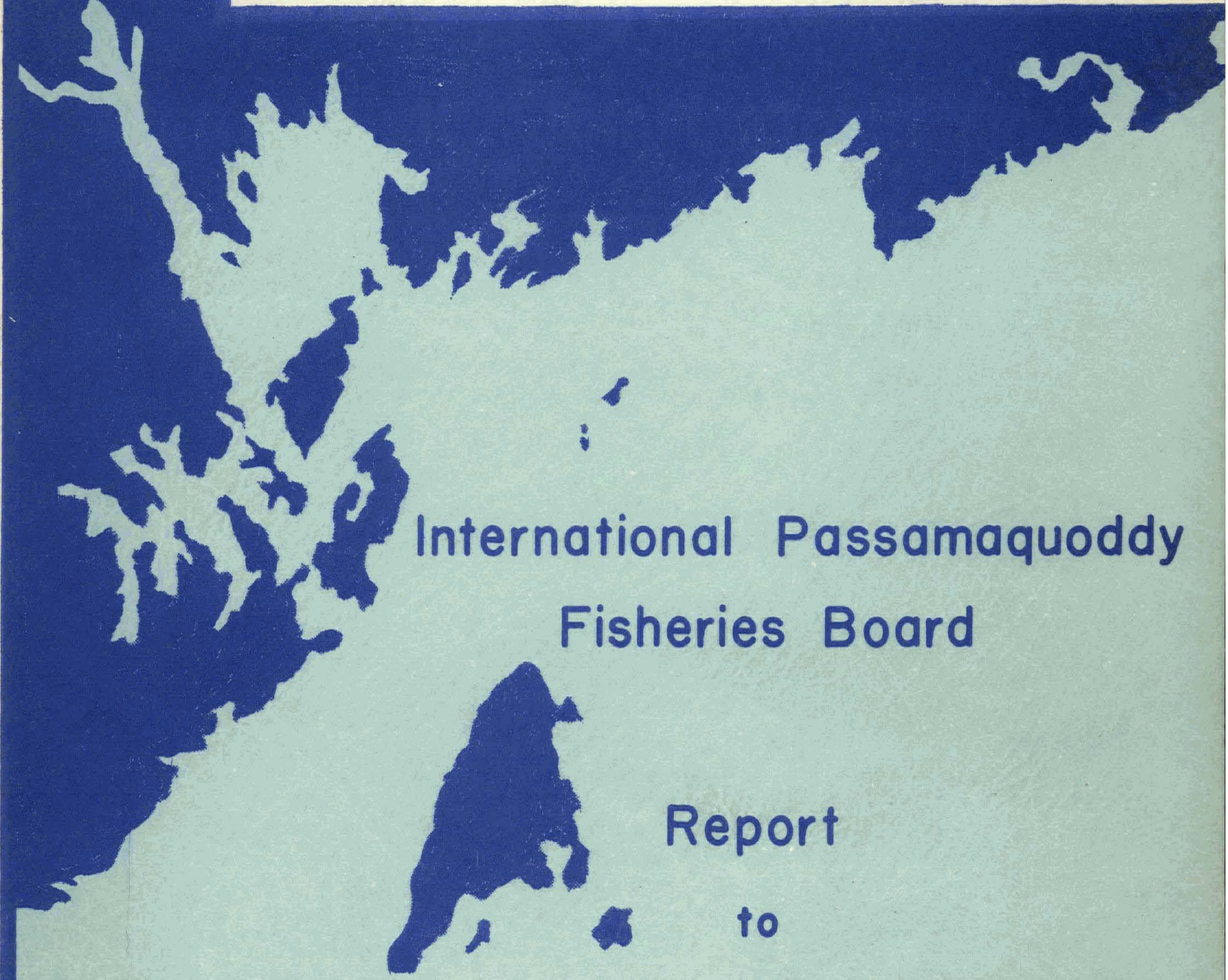
PASSAMAQUODDY

FISHERIES INVESTIGATIONS



International Passamaquoddy
Fisheries Board

Report
to

International Joint Commission

Appendix II

Biology—Canada

October 1959

INTERNATIONAL PASSAMAQUODDY
FISHERIES BOARD

Report

to

INTERNATIONAL JOINT COMMISSION

OTTAWA, ONTARIO
WASHINGTON, D. C.

Appendix II Biology - Canada

STUDIES IN FISHERIES BIOLOGY FOR THE PASSAMAQUODDY POWER PROJECT

by

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October 1959

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FOREWORD

In 1956, the International Joint Commission established the International Passamaquoddy Fisheries Board to study the effects which the construction, maintenance and operation of a proposed tidal power project might have upon the fisheries in the Passamaquoddy and Cobscook areas. Responsibility for studies in oceanography, biology and economics was assumed jointly by the Fisheries Research Board of Canada and the U. S. Bureau of Commercial Fisheries. This appendix contains the Canadian reports on the results and conclusions of the biological program.

Almost half of the chapters are devoted to assessing the present status and probable effects of power dams on the herring fishery--the most important species in the area. The remaining chapters deal, in a similar manner, with groundfish, lobster, molluscs and anadromous species.

A major contribution to the biological studies was made by Mr. B. B. Parrish, a fishery scientist from the Scottish Home Department. Mr. Parrish's experience and sound critical judgement had considerable influence on the course of such investigations as migrations, catch statistics, population dynamics and behaviour of herring.

Special thanks are due Mr. L. R. Day, Assistant Director of the Biological Station, St. Andrews, N. B. Mr. Day was secretary of the Research Committee throughout its existence and contributed a great deal to the development and conduct of the research program. His editorial criticisms and advice during the preparation of the manuscripts were invaluable. S.N.T.

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THE HERRING FISHERY OF SOUTHERN NEW BRUNSWICK

by

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ABSTRACT

Most of the herring taken in the Passamaquoddy area of southern New Brunswick are caught in stationary weirs built close to shore. Analyses of weir catches show no significant relationships between average catches inside Passamaquoddy Bay and catches in outside areas for the same year. Weirs inside Passamaquoddy Bay are more efficient and catch about twice as many herring per weir as those outside the Bay.

Seasonal and annual variations both in individual weir catches and in total catches in the various statistical districts of Charlotte County are far greater now than any changes that can be forecast as resulting from the installation of the proposed Passamaquoddy tidal power dams.

INTRODUCTION

One of the most important areas in eastern Canada where herring (Clupea harengus L.) are fished is in the Bay of Fundy. Scattergood and Tibbo (1959) reviewed the herring fishery of the northwest Atlantic including the Bay of Fundy and dealt with statistics of landings, methods of capture and utilization. The present account deals particularly with the herring fishery of the Passamaquoddy region of the Bay of Fundy (Fig. 1).

In the nineteenth century the herring fishery was chiefly for large fish that were used for a frozen herring trade with the United States. This fishery reached a peak about 1880 but declined thereafter (Huntsman, 1948). Huntsman (1953) reviewed the changes which occurred in the herring fishery of the Passamaquoddy area and showed that the utilization of the small, immature fish, known as "sardines" increased from about 5 million pounds in the 1880's to nearly 70 million pounds in the 1920's. On the other hand, landings of large, mature fish declined from about 25 million pounds to less than 5 million pounds over the same period.

The small herring were first used as bait and fertilizer, then as a source of fish meal and oil, and a substantial industry developed. Utilization of the small fish in large quantities, however, was directly connected with success in canning them as sardines. The first attempt at canning these sardines in North America was made at Eastport, Maine, in 1867 (Earll, 1887). It failed, but by 1875 some success was attained, and the first cannery was established. Canneries in the Passamaquoddy area increased to about 36 by the end of the nineteenth century with a consequent increase in the quantity of sardines used. While canning sardines is still a big industry the production of fish meal and pet food is rapidly becoming equally important.

