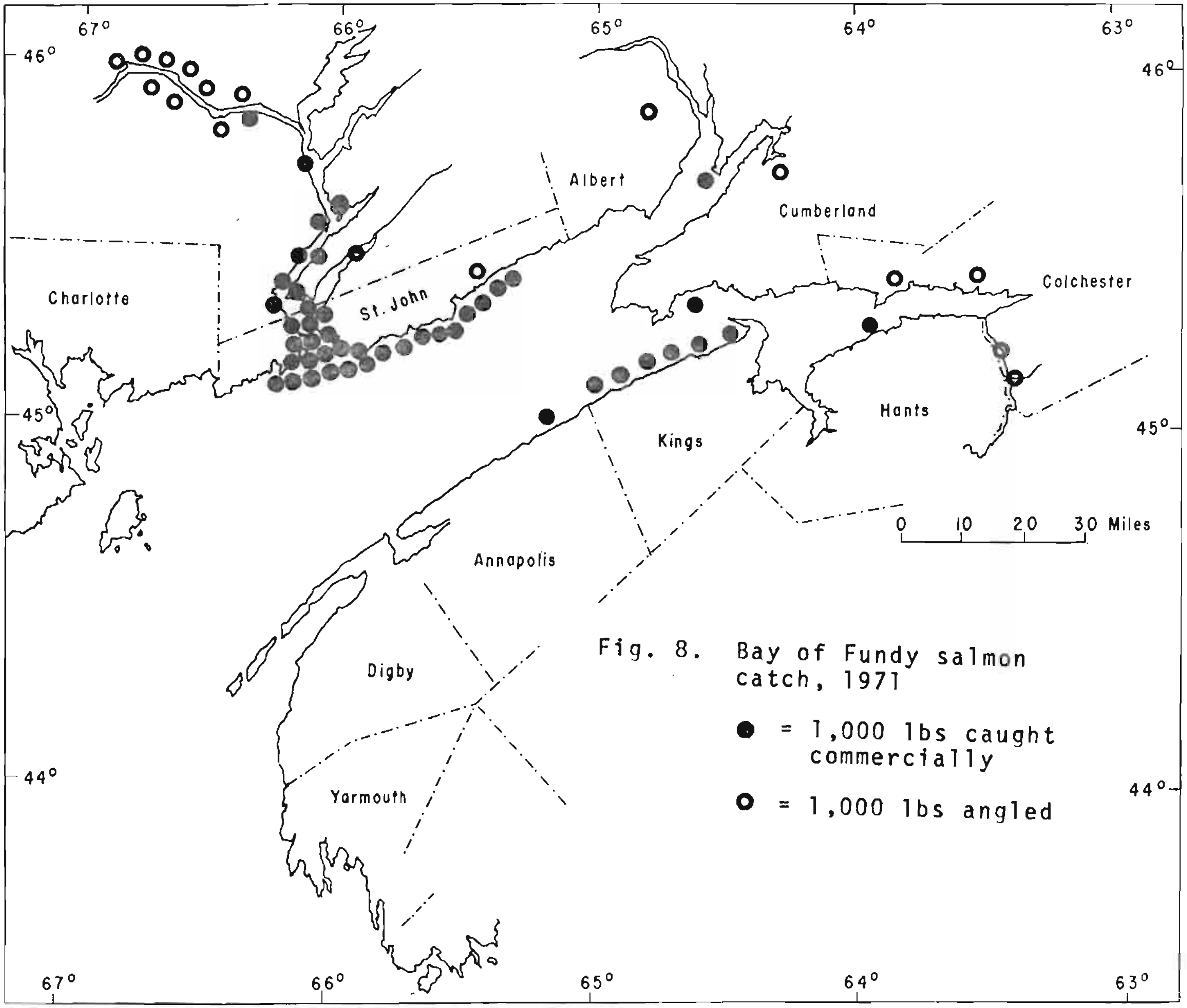

Fig. 8. Bay of Fundy salmon catch, 1971

● = 1,000 lbs caught commercially

○ = 1,000 lbs angled

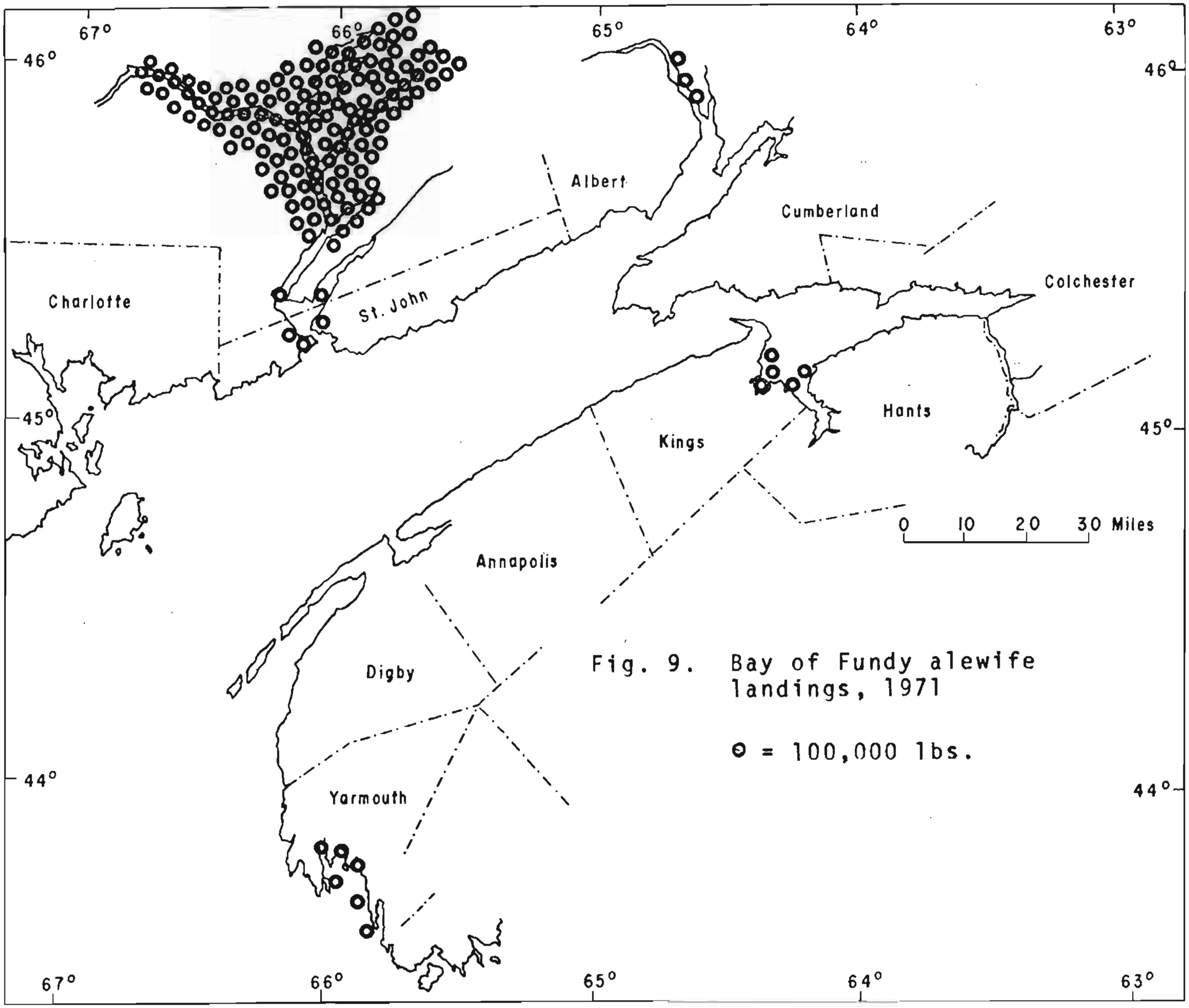

Fig. 9. Bay of Fundy alewife landings, 1971

⊖ = 100,000 lbs.

5.2 Sport Fisheries

At least four Charlotte County streams have salmon stocks which move through Passamaquoddy Bay as smolts and adults. These streams support limited angling with a total of possibly 100 salmon being taken annually.

Salmon angling is important in more distant streams. The Saint John River, for example, yielded 2636 salmon to anglers in 1954. In recent years the catch in this river has fallen to a few hundred fish, primarily because of forest spraying, hydro-electric development, and pollution. Hopefully, conservation efforts will be successful in restoring the recreational potential exemplified by the 1954 catch. Economists have estimated values of $50 to $200 for each large salmon angled. At the intermediate figure of $100, the 1954 Saint John angling catch would have a value of $264,000 - equivalent to the average total value of all diadromous species caught commercially in the Bay of Fundy.

The striped bass sport fishery is of increasing importance on both sides of the Bay of Fundy. These fish are believed to move coastwise, frequently within 2 to 5 miles of shore. They are angled seasonally in the estuaries of at least four Charlotte County rivers but are more important in the Saint John, Shubenacadie and Annapolis rivers. They frequently swim near the surface and are voracious. Hence they would be vulnerable to direct effects of oil spills and to indirect effects from eating contaminated prey.

Anadromous speckled trout *(Salvelinus fontinalis)* provide an added attraction in many streams.

There is no accurate method for assessing the value of angling for anadromous species in the Bay of Fundy as a whole. However, a figure of $750,000 is believed to be realistically conservative.

5.3 Combined Commercial and Sport Fisheries

There is a negligible commercial fishery for diadromous species in Charlotte County but possibly 100 salmon are angled there each year. If, as estimated by economists, each fish is worth $100 (or more) their annual recreational value would exceed $10,000.

For the Bay of Fundy as a whole, the combined landed value from the commercial fishery and the value of angled fish possibly exceeds $1 million. The product value from the commercial fishery would be considerably higher than the landed value of $279,000.

6. SEAWEEDS

The only seaweed used commercially in Charlotte County at present is dulse *(Rhodymenia palmata)*. Annual landings from 1968-72 were quite consistent, averaging 75,000 pounds with a landed value of $36,000. About 95% of the harvest came from Grand Manan, the remainder from Charlotte County East. According to Neish (1973b) the probable sustainable yield is 10 times the present harvest.

There is no other seaweed harvest on the N.B. side of the Bay of Fundy. However, Neish (1973b) estimates the standing crop of kelp *(Laminaria* spp.*)* in the Grand Manan area at 29 million pounds and believes there are excellent prospects for commercial exploitation. Similarly, the standing crop of rockweed *(Ascophyllum nodosum)* on the N.B. side of the Bay of Fundy has been estimated at over 100 million pounds with a possible sustainable yield of 12 million pounds (Legare, J.E.H., 1973).

On the N.S. side of the Bay, the most important commercial seaweed is Irish moss *(Chondrus crispus)* with average landings of 14.9 million pounds valued at $484,000. Production has been relatively stable with 98% of the harvest coming from Yarmouth County, the remainder from Digby County (Fig. 10).

The Nova Scotia harvest of dulse averaged 3000 pounds a year valued at $2300. About 98% of the harvest came from Annapolis and Kings Counties.

In addition, average annual landings of 3.1 million pounds of rockweed *(A. nodosum)* valued at $21,000 are reported from the N.S. side of the Bay of Fundy. About 99% of the variable harvest is reported from Digby County.

Current average production of seaweeds from the Bay of Fundy totals 18 million pounds valued at $540,000. Of this, Irish moss contributes over 80% by weight and nearly 90% in value. Undoubtedly production of seaweeds could be increased, perhaps through artificial culture.

7. LARGE PELAGICS

Bluefin tuna *(Thunnus thynnus)* is the only large (> 50 lb) pelagic species that occurs regularly in the Bay of Fundy. They are summer visitors mainly to the Nova Scotian shores but are reported in varying quantities from Grand Manan and even inside Passamaquoddy Bay. There is little commercial fishing for the species but it does provide the basis of a significant sports fishery in Yarmouth and Digby Counties. It is anticipated, however, that the recent development of markets in Japan and the corresponding increase in price will result in an increase in the commercial fishery.

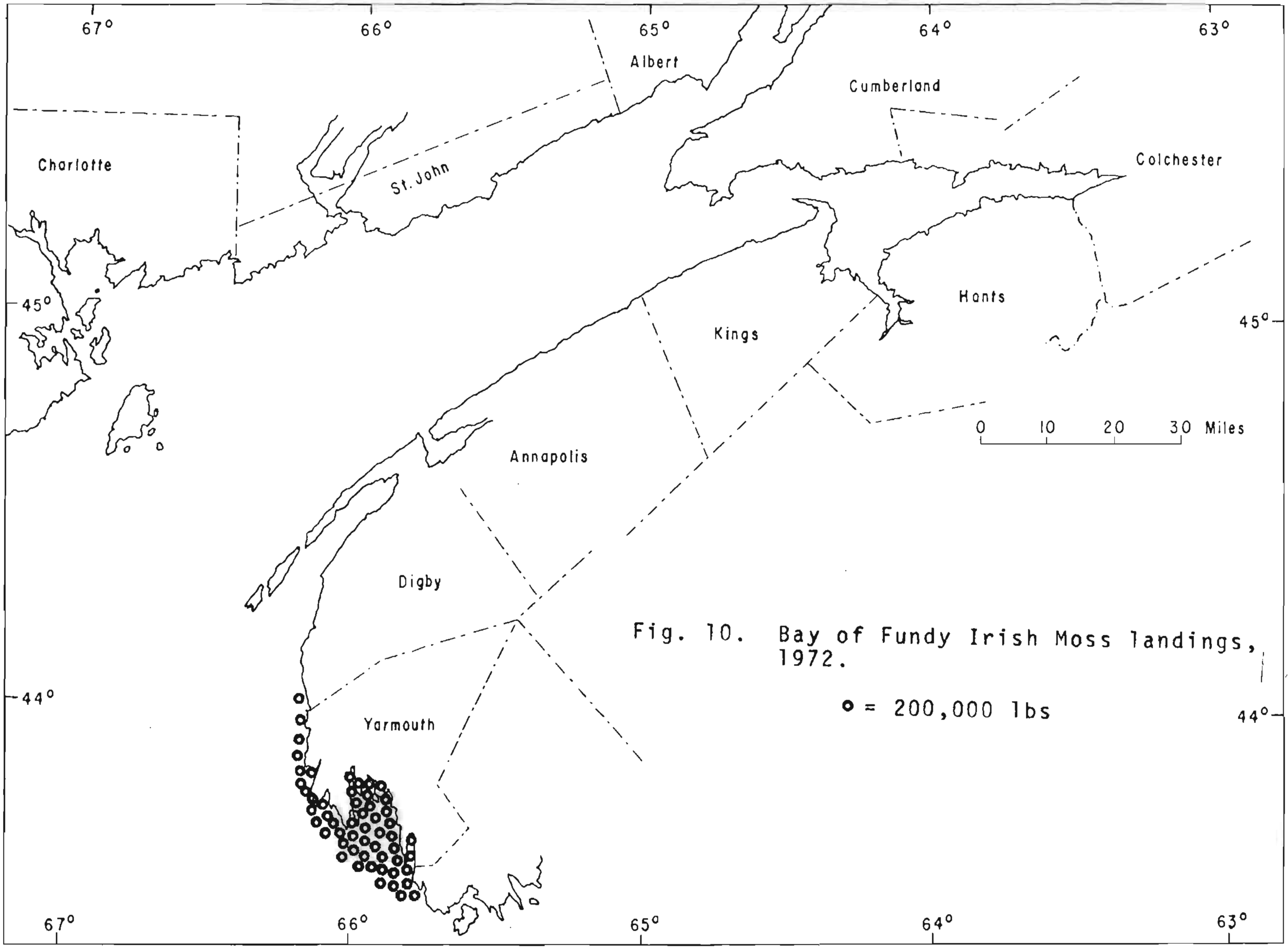

Fig. 10. Bay of Fundy Irish Moss landings, 1972.

Other large pelagic species have been recorded from the Bay of Fundy, but none of these are of commercial interest in the area, largely because the abundance is not sufficient to support a fishery. A possible exception is the blue shark *(Prionace glauca)*. The species reported include the sand shark *(Carcharias taurus)*, thresher *(Alopias vulpinus)*, basking *(Cetorhinus maximus)*, white *(Carcharodon carcharias)*, porbeagle *(Lamna nasus)*, mako *(Isurus oxyrinchus)*, hammerhead *(Sphyrna zygaena)*, greenland *(Somniosus microcephalus)*, and the Atlantic sharpnose shark *(Rhizoprionodon terraenovae)*. The spiny dogfish *(Squalus acanthias)*, a small shark, is seasonally abundant in most of the Bay of Fundy and while it is not harvested at present, it does have a substantial potential for commercial explotation.