The center of the herring industry in southern New Brunswick is located in the Passamaquoddy area where about 80% of the weight and 50% of the value of all fish landings consist of herring. This report considers possible effects of the proposed Passamaquoddy power project (Appendix I, Chapter 7) on the herring fishery in this area.

METHODS OF CAPTURE

Many methods have been used for fishing both adult herring and sardines in the Passamaquoddy area. The relative importance of these methods has changed with the development of the fishery, but most of them are still in use and a brief history and description seems appropriate.

Torching

Torching, sometimes known as "driving", was practically the only method used for taking sardines until early in the nineteenty century. Herring are attracted to a moving or flickering light at night, and when such a light is carried on a boat moving through the water, the fish are attracted to it and may be dipped into the boat. A small amount of torching is still carried on; the catch used chiefly as bait for other species.

Gill netting

Gill nets were first used in the Passamaquoddy area about 1829. By the middle of the nineteenth century a large gill-net fishery had developed, chiefly in the Musquash-Lepreau and the southern Grand Manan areas. This fishery was concerned chiefly with large herring for a pickled-herring trade with the United States. It began to decline late in the nineteenth century and ceased altogether about 1945. Gill nets were always anchored and fishing was carried on at night in depths of 5 to 15 fathoms. The stretched mesh size of the nets varied from 2-1/4 to 2-3/4 inches.

Drag or shut-off seining

The first recorded attempt at drag or shut-off seining (sometimes called stop seining, Fig. 2, upper) was about 1875 when fishermen at Deer Island used a 75-fathom seine to surround sardines and haul them onto the beach (Earll, 1887). This gradually developed into an important fishing method. Drag seining is now carried on separately but formerly it was used in association with weir fishing. Drag seines may be up to 300 fathoms in length. Stretched mesh sizes vary from 5/8 to 1-1/8 inches.

Purse seining

United States fishermen began using purse seines about 1865 and the method spread rapidly from the Massachusetts area to the eastern part of Maine (Earll, 1887). Purse seining did not become important in southern New Brunswick, however, until about 1934. It reached a peak during World War II when 40 to 50 purse-seine boats were licensed annually by the Department of Fisheries. Purse seines are restricted by law to a length of 100 fathoms and a depth of 120 ft. Purse seining is a far more efficient method of catching herring than any of the other methods now being used and is accounting for an increasing proportion of the total catch.

Weir fishing

Weir fishing is, by far, the most important method of catching herring in the Passamaquoddy area (Fig. 2, lower). Weirs were used on the Nova Scotia side of the Bay of Fundy before the beginning of the nineteenth century (Moore, 1898) but, it was not until about 1820 that they were introduced into the New Brunswick area. The earliest attempts at weir fishing in the Passamaquoddy area failed, but in 1828, a large weir was built and operated successfully at Rodgers Island near North Lubec, Maine. The number of weirs in Charlotte County increased rapidly from 55 in 1849, to 142 in 1880 and to 239 in 1893. More than 1,100 registered weir sites have now been used. The maximum number of weirs used in any one season, however, was in 1920 when 476 weir licenses were issued. At the present time from 300 to 400 weirs are licensed annually in Charlotte County (Table IX).

QUANTITIES LANDED

Following World War I there was considerable improvement in the methods of collecting fisheries statistics in Canada. Department of Fisheries officers, each responsible for a small district, collected monthly records based on interviews with fishermen and processors. This method remained essentially the same until 1956 when a purchase slip system was introduced in some districts. This system has now been extended to most of the fishery districts in eastern Canada. Statistics are submitted to the Department of Fisheries regional offices and compiled on monthly and annual bases by the Dominion Bureau of Statistics.

In addition to the monthly statistics, records of individual daily weir catches were obtained in 1957 and 1958 for Charlotte and Saint John Counties. These have been especially valuable in the present study both for establishing the exact location of the catches and for showing variations in landings with time.

Annual landings

Data from Scattergood and Tibbo (1959) for the years 1920 to 1954 together with information for the years 1955 to 1958 show that the average herring catch for the Canadian Atlantic area including Newfoundland and Labrador has been 217 million pounds. Of this amount, slightly more than 78 million pounds of 36% was taken in the Bay of Fundy and chiefly in Charlotte, Saint John, Digby, and Yarmouth Counties.

Table I. Average landings of herring by counties in the Bay of Fundy area, 1920-58. (X denotes amounts <.1%.)

Counties	Average landings	
	lb	%
Yarmouth	4,837,100	6.2
Digby	6,120,800	7.9
Annapolis	1,578,500	2.0
Kings	297,000	0.4
Hants	4,600	X
Colchester	11,200	X
Cumberland	19,400	X
Westmorland	1,100	X
Albert	1,800	X
Saint John	4,308,000	5.5
Charlotte	60,947,200	78.0
Totals	78,126,700	100.0

Bay of Fundy landings: A study of the landings in the Bay of Fundy over the 1920-58 period shows (Table I) that the most of the herring catch was made near the entrance to the Bay. Charlotte and Saint John Counties accounted for 83.5% of the catch and Digby and Yarmouth Counties accounted for 14.1%. The balance of the catch (2.4%) was made chiefly in Annapolis and Kings Counties, with very small quantities taken in the other counties bordering on the Bay of Fundy. A comparison between landings on both sides of the mouth of the Bay of Fundy is given by 5-year periods in Table II. There was no trend in the landings for both areas until the beginning of World War II when landings increased substantially. This increase continued in Nova Scotia but in New Brunswick it reached a peak in the late 1940's and since then catches have dropped below the average prewar level. Figure 3 shows the annual herring landings for the 1937 to 1958 period in Yarmouth and Digby Counties on the Nova Scotia side of the Bay of Fundy and in Charlotte and Saint John Counties on the New Brunswick side. Total landings for the Bay of Fundy are included in the Figure.

Table II. Comparison of herring landings in Nova Scotia and New Brunswick sides of the mouth of the Bay of Fundy by 5-year periods from 1920 to 1958 inclusive.

Period	Nova Scotia (Yarmouth & Digby)	New Brunswick (Charlotte & Saint John)
	lb	lb
1920-24	2,189,200	53,146,400
1925-29	4,590,200	59,748,600
1930-34	3,109,200	41,785,200
1935-39	3,576,800	62,262,600
1940-44	11,675,600	86,097,200
1945-49	13,069,000	91,914,200
1950-54	17,200,400	76,405,000
1955-58*	37,577,000	47,039,500

* 4 years

Southern New Brunswick landings: Table III gives the annual herring landings in Charlotte and Saint John Counties by statistical districts for the 1937-58 period. During this period, total landings reached a peak of nearly 112 million pounds in 1946. The smallest catch was in 1955 when less than 25 million pounds were landed. A percentage breakdown of landings gives 29% for Charlotte East; 27% for Grand Manan; 23% for West Isles (all of the islands at the entrance to Passamaquoddy Bay); 15% in Charlotte West (chiefly Passamaquoddy Bay) and 6% in Saint John County. The extreme variations in landings for individual areas should be noted. For example, Charlotte East landings varied from 3.9 to 41.8 million pounds, while Charlotte West landings varied from 3.0 to 28.2 million pounds.

Quoddy Region landings: Because the proposed Passamaquoddy tidal power dams will divide the area into pools which will not coincide with existing fisheries statistical districts, an attempt was made to allocate the annual herring landings for the 1947-58 period to these new areas. This was done from the detailed landing records for 1957 and 1958 plus information received from a large sample of weir fishermen who were interviewed primarily for an economic survey of the herring fisheries (Appendix IV).

Table IV and Figure 4 show the 1947-58 herring landings in various parts of the Quoddy Region (all of the area inside a line drawn from Point Lepreau, N. B. to Northern Head, Grand Manan, and thence to West Quoddy Head, Maine) and in the remainder of Charlotte County and in Saint John County. The detailed distribution of the landings for each year is given in Figures 5 to 16 inclusive. Of special interest is the high pool catch which averaged 13.2 million pounds or 18.8% of the total, the low pool catch

Table III. Herring landings in Charlotte and Saint John Counties, 1937-58. Landings in thousands of pounds.

Years	Charlotte County: Charlotte East	Charlotte West	West Isles	Grand Manan	Saint John County	Total
1937	5,152	6,247	19,395	16,663	3,897	51,353
1938	27,101	4,602	4,986	7,912	3,740	48,340
1939	29,074	7,614	22,613	20,888	1,845	82,033
1940	21,164	8,138	8,560	25,076	2,542	65,481
1941	30,321	9,228	34,948	24,949	2,230	101,676
1942	38,396	7,180	15,376	16,202	5,148	82,303
1943	22,065	8,921	27,426	27,016	5,698	91,125
1944	29,403	4,222	38,505	15,687	2,084	89,901
1945	29,586	3,409	20,869	22,475	1,137	77,476
1946	39,713	7,821	40,697	21,563	1,897	111,691
1947	41,844	17,075	30,958	12,045	8,547	110,469
1948	30,527	12,546	13,070	35,150	3,157	94,450
1949	17,656	3,032	14,486	23,794	6,513	65,481
1950	25,902	11,943	17,702	32,407	12,102	100,056
1951	13,021	24,091	17,135	10,867	5,389	70,503
1952	22,196	28,159	10,029	20,520	9,676	90,580
1953	11,991	12,953	7,370	11,685	5,864	49,863
1954	4,226	11,889	4,436	43,540	6,932	71,023
1955	3,908	7,029	4,291	7,551	1,974	24,753
1956	16,301	5,756	10,752	12,706	1,957	47,472
1957	10,893	26,399	11,520	20,474	5,083	74,369
1958	9,920	10,033	2,372	13,298	5,941	41,564
Average	21,834	10,831	17,159	20,112	4,698	74,635
Percentage	29.2	14.5	23.0	26.9	6.4	100

which averaged 0.8 million pounds or 1.1% of the total and the outer Quoddy Region catch which averaged 29.8 million pounds or 42.4% of the total. Nearly two thirds (62.3%) of the total herring catch in southern New Brunswick is, therefore, taken in the Quoddy Region.

There are large variations in annual landings from the various parts of the Quoddy Region. High pool landings varied from 4.5 to 28.4 million pounds; low pool landings varied from less than 0.1 to 1.6 million pounds and outer Quoddy landings varied from 6.8 to 68.1 million pounds.

Monthly landings

Southern New Brunswick landings: Table V shows that the herring landings in the various statistical districts of Charlotte and Saint

Table IV. Herring landings (thousands of pounds) 1947-58 in Charlotte and Saint John Counties arranged according to the proposed Passamaquoddy tidal power structures.

Year	High pool	Low pool	Outside	Grand Manan	Saint John County	Totals
1947	21,000	800	68,100	8,600	12,000	110,500
1948	9,800	<100	46,100	3,000	35,500	94,400
1949	5,200	600	29,200	6,600	23,800	65,400
1950	8,800	<100	46,200	12,200	32,800	100,000
1951	28,400	<100	26,300	5,000	10,800	70,500
1952	19,500	<100	41,300	9,600	20,200	90,600
1953	9,800	1,400	20,900	5,900	12,000	50,000
1954	6,400	200	13,800	7,000	43,600	71,000
1955	8,400	<100	6,800	2,000	7,600	24,800
1956	4,500	800	28,900	2,200	13,100	47,500
1957	26,400	1,600	21,000	5,000	20,400	74,400
1958	10,000	400	11,700	5,900	13,300	41,300
Average	13,200	800 *	29,800	6,100	20,400	70,000
Percentage	18.8	1.1	42.4	8.7	29.0	100

* Quantities less than 100 thousand pounds not included in average or totals.

John Counties varied from month to month, being greatest in the summer and poorest in the winter. In Charlotte West, West Isles, Grand Manan and Saint John, 70 to 76% of the landings were made from June to September. In Charlotte East, however, only about 53% of the landings were made during these months. A purse-seine fishery produced substantial landings in this district during the winter months.

Within some of the statistical districts there are seasonal differences which are quite regular and well known among the fishermen. As a rule the weir fishery in Saint John County takes place during the summer and autumn, especially in the Lorneville and Musquash areas. Near Dipper Harbour and Chance Harbour, however, it may be both earlier and later. Purse seining is usually carried on in Saint John County from late summer to late winter. It is most actively pursued, however, when herring are scarce in Charlotte County, which is closer to the canneries at Blacks Harbour.

At Grand Manan herring are taken at almost all times of the year, principally in weirs from May to November and in purse seines during the winter and early spring.

Table V. Average monthly herring landings in Charlotte and Saint John Counties, 1937-58 (thousands of pounds).

	Fisheries Statistical Districts					
Months	Saint John County	Grand Manan	West Isles	Charlotte West	Charlotte East	Totals
January	88	367	126	3	1,127	1,711
February	23	394	14	0	1,493	1,923
March	209	552	12	41	1,927	2,742
April	173	664	237	88	1,687	2,848
May	216	360	1,188	396	1,601	3,762
June	785	1,020	1,443	911	1,783	5,942
July	840	3,589	2,570	1,273	2,986	11,259
August	1,037	5,549	3,869	1,635	4,112	16,203
September	847	4,034	3,449	3,139	2,856	14,325
October	395	2,208	1,973	2,194	1,459	8,229
November	48	1,190	1,431	863	449	3,982
December	54	285	559	84	323	1,304

Quoddy Region landings: Maximum monthly landings in the Quoddy Region occur in August. The fishery in Charlotte West (Passamaquoddy Bay) is an exception to this with peak landings being made in September and comparatively large landings in October. Since almost all the high pool landings are made in Charlotte West, it follows that the maximum monthly landings in this pool are made a month later than those outside the proposed dams. However, some weirs, close to deep water such as the Protection weir off St. Andrews Point and the Mascarene weir off Upper Green Point just inside Letite Passage are known as early weirs. Their catches are made both as the fish move into the Bay in spring, and during the summer and early autumn. On the high-pool side of Deer Island, the fishery is small because the shore is generally unsuitable for weirs. This fishery usually takes place during the summer now, although at one time there was an autumn fishery in Northern Harbour. In Pendleton and Little Letite Passages the main fishery takes place in the autumn as the fish move out of Passamaquoddy Bay.

Immediately outside of Passamaquoddy Bay the herring fishery is generally most active in late summer and autumn. Exceptions to this are associated mainly with the fish entering Passamaquoddy Bay in the spring. For example, at Mill Cove on the eastern end of Campobello Island herring are often caught in the spring. This also occurs at Bar Island between Deer Island and Campobello Island and at the eastern ends of Adam Island and Hardwood Island. The appearance of herring in the weirs at these locations in the spring is an indication to fishermen that the fish are moving into Passamaquoddy Bay.