None of the spearfishes, sailfishes and marlins have been reported from the Bay of Fundy although white marlin *(Tetrapturus albidus)*, blue marlin *(Makaira nigricans)* and swordfish *(Xiphias gladius)* have been taken nearby on Georges and Browns Banks.

8. PLANKTON

Plankton in the Bay of Fundy have been studied by many scientists including Huntsman and Reid (1921); Gran and Braarud (1935); Fish (1936); Fish and Johnson (1937); Huntsman (1952); Jermolajev (1958); and Legare and Maclellan (1960). Although most of these studies have been concerned with specific aspects of plankton production and distribution, the general conclusion is that plankton production in the Bay of Fundy as a whole is low. Heavy tidal action creates turbulence and turbidity with the result that light usually does not penetrate more than 10 metres. Tidal mixing also decreases the time that phytoplankton is close enough to the surface to have enough light for growth. It is axiomatic that production of zooplankton is also low since there is insufficient food to support it.

Most of the zooplankton that occurs in the Bay of Fundy is brought in from outside - particularly from the Gulf of Maine. There are some endemic estuarine copepods such as *Acartia tonsa*, *Eurytemora herdmani* and *Centropages hamatus* that thrive in shallow inshore areas with heavy river discharge. Immigrants include the copepod *(Calanus finmarchicus)*, the chaetognath *(Sagitta elegans)* and the schizopod *(Meganyctiphanes norvegicus)* which constitute much of the food for commercial fish species, particularly herring.

The method of transport of zooplankton into the Bay of Fundy is not completely understood. Water currents vary considerably with depth and the various plankters not only have depth preferences but undergo diurnal vertical migrations. The complexities of the currents along with the changes in depth distribution of the plankton make it difficult to do more than establish some general patterns of distribution and transport. Plankton are abundant at the entrance to the Bay. Their numbers decrease rapidly going into the Bay and they are extremely scarce at the head of the Bay. Presumably most forms enter the Bay on the east side and are distributed chiefly by nontidal currents that flow counter-clockwise along the Nova Scotia shore - across the Bay towards the Saint John River outflow and then westward along the New Brunswick shore to Grand Manan.

Effects of an oil spill on plankton in the Bay of Fundy would depend on many factors including the kind of oil and the amount of the spill and the season of the year, but basically they would be similar to effects on other organisms including larval fishes. Heavy tidal mixing will distribute minute particles of oil throughout the water column. Water currents, both tidal and nontidal, will assure their dispersal to most areas within the Bay. The over-all effect would be a lower level of plankton and consequently less food for species that depend on plankton for food. Quantitative estimates of these effects are impossible but they would undoubtedly be substantial from a major spill of toxic oil.

9. MAMMALS

The harbour porpoise *(Phocoena phocoena)* is the dominant sea mammal in the Bay of Fundy. As many as 200 may occur in the approaches to Head Harbour Passage in August and considerable numbers in Western Passage, Passamaquoddy Bay and along shore from Bliss Island to Lorneville. The population is strongly migratory peaking from mid-July to mid-September.

The minke whale *(Balaenoptera acutorostrata)* occurs regularly in Charlotte County waters in small numbers. Fin whales *(B. physalus)* occurred in moderate numbers (5-20 animals) from 1969 to 1971. Right whales *(Eubalaena glacialis)*, an endangered species of exceptional scientific interest which regularly occur between Lockeport, N.S., and Grand Manan, remained in Head Harbour Passage for over a week in 1971. Blue whales *(B. musculus)*, humpback *(Megaptera)* and sei whales *(B. borealis)* occur quite frequently south of Grand Manan. The blue and humpback are considered endangered species. All cetacean species show a distinct seasonality entering the Bay during late spring and summer and leaving, except for a few over-wintering stragglers, in late fall.

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SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

SECTION 4

IMPACT OF SPILLS AND CLEAN-UP TECHNOLOGY ON LIVING NATURAL RESOURCES, AND RESOURCE-BASED INDUSTRY

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CONTENTS

SUMMARY

The effects of oil spills are a function of the type and quantity of oil and the conditions of spillage, but in principal five responses can be identified:

(1) lethal toxicity to organisms,

(2) physiological or behavioural disruption,

(3) mechanical interferences,

(4) accumulation in organisms,

(5) changes in biological habitats.

Generally, the refined oils are more toxic and residual oils are more messy. Crude oils occupy an intermediate position. The nature of the principal fisheries of the Charlotte County area and the Bay of Fundy is such as to render these fisheries particularly vulnerable to oil spills, which would seem to be inevitable if a refinery and marine terminal were built at Eastport. The value of these fisheries, the capital investment in gear, the vulnerability of many of the fish plants, the cost and difficulty of adequate protection are such as to throw serious doubt on the wisdom of siting an oil port in the Passamaquoddy region.

1. INTRODUCTION

The literature available on the chemistry of oils, its effect on living beings, and the effects of spills and clean-up technology on individuals, communities, and systems is extensive both in time and scope. This review does not pretend to be exhaustive, nevertheless reference has been made to most recent papers dealing with the potential ecological impact of spilled oil and refinery wastes. Many references are covered in major reviews by Nelson-Smith (1972) and Moore et al. (1973). Statements referable to those sources will not necessarily be identified, but all statements derived from other sources, or meriting special attention, are appropriately referenced.

Details of local living natural resources are taken from other sections of this report or from documents submitted to the Working Group and retained by them. For check lists of species recorded from the Passamaquoddy area refer to Shenton and Horton (1973) which is a literature review of Marine Environmental Data for Eastport, Maine, U.S.A., prepared for the Pittston Company.

Details of the Refinery, Marine terminal proposals and spill prevention and clean-up plans are taken from the Pittston letter of application to the Maine Board of Environment Protection (Kaulakis, 1973) and its supporting documents.

2. EFFECTS OF SPILLED OIL ON MARINE ECOSYSTEMS

The effects of oil are varied and are a function of the type and quantity of oil spilled and the conditions of spillage. In principle, five different responses can be identified:

(1) Lethal toxicity to individual organisms and species,
(2) Sublethal disruption of physiological or behavioural activities,
(3) Mechanical interferences,
(4) Incorporation into organisms causing accumulation in food chains or tainting, and
(5) Changes in biological habitats.

(1) Toxicity of oil is closely related to solubility in water which decreases with the number of carbon atoms in the molecule. Low boiling point aromatic hydrocarbons are very soluble and most toxic; low boiling point saturated hydrocarbons (paraffins) are less soluble and produce narcosis which may lead to death; low boiling point olefinic hydrocarbons occupy an intermediate position. More complex, larger molecules have higher boiling points and are less toxic but some have carcinogenic properties (Blumer, 1971).

Thus, refined oils containing the low boiling fractions such as gasoline, diesel fuel, and light fuel oils are extremely toxic and may have pronounced lethal, sublethal, and tainting effects. Residual oils, from which the lighter fractions have been distilled are relatively nontoxic and their effect on living organisms is principally mechanical; however, they may have additional mechanical effects on sediments and beaches and become incorporated in organisms and cause tainting. Crude oils occupy an intermediate position in that they contain all fractions. They may be initially very toxic but this will be reduced in hours or days as the light fractions dissolve or volatilize. Table 1 (from Moore et al., 1973) is a useful summary of toxicity data.

TABLE 1

Summary of Toxicity Data

Class or Organisms	Estimated Typical Toxicity Ranges (ppm) for Various Substances			
	SAD*	#2 Fuel Oil/ Kerosene	Fresh Crude	Weathered Crude
Flora	10-100	50-500	10^4-10^5	Coating more significant than toxicity ↓
Finfish	5-50	25-250	10^4-10^5	
Larvae	0.1-1.0	0.5-5	10^2-10^3	
Pelagic Crustaceans	1-10	5-50	10^3-10^4	
Gastropods	10-100	50-500	10^4-10^5	
Bivalves	5-50	25-250	10^4-10^5	
Benthic Crustaceans	1-10	5-50	10^3-10^4	
Other benthic invertebrates	1-10	5-50	10^3-10^4	

* Soluble aromatic derivatives (aromatics and napthenoaromatics).

(2) Sublethal physiological or behavioural disruption can take a number of forms such as: the inhibition of respirating movements in clams, oysters, and barnacles; the attraction of lobsters to kerosene fractions followed by inhibition of feeding responses and stimulation of grooming behaviour (Blumer et al., 1973); the tendency of some fish species and marine

mammals to avoid contaminated areas; the interference with communication by blocking or mimicking via chemical senses between marine organisms which could upset feeding and reproductive mechanisms in a number of important species; the inhibition of sexual maturation (.e.g, in clams, mussels, Sanders et al., 1972).

Renzoni (1973) shows spermatozoa of some marine bivalves are particularly sensitive to crude oils and light derivatives. Larval development is adversely affected at oil concentrations which are not likely to be found at sea but which may occur in estuaries or lagoons. These areas may be the sites of commercial fisheries. Similarly, Wells (1972) shows increased frequency of abnormal development of lobster larvae in dispersions containing less than 1 ppm crude oil. It is unlikely that abnormal larvae will have normal probability of survival (Allen, 1971).

(3) Mechanical effects are most likely to occur as a result of heavy oil stranding on beaches. These include the physical smothering of clams, barnacles, and limpets; interference with the byssus attachment of mussels; detachment of limpets (e.g. *Acmaea*) due to the weight of oil on the shell; the flow of oil into the burrows of clams *(Mya arenaria)* causing the clams to emerge onto the substrate where they are subject to increased predation (Thomas, 1973a); the detachment of some algae, e.g. *Fucus serratus*, due to weight of contaminating oil (Thomas, 1973a). In addition, there are the well documented effects of oil on the plumage of birds.

(4) Incorporation of hydrocarbons into organisms offers two principal concerns. The first is tainting. Due to the large volumes of water filtered, some filter feeders, e.g. oysters, clams, rapidly become tainted in hydrocarbon concentrations as low as 0.01 ppm. Tainting is noticeable at concentrations of 5-50 ppm wet weight, but there is some capacity for self-cleaning following exposure to non-contaminated water (Wilder, 1970). Note, however, that absence of tainting is no indication of total loss of contamination (Sanders et al., 1972). Farrington and Quinn (1972) show the presence of petroleum hydrocarbons similar to those found in crude and fuel oils, in clams and sediments, from parts of Narragansett Bay which are subjected to chronic contamination from urban sewer effluents. Clams from uncontaminated areas did not show this range of hydrocarbons.

Of more concern than tainting may be the incorporation of polycyclic aromatic hydrocarbons (PAH) such as 3,4-benzpyrene, and 1,2,3,4-tetrahydronaphthalene which are known carcinogens. PAH carcinogens are growth stimulants in plants and their carcinogenic and growth stimulating properties are directly related. They occur naturally, and also in crude and residual oils. Lee et al. (1972) showed mussels with PAH in the gut up to concentrations of 3-10 μg/animal of 3,4-benzpyrene, and 20 μg/animal of 1,2,3,4-tetrahydronaphthalene, although much of this was discharged following transfer to clean water. The rate of degradation of these compounds in nature is low.

(5) Oil-induced alteration of habitats can occur either mechanically or physiologically. Mechanical effects are the incorporation of oils into sediments. With light oils this results in long-term suppression of the local indigenous fauna or persistent tainting (e.g., the West Falmouth spill where some 5500 acres are still affected four years after a spill of 700 tons of diesel fuel). With heavier oils there may be the development of impervious 'pavements' of oil-soaked gravel such as now exist on parts of the shoreline of Chedabucto Bay, or the impervious layers in salt marshes (Thomas, 1973; Baker quoted by Nelson-Smith, 1972; and Moore et al., 1973) which prevent the penetration of marsh plant roots and shoots leading to denudation of the marsh. Oils, both light and heavy, can become incorporated into sediments at significant depths depending on the degree of turbulence and mixing, e.g., 10 m at West Falmouth, 20 m in Chedabucto Bay. Oil incorporated into sediments degrades slowly and may be present for years assuming no new oil is added.

3. ASPECTS OF THE PITTSTON PROPOSAL RELATING TO THE POSSIBILITY OF OIL SPILLS OR DISCHARGES

(1) Current refinery and marine terminal plans call for 250,000 DWT VLCCs delivering Persian Gulf crude oil at the rate of one tanker per week.

(2) Products are to be shipped mainly by sea in tankers up to 70,000 DWD or barges up to 4000 DWT at the rate of about one per day.

The products are to be low and high octane gasoline, number 2 fuel oil, and number 5 fuel oil.

Liquefied petroleum gas will be shipped in suitable tankers 3500-10,000 DWT at one per week.

Liquid (molten) sulphur will be shipped in suitable tankers, 7000 tons every two weeks.

(3) The refinery will be largely air-cooled, nevertheless some cooling water will be discharged, mixed with ballast water, water from slop tanks, site run-off domestic and process waste water, all of which will have been treated before discharge.

No firm figures are available on the amounts of the different products, similarly there are few details of effluent volumes and characteristics. It is not anticipated that waste discharge at 20°F over-ambient will have significant thermal effects; however, calculations presented at the public hearings suggested that a minimum of 7 tons of oil per year would be released as a chronic discharge from treated ballast water alone. As the outfall will be in an area of strong tidal flushing, the Pittston Company does not anticipate any significant effects.

No statements have been made on the possible frequency or size of oil spills except that the company clearly assumes that spills will occur as they have devised a spill prevention, control and clean-up capability. Some of their ideas are questionable in the light of known tidal and meteorological conditions and there is no way of assessing whether their proposals are adequate. Their list of spills attended elsewhere gives no indication of the spill size, the conditions of spillage, the material used for containment or clean-up, or the effectiveness of clean-up attempts.

To calculate the possible size and frequency of major spills is clearly speculative; however, Moore et al. (1973) claim on the basis of Jellineck (personal communication) without stating their reasoning, that the likelihood of the Machias Bay proposal would be one 500-ton spill per year, with a major 30,000-ton spill in 20 years, superimposed on chronic spillage of around 80 tons per year. No figures are given for the proposed thruput of the port but if the 391 supertankers claimed carry 250,000 tons each then thruput would be 97.75 metric tons and chronic spillage equal to 0.81 tons per million.

By comparison, Captain Dudley of Milford Haven Conservancy, testifying before the Maine Board, claimed a chronic spillage rate of 0.3 tons per million on a thruput of 45.7 metric tons annually, with an accidental major (100-500 tons) spill rate of 5 in 13 years. The *Torrey Canyon*, though bound for Milford Haven, is not included on the Milford Haven statistics, and no figures for catastrophic spills are known.

By extrapolating from Milford statistics and Machias predictions, a minimum rate of 500-ton spills might be 1 per 8 years with a chronic spill rate of between 3 and 10 tons per year. However, oil spills are not predictable and it could well be that incidence of accidents is initially high at new installations (e.g. Gulf refinery oil spill at Milford Haven 1969 where 3000 tons were pumped into a 2000-ton tank!) or where new equipment is being proved, nor can it be guaranteed which commodities may be spilled. The only guarantee, admitted by all parties, is that spills will occur.

It may reasonably be assumed that most of the minor spills will be contained and cleaned up rapidly with negligible effect on the immediate vicinity. In a letter dated February 1972, referring to the original 1971 Metropolitan Eastport proposal, Captain Dudley of Milford

Haven anticipates a minor spill for each 1½ million tons landed which would be 1 per 6 weeks of incoming crude, and the same for product if shipping is to be by sea.

Major spills of up to 500 tons are less easy to predict, but some assumptions can be made of their behaviour. A 500-ton spill of crude oil would spread in its inertial regime (Moore et al., 1973; Fig. 7-2) to cover about 40 acres in ½ hour. Loucks (Section 2 of this report) shows how local turbulence will increase the rate of spreading expected under static conditions and that the area covered by a 500-ton slick (assume 10^5 gallons) will be nearly ½ nm in 1 hour and will cover about 3.3 square miles to approximately 200 microns thickness in about 3 hours. This is assuming the slick does not fragment into several smaller slicks which is highly unlikely anywhere in the Head Harbour Passage area. It is clear, therefore, that containment will be difficult or impossible and that large volumes of oil will be distributed about the passages and bays. Analysis of the distribution of recovery points of drift bottles released in the Passage shows that spilled oil will contaminate beaches closest to the release point first, but that floating oil not going ashore may be transported to the nethermost areas of Passamaquoddy Bay and Cobscook Bay within a week, western Nova Scotia within 4 weeks, and to Cape Cod in 5-6 weeks.

4. EFFECTS OF SPILLS ON LOCAL FISHERIES AND NATURAL SYSTEMS

There are a number of effects which should be considered here. First are the direct biological effects on the species concerned. Some of these have been outlined earlier in this report. Second are the effects on a fisherman's ability to fish, either because the grounds or gear are contaminated. Third are the effects that oil spills may have on fish processing plants, and fourth is the effect on the retail market itself. In this latter case, it was clearly found after *Torrey Canyon* that shellfish markets in England were depressed (Cowan, 1968, p. 147) but the effect was most severe in France where retail fish sales fell 40% in the week following the arrival of oil on Brittany beaches (Cowan, *loc. cit.*, p. 169). The collapse of the market included species which had no likelihood of being contaminated and represented a loss of confidence in the fishing industry as a whole.

Fish processing plants are vulnerable insofar as many are dependent on raw material supply from a limited area, and any oil contamination of beds or grounds could reduce supplies. In addition, many require clean sea water for part of their processing routines. In the event that approval was given for the Pittston proposal it would be imperative to design and construct emergency water filters for those plants which did not have access to an alternate source of uncontaminated water. Plants close to the terminal (e.g., plants at Wilson's Beach) would require these to be in line, and operable, at immediate notice.

Construction of a filter for the Booth fish plant at Petit de Grat following the wreck of the *Arrow* cost $15,000 in 1970. It is conceivable that such filters might not be effective for all types of oil, particularly the light fractions, in which case plants might have to interrupt production until the area was clean.

Damage to specific fisheries is difficult to predict insofar as much will be dependent upon the type and volume of oil spilled and the time of spillage. The following is an indication of the problems that might be expected to arise.

Herring and Mackerel. The Charlotte County fishery is principally a fixed gear fishery for migratory fish. Significant concentrations of light hydrocarbon fractions would be toxic to fish close to a spill, or cause migrating fish to avoid contaminated water. Heavy fractions (residual crude fractions) would cause significant contamination of fixed gear (herring weirs) and seines with the subsequent cost of cleaning. Experience gained after the *Arrow* spill shows that a suitable net laundry can be operated satisfactorily. The laundromat (Anon., 1970, Vol. 1) cost about $30,000 to build. A large seine net cost about $2500 to clean, discounting cost of ships' crews' wages and some other overheads. Twine off weirs would be less bulky than seines but there would be the additional cost of divers' time to strip the net and replace it when clean together with the cost of steam cleaning the permanent frame of the weir and replacing brush. Current estimates of local fishermen show a weir to cost in excess of $5000. It seems unlikely that effective cleaning would cost much less than total replacement. Shallow water and beach sediments would become contaminated within the vicinity of a spill and the size of the contaminated area would increase with time.

Massive spills in southwest Nova Scotia (such as an accident to a VLCC near Trinity Ledge or Lurcher Shoal) in fall could cause significant interference with spawning success and larval development of southwest Nova Scotia herring stocks. Contamination of sediments in spawning areas could cause significant interruptions in spawning over several years. 0.1 ppm oil in water gives a high incidence of deformed herring larvae (Kühnhold, 1969).

Invertebrates. Lobsters have been reported killed by spills of light fuel oil and are known to be tainted by fresh Bunker C. Fresh crude oil would be toxic in shallow turbulent areas. There are no areas (with the possible exception of St. Mary's Bay, N.S.) where larval lobsters are found in abundance so no significant interference with breeding potential would be anticipated. Stored lobsters would be particularly vulnerable to spills of all types of oil either from direct toxicity or tainting. Lobsters so killed could not be salvaged by immediate cooking. An oil spill of 1000 gallons of Venezuelan crude in Eastern Passage, Halifax Harbour, January 1973, caused tainting of 1800 pounds of lobsters in storage tanks ½ mile downstream (Coté, personal communication).

Water samples from the tanks contained 180 ppb hydrocarbons. After two days the lobsters were removed to clean water in St. Margaret's Bay and checked regularly; by March 31 only 50 pounds remained alive. These were still tainted. Mortality among other lobsters in this pound was considered to be normal. Thus, it appears possible that mortality may be considerably delayed and lobsters exposed to certain types of fuels may be a total commercial loss. Spills in the vicinity of or affecting lobster pounds could have serious consequences for stock in the pounds, and cause long-term contamination of the sediments forming the floor of the pound. Note that booming might only be partially successful in reducing contamination; the sea water intake to the tanks contaminated in the Halifax spill was 6 feet below low-water mark!

Clams would suffer significantly from a spill or from exposure to water containing dissolved low boiling point hydrocarbons. The effect of the West Falmouth diesel oil spill is well documented, e.g. Blumer and Sass, 1972, and the area affected by it is extending as contaminated sediments are redistributed. At the other extreme, clam beds contaminated by Bunker C oil in Chedabucto Bay suffered extensive mortality, and clam beds remain closed. Clams from beaches 'cleaned' of oil three years earlier contained 48 μg/g Bunker C (Scarratt and Zitko, 1973).

Shrimp, being fished in relatively deep water, are not likely to be affected other than by large crude or refined oil spills. Turbulence would promote dispersion, dissolution, and adsorption of oil onto particles which might then become incorporated into sediments. Scallops might similarly be affected. Periwinkles are remarkably resistant to oils, but will incorporate large quantities in their digestive systems. It is unlikely that periwinkles from oil-contaminated beaches would be marketable.

Sea urchins are particularly sensitive to low-boiling-point oil fractions. The rapid development of a kelp forest following the wreck of *Tampico Maru* in California was due to elimination of sea urchins by diesel oil. Full recovery is not evident here after 10 years (Hinson, 1972). A developing fishery for sea urchins at Grand Manan could be affected by light or crude oil spills in the vicinity. Other invertebrate fisheries or fisheries potentials, e.g. mussel and mussel culture, baitworms, etc., would be vulnerable to spills threatening the areas concerned, or becoming incorporated into sediments in the near vicinity.

Diadromous fisheries are vulnerable principally to massive spills which might kill fish unable to move out of the path, or more likely to low level chronic or residual pollution which might block or otherwise interfere with migration stimuli (Rice, 1973). The potential for restoration of anadromous species runs in the St. Croix River should be emphasized. It would be tragic to clean up pulp mill pollution on one part of a migration route if it were replaced by oil contamination further downstream! Anadromous species are susceptible to tainting (Mackie et al., 1972).

One significant area not explored is the relationship between Euphausiids, fish and birds. Gaskin (1973) shows clearly the relationship that exists in summer between surface swarming Euphausiids *(Meganyctiphanes* and *Thysanoessa)*, the location of schools of predatory fish (herring and mackerel and flocks of gulls, terns and phalaropes). These swarms form principally on the ebb tide in predictable locations from mid-July through mid-September. The majority of the swarms form in Head Harbour Passage seaward of Pope Island. The whole system would therefore be extremely vulnerable to spilled oil being carried out of the Passage on a falling tide. Harbour porpoises are similarly associated with the schools of herring and mackerel and Gaskin estimates half of the proven porpoise population of the Canadian east coast south of the St. Lawrence feeds within 20 miles of the mouth of Head Harbour Passage.

One other area not explored is the response of plants to oil. A few species are sensitive to concentrations as low as 1 ppm. The response of most is a reduction in photosynthesis with the exception that crude oil in low concentrations (e.g., 45 μg/ℓ) (Gordon and Prouse, 1973) stimulates phytoplankton photosynthesis possibly due to growth stimulating polycyclic aromatic hydrocarbons. Inhibiting concentrations are found underneath or close to oil slicks.

5. INTERTIDAL BIOLOGICAL COMMUNITIES

From available data (nautical charts, topographic maps and aerial photographs) (Thomas, 1973b, unpublished report), the shoreline of Charlotte County including the three large islands Grand Manan, Deer and Campobello but excluding the large number of smaller islands comprises about 280 miles of tidal shoreline.

About 35% of the shoreline is composed of rock (Table 2) which supports a community strongly dominated by rockweed *(Ascophyllum nodosum)*. Data gathered by Thomas (1973a) showed that the quantity occurring on shores between Point Lepreau and Saint John averaged 26.4 lb/yd^2 (10 kg/m^2). This is about half the crop considered minimal for commercial harvest. However, increased prices for seaweed products could easily alter this situation. Macrophytes are reasonably resistant as a result of mucus secretions with the exception perhaps of *F. serratus* noted above and of the red algae which are less resistant. An oil spill, if heavy, could cause mortality of *Ascophyllum* or if lighter may cause long-term contamination, preventing harvest. In a few locations, notably on Grand Manan, the rocky shores yield a harvest of dulse *(Rhodymenia palmata)*. In 1971, the crop for the entire County was 69,000 pounds valued at $35,000. Most of this was from Grand Manan. Spills in the vicinity of Grand Manan could conceivably affect the dulse harvest, and in southwest Nova Scotia the Irish moss and rockweed harvest.

TABLE 2

Extent in statute miles of shores of various types on the large islands and mainland of Charlotte County, New Brunswick.

Type	Grand Manan	Campobello	Deer	Mainland	Total
Rock	25.6	11.9	13.4	47.2	98.1
Coarse Sediment	18.1	19.6	10.0	105.6	153.3
Mud	1.1	5.6	3.7	15.3	25.7
Salt Marsh	-	1.2	-	0.1	1.3
Totals	44.8	38.3	27.1	168.2	278.4

In addition to the rocky shores, shores of very coarse sediment, for example boulders, also support heavy growths of intertidal algae. Probably at least one third of the 55% of shores in this general class are of this nature, hence about half the total shore line supports heavy seaweed growths.

The remainder of the coarse sedimentary type shores support only small quantities of living organisms and are more important from an aesthetic and recreational point of view.

Sheltered sedimentary shores, predominantly of mud, support extensive populations of soft shell clams *(Mya arenaria)*, their potential harvest is reduced by closures due to pollution and the danger of paralytic shellfish poisoning (Prakash et al., 1971). Nevertheless, oil pollution would seriously affect the clam fishery.

Salt marshes are rare in Charlotte County (0.5%) but common just farther east. Marsh plants will survive single oilings, but are susceptible to repeated or chronic exposure to oil. Their elimination results in the surface of the marsh being lowered and eroded.

6. IMPACT OF CLEAN-UP

The Pittston proposal calls for the containment by booms of all spilled oil. Booms are to be rigged around all tankers loading or discharging to contain accidental spills. This is in contrast to practice at Milford Haven where booms are not used as oil retained alongside a tanker is considered a fire hazard (Dudley, Eastport Hearings, Vol. 5). Unlike Milford Haven, the Eastport facility would not rely on dispersants to promote emulsification and dispersion of oil. Spills of heavy oil near the terminal will be contained and removed by oil skimmers or absorbent padding. Light oils not responsive to skimming will be volatilized by agitation with high pressure water hoses (Green, Eastport Hearings, Vol. 7) to reduce fire hazard. As these light oils (gasoline, diesel fuel) are also relatively soluble, this action should materially increase the amount of oil going into solution and hence the impact on the local biota. Whether the net result would be greater than if detergents were used or the oil merely allowed to drift away is speculative.

Major spills not within the ship booms or escaping from the booms would be either encircled by booms deployed from boats or alternately diverted into pre-selected containment areas by means of strategically placed booms. These areas have not been selected, nor have other areas which may be ultra-sensitive and require protection at all costs. One of the areas mentioned as a 'containment area' into which spills would be boomed pending clean-up is Harbour Lute, Campobello (Eastport Hearings, Vol. 6). This area is one from which particularly choice herring are taken (Battle et al., 1936), and which would not benefit from having oil on the beach or in the sediments. Under cross-examination the 'expert' on clean-up admitted that up to two-thirds of oil in a spill in 3- to 5-knot currents would not be contained. No statement was made as to how oil-contaminated fish weirs or seines would or could be cleaned or what compensation might be offered. It was stated that shore cleaning would be by hot sea water lances and absorbent padding and that no detergents would be used, 'Shell herder' would be used if appropriate under U.S. Federal limitations.

Thus, the total impact of spills cannot be foreseen as the clean-up procedures are so ill-defined. The testimony and cross-examination on clean-up were so unconvincing that it would be wise to assume that clean-up capability by the Pittston Company in Canadian waters will be extremely limited.

7. IMPACT OF NON-OIL SPILL EVENTS ON MARINE FLORA AND FAUNA

Accidents during the loading of molten sulphur (120°C) or to sulphur barges could be spectacular but might not harm the environment significantly. Sulphur is largely inert and insoluble. If incorporated into sediments, it would be reduced to H_2S. It is unlikely to have any significant environmental effect (Zitko, personal communication).

The construction of wharves, jetties, and appropriate dredging are not likely to have any significant effects on Canadian resources.

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SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

SECTION 5

THE POSSIBLE EFFECTS OF OIL SPILLS ON MARINE BIRDS

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CONTENTS

SUMMARY

The Passamaquoddy Bay area is an important wintering area or migratory stopover for several species of diving ducks, as well as phalaropes, Greater Shearwaters and Kittiwakes. All of these could be directly affected by oil slicks in the area. Brant Geese could be indirectly affected, through contamination of the eelgrass beds on which they feed. It is unlikely that any single spill would lead to the extinction of any of these species; however, the cumulative effect of relatively small spills could be serious.

1. INTRODUCTION

Marine birds are particularly vulnerable to oil spilled in the marine environment. Since it is generally agreed that oil transportation and handling inevitably lead to accidental spillage, it is important to identify the threat posed from proposed or planned new ventures. In the light of the proposal to build an oil refinery and deep-water port at Eastport, Maine (Pittston, 1973), it was thought to be worthwhile to make an initial appraisal of the threat posed to marine birds should oil be spilled in the Head Harbour Passage-Eastport area.

The scenario in Section 2 takes two oil spill possibilities into account: a spill at the refinery site; and a spill in Head Harbour Passage, just northwest of Campobello Island and the narrowest part of the refinery approaches. For present purposes it is sufficient to say that for the first few hours after either spill, the scenario predicts that the oil will stay in the narrow channels between the Maine coast and Campobello and Deer Islands, New Brunswick. But less than 12 hours after the spill, oil will probably begin to leak past Campobello Island and out into the Bay of Fundy. Once out there, the oil's drift will be influenced more by winds than by currents. The prevailing winds in winter are from the northwest, which would take it down towards Grand Manan Island, New Brunswick. In summer, they come from the southwest, and so would tend to take the oil up the New Brunswick coast.

2. THE VULNERABILITY OF BIRDS TO OIL

The species most vulnerable to oil are those which spend much time sitting on the water. A tendency to form fairly dense flocks will increase this vulnerability; this will be particularly apparent close to a breeding area, especially in a colonial species. This is clearly shown in the toll taken by the *Arrow* and *Irving Whale* oil spills of February 1970 (Brown et al., in press). There, large numbers of diving ducks were killed - especially Common Eiders, Oldsquaws and Redbreasted Mergansers; but Black Ducks, which do not dive and which spend much of their time on land or in shallow water, were hardly affected at all. Most of the other species affected were also divers - grebes, loons, and the various auk species (Thick-billed Murres, Dovekies, Black Guillemots, Razorbills, Puffins). A spill later in the year might have involved other divers such as the Great and Doublecrested Cormorants; possibly Northern and Red Phalaropes, swimming shorebirds which form large, extremely dense flocks; perhaps even Greater Shearwaters, which spend much time on the water while they are moulting. On the other hand, the spill did relatively little damage to any gull species - these spend much of their time on land. The only gull which might be vulnerable is the Kittiwake, a pelagic species which only comes to land during the breeding season. Other birds of the marine environment would be affected only indirectly. Brant, for example, feed on eelgrass and similar tidal vegetation of the tidal zone; oil would deprive them of this specialized and rather limited food supply.

3. BIRD NUMBERS AND DISTRIBUTIONS IN THE SCENARIO AREA

Birds and their movements cannot be predicted with anything near the precision of tidal streams, even in an area which is ornithologically well known. Information from the scenario area is, in fact, rather patchy. Therefore, for descriptive purposes, the year has been divided into quarters, and the main vulnerable species found in the scenario area during each quarter have been listed. (For good measure, they have also been listed for the offshore zone running south from the scenario area to the shallows south of Grand Manan Island. Brown et al. (1973) showed that an oil slick may do more damage when it drifts out to sea than while it remains in coastal waters. A vulnerable species has been included in a quarterly list when a count suggests that an oil slick in the wrong place might lead to a kill of the order of 1000 birds. The criterion is, of course, only guesswork.