Herring are usually present in the outer Quoddy Region during the winter but are in deep water where they may be taken with purse seines or by torching, not by weirs.

In Charlotte East (Back Bay to Point Lepreau) herring are abundant throughout the year as indicated by the landings in Table V. The weir fishery in this district usually begins earlier than in other areas. One weir, located just northeast of Pocologan Island close to deep water, but protected from storms by ledges, is often fished late in winter (March). This is about the only location in the Quoddy Region where a weir can be operated successfully during the winter. Late in April or early May other weirs are fished as the herring move into shallow water and fishing continues until late September or October. Purse seining sometimes begins in November and continues into April. It is most active from Deadman Head to Maces Bay in depths of 60 to 160 ft.

In Saint John County and in Grand Manan, the period of high catches may be slightly longer than in the Quoddy Region, beginning in July and continuing into September.

Landings by gear

Detailed records of landings by gear in southern New Brunswick are only available for 1957 and 1958. Some additional information is available, however, to indicate the relative importance of the various methods of fishing.

Torching: The amount of torching for herring carried on in the Quoddy Region depends on markets for bait used in lobster fishing and in line trawling for groundfish species. Most of the torching is done in the autumn and winter and catches sometimes amount to 10 to 15,000 pounds per boat per night's fishing. Although torching has declined drastically in Saint John and Charlotte Counties, there are a few boats which still operate. No records of monthly or annual landings are available.

Gill netting: The gill-net fishery in the Quoddy Region ceased about 1945. No records are available to show the amount of herring taken in gill nets but it was probably small especially in the 1930's and early 1940's.

Drag or shut-off seining: The numbers of shut-off and drag-seining licenses issued by the Department of Fisheries gives some indication of the importance of this method of fishing, although, except for 1957 and 1958, no catch records are available. Essentially, there is no difference between drag and shut-off seining although licenses have been issued for both. Up to 1954, shut-off licenses were issued along with weir licenses and shut-off seines were used in association with weir fishing. Since 1954 separate licenses (now called drag-seining licenses) have been issued and fishermen are not permitted to use the seines within 1,000 ft of an operating weir. This has resulted in a substantial reduction in the numbers of licenses issued but there has perhaps been little change in the number of gear units operated or the amount of fish caught. The numbers of shut-off licenses issued for the period 1947 to 1954 are given in Table VI.

Table VI. Numbers of shut-off licenses issued from 1947 to 1954 inclusive in Saint John and Charlotte Counties.

Years	Saint John County	Charlotte County				Total
		Grand Manan	West Isles	Charlotte West	Charlotte East	
1947	3	0	4	22	52	81
1948	3	38	3	55	52	151
1949	3	25	1	26	68	123
1950	2	21	11	48	69	151
1951	-	10	25	20	73	128
1952	-	9	2	44	68	123
1953	-	19	16	36	79	150
1954	-	--	25	14	72	111

Some records of the operation of shut-off seines are available. Although these are by no means complete, it is probable that not more than 25 or 30 % of the shut-off seines licensed were ever operated. For example, in 1948 there were 151 licenses issued for all areas and 45 seines operated. In 1953, 79 licenses were issued in Charlotte East but only 20 seines were operated there.

From 1955 to 1958 inclusive, when only drag-seining licenses were issued, the number of licenses for both Charlotte and Saint John Counties has varied from 22 to 47.

Table VII. Landings of herring caught by drag seines in Charlotte and Saint John Counties 1957 and 1958.

District	Landings		
	1957	1958	Average
Saint John	179,000	1,850,000	1,015,000
Grand Manan	596,000	--	596,000
West Isles	15,000	182,000	99,000
Charlotte West	3,137,000	55,000	1,596,000
Charlotte East	321,000	437,000	379,000
Totals	4,248,000	2,524,000	3,386,000

Table VII gives the total landings by drag seines in Charlotte and Saint John Counties for 1957 and 1958.

The drag-seine fishery was carried on almost entirely from June to October with more than 59% of the landings being made in September. In 1957 most of the catch (74%) was made in Charlotte West while in 1958 the largest landings were made in Saint John County (73%). The average catch per seine licensed in 1957 was approximately 150,000 pounds while in 1958 it was approximately 80,000 pounds. This compares favourably with the average catch per weir. The total drag-seine catch made up only a small proportion (less than (6%) of the total herring catch for the two years.

<u>Purse seining:</u> Purse seining in southern New Brunswick waters reached a peak during World War II when 40 to 50 boats were licensed annually. In the post-war years (1947 to 1958) fewer purse seiners have operated and the records show that the numbers have varied from 9 to 21, except in 1950 when no purse-seine licenses were issued.

Since purse seiners are fairly large they can operate anywhere in the Bay of Fundy. Partly because of local opposition to their method of fishing, they tend to stay away from areas where there are large numbers of weirs. A substantial proportion of the purse-seine catch is made on the east side of the Bay of Fundy, off Digby and Yarmouth Counties. The New Brunswick catches are made chiefly in Charlotte East and in Saint John Counties during the winter months when few if any weirs are in operation.

Although no record of purse-seine landings is available prior to 1957, the extent of purse-seine operations can be approximated by examining the landings for the months of December to April inclusive. Table VIII gives the herring landings for Charlotte and Saint John Counties during the winter seasons from 1947 to 1958. These landings were made chiefly, if not entirely by purse seiners. The landings vary considerably both for individual areas and for seasons. The most successful years were 1948 and 1952 when more than 20 million pounds of herring were landed. These figures are minimum landings because they do not take into account the catches that were made by purse seiners from May to November. The percentage of the total herring catch contributed by purse seiners, varies considerably but may be as much as 25% in some years. This is especially significant in view of the small numbers (9 to 21) of purse seiners as compared with the large numbers (300 to 400) of weirs.

Table VIII also shows that about 70% of the purse seining is carried on in Charlotte East with only minor catches (average 2.6%) in Charlotte West (Passamaquoddy Bay).

Table VIII. Herring landings in Saint John County and the districts of Charlotte County during the winter seasons 1947-1958. Landings in thousands of pounds. (Winter = Jan., Feb., Mar., Apr., Dec.)

Years	Saint John County	Grand Manan	West Isles	Charlotte West	Charlotte East	Totals
1947	1,067	936	1,574	217	13,021	16,815
1948	32	288	2,434	241	17,803	20,798
1949	1,039	297	1,152	144	3,916	6,548
1950	0	0	165	209	376	750
1951	55	1,259	1,168	836	2,560	5,878
1952	5,692	672	560	44	13,058	20,026
1953	1,148	189	38	43	576	1,994
1954	0	1,541	397	50	1,550	3,538
1955	0	1,754	367	68	1,258	3,447
1956	385	5	128	664	10,090	11,272
1957	249	1,825	209	175	5,109	7,567
1958	211	1,022	15	0	2,298	3,546
Average	823	816	684	224	5,968	8,515
Percentage	9.7	9.6	8.0	2.6	70.1	100

Table IX shows the total purse-seine landings for 1957 and 1958. The differences between the totals for these two years given in Table IX and those given in Table VIII represent the amount of the purse-seine catches during the period May to November. This amounted to 618,000 pounds in 1957 and 4,337,000 pounds in 1958.

Table IX. Landings of herring caught by purse seines in Charlotte and Saint John Counties 1957 and 1958.