The vulnerability of birds in the scenario area must be put into perspective. Passamaquoddy Bay is on a major migratory flyway for scoters, a very vulnerable group of species, as well as for the less vulnerable Black Duck and other dabbling ducks. About half the population of Brand moving through the Maritimes in spring do so through the area. It is an important wintering area for both Common Eiders and Goldeneye; it is, in fact, the main wintering area for the eiders in the Maritimes. On the other hand, none of the species listed here is in imminent danger of extinction - most of them in fact, are very common. The only qualifications to be made to that statement are as follows:

<u>Great Cormorant</u>: A common species of worldwide distribution. However, the western North Atlantic population is rather small, and many of these birds winter in or near the scenario area.

<u>Brant</u>: These geese are quite common; however, their numbers have fallen in recent decades since the partial disappearance of eelgrass, their preferred food.

<u>Puffin</u>: Over a quarter of a million pairs breed elsewhere in Atlantic Canada. There is a relict southern breeding population, totalling perhaps 100 pairs, on Machias Seal Island, New Brunswick, and Matinicus Rock, Maine.

<u>Razorbill</u>: Probably the rarest of the birds listed here. It is fairly common in the eastern Atlantic, where oil losses are beginning to become serious. The population in Atlantic Canada is about 7000 pairs; about 50 of these breed on Machias Seal Island and near Grand Manan.

Therefore a single spill, even if quite spectacular, in the scenario area ought not to have too drastic an effect on any given species. On the other hand, the cumulative effects of several, even quite small, spills could eventually become serious. Only a small amount of oil is needed to contaminate a bird, and such cumulative effects could come about through casual leakages seemingly too small even to be worth recording as spills.

Seasonal Distributions of Birds
(Note: The Herring and Great Black-Backed Gulls, abundant all through the year in the scenario area, are omitted from the lists below.)

<u>December-February</u>

Scenario area:	Eiders and Scoters common, as are other diving duck species - notably Oldsquaw, Bufflehead, Common Goldeneye and Greater Scaup. Dovekies have been recorded in the thousands. Great Cormorants common.
Grand Manan area:	Little data available. Dovekies are abundant in the shallows south of Grand Manan, and so possibly are Razorbills. Eiders and Scoters are probably also common. Brant migrate through the area in February.

<u>March-May</u>

Scenario area:	Common, Surf and White-winged Scoters, Common Eiders, Double-crested Cormorants abundant. The Eiders and Cormorants breed from May onwards, and vulnerable local concentrations may occur near breeding areas.
Grand Manan area:	Common Eider abundant all through the period, and several thousand pairs remain to breed from May onwards. Double-crested Cormorants, Razorbills and Puffins also breed - the latter only in very small numbers. The shallows south of Grand Manan may also be an important wintering area for Razorbills. Large numbers of Brant move through the area in March.

<u>June-August</u>

Scenario Area:	Common Eiders and Double-crested Cormorants breed. Large flocks of Phalaropes start to arrive in July. Scoters migrate through the area in August.

Grand Manan area:	Large numbers of breeding Eiders and Cormorants, small numbers of breeding razorbills and Puffins. Scoters migrate through in August. Large flocks of Phalaropes and Greater Shearwaters from July onwards.

September–November

Scenario area:	Phalaropes and Bonaparte's Gulls are abundant all through this period; they seem to be attracted to food brought to the surface by tidal upwellings and whirlpools in the channels of the Deer Island and Campobello Island area. Large flocks of Kittiwakes arrive in late October.
Grand Manan area:	Phalaropes remain abundant until November; Kittiwakes become abundant from October onwards. Some flocks of Greater Shearwaters still present. Common Eiders present, though migrants from northern areas have probably not yet arrived in force to swell the population.

Waterfowl Surveys - Southwestern New Brunswick*

Species	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Brant	0	0	3240	2070	-	-	-	0	-	-	-	0
Canada geese	0	0	220	220	-	-	-	0	-	-	-	0
Black duck	3010	1710	2590	930	-	-	-	170	-	-	-	2310
Teal	0	0	0	40	-	-	-	10	-	-	-	0
Pintail	0	0	0	0	-	-	-	0	-	-	-	0
Scaup	0	0	0	0	-	-	-	0	-	-	-	0
Goldeneye	870	390	350	80	-	-	-	0	-	-	-	810
Merganser	40	70	590	300	-	-	-	0	-	-	-	280
Oldsquaw	490	450	30	0	-	-	-	0	-	-	-	180
Scoter	280	440	720	5060	-	-	-	3660	-	-	-	800
Eider	490	280	3660	6130	-	-	-	0	-	-	-	770
Total	5180	3340	11400	14830	-	-	-	3840	-	-	-	5150

* Taken from a report on Canadian Wildlife Service surveys covering the period between April 1966 and April 1973.
Numbers given are rounded to the nearest 10, and are a summation of the highest counts for the survey blocks from Lorneville to the St. Croix River and Grand Manan.

\- Indicates no data.

4. REFERENCES AND SOURCES OF DATA

BROWN, R.G.B., GILLESPIE, D.I., LOCK, A.R., PEARCE, P.A., and WATSON, G.H. (1973). Bird mortality from oil slicks off eastern Canada, February-April, 1970. Canadian Field Naturalist 87: 225-234.

Canada Land Inventory Map Series 1968-1970, Land Capability for Waterfowl, Maps 21B and 21G.

Source Material

Baird, J.C., Christie, D.S., and Pearce, P.A. 1972. Lorneville Environmental Impact Study: Birds and Mammals. MS Report, April 15, 1972.

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New Brunswick Naturalist 1971: Vol. 2, No. 5-6.

Pearce, P.A., and Smith, A.D. 1973. Port and tidal power development in the Bay of Fundy and an assessment of their potential influence on waterfowl. MS Report to CWS, May 1973.

Unpublished data collected by P.A. Pearce (CWS), and by the PIROP seabird recording scheme (CWS and Université de Moncton) have also been included.

9. APPENDIX

Loons	*Gavia spp.*
Grebes	*Colymbus spp.*
Greater Shearwater	*Puffinus gravis*
Great Cormorant	*Phalacrocorax carbo*
Double-crested Cormorant	*Phalacrocorax auritus*
Brant	*Branta bernicla*
Black Duck	*Anas rubripes*
Greater Scaup	*Aythya marila*
Coldeneye	*Glaucionetta clangula*
Bufflehead	*Glaucionetta albeola*
Oldsquaw	*Clangula hyemalis*
Common Eider	*Somateria mollissima*
White-winged Scoter	*Melanitta fusca*
Surf Scoter	*Melanitta perspicillata*
Common Scoter	*Oidemia nigra*
Red-breasted Merganser	*Mergus serrator*
Red Phalarope	*Phalaropus fulicarius*
Northern Phalarope	*Lobipes lobatus*
Great Blackbacked Gull	*Larus marinus*
Herring Gull	*Larus argentatus*
Bonaparte's Gull	*Larus philadelphia*
Kittiwake	*Rissa tridactyla*
Razorbill	*Alca torda*
Thick-billed Murre	*Uria lomvia*
Dovekie	*Plautus alle*
Black Guillemot	*Cepphus grylle*
Puffin	*Fratercula arctica*

SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

SECTION 6

POPULATION, FISHING ACTIVITY AND FISH PROCESSING, CHARLOTTE COUNTY, NEW BRUNSWICK, AND BAY OF FUNDY

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CONTENTS

SUMMARY

Of a total population of approximately 25,000 in Charlotte County, New Brunswick, 2850 people or about 11% of the population are engaged directly in the fishing industry either as fishermen or employees of fish processing companies. The number of persons dependent upon the fishing industry would, of course, be several times as great. In regions such as Grand Manan and West Isles, virtually the whole economy depends upon this industry. In the entire Bay of Fundy, the fishing industry is somewhat less important with approximately 2% of the population employed directly in the fishing industry. At the mouth of the Bay of Fundy (Charlotte County, N.S., and Digby and Yarmouth Counties, N.S.), the fishing industry is of about the same relative importance as in Charlotte County with approximately 9% of the population deriving part or all of their income from fishing or working in fish processing plants. Along the coastal areas of the mouth of the Bay, virtually the entire economy is dependent upon the fishing industry as very little other industry exists.

Fishermen in Charlotte County, N.B., have a total of 876 boats with a current value of approximately $8.6 million. Within the entire Bay of Fundy, there are over 3000 fishing vessels having an estimated current value of $25.4 million. There is, as well, an undisclosed amount of investment in fishing gear and shore facilities, including public and private wharves and harbours. The estimated current value of assets of fish processing companies is $25 million in Charlotte County and $53 million in the entire Bay of Fundy region.* Total current value of private assets is, therefore, approximately $40 million in Charlotte County and $100 million in the Bay of Fundy region.

In Charlotte County, N.B., the herring and lobster fisheries are most important with approximately 60% and 50%, respectively, of the total fishermen engaged in fishing these species. Groundfish (approximately 20% of fishermen) and clams (approximately 15% of fishermen) are also important. For the Bay of Fundy as a whole, the lobster fishery is most important with approximately 60% of the total fishermen engaged in the herring and ground fisheries. Other fisheries of lesser, but still significant, proportions are those for scallops, Irish moss, clams, and salmon.

There are 28 active fish processing plants, 8 handlers and 18 tidal lobster pounds in Charlotte County. The total value of their production is approximately $25 million per year. Within the Bay of Fundy region, there are 78 active fish processing plants, 41 handlers and 20 tidal lobster pounds. The total value of their production is approximately $53 million per year.

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* Based on assumption that $1 worth of assets produces $1 worth of fish which is a reasonably accurate guide for the fish processing industry.

1. POPULATION

Charlotte County

The population of Charlotte County, N.B., as of June 1, 1971, was 24,551.[1] The population was distributed as follows:

Grand Manan	2,547
West Isles	2,248
Western Mainland	15,659
Eastern Mainland	4,097

Bay of Fundy

The population of the Bay of Fundy region (counties and sub-division of counties where a county also borders the Northumberland Strait), from Charlotte County, N.S., to the Yarmouth-Shelburne County boundary as of June 1, 1971, was 411,000[2] distributed as follows (x1000):

Charlotte County, N.B.	24.6
Saint John County, N.B.	92.2
Albert County, N.B.	16.3
Westmorland County, N.S.	82.5
Cumberland County, N.S.	28.8
Colchester County, N.S.	25.8
Hants County, N.S.	28.9
Kings County, N.S.	45.0
Annapolis County, N.S.	21.8
Digby County, N.S.	20.3
Yarmouth County, N.S.	24.7

2. NUMBER OF FISHERMEN

Charlotte County

Of the 986 fishermen in Charlotte County, N.B., in 1971, 368 lived on Grand Manan, 331 on Deer and Campobello Islands, and 287 on the mainland. The distribution of fishermen by communities and duration of fishing activity[3] follows.

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1. Statistics Canada, 1971 Census of Canada, Census Divisions and subdivisions (September 1972), Cat. No. 92-704, Vol. 1, Part 1 (Bulletin 1.1-4).

2. *Ibid.*

3. Full time fishermen are engaged 10 months or more, part time are engaged 5-9 months, and occasional less than 5 months in fishing.

	Full Time	Part Time	Occasional	Total
Castalia, Grand Manan Island	12	10	16	38
Grand Harbour, "	16	26	6	48
Ingalls Head, "	2	18	8	28
North Head, "	19	32	18	69
Seal Cove, "	11	63	23	97
Woodwards Cove, "	10	11	8	29
White Head, White Head Island	8	43	8	59
Fairhaven, Deer Island	4	6	2	12
Lambertville, "	9	11	1	21
Leonardville, "	23	11	3	37
Lord's Cove, "	10	13	--	23
Richardson, "	6	13	--	19
Chocolate Cove, "	--	1	1	2
Cumming Cove, "	--	1	--	1
Welshpool, Campobello Island	38	24	3	65
Wilson's Beach, "	101	34	16	151
Back Bay, western Mainland	--	62	13	75
Bocabec, "	--	10	1	11
Chamcook "	--	4	11	15
Digdeguash, "	--	4	1	5
L'Etite, "	--	8	--	8
Mascarene, "	--	1	--	1
St. Andrews, "	--	8	3	11
St. George, "	--	--	1	1
St. Stephen, "	--	1	1	2
Beaver Harbour, eastern Mainland	18	12	--	30
Blacks Harbour, "	3	9	5	17
Lepreau, "	11	19	11	41
Maces Bay, "	13	10	7	30
Pocologan, "	3	10	5	18
Seeley Cove "	6	12	4	22

Bay of Fundy

There are approximately 3700 fishermen living along the coast of the Bay of Fundy. Of this total, approximately 32% are full time, 46% part time, while the remaining 22% are occasional. The largest proportion of full time fishermen is at the mouth of the Bay on both the New Brunswick and Nova Scotia sides whereas at the head of the Bay there is a large proportion of occasional fishermen. The breakdown by counties for the year 1971, the last year for which there is accurate information, is given below.

County	No. of Fishermen			
	Full Time	Part Time	Occasional	Total
Charlotte, N.B.	323	487	176	986
Saint John, N.B.	11	49	188	248
Albert, N.B.	--	--	27	27
Westmorland, N.B.	--	1	38	39
Cumberland, N.S.	6	7	59	72
Colchester, N.S.	--	16	26	42
Hants, N.S.	--	--	31	31
Kings, N.S.	1	24	52	77
Annapolis, N.S.	183	125	18	326
Digby, N.S.	421	265	102	788
Yarmouth, N.S.	240	706	96	1042
Total	1185	1680	813	3678

3. VESSELS

Charlotte County

In 1971 there were 876 fishing vessels of all sizes in Charlotte County, New Brunswick. The mainland tends to have a large number of small vessels (less than 10 tons) whereas Grand Manan and West Isles have a large proportion of large vessels (over 10 tons). The distribution of vessels, by size classes, and districts is given in the following table.

	Vessels less than 10 tons				Vessels over 10 tons		
	Less than 30 ft	30 ft and over	Row boats	Lobster carrying smacks	Less than 50 ft	50-74.9 ft	75 ft and over
Grand Manan	60	10	26	1	95	38	4
West Isles	75	27	8	-	46	41	6
Western Mainland	91	15	65	-	19	3	5
Eastern Mainland	56	28	100	-	33	19	5

The current value of these vessels is approximately $8.6 million.

Bay of Fundy

Including Charlotte County, in 1971, there were over 3000 fishing vessels in the Bay of Fundy region. Approximately 80% of the fishing vessels are located in Charlotte County, N.B., Digby and Yarmouth Counties, N.S. These three counties as well as having the largest proportion of vessels also have the largest vessels. There are no vessels over 50 feet in length from mid-Annapolis County along the head of the Bay to Charlotte County. The current value of all vessels in the Bay of Fundy is approximately $25 million. The number of vessels, by size and county, along with their approximate value is given in the following table.

	Vessels less than 10 tons				Vessels over 10 tons			Approximate
	Less than 30 ft	30 ft and over	Row Boats	Lobster carrying Smacks	Less than 50 ft	50-74.9 ft	75 ft and over	Current Value ($ million)
Charlotte, N.B.	282	80	199	1	193	101	20	8.6
Saint John, N.B.	69	85	163	-	-	-	-	0.2
Albert, N.B.	2	8	10	-	-	-	-	Ø*
Westmorland, N.B.	14	6	11	-	-	-	-	Ø
Cumberland, N.S.	16	5	7	-	10	-	-	0.1
Colchester, N.S.	--	1	13	-	-	-	-	Ø
Hants, N.S.	2	12	20	-	-	-	-	Ø
Kings, N.S.	13	19	23	1	6	-	-	0.1
Annapolis, N.S.	27	35	53	-	9	32	-	1.0
Digby, N.S.	47	204	3	-	94	37	10	4.7
Yarmouth, N.S.	274	115	350	-	338	29	34	10.8
Total	746	570	852	2	650	199	64	25.4

* Ø indicates less than $500,000

4. FISHING ACTIVITY

Charlotte County

Within Charlotte County, the greatest number of fishermen are engaged in the herring fishery. There are three types of gear used in this fishery--weirs, drag seines, and purse seines. Herring weirs are located along most of the Charlotte County shore (including Grand Manan, West Isles, and the Wolves (Fig. 1). In 1972, licences were issued for 218 weirs distributed as follows:[4]

Grand Manan	31
West Isles	76
Western Mainland	52
Eastern Mainland	59

4. 1972 Annual Report, Conservation and Protection Districts No. 5 and 6.

Licences were issued to 29 purse seiners and for 30 drag seiners in 1972. There are, as well, 88 vessels engaged in carrying and/or pumping herring. Drag seiners operate entirely within shore waters and they normally fish from June to October. Their average annual catch over the past ten years has been about 1.5 million pounds equivalent to approximately 1% of the herring catch of the area.[5] In 1972, licences were issued to 30 drag seiners in Charlotte County (one for Grand Manan, 9 for West Isles, 9 for the Western Mainland and 11 for the Eastern Mainland).[6] Licences were issued for 29 purse seiners, in the same year, about equally divided between Grand Manan and Campobello. There are no purse seiners at mainland ports. The purse seiners normally operate off the Nova Scotia coast during the spring and summer months and, when fish are available, fish the Grand Manan area and off the Charlotte County shore during the fall and winter months. Five or six purse seiners from Nova Scotia normally fish off Grand Manan in the fall of the year. Seining is prohibited at all times in Passamaquoddy Bay north of the International Bridge joining Campobello and the United States, north of a line from East Quoddy Head to Bliss Harbour, and north of a line from southeast Bliss Island to Pea Island light, near Black's Harbour. From April 15 to September 30, seining is prohibited north of a line from Gannet Rock light (south of Grand Manan) to Split Rock, Saint John County.

There are nearly as many lobster fishermen in Charlotte County as there are herring fishermen. Lobsters are trapped within a few miles of shore throughout the country. The open season is from November 15 to June 24. Lobster fishing effort is normally high in December, declines considerably during January and February, and increases once again during March when weather conditions improve.

Groundfishing is of much less relative importance to Charlotte County than either herring or lobsters. Most fishermen who engage in groundfishing are from Grand Manan and West Isles. Draggers (50-75 ft), of which there are approximately 20, mainly on Grand Manan and West Isles, fish along the mainland coast, The Wolves and Grand Manan Bank during the spring and fall and off Nova Scotia during the summer. There are two large trawlers (over 100 ft) which operate on Grand Manan Bank and off Nova Scotia but, as these vessels are also purse seiners, most of their effort is concentrated on fishing herring. There are approximately a dozen long-liners, mainly on Campobello Island, which fish off eastern Campobello during the summer and fall. Hand-lines are fished from approximately 75 boats, mainly from Grand Manan and West Isles. Hand-lining effort is fairly heavy off Grand Manan and West Isles during the summer and fall. Friar Road (between Campobello and Deer Islands) through which tankers would have to pass is a relatively heavy hand-lining area. Although there is some hand-lining off the mainland, it is not nearly as extensive as off Grand Manan and West Isles.

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5. Correspondence, District Protection Officer, St. Andrews, N.B., to R.S. Collie, Chief, Conservation and Protection branch, Halifax, N. S.

6. 1972 Annual Report.

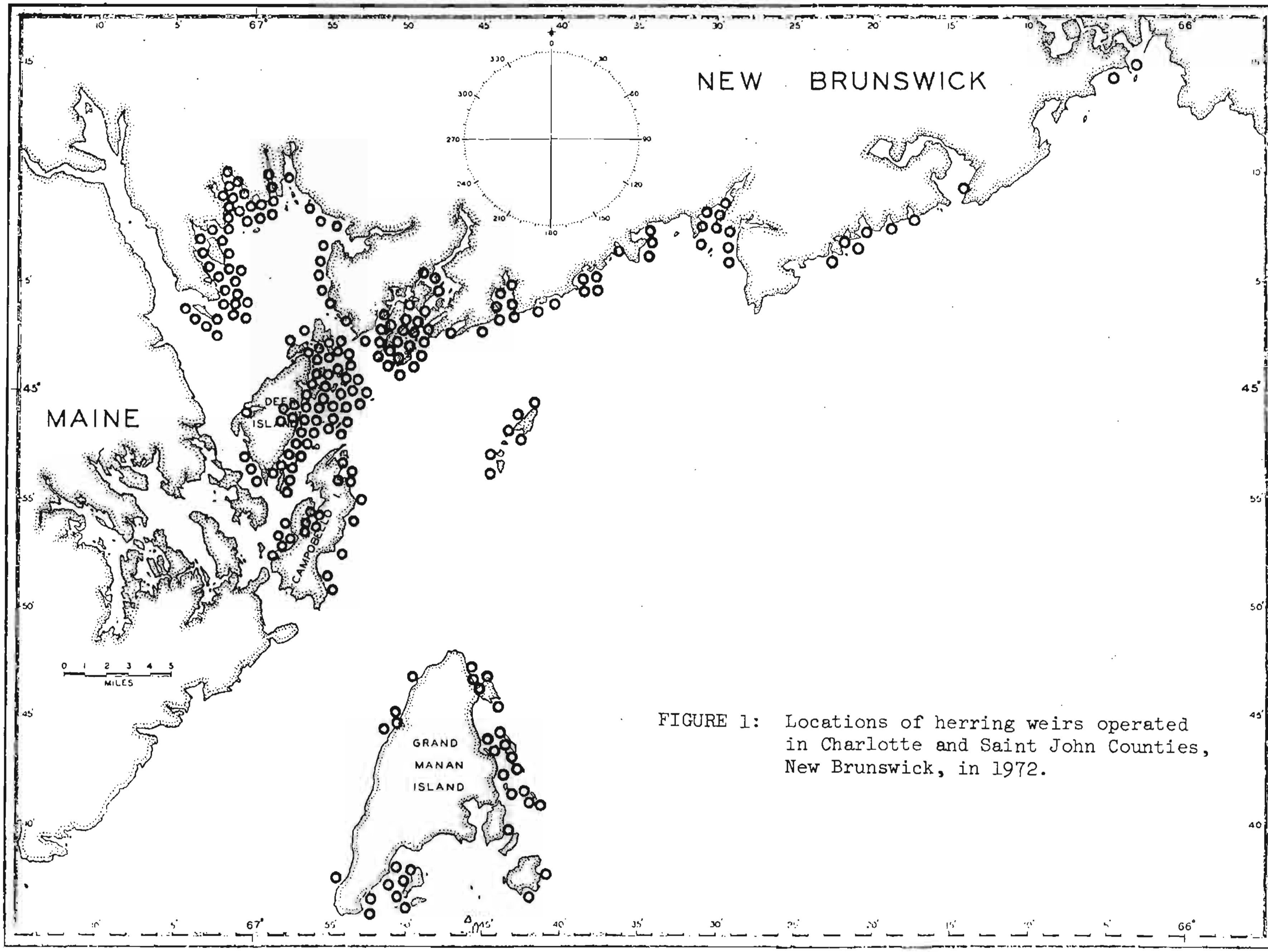

FIGURE 1: Locations of herring weirs operated in Charlotte and Saint John Counties, New Brunswick, in 1972.

Clams are dug both commercially and recreationally. Clams are dug along the foreshore of the coast principally in mainland areas, although there is a small clam fishery on Deer Island. Commercial fishermen dig about ten months of the year (March–January), except when an area is closed because the toxicity of the clams is above acceptable levels. Recreational diggers normally harvest clams in the summer although they may dig on holidays and weekends at other times of the year. Although it is impossible to be precise, at peak periods, there would be several hundred recreational clam diggers. They probably take less than 50% of the commercial catch, however.

There is a small commercial scallop fishery in Charlotte County. Twenty-six licences were issued to scallop draggers in 1972, all but two of which were for Grand Manan and West Isles. Most of the scallop fishing was conducted during the winter months (January to April) on local inshore beds around Grand Manan and Machias Seal Island. Seven or eight scallop draggers come from Digby to drag on these beds in the spring and fall. The vessels used in this fishery are all less than 65 feet in length. The fishermen engaged in other fisheries (herring, groundfish) at various times of the year; consequently, there is not a distinct fleet of scallop vessels. Like clams, there is a recreational scallop fishery. Scuba divers, largely from inland areas, dive for scallops mainly in Maces Bay (eastern mainland). There were 38 licences issued to scuba divers in 1972.

A small shrimp fishery developed in Charlotte County in the late 1960s. About a dozen boats drag for shrimps off the coast of the mainland, The Wolves, and West Isles, during the fall and winter. The vessels used are mainly in the 55-60 foot range and, like scallops, the fleet is not a distinct one.

In 1972 licences were also issued to two gaspereau trap nets in Passamaquoddy Bay, one eel trap on Deer Island, five tuna purse seiners in Passamaquoddy Bay and one on Campobello Island. None of the tuna vessels fish within the Bay of Fundy.

Data on the number of fishermen engaged in each of the various fisheries, by region, for the year 1971 are given below.

	Number of Fishermen Engaged						
	Clams	Groundfish	Herring	Lobster	Scallop	Shrimp	Other
Grand Manan	-	83	199	222	6	3	48
West Isles	14	111	240	96	5	32	2
Western Mainland	72	5	70	77	2	1	3
Eastern Mainland	62	11	74	103	2	4	19
Total	148	210	583	498	15	40	72

Bay of Fundy

Fishing activity within the Bay of Fundy can be divided roughly into two categories--a fairly intense fishing activity at the mouth and a very light activity in the remainder of the Bay. For this purpose the mouth would include the coastal regions west of a line from the Charlotte-Saint John County boundary in New Brunswick to mid-Annapolis County, Nova Scotia.

Approximately 61% of all fishermen in the Bay of Fundy trap lobsters within a few miles of shore from numerous ports scattered along most of the coast. Fishing effort is most intensive, however, at the mouth of the Bay. There are three lobster seasons in the Bay of Fundy. In Lobster District 1 (Charlotte County and Saint John County, N.B.) trapping is permitted from November 15 to June 24. In Lobster Fishing District 3 (Albert and Westmorland Counties, N.B., and Cumberland, Colchester, Hants, Kings, Annapolis and a small portion of Digby County, N.S.) trapping is permitted from October 15 to December 31 and from March 1 to July 20. In District 4 (Digby and Yarmouth) the open season is from the last of November to May 31.

The herring and groundfish fisheries rate next to the lobster fishery in terms of number of fishermen engaged--approximately 31 and 27%, respectively, of the total number of fishermen. The nature of the herring fishery varies considerably throughout the Bay. The herring fishery in Charlotte County was discussed previously. In Yarmouth County and Digby County as far as St. Mary's Bay the herring fishery is largely a purse seine fishery. In the remainder of Digby County, Annapolis County and Kings County, N.S., herring are taken almost exclusively in weirs and gill nets while in Saint John County, N.B., there is a small weir fishery. Few herring are captured in the remainder of the Bay.

As in the case of herring, the fishery for groundfish is most intense at the mouth of the Bay. In Yarmouth ahd Digby Counties, in 1972, there were 5 trawlers (over 75 ft), 133 draggers (35-75 ft), 6 offshore longliners (over 75 ft), and 164 inshore longliners (less than 75 ft).[7] A large number of fishermen using small boats (approximately 150) in this region fish for groundfish with handlines. Generally speaking, the small vessels fish from Brier Island to Brown's Bank during the summer and fall, while the large otter trawlers and longliners fish all year the same areas plus Brown's, Georges and LaHave Banks. In the remainder of the Bay of Fundy, there are a few small draggers and longliners (approximately 30 in total) which fish close to shore. The small draggers may go as far as Brier Island and, in the past, some vessels from Digby and Annapolis County, N.S., have gone to Grand Manan Bank to fish groundfish in the spring of the year. The Charlotte County fishery for groundfish was described earlier.

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7. 1972 Annual Report - Protection District No. 4.

There are two distinct scallop fleets on the Nova Scotia side of the Bay of Fundy. There are approximately 25 large scallop draggers (over 90 ft), operating out of the ports of Wedgeport, Yarmouth and Saulnierville which fish all year on George's Bank. An inshore scallop fleet, totalling approximately 40 vessels, 50 to 60 feet in length, operates out of the Digby region. These boats drag for scallops around Brier Island for most of the year.

There is a fairly large Irish moss fishery in Yarmouth County. Moss is raked by hand in shallow water. Very small boats are used in this fishery. Dulse is also hand-picked by an unknown number of persons in this region and in Charlotte County, particularly Grand Manan.

Outside of Charlotte County, there are three distinct clam beds. The largest is in the Annapolis Basin but there are also beds in St. Mary's Bay and Cobequid Bay. As in Charlotte County, clams are dug for approximately ten months a year, except when an area is closed because of high toxicity.

Unlike the fisheries for other species, the commercial salmon fisheries are not located at the mouth of the Bay. The largest commercial salmon fishery was in Saint John County. Until this fishery was closed in 1972, fishermen from Point Lepreau to Saint John and up the Saint John River as far as about Fredericton exploited a run of salmon returning to the Saint John River to spawn. There are smaller commercial salmon fisheries at the head of the Bay on both the New Brunswick and Nova Scotia sides. Both drift gill nets and fixed gear (weirs and traps) are used by commercial salmon fishermen. Although the legal open season varies, salmon are generally fished commercially in the late spring and summer.

Other species exploited by fishermen in the Bay but of less economic significance than those described above are mackerel, smelts, gaspereau, shad, eels, sturgeon, bass and coarse fish. There is also a very small tuna sport fishery out of western Nova Scotia. Approximately 18 boats took part in this fishery in 1972 fishing approximately 150 boat-days.[8]

The following table gives data on the number of fishermen engaged in the major fisheries, by counties, for 1971.

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8. J.S. Beckett, personal communication.

County	Clams	Ground-fish	Her-ring	Irish moss	Lob-ster	Mac-kerel	Sal-mon	Scal-lops	Shrimp	Others
	Number of Fishermen Engaged									
Charlotte, N.B.	138	210	583	1	498	1	1	15	40	69
Saint John, N.B.	-	16	45	1	123	-	148*	-	-	82
Albert, N.B.	-	-	-	-	20	-	2	-	-	12
Westmorland, N.B.	-	2	1	-	1	-	28	-	-	38
Cumberland, N.S.	-	11	10	-	59	1	1	7	-	14
Colchester, N.S.	22	6	6	-	1	-	15	-	-	20
Hants, N.S.	-	2	-	-	1	-	18	-	-	29
Kings, N.S.	-	50	38	-	40	18	17	1	-	21
Annapolis, N.S.	86	150	116	-	89	1	-	138	-	1
Digby, N.S.	147	310	157	12	496	49	1	61	-	9
Yarmouth, N.S.	-	228	199	446	934	24	1	101	1	140
Total	393	985	1155	460	2262	94	232	323	41	435

* not fishing at present because of ban on commercial salmon fishery in Saint John River.

5. PROCESSING

Charlotte County

At the end of 1972 there were 28 fish processing plants, 8 handlers, and 18 tidal lobster pounds in Charlotte County, N.B. The processing plants, handlers, and pounds operated an average of 10 months and employed a total of 1872 workers at peak periods. Of these workers, 908 were permanently employed (Fig. 2). The distribution of processors, handlers, and pounds and the number of employees, by type of processing, is given following.

County	Number of Plants, Handlers and Pounds		
	Processing Plants	Handlers	Tidal Lobster Pounds
Grand Manan	13	7	10
West Isles	3	-	8
Western Mainland	5	1	-
Eastern Mainland	7	-	-

	Processing Plants		Handlers		Tidal Lobster Pounds	
	Permanent	Peak Periods	Permanent	Peak Periods	Permanent	Peak Periods
Fresh, frozen and salt groundfish	6	12	-	-	-	-
Marinated, smoked and frozen herring, bloaters, frozen alewives	54	188	-	-	-	-
Shellfish	85	146	9	53	50	122
Canned sardines, herring meal and oil	619	1205	-	-	-	-
Combination groundfish, pelagic shellfish	85	146	-	-	-	122

Bay of Fundy

Including Charlotte County, at the end of 1972 there were a total of 78 fish processing plants, 41 handlers, and 20 tidal lobster pounds in the bay of Fundy region. Thsee plants employed a total of 3638 employees at peak periods and of these 1572 were permanently employed. The number of processing plants and the number of employees, by type of processing, for the whole of the Bay Region is given in the following tables.