District	Landings		
	1957	1958	Average
	lb	lb	lb
Saint John	125,000	1,517,000	821,000
Grand Manan	2,169,000	874,000	1,522,000
West Isles	12,000	22,000	17,000
Charlotte West	63,000	2,272,000	1,167,000
Charlotte East	5,816,000	3,198,000	4,507,000
Totals	8,185,000	7,883,000	8,034,000

Since purse seiners operate for most of the year in other areas the catches made in southern New Brunswick represent only a small part of their effort. It is significant, however, that this small part is, on the average, three or four times larger than the average annual weir catch in southern New Brunswick.

Weir fishing: For many years weirs have been the most important gear used for catching herring in southern New Brunswick. The weir fishery usually begins late in April or early in May and continues into November, occasionally into December. Weir operation is impossible during the other months, partly because of weather conditions but also because the herring spend the winter months in deeper water where weirs cannot be built.

Because of its importance in the herring fishery a great deal of information about the weir fishery has been recorded. In the development of the weir fishery many weir sites have been used and altogether there are now more than 1,100 registered sites in Charlotte and Saint John Counties. Some of these sites were abandoned altogether after a few trials, while others have been fished intermittently. Many weirs have a long history of continuous operation even though in some years they caught no fish.

The Department of Fisheries records show the locations and operations of each weir site. Each weir is named and carries a code number for positive identification (Table A-1 and Fig. A-1 to A-5). In spite of the large number of operating weirs and approved locations, there is surprisingly little duplication of names some of which such as "Grab-all!"

Table X. Numbers of weirs licensed in Charlotte and Saint John Counties, 1947 to 1958 inclusive.

Years	Saint John	Grand Manan	West Isles	Charlotte West	Charlotte East	Total
1947	15	33	180	95	148	471
1948	20	70	129	53	102	374
1949	20	85	136	61	96	398
1950	22	94	123	67	94	400
1951	21	95	128	76	94	414
1952	24	91	116	59	100	390
1953	23	84	98	67	93	365
1954	22	93	95	70	85	365
1955	32	88	102	64	83	369
1956	26	90	102	62	86	366
1957	20	95	99	71	86	371
1958	26	85	92	96	77	376
Average	23	84	116	70	95	388

and "Poor and Needy" are very picturesque and probably describe the catches made at some period during their operation.

For most years and districts complete records are available not only for weirs licensed but also for weirs that were built and operated. Table X gives the numbers of weirs licensed from 1947 to 1958 in Charlotte and Saint John Counties. This table shows that in recent years from 300 to 400 weirs (occasionally more) are licensed annually. The average number of weirs licensed annually for the whole period was 388. Records of weirs built and operated are incomplete but show an average number of 318 weirs built each year.

Table XI. Frequency of weir licensing in Saint John and Charlotte Counties during 1947 and 1958 inclusive.

Number of years	Saint John	Grand Manan	West Isles	Charlotte West	Charlotte East	Total	Percent
12	15	16	53	21	39	144	20.9
11	1	27	19	14	10	71	10.3
10	2	16	8	11	20	57	8.3
9	2	8	11	7	8	36	5.2
8	0	9	6	4	9	28	4.1
7	1	9	10	9	8	37	5.4
6	0	2	11	7	4	24	3.5
5	2	8	8	10	7	35	5.1
4	5	11	11	7	6	40	5.8
3	3	9	14	6	8	40	5.8
2	5	5	10	4	10	34	4.9
1	14	14	48	29	38	143	20.7
Total	50	134	209	129	167	689	100.0

Table A-1 gives a record of each weir that has been licensed in Charlotte and Saint John Counties since 1947. Table XI summarizes the information presented in Table A-1. Of the 689 weirs that have been licensed since 1947 only 144 (20.9%) have been licensed every year, while 143 (20.7%) were licensed for only one year out of the 12.

The weir records were examined in relation to the proposed dams and showed that from 1947 to 1958 there were from 56 to 85 weirs licensed and built in the high pool each year. In the low pool the numbers varied from 9 to 21. Although no actual survey was carried out a few weir sites (not more than 6) appear to be located at or sufficiently near the proposed dams to be destroyed by the power project.

The weir fishery is most active from May to November and although no records of weir catches are available prior to 1957 a study of catches during May to November is instructive because most of the landings during these months were the result of weir catches. Table XII gives landings by years for Saint John County and for the four divisions of Charlotte County over the period 1947 to 1958. Saint John County catches are usually small and Grand Manan catches usually large. Within the Quoddy Region which includes West Isles, Charlotte West and Charlotte East, the average annual landings are quite similar. Within these districts, however, there are enormous variations from year to year. In Charlotte West, for example, the catches varied from 2.9 to 28.0 million pounds.

Table XII. Herring landings in Saint John County and districts of Charlotte County during the summer seasons 1947 to 1958. Landings in thousands of pounds. (Summer = May to November inclusive.)

Years	Saint John County	Grand Manan	West Isles	Charlotte West	Charlotte East	Totals
1947	7,482	11,109	29,384	16,858	28,624	93,457
1948	3,076	33,427	10,636	12,306	12,724	72,169
1949	5,473	23,798	13,335	2,883	13,707	59,196
1950	12,102	32,407	17,537	11,738	25,525	99,309
1951	5,335	9,520	15,967	23,255	10,461	64,538
1952	3,985	19,848	9,470	27,997	9,138	70,438
1953	4,716	11,497	7,332	12,911	11,402	47,858
1954	6,932	42,000	4,040	11,839	2,677	67,488
1955	1,955	5,797	3,924	6,961	2,650	21,287
1956	1,573	12,701	10,624	5,091	6,211	36,200
1957	4,835	18,650	11,311	26,224	5,784	66,804
1958	5,713	11,974	2,208	9,865	6,948	36,708
Average	5,265	19,394	11,314	13,994	11,321	61,288
Percentage	8.6	31.6	18.5	22.8	18.5	100.0

Daily landing records by individual units of gear were obtained for 1957 and 1958 and the weir catches for the two years are presented in Table XIII.

Table XIII gives further evidence of the variations in herring landings. Total catches were nearly three times larger in 1957 than in 1958, and catches in the various districts were five or six times larger in one year than in another.

Table XIII. Landings of herring caught by weirs in Charlotte and Saint John Counties in 1957 and 1958.

District	Landings 1957	1958	Average
	lb	lb	lb
Saint John	6,348,000	3,522,000	4,935,000
Grand Manan	16,351,000	6,051,000	11,201,000
West Isles	12,231,000	1,821,000	7,026,000
Charlotte West	33,429,000	6,724,000	20,077,000
Charlotte East	6,024,000	7,367,000	6,696,000
Totals	74,383,000	25,485,000	49,934,000

The average landings per weir in each of the four statistical districts of Charlotte County are shown in Table XIV. The average catch per weir in Charlotte West, which is almost entirely the proposed high pool area, is, in general, about twice that in West Isles and Charlotte East (the area outside the proposed dams). The average catch per weir in Grand Manan is similar to that for Charlotte West.

In Figure 17 from Parrish (1958) and in Table XIV great variations in average herring catches from year to year and place to place are apparent. The average catch per weir in Charlotte West (inside Passamaquoddy Bay), for example, was more than ten times larger in 1952 than in 1949.

It is scarcely conceivable that variations of such magnitude reflect variations in the overall abundance of herring. They may, however, reflect changes in distribution and hence in availability to the weir fishermen who operate only on the fringes of the areas of distribution. No measure of market demand is available but it is known to be extremely variable too and may, at least in some seasons, have more effect on landings than does the availability of fish.

UTILIZATION OF CATCHES

The market for herring is limited. This prevents the expansion of the fishery which, based on present evidence of herring abundance, could be much greater.