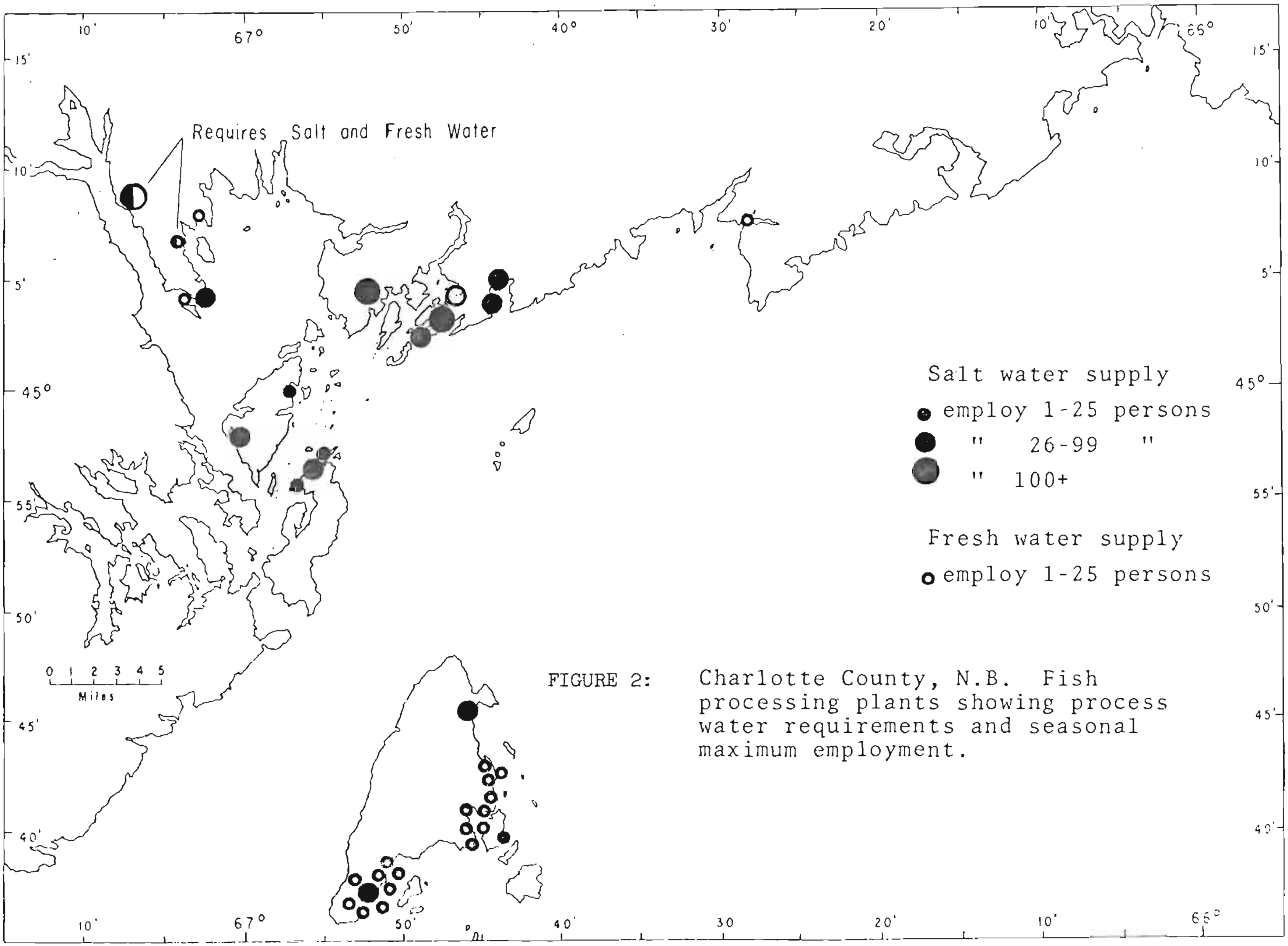

FIGURE 2: Charlotte County, N.B. Fish processing plants showing process water requirements and seasonal maximum employment.

County	Number of Plants, Handlers and Pounds		
	Processors	Handlers	Tidal Lobster Pounds
Charlotte, N.B.	28	8	18
Saint John, N.B.	-	-	-
Albert, N.B.	-	-	-
Westmorland, N.B.	-	-	-
Cumberland, N.S.	-	-	-
Colchester, N.S.	-	3	-
Hants, N.S.	-	-	-
Kings, N.S.	-	-	-
Annapolis, N.S.	1	-	-
Digby, N.S.	27	9	-
Yarmouth, N.S.	22	21	2
Total	78	41	20

	Processing Plants		Handlers		Tidal Lobster Pounds	
	Permanent	Peak Periods	Permanent	Peak Periods	Permanent	Peak Periods
fresh, frozen and salt groundfish	197	530	-	-	-	-
marinated, smoked, canned and frozen herring, bloaters, meal and oil	905	1900	-	-	-	-
shellfish	132	227	73	157	56	146
combination groundfish, pelagic, shellfish	188	641	-	-	-	-
Seaweeds	21	37	-	-	-	-
Total	1443	3335	73	157	56	146

The total value of fish products produced by the processing plants in the Bay of fundy region was $52.7 million in 1972. This figure should not be interpreted as the total value of fisheries in the Bay of Fundy as it does not include fish that was not processed; frozen fish, the information for which is not available on a county basis; and tuna processed by a company near St. Andrews, Charlotte County, N.B., as its source of supply is not from the Bay of Fundy and it has a fresh water supply which presumably would not be affected by an oil spill. It must also be pointed out that production figures can only be related in general terms to raw material supply in a particular region as some plants may purchase fish from outside the region for processing. Conversely, fish from outside the region may be sold to plants in the region for processing. In particular, some of the herring processed in Charlotte County, N.B., comes from outside the Bay of Fundy. This is also true of groundfish processed in southwestern Nova Scotia. The value of products for Charlotte County and the Bay of Fundy (including Charlotte County) is given below.

	Charlotte County ($x1000)	Bay of Fundy ($x1000)
Groundfish products	320	6,288
Herring products	17,792	25,174
Shellfish products	6,695	19,702
Seaweeds	135	671
Other and unspecified	214	830
Total	25,156	52,665

SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

SECTION 7

TOURISM AND RECREATION,

AND RECREATIONAL FISHING AND BOATING

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CONTENTS

SUMMARY

It is estimated that tourists spent approximately $10.0 million in Charlotte County, New Brunswick, in 1973 and that $2.8 million of this was associated directly with shoreline use. Total tourist expenditures in the Bay of Fundy Region, for 1973, are estimated to be $24 million of which $13.9 million is directly attributable to the use of the coast. Approximately 25% of all travel accommodations along the coast of the Bay of Fundy are in the Passamoquoddy Bay region (Charlotte County, New Brunswick) and approximately 40% of total Bay of Fundy tourist expenditures are in coastal Charlotte County. There are, as well, unquantified recreational values of local residents using the coast.

Possibly, angling in fresh water streams could be affected by an oil spill, particularly salmon angling. The striped bass fishery might also be affected.

The extent of recreational boating is not known. There are boat clubs at St. Andrews, New Brunswick, Cornwallis and Digby, Nova Scotia. There are nine charter boats for deep sea fishing in Charlotte County, New Brunswick and 17 in the remainder of the Bay of Fundy.

1. TOURISM AND RECREATION

It is impossible to put precise figures on the value of tourism and recreation because (a) data that do exist are not really suitable for an economic evaluation and (b) there is no single methodological approach accepted by everyone. The approach used here is basically the same as the one used by Pearse Bowden in the Lorneville Impact Study.[1] Their approach is reasonably simple in that an estimate is made of total expenditures by non-resident tourists from which, under certain assumptions, they estimate net losses. The approach here differs in some respects, however. Whereas Pearse Bowden used only the expenditures on non-residents, it is felt that to calculate the costs of an oil spill to the Bay of Fundy region, expenditures for residents visiting the area should also be included. As well, no attempt has been made to estimate net losses.

Charlotte County

Precise data on the number of resident and non-resident visitors to the coastal regions of Charlotte County are not available. Consequently, approximations of the number of visitors and expenditures have to be made using data that are available. It seems reasonable to assume that the number of visitors to the coastal regions of Charlotte County are proportionate to the number of units for accommodating visitors. These units, by type and area are given below. Units in inland Charlotte County are not included.

	No. of Establishments	No. of Units Seasonal	Yearly	Total	No. of Campgrounds
Grand Manan	10	52	44	96	1
West Isles	4	25	10	35	3
Western Mainland	33	405	153	558	5
Eastern Mainland	10	69	33	102	7
TOTAL	57	551	240	791	16
Per Cent of N. B.	16.1	33.0	4.3	10.8	7.8

Source: New Brunswick, Department of Tourism, "New Brunswick Accommodations, 1973".

Coastal Charlotte County has a very high proportion of seasonal units and a very low proportion of yearly units which gives some indication

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[1] Pearse Bowden Economic Consultants Limited, Lorneville Environmental Impact Study, Section 14, "A Socio-Economic evaluation of possible external effects".

of the importance of the tourist industry to the region. The proportion of campgrounds is low, however. Assuming that tourists are indifferent between staying at establishments opened all year and establishments opened on a seasonal basis, and allowing for the low proportion of campgrounds in the region, a figure of 10% as the proportion of tourists to New Brunswick visiting the coastal regions of Charlotte County does not seem unreasonable. A much larger proportion of visitors apparently pass through Charlotte County, largely because of its being one of the major entry points for U.S. travellers but presumably this movement would not be affected by an oil spill.

Total expenditures by non-New Brunswick residents entering the province by motor vehicles between May 15 and October 31 were approximately $52 million[2] in 1971. Assuming that 10% of this expenditure was in coastal Charlotte County, expenditures in that region for the same period were approximately $5.3 million. Using the same proportion as Pearse Bowden[3] to adjust this to an annual figure, expenditures become $7.0 million. New Brunswick residents, making trips of 100 miles or more, spent approximately $13 million in New Brunswick in 1971.[4] On the same assumption, as above, their expenditures in Charlotte County would have amounted to approximately $1.3 million. Total expenditures by New Brunswick and non-New Brunswick residents, in 1971, were, therefore, in the range of $8.3 million.

Not all trips to coastal Charlotte County would necessarily be associated with shoreline recreation. Pearse Bowden[5] use a figure of 30% which is probably as reliable an estimate as any given that 34 per cent of the drivers of vehicles included in the 1971 New Brunswick auto exit survey indicated sightseeing was the main purpose of their trip[6] and 20.1 per cent of New Brunswick residents indicated that sightseeing, recreation and sports were the main purpose of their trips.[7] Total expenditures in coastline Charlotte

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[2] New Brunswick, Department of Tourism, "New Brunswick 1971 Auto Exit Survey.

[3] Lorneville Study, p. 470.

[4] Canada, Travel Industry Branch, Office of Tourism, Department of Industry, Trade and Commerce, Canadian Travel Survey, 1971, Highlights (Ottawa, 1972).

[5] Lorneville Study, p. 470.

[6] N.B. Auto exit survey, p. 5.

[7] Canadian Travel Survey, p. 60.

County which could be affected by an oil spill would, therefore, be approximately \$2.5 million for 1971. Using a six per cent annual rate of growth,[8] this would amount to \$2.8 million in 1973. The net loss to the province of New Brunswick would be lower than this and, although Pearse Bowden made such a calculation, the figure of \$2.8 million used above is based on so many assumptions that making another calculation, based on another assumption, even though theoretically sound, introduces too great a refinement to a process that at best gives an estimate and is probably closer to a guess.

Bay of Fundy

The same method has been used to calculate the effects of a spill on the Bay of Fundy tourist industry as was used for Charlotte County. The number of units of accommodation for the coastal areas of the Bay of Fundy was derived in the same manner and are given below.

County	No. of Establishments	No. of Units			No. of Campgrounds
		Seasonal	Yearly	Total	
Charlotte, N.B.	57	551	240	791	16
Saint John, N.B.	32	118	822	940	4
Albert, N.B.	18	189	10	199	16
Westmorland, N.B.	8	15	94	109	3
Cumberland, N.S.	6	37	12	49	2
Colchester, N.S.	18	12	357	369	6
Hants, N.S.	5	2	58	60	2
Kings, N.S.	2	25	--	25	2
Annapolis, N.S.	5	23	24	47	5
Digby, N.S.	22	189	160	349	7
Yarmouth, N.S.	24	44	504	548	5
TOTAL	197	1,205	2,281	3,486	68

Sources: New Brunswick, Department of Tourism, "New Brunswick Accommodations, 1973".

[8] Lorneville Study, p. 472.

Nova Scotia, Department of Tourism, "Where to Stay in Nova Scotia, 1973".
Nova Scotia, Department of Tourism, "Campgrounds and Day-Use Parks, Nova Scotia, 1973".

The data in the preceeding table include only establishments which are in towns that are on the coast of the Bay of Fundy or its bays and inlets. No establishments in the Moncton region are included. However, establishments in Saint John, Amherst, Truro, and Yarmouth are included. The proportion of establishments, units, and campgrounds of the provincial totals are given below.

	No. of Establishments	Number of Units Seasonal	Yearly	Total	No. of Campgrounds
New Brunswick	33%	52%	21%	28%	19%
Nova Scotia	19%	26%	16%	17%	15%

A reasonable figure for the number of tourists visiting the coastal regions of the Bay of Fundy for New Brunswick and Nova Scotia, respectively, would be 25 per cent and 15 per cent of the totals. In Nova Scotia, in 1971, non-Nova Scotia residents travelling by automobile, between May 15 and October 31 spent a total of $45.7 million.[9] Using this figure and the expenditures for New Brunswick quoted above, adjusting both Nova Scotia and New Brunswick expenditures to an annual basis by the method used previously, and adjusting these figures for the purpose of travel would indicate that 1971 expenditures by non-residents, for the purpose of visiting the coastal regions of the Bay of Fundy, was approximately $4.3 million in New Brunswick and $5.6 million in Nova Scotia in 1971. Residents, travelling 100 miles or more, according to the information contained in the 1971 Canadian Travel Survey and applying the same procedure as for Charlotte County spent approximately $0.3 million and $0.7 million in the Nova Scotia and New Brunswick Bay of Fundy regions, respectively. Total expenditures, by residents and non-residents, in the Bay of Fundy region, therefore, would have amounted to approximately $10.9 million in 1971. In 1973, using a 15 per cent growth rate for Nova Scotia,[10] and a 6 per cent growth rate for New Brunswick, expenditures would have amounted to approximately $13.9 million.

This figure and the one given for Charlotte County are for total expenditures of tourists in the coastal areas of the Bay of Fundy. How much of a loss would result from an oil spill is not known nor can it be predicted. Some of these expenditures would, if in the extreme an oil spill damaged the entire coastline, be

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[9] Nova Scotia, Department of Tourism, Some Aspects of the Tourist Industry in Nova Scotia, (February, 1973).

[10] Ibid.

diverted to other areas of both provinces. Some people would continue to visit the area if their planned activities were not affected by an oil spill. Both the figure for Charlotte County and the Bay of Fundy, therefore, must be considered as maximum values.

Recreation refers to the use of the coastal region by residents of the area. In this particular case the term refers to the use of the coastal regions of the Bay of Fundy by residents of Nova Scotia and New Brunswick not included, above, as tourists. This distinction between tourism and recreation is somewhat arbitrary and possibly confusing. The point to be made is that there is a loss, in the event of an oil spill, over and above that measured by tourist expenditures. In economic terminology, there is a loss in welfare. In some cases it is possible to make a quantitative assessment of this loss but, generally, data are so inadequate that this is impossible.

The recreational potential of the shoreland and a description of wildlife in Charlotte County is given in the paper by Beanlands.[11] Other uses such as nature instruction and nature walks, beach use, cottage use and hunting along the New Brunswick Bay of Fundy coast have been outlined by Pearse Bowden and the New Brunswick Department of Tourism in the Lorneville Impact Study. Since this is basically an economic assessment no attempt has been made to expand upon the three above-mentioned papers. It should be pointed out that activities in Nova Scotia would be similar to those in New Brunswick.

2. RECREATIONAL FISHING AND BOATING

Some information is available on recreational fishing but little or no information exists on recreational boating. Recreational fishing is basically of two types -- salt water fishing and fresh water fishing.

Charlotte County

Salt water fishing is becoming increasingly popular. Nine charter boats operate out of Grand Manan (2), Campobello (3), Deer Island (3) and St. Andrews (1). The main species sought are mackerel and groundfish. This activity is quite small, at present, but if other areas are an indication, it will grow substantially.

Angling is popular in fresh water streams in Charlotte County. The only species that would be affected by an oil spill however, would be Atlantic salmon, as it spends part of its life

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[11] G. E. Beanlands, Lands Directorate, Environmental Management Service, "Shoreland Quality for Recreation", Section 8.

at sea. The only Charlotte County rivers from which salmon have recently been angled are the Magaguadavic, Digdeguash and St. Croix. The average number of salmon taken in 1971 and 1972 from each of these rivers is given below:

River	Bright		Black	
	Salmon	Grilse	Salmon	Grilse
Magaguadavic	15	12	--	--
Digdeguash	1	--	2	--
St. Croix	--	--	1	--

Bright salmon and grilse are angled during the summer months while black salmon are angled during the spring on their return run to the sea.

Recreational boating is quite extensive in Charlotte County particularly in the St. Andrews area and Campobello Island. There is a boat club at St. Andrews whose members own approximately 50 boats. There are, as well, many private boats in Charlotte County, particularly Campobello, which are not moored at marinas or yacht clubs. The number of these boats is not known.

Bay of Fundy

Salmon angling is the most important recreational fishery in the Bay of Fundy tributaries, but there is also a fishery for striped bass which is growing rapidly. The most important salmon river in the Bay is the Saint John. Cumberland and Colchester counties also have some fairly good salmon rivers. Average 1971 and 1972 landings for the counties bordering the Bay of Fundy are given below:

County	Number of Fish Angled			
	Bright		Black	
	Salmon	Grilse	Salmon	Grilse
Charlotte	16	12	--	--
Saint John (Including inland counties)	1,251	758	38	53
Albert	13	49	1	4
Westmorland	0	15	13	25
Cumberland	57	208	--	--
Colchester	198	497	--	--
Hants	7	32	--	--
Kings	8	1	--	--
Annapolis	3	--	--	--
Digby	7	3	--	--
Yarmouth	14	9	--	--
TOTAL	1,574	1,584	52	82

Salmon are angled by both residents and non-residents. In both Nova Scotia and New Brunswick, the price of angling permits are administered rather than determined by the market. Consequently it is impossible to put a value figure on the recreational salmon fishery although sometimes gross expenditures of anglers are used.

The same is true of the striped bass fishery. The Annapolis River is by far the most popular striped bass river although some fish are taken in the other counties of western Nova Scotia and a few in the Saint John River system. Little is known of the extent of angling and even less of its economic significance. The average number of striped bass angled in 1971 and 1972, by counties, is given in the following table:

County	No. of Striped Bass Angled
Charlotte	--
Saint John (including inland counties)	105
Albert	--
Westmorland	--
Cumberland	--
Colchester	--
Hants	1,800
Kings	500
Annapolis	35,375
Digby	254
Yarmouth	727

Charter boat operations are located in Yarmouth and Digby counties, Nova Scotia and Saint John County, New Brunswick in addition to those in Charlotte County. There are eight charter boats from Wedgeport (all equipped for tuna) and two out of Port Maitland, in Yarmouth County. In Digby there are six charter boats at Cape St. Mary's, four of which are equipped for tuna, and one at Meteghan, also equipped for tuna. One charter boat operates from Dipper Harbour in Saint John County, New Brunswick. There are no charter boat operations in the remainder of the Bay.

As in the case of Charlotte County the extent of recreational boating in the Bay of Fundy is unknown. Many residents of the area have boats, large and small, which are used for recreational purposes. There are yacht clubs at Cornwallis and Digby in Digby County, Nova Scotia.

The effect an oil spill might have on recreational fishing and boating will depend upon the extent of the spill and where it occurs. The main effect would be probably a curtailment of such activities until the oil was either removed from the water or until it came ashore. There might be some fouling of hulls and shore installations if there was a large spill in the vicinity of yacht clubs, marinas, or areas where there are private boats moored. There would be a cost involved in cleaning these boats and installations varying with the extent of the spill and the number of boats involved. There would be no direct effect on recreational fishing in fresh waters but possibly an indirect effect if a spill affected the fish population. Other recreational activities, such as beach use, would be much more directly affected.

SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSMAQUODDY REGION OF THE BAY OF FUNDY

SECTION 8

SHORELAND QUALITY FOR RECREATION

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CONTENTS

SUMMARY

The shoreline and coastal waters of southwestern New Brunswick have a significant potential for a wide spectrum of recreational activities. Of the approximately 150 square miles of shoreland from the Maine border to the city of Saint John, nearly 50 square miles have a high capability for family-oriented recreational pursuits based on the physical and aesthetic characteristics of coastal lands and waters.

Passamaquoddy Bay has the highest potential for intensive recreational use with nearly the entire coastline being rated moderate to moderate-high according to the Canada Land Inventory recreation survey. For this coastal area practically all of the best potential uses identified are among those which would be seriously affected by oil contaminating the beaches and inshore waters.

Although it is difficult to forecast the exact nature of the effects of a marine oil spill on water-based recreational activities it is important to recognize that not only would the impact have to be evaluated in terms of immediate and long-term financial losses to private and commercial interests, but some realistic appraisals would have to be made of significant aesthetic and social losses.

1. INTRODUCTION

The following comments are provided as a preliminary description of the coastline of southwestern New Brunswick in terms of its suitability for water-oriented recreation. The objective was to develop an overview appreciation for the general quality of shoreland in the area as a useful component in the analysis of environmental effects from potential oil spills related to the proposed refinery at Eastport, Maine.

Most of the comments are based on land capabilities as determined by the results of the Canada Land Inventory (C.L.I.) recreational survey published in 1971. It should be noted that land was classified in the C.L.I. program on the basis of its *potential* capability to support and sustain a variety of recreational activities and present uses may not reflect its future value as indicated by the C.L.I. rating. Under the inventory program capabilities for recreation were classified on a scale from 1 to 7 (higher numbers indicating lower capabilities). For purposes of classifying the recreational potential of coastal land, the strip of land within approximately one-half mile of the water's edge was apportioned to the various classes based on the physical and aesthetic attributes of the area. In this report, 'shoreland' refers to this strip of coastal land which will be the focus of increasing recreational pressures.

In addition to the major class breakdown, shoreland units were assigned various subclasses which indicated the best recreational use for the land. About 25 subclasses were identified in the C.L.I. program and these are important in determining the degree to which an area will be affected by particular developments. For example, in this report attention was focused on those uses which would be most severely curtailed in the event of a marine oil spill. Four most vulnerable uses were selected, namely: family beach activities (swimming), organized camping, recreational lodging (summer cottages), and general outdoor recreation (hiking, nature study, collecting and scenery).

2. OBSERVATIONS

The numerous inland lakes and rivers of southwestern New Brunswick support the largest potential for concentrated water-oriented outdoor recreation in the province. By contrast, the Fundy shore in this area of the province is not generously endowed with prime recreational areas. This is particularly true with regard to higher class sandy beaches which tend to be well suited for intensive family-oriented water activities. Furthermore, because of high tides and cold water most classifications of shoreland units have been reduced by one class.

However, in assessing the recreational potential of the area in general, it should be borne in mind that Classes 3 and 4 represent the best ocean shoreland available to satisfy the recreational pursuits of residents and tourists alike. These areas are expected to become the focal points of summer cottage and commercial recreational developments since many of the inland waters are either inaccessible or already highly developed.

Access to the coastal waters in this area is generally good and the proximity to a major road link with the United States would suggest that future developments will keep pace with the exponential increase in the tourist industry. A factor which may influence the general use of the Fundy shore for recreational activities over the long term is the projected Fundy Trail. This route, which would closely follow the shoreline of the entire bay, has been planned for some time and may be given an added impetus with the burgeoning tourist industry.

In many areas such as Passamaquoddy Bay the shoreland has been classified under C.L.I. as having high capability for supporting both recreation and migrating waterfowl, which gives added importance to their protection from major catastrophe. In other areas the classifications may not coincide although in some cases the ability to view aggregations of wildlife is a factor in determining the recreational potential of an area.

In order to facilitate more detailed discussion the area in question was arbitrarily divided into five major units: (1) Passamaquoddy Bay, (2) Blacks Harbour Area, (3) Maces Bay, (4) Point Lepreau to Lorneville, and (5) Grand Manan Archipelago.

3. RECREATION POTENTIAL

Passamaquoddy Bay

Over three-quarters of the best recreational shoreland from the United States border to Saint John is located in Passamaquoddy Bay. Gentle topography, sheltered waters and proximity to an aggregate urban population of about 100,000 (Saint John, St. Stephen, St. Andrews) make this area one of the most important recreational zones in the province.

Over 60 miles of coast, virtually the entire shoreline of the bay, is given a moderate to moderate-high capability for water-oriented recreation. More importantly, the shores are particularly well suited to family activities including boating, swimming, camping, beach sports and the siting of recreational lodging. These uses would be seriously affected by an oil spill.

The only other extensive area of coastline having a similar classification and within convenient driving distance of Saint John is to the east of the city. Here, by contrast, the attractive feature is a rugged topography which affords panoramic vistas and views of scenic coastal landforms - uses which would not be seriously affected by an oil spill. The main point is that there are virtually no coastal regions in this part of New Brunswick which could serve as an alternative to Passamaquoddy Bay for intensive, family-oriented recreation.

Blacks Harbour Area

Shoreland in the vicinity of Blacks Harbour is generally classified as having a low potential for outdoor recreation. A very convoluted coastline precludes easy road access to many sections of the shore and potential uses have more to do with land-based activities such as hiking and camping. There is some potential for summer cottage development.

Maces Bay

There is a fairly good distribution of quality recreation shoreland in Maces Bay with over 60% classed as 5 or better. Two areas of particular importance are 7 miles along the eastern shore which have a limited potential for cottage development and a Class 2 beach on the north shore. This latter beach is one of the finest recreational spots on the entire Fundy coast and is the site for a provincial park. With prevailing southwesterly winds during the summer Maces Bay would be extremely vulnerable to the effects from an oil spill in the vicinity of Head Harbour Passage; it may, in fact, act as an entrapment basin to the eastward movement of oil along the coast.

Point Lepreau to Lorneville

With the exception of areas near Chance Harbour and Lorneville this stretch of coast has a low capability for outdoor recreation. Although there is some potential for cottage development much of the coast is exposed to the open waters of the Bay of Fundy and not suitable for most water-based activities.

Grand Manan Archipelago

Next to Passamaquoddy Bay the islands of Deer, Campobello and Grand Manan offer the most extensive stretches of high class recreational shoreland in southwestern New Brunswick. The uses, however, relate more to the variety of coastal landforms and abundant bird life than the water-oriented sports or activities. It appears that the Harbour Lute area is scheduled for recreational developments (Macdonald, personal communication). These islands are already well known for their natural beauty and recreational opportunities and it is safe to assume that they will gain in popularity.

The relative importance of the various areas previously described is indicated in Table I which gives the percentages of shoreland in each of the recreational classes and selected subclasses. The variation in recreational potential between the areas is quite evident. At one extreme is Passamaquoddy Bay which has almost 45% of the shoreland in Classes 3 and 4 and less than 15% in Class 6. In addition, the last column in the table shows that virtually all of the land classes as 5 or better is best suited to family-oriented activities which would be seriously affected by oil contaminating the beaches and inland waters. It is safe to conclude that if this area is to continue to supply important recreational resources to residents and tourists alike the maintenance of a clean environment at the water's edge is essential.

At the other end of the scale is the shoreland around Black's Harbour of which 65% is classed as 6-7 and less than 10% of the better classes are suitable for water-oriented activities. The other three areas fall between these two extremes.

Calculations based on the last two columns in the table show that about 50 square miles (based on a ribbon of land one-half mile inland) from the Maine border to the city of St. John are capable of sustaining a high degree of human activity related to the recreational use of the immediate coastal lands and waters. These activities would likely be seriously curtailed or prevented in the event that a major marine oil spill resulted in contamination of the area.

Table I

Classification of Recreational Shoreland in Southwestern New Brunswick According to Canada Land Inventory Recreation Survey

Area	Percentage of Shoreland in Recreation Classes*						Total Shoreland (sq mi)	Shoreland in Classes 1-5 suitable for family recreation** (% of total shoreland)
	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7		
Passamaquoddy Bay		4.25	40.72	41.30	13.73		41.36	86.27
Blacks Harbour Area			2.06	32.05	61.89	4.00	21.76	6.25
Maces Bay	10.55		28.44	20.00	41.01		15.24	61.01
Point Lepreau to Lorneville			19.34	4.45	74.67	1.54	20.68	19.34
Grand Manan Archipelago		9.22	14.06	11.35	64.61	0.76	47.24	12.85

* Class 1 is not represented in this area.

** Shoreland with potential for family bathing, organized camping, cottage development or general outdoor recreation.

SUMMARY OF PHYSICAL, BIOLOGICAL, SOCIO-ECONOMIC AND OTHER FACTORS RELEVANT TO POTENTIAL OIL SPILLS IN THE PASSAMAQUODDY REGION OF THE BAY OF FUNDY

SECTION 9

THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE OPERATION OF OIL TERMINALS

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CONTENTS

SUMMARY

A simulation model has been constructed for exploring the gross influence of environmental criteria on oil terminal operations. Simple analyses are given showing performance as a function of the various weather criteria which could be used as delineating conditions unsafe for navigation. The effect of ocean currents and water-levels is taken into account only through the time-step (i.e. a time step of 12 hours implies that the currents and water-levels are suitable for the passage of one ship in each 12-hour period). The model presents the detailed circumstances accompanying tanker delays although delays for all reasons have been lumped in the examples shown. The model can be used in factor analysis to test performance with a variety of values for the constraints.

The sample analyses show that shifts in rules to prohibit navigation more and more frequently during the course of a year lead to a corresponding reduction in oil terminal performance. Moreover, prohibition of navigation during darkness, for example, was shown to be as influential with respect to performance as fleet size and diversion criterion. Varying the tank farm capacity from three to ten tankerloads has no effect at the operating points chosen.

1. PURPOSE

The planning and design of an oil terminal must take into account many factors before decisions on its desirability and acceptability can be reached. The purpose of this chapter is to examine, through the use of a tactical model, the role that environmental criteria play in developing an over-all plan.

2. INTRODUCTION

Conceptually it is useful to think of a comprehensive model comprised of a hierarchy of submodels with varying degrees of lateral and vertical interaction or coupling. The following levels of modelling can be envisaged for the planning of oil terminals.

A. An economic model. This would have as output an estimate of profit based on such input parameters as the production capacity, storage capacity of the tank farm, the size of the tanker fleet, the number and capacity of tankers served at the terminal during a year, the number of days per year when production (refining and/or transshipment) is ongoing (i.e., supplies of crude are not interrupted by spells of bad weather), the number of tanker days spent waiting for weather conditions to improve, and as discussed in chapters 3 to 8, the costs associated with the spills and risks of spills. Those values of the input parameters which will optimize profit can be determined by linear programming techniques (e.g., Frankel et al., 1973). The economic consequences arising from delays in docking supply ships owing to unfavourable weather, or from installation and maintenance of a variety of pollution prevention or clean-up facilities or from navigating the harbour approaches only under given current conditions, for example, can be estimated by such a model.

B. Terminal operations model (the present model). This produces the number of ongoing production days, the number of days lost while waiting for the weather to improve and the number of days when a tanker was successfully docked during a year's operation of the terminal. These outputs are simulated in response to the daily production rate, to tank farm capacity, to given environmental conditions and prerequisites, and to certain tanker fleet strategies pertaining to intervals between arrivals and criteria for diverting to another terminal.

C. A detailed pilotage model. This would produce environmental prerequisites for safe approach and docking at the terminal and tolerances on ships's position, heading, speed and the time with respect to slack water (where relevant) at a number of check points in the approaches. The inputs required are the water currents in space and time, the winds in real time, gauges of the random or unpredictable component of currents and winds, and, finally, the ship's response characteristics.