In Canada, the small herring are used almost exclusively for canning as sardines, though 10 to 15% of the catch is used for bait, pet food and reduction to meal and oil. Large quantities of cuttings from the canneries are also used for reduction.

Table XIV. Average landings per weir in Charlotte County statistical districts for the period May to November inclusive, 1947-1958. Landings in thousands of pounds.

	Charlotte West			West Isles		
Years	Catch	Weirs built	Catch per weir	Catch	Weirs built	Catch per weir
1947	16,858	39	432.3	29,384	121	242.8
1948	12,306	53	232.2	10,636	129	82.4
1949	2,883	61	47.3	13,335	136	98.1
1950	11,738	67*	175.2	17,537	123*	142.6
1951	23,255	76*	306.0	15,967	125	127.7
1952	27,997	59*	474.5	9,470	116	81.6
1953	12,911	67*	192.7	7,332	98	74.8
1954	11,839	70	169.1	4,040	95	42.5
1955	6,961	62	112.3	3,924	81	48.4
1956	5,091	57	89.3	10,624	75	141.7
1957	26,224	63	416.3	11,311	73	154.9
1958	9,865	67	147.2	2,208	64	34.5
Average	13,994	61.8	226.6	11,314	103.0	109.8

	Charlotte East			Grand Manan		
Years	Catch	Weirs built	Catch per weir	Catch	Weirs built	Catch per weir
1947	28,624	103	277.9	11,109	33	336.6
1948	12,724	99	128.5	33,427	69	484.4
1949	13,707	96*	142.8	23,798	85	280.0
1950	25,525	94*	271.5	32,407	91	356.1
1951	10,461	94	111.3	9,520	93	102.4
1952	9,138	100	91.4	19,848	91	218.1
1953	11,402	77	148.1	11,497	83	138.5
1954	2,677	85	31.5	42,000	93	451.6
1955	2,650	83*	31.9	5,797	85	68.2
1956	6,211	76	81.7	12,701	73	174.0
1957	5,784	68	85.1	18,650	73	255.5
1958	6,948	57	121.9	11,974	64	187.1
Average	11,321	86.0	131.6	19,394	77.8	249.4

* Number of weirs licensed.

About half the herring caught in Charlotte and Saint John Counties are exported fresh to the United States, principally to Eastport and Lubec, Maine. In recent years most of the sales have been made to plants producing pearl essence and fish meal and oil. Other products include sardines, pet food, bait and smoked herring. In 1957 and 1958, about 60% of the exported herring were processed as pearl essence and fish meal, 20% as sardines, 19% as pet food, and 1% as bait and smoked herring.

In 1957, a year with above average landings in Charlotte and Saint John Counties, the catch was utilized as follows: sardine canning 47%, pearl essence and fish meal 41%, pet food 11% and smoked herring and bait 1%.

For 1958, a year of below average landings in Charlotte and Saint John Counties, the catch was utilized as follows: sardine canning 55%, pearl essence and fish meal 31%, pet food 7% and smoked herring and bait 7%.

SUMMARY AND CONCLUSIONS

The herring industry in southern New Brunswick is centered around Passamaquoddy Bay. Formerly the fishery was for large herring but from about 1880 to 1920 the large herring fishery declined to almost zero while a small herring fishery developed.

Torching and gill netting, the earliest methods of capture have been supplanted by weir fishing, drag seining and purse seining.

Of the herring landings (217 million pounds, 1920-58 average) on the Canadian Atlantic coast including Newfoundland and Labrador, about one-third (78 million pounds) was made in the Bay of Fundy, 15% on the Nova Scotia side and 85% on the New Brunswick side. The New Brunswick landings increased from about 50 million pounds in 1920 to 110 million pounds in 1946 and then gradually declined to the 50 million pound level. On the other hand the landings on the Nova Scotia side increased throughout the period from about 2 million pounds to nearly 40 million pounds.

On the New Brunswick side of the Bay of Fundy about 29% of the landings were made in Charlotte East, 27% in Grand Manan, 23% in West Isles, 15% in Charlotte West and 6% in Saint John County (1937-58 averages).

The proposed Passamaquoddy tidal power dams will divide the area into a high pool (Passamaquoddy Bay), a low pool (Cobscook Bay, Lubec Channel, Friar Roads and part of Head Harbour Passage), and an outside area. During 1947-58, 18.8% (13,200,000 lb) of the Charlotte and Saint John County landings were made in the high pool, 1.1% (800,000 lb) in the low pool, 42.4% (29,800,000 lb) immediately outside and 37.7% (26,500,000 lb) in the remainder of the area.

In most of Charlotte and Saint John Counties about three-quarters of the landings were made from June to September. August was the peak landing month except in Charlotte West where largest landings were made in September.

Landings from torching and gill netting were insignificant. Drag seining, carried on chiefly in Charlotte West in September, accounted for 5.5% of the total catch in 1957 and 1958. Purse seining carried out chiefly in Charlotte East from January to April produced about 13% of the landings in 1957 and 1958. Of approximately 1,100 registered weir and shut-off sites in Charlotte and Saint John Counties, only 388 on the average (1947-58) were licensed annually. Weirs accounted for about 81% of the catch in 1957 and 1958. During 1947-58 about 32% of the weir catches were made in Grand Manan, 23% in Charlotte West, 18% in each of West Isles and Charlotte East and 9% in Saint John County.

In general the average yearly landings per weir in Passamaquoddy Bay (high pool) were much better than outside, the average for Charlotte West being 226,600 pounds, for West Isles 109,800 pounds and Charlotte East 131,600 pounds. This indicates that the weirs in the proposed high pool are more efficient and suggests that Passamaquoddy Bay may act as a natural fish trap.

About half the herring caught in Charlotte and Saint John Counties are processed locally--almost exclusively canned as sardines--while the other half are exported to Maine where about 60% are processed as pearl essence and fish meal, 20% as sardines, 19% as pet food and 1% used for bait and for smoked herring.

ACKNOWLEDGMENTS

The authors wish to record their appreciation for assistance given during the course of this study. The benefit of B. B. Parrish's experience and advice as a consultant is gratefully acknowledged. Detailed records of herring catches for 1957 and 1958 were provided through the kindness and co-operation of Connors Bros. Ltd., Blacks Harbour, N. B. and H. W. Welch Ltd., Fairhaven, N. B. J. P. Wentworth of the U. S. Bureau of Commercial Fisheries provided records of herring exported to the United States. Department of Fisheries officers including W. F. Doucet, K. E. Bates, F. Durant, G. Eldridge and M. Storr were especially helpful in supplying data on the licensing and operations of the various types of gear. Our thanks are also expressed to C. D. Burnett for organizing the great masses of records and for preparation of many of the tabulations.

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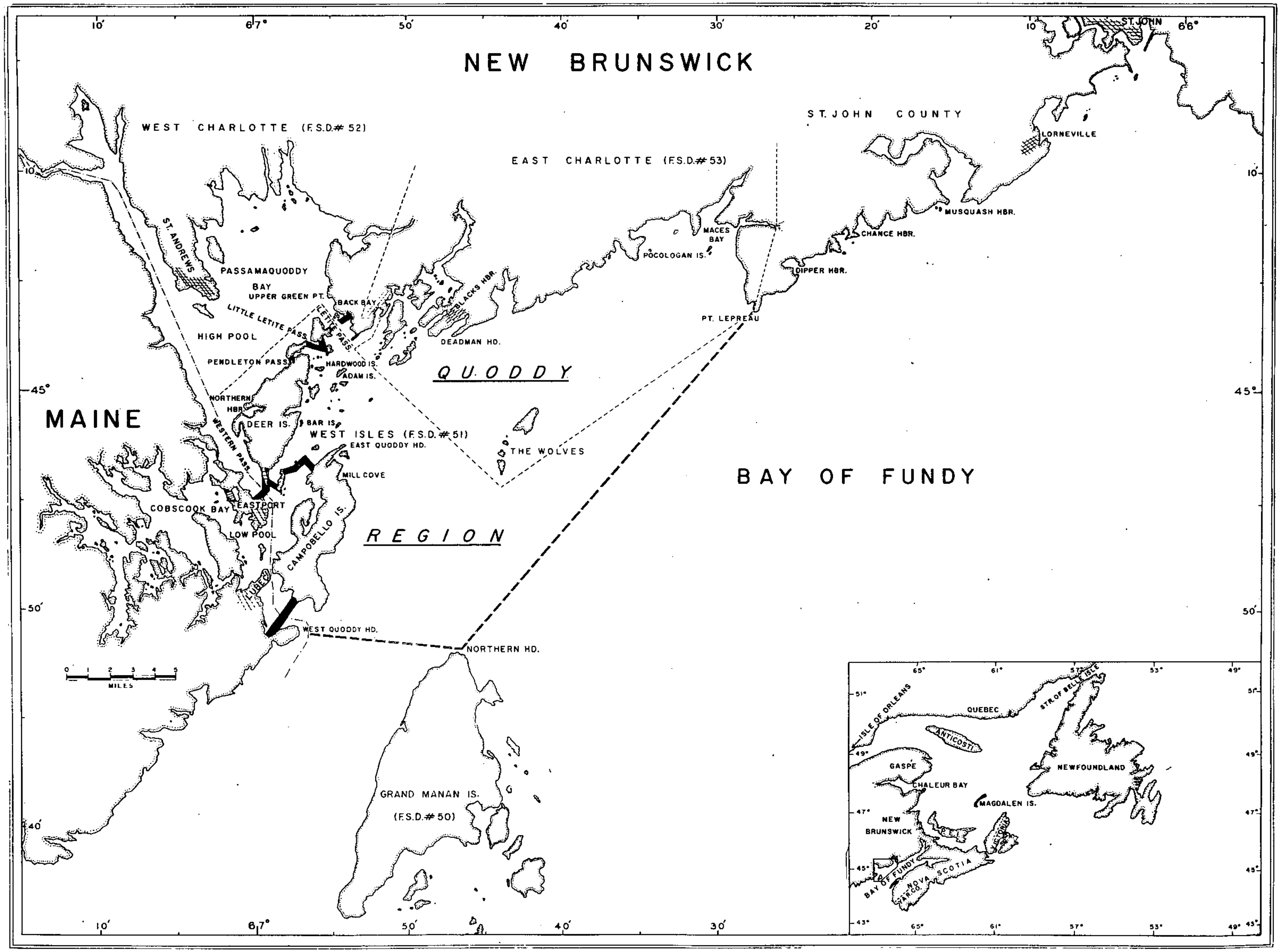

Figure 1. Map of the Passamaquoddy region.

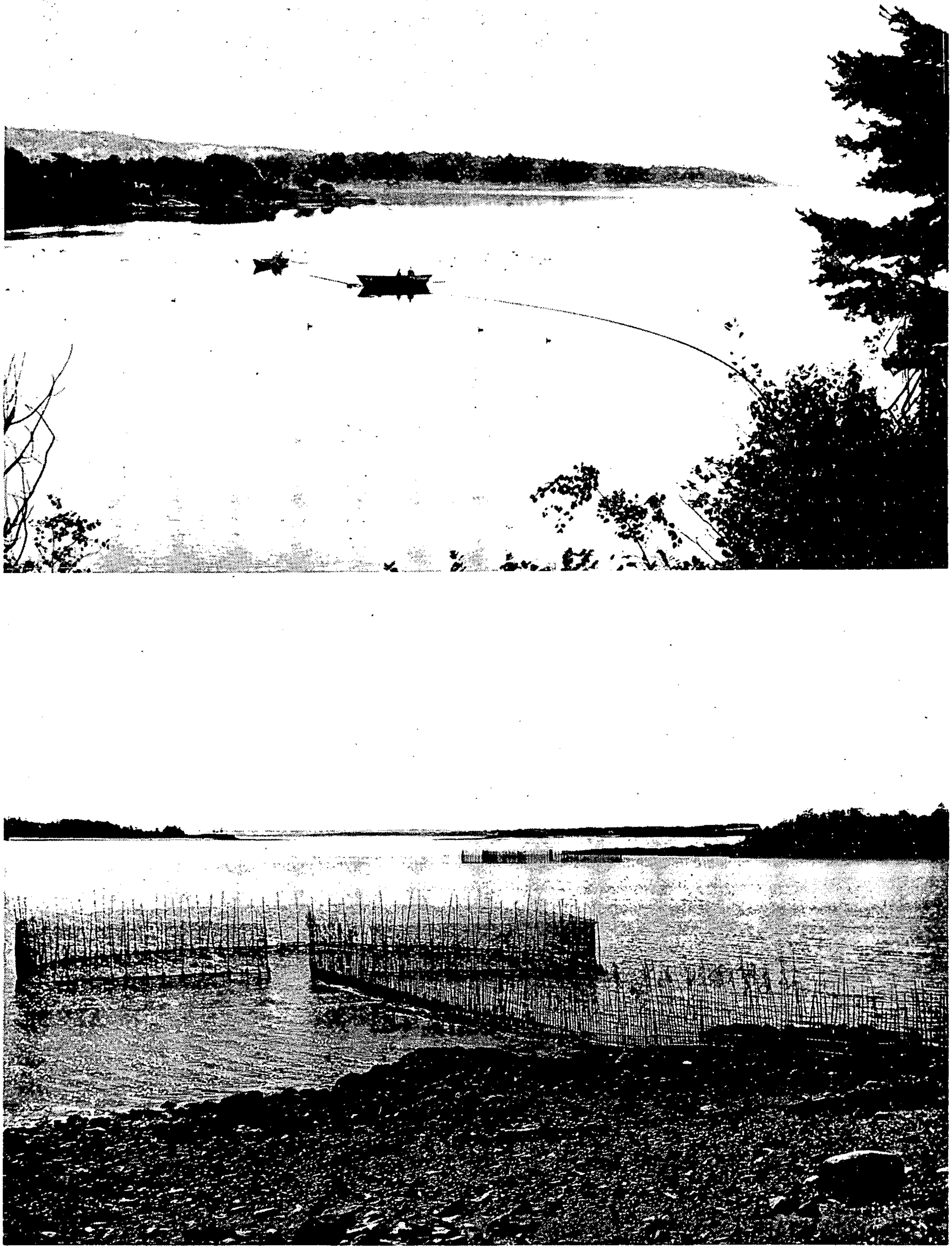

Figure 2. Typical "sardine" fishing gear (upper) stop seine (lower) weir.