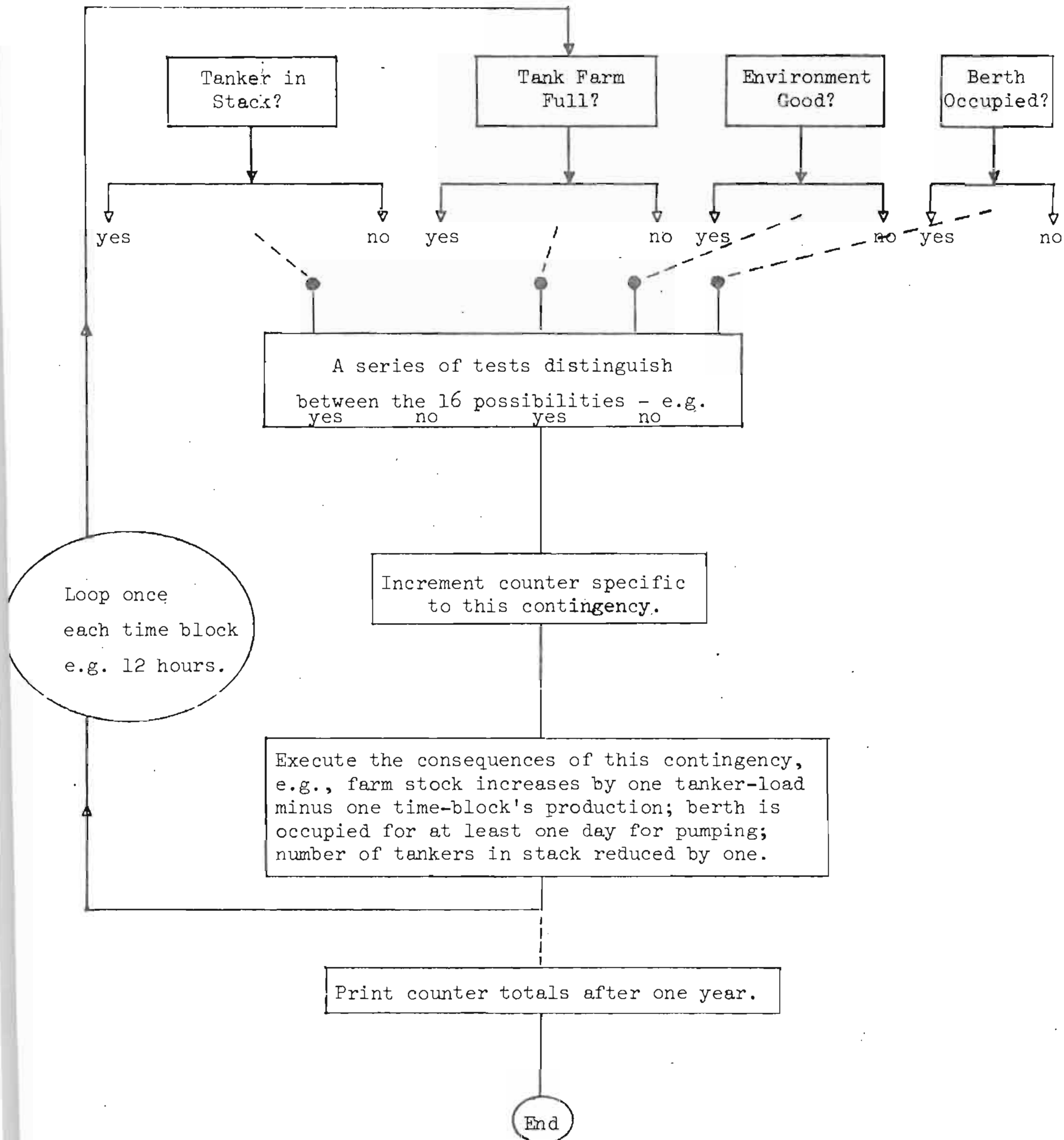

FIGURE 1: Flow chart of simulation model for superport-refinery system.

D A port mishaps model. As attempted in chapter 2, this would produce the rate and direction of dispersion of oil given the size, time and location of the spill.

The second model has been completed and is described below. Lacking set environmental prerequisites (because Model C has not been built), Model B is operated over a range of environmental standards. Its ultimate application is in determining effects of environmental standards on profits, however, since Model A has not been built the outputs will be presented in quantitative but non-economic terms.

3. THE TERMINAL OPERATIONS MODEL

This model has as inputs an environmental criterion, tank farm size, ship arrival times and a diversion threshold (beyond which waiting time the ship is diverted to another port). Internal accounting is maintained for the number of tankers in the waiting line or stack, the tank farm stocks taking into account the production daily, and the status of the single berth (occupied or free). The per annum outputs are: the number of tankers served, the number of tanker-days spent waiting, the number of trans-shipment or refinery days shut down for lack of crude oil, and the number of tankers diverted. (Note: In this model with a tidal cycle as the basic time step, the units of hours and days are taken to be lunar hours and lunar days where one lunar day equals 24.84 solar hours.)

The logic, illustrated in Figure 1, is to test four key indices (Is there a tanker waiting? Is there room for more crude oil stocks? Is the weather good? Is the berth open?), count the frequency of occurrence of each of 16 possible time block categories (Fig. 2), adjust the key indices as a consequence of the particular category which occurred and to continue to do this for each of the time blocks in a year. At the same time a parallel accounting is carried on for the tanker-time spent waiting in each of the seven possible delay categories. For example, in Figure 1, if the tanker arrivals submodel has produced a tanker waiting in the stack, if the tank farm has capacity to receive its load, if the currents and weather are acceptable for docking and if the berth is unoccupied then the tanker docks and begins discharging. The counter for the number of time blocks during which a tanker is docked (Fig. 2) is incremented by one. The number of tankers waiting in the stack is reduced by one; the tank farm stock is incremented and the berth is posted 'occupied'.

The question of whether tidal plus residual currents are acceptable for docking has been handled crudely and implicitly. It has been assumed that current conditions are acceptable once per 12-hour tide cycle and that the duration of 'slack water' is sufficient for the passage of only one tanker. These assumptions are reflected in the 12-hour time step of the model--i.e. if a tanker arrives just after the 'slack water' period, it must wait for at least 12 hours before the next opportunity occurs. An improved version would base the decision about acceptability of the currents at a given time on a pilotage or ocean currents model and would re-examine that decision frequently.

Not all the details are shown in Figure 1. For example, two tanker stack submodels are available. One simulates tanker arrivals at random time intervals; the other, at fixed intervals (e.g. dedicated fleet). As mentioned, the stack submodels also include a diversion criterion whereby if the accumulated tanker-days spent waiting exceed a given preset number, then the tankers are diverted to some other port to save further delay.

The environment criterion is designed to operate either from a simulated weather signal or from actual weather data. However, the actual data used thus far has been that for southern New Brunswick in 1972 only.

The berth index is designed so that a tanker remains alongside for at least 24 hours discharging cargo. Thereafter departure is dependent upon weather; however, these standards may be set independently of those for docking.

The crude oil stocks on hand are decremented by 0.07 tanker-loads per 12-hour time step to simulate either trans-shipment or refinery production.

The output of the model for a run consists first of a catalogue showing the number of time blocks per year in each of the 16 categories of Figure 2. To continue the above example in Figure 2 during 61 time blocks conditions were met for a tanker to dock. A comparable array is printed out showing the number of tanker-days spent waiting in each category. Finally, other counters such as the number of days when the tank-farm was empty and the number of times the diversion threshold was exceeded are printed out. The model is programmed in BASIC and is accessed on a computer terminal.

4. ANALYSIS

In the first analysis, three of the four input parameters were fixed and the fourth, the environmental or weather criterion, was varied. Tankers were diverted when delays exceeded five tanker-days in any one episode. The tank farm capacity was taken as three tanker loads. The tanker arrival rate was taken as one per 7 days. The resulting (simulated) numbers of tankers served, tanker-days waited, and days shut down for lack of crude over a year are shown in Figure 3 (a-c).

The results show that delays increase monotonically as the percentage of time blocks when conditions are unacceptable for navigation increases. (Apparently the greater persistence of low visibility compared to darkness is unimportant at these frequencies of occurrence since the curves of Figure 3 are not perturbed by replacing a low visibility constraint with a darkness constraint.) If the divert criterion were reduced, say, to two tanker-days, tanker waiting time would be reduced and refinery shut-down time increased.

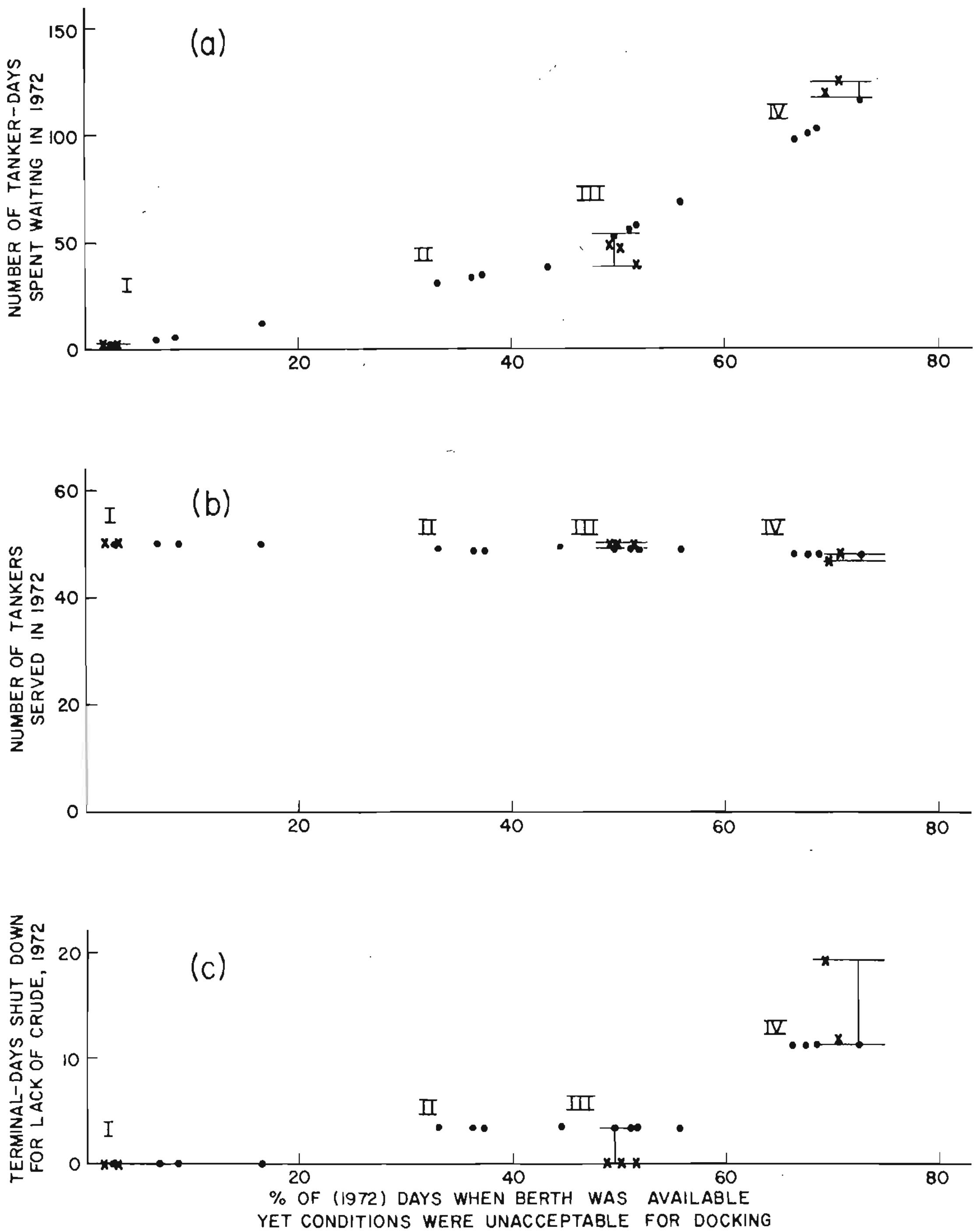

FIGURE 3 a,b,c: Simulated performance characteristics for an oil terminal with navigation governed by varied environmental criteria described as follows: docking prohibited (I) during winds, (II) during winds or poor visibility, (III) during winds or darkness, (IV) during winds or poor visibility of darkness. (The wind criteria was varied from 15 to 30 mph as measured at Eastport at time of slack water. The operation of the Head Harbour fog signal (two miles threshold) designated times of poor visibility. Darkness was chosen arbitrarily to extend from one hour after sunset to one hour before sunrise. The range lines on the figure encompass the variability due to shifting the regular day of arrival of the weekly tanker.)

Secondly, the technique of factor analysis (Davis, 1967) was used. In this procedure, 16 trial runs of the model were made covering the combinations of the four inputs and at two levels for each input parameter. These levels are presented in Table 1. Of course, other levels can be chosen; the case where low visibility was made the difference between high and low levels would also be interesting.

TABLE 1

The Chosen Levels of the Four Input Parameters for a Sample Experiment

	Parameter	Low Level (-)	High Level (+)
A.	Environmental (good weather) criterion.	Docking prohibited in darkness, low visibility or ≥ 20 mph winds.	Docking prohibited in low visibility or winds ≥ 20 mph.
B.	Tanker-days diversion criterion.	2 tanker-days	5 tanker-days
C.	Tank farm capacity.	3 tanker loads	10 tanker loads
D.	Tanker arrival rate (or fleet size)	1 per 7 days	1 per 5 days

5. RESULTS

The results for the 16 runs are shown in Table 2.

		Farm full		Farm not full	
		Tanker in Stack	Stack Empty	Tanker in Stack	Stack Empty
Berth occupied	Bad weather	5	29	5	40
	Good weather	1	54	1	91
Berth open	Bad weather	23	21	47	79
	Good weather	51	37	58	165

* Tanker is served.

FIGURE 2: The Array of Categories into Which the Year's Time-Blocks may be Classified. The entries are those of Trial #1, Table 2. Their sum is 707, the number of high slack periods in 1972 at Head Harbour Passage.

TABLE 2

A Sample of Model Responses to the Four Controlling Factors - Each at Two of Many Possible Levels. For these Trials Initial Tank Farm Stocks were Taken as One Tanker Load

Trial	Factor Level				Responses (per year)		
No.	A	B	C	D	No. tankers served	No. terminal-days shut down	No. tanker-days waiting
1	+	+	+	+	58	0	92.5
2	-	+	+	+	57	9.5	164
3	+	-	+	+	59	0	51
4	-	-	+	+	44	42.5	115.5
5	+	+	-	+	52	0	94.5
6	-	+	-	+	50	9.5	174.5
7	+	-	-	+	51	2	61.5
8	-	-	-	+	44	42.5	115.5
9	+	+	+	-	49	6	33.5
10	-	+	+	-	48	10	99
11	+	-	+	-	44	37.5	28
12	-	-	+	-	33	114	68
13	+	+	-	-	49	6	33.5
14	-	+	-	-	48	10	99
15	+	-	-	-	44	37.5	28
16	-	-	-	-	33	114	68
	Averages				47.7	27.6	82.9

The equations for performance parameters based on the four inputs have been estimated following Davies (1967) and are discussed below. The (simulated) number of tanker-days spent waiting (Y_1) in 1972 is approximated by:

$$Y_1 = 82.9 - 30.1\ (sgnA) + 15.9\ (sgnB) - 1.4\ (sgnC)$$
$$+\ 25.7\ (sgnD) - 5.2\ (sgnAB) - 3.7\ (sgnAD)$$
$$+\ 6.8\ (sgnBD)$$

where sgnX = +1 if X (factor or product of factors) is positive,
= -1 if X (factor or product of factors) is negative.

Factor A (to permit or prohibit night-time navigation) has a larger effect on tanker-days spent waiting than factor D (fleet size) or factor B (diversion criterion).

The (simulated) number of tankers actually served in 1972 (Y_2) is approximated by:

$$Y_2 = 47.7 + 3.06\ (sgnA) + 3.69\ (sgnB) + 1.31\ (sgnC)$$
$$+\ 4.19\ (sgnD) - 2.44\ (sgnAB)$$

Factors A, B and D are about equally important.
Factor C (tank farm capacity) is less important.

The (simulated) number of refinery-days shut-down due to lack of crude is approximated by:

$$Y_3 = 27.6 - 16.4\ (sgnA) - 21.2\ (sgnB) - 14.3\ (sgnD)$$
$$+\ 13.1\ (sgnAB) + 12.7\ (sgnBD) + 3.7\ (sgnAD) - 5.1\ (sgnABD)$$

Again, factors A, B and D but not C are effective.

5. CONCLUSIONS

The sample analyses show that shifts in rules to prohibit navigation more and more frequently during the course of a year lead to a corresponding reduction in oil terminal performance. Moreover, prohibition of navigation during darkness, for example, was shown to be as influential with respect to performance as fleet size and diversion criterion. Varying the tank farm capacity from three to ten tankerloads has no effect at the operating points chosen.

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