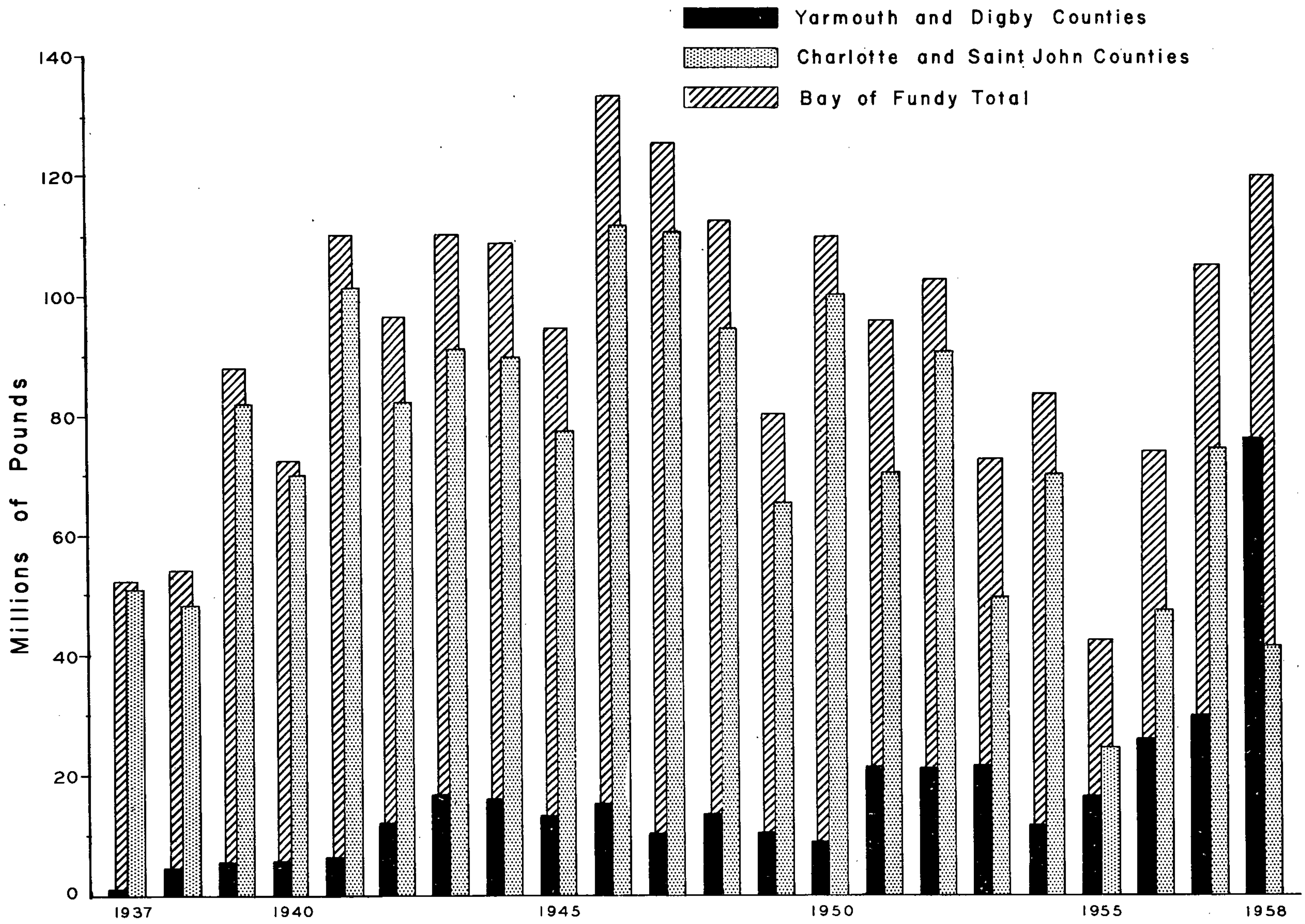

Figure 3. Annual herring landings from 1937 to 1958 on the Nova Scotian side of the mouth of the Bay of Fundy (Yarmouth and Digby Counties), on the New Brunswick side (Charlotte and Saint John Counties) as well as the totals for the Bay of Fundy.

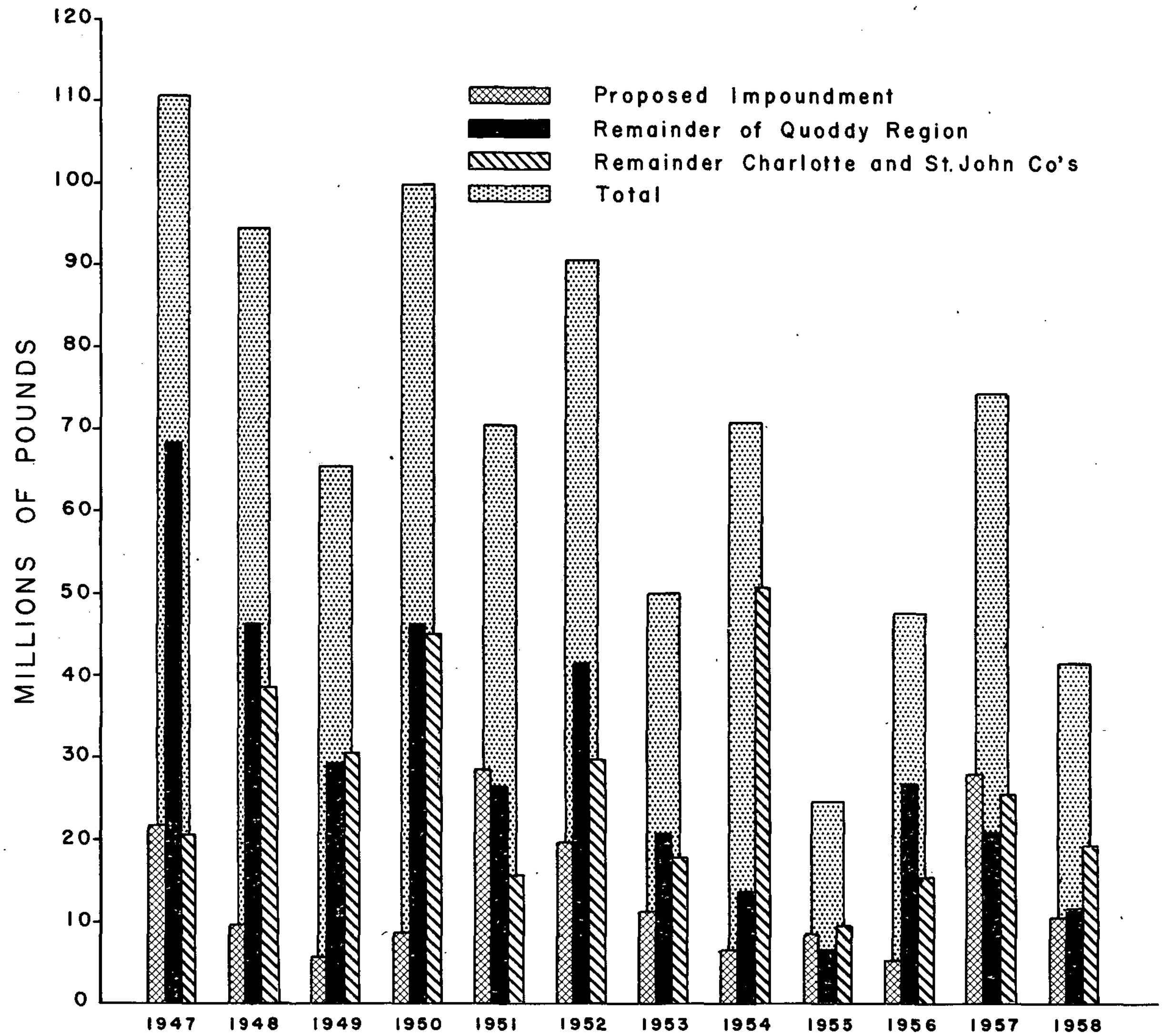

Figure 4. Annual herring landings from 1947 to 1958 within the impoundment (high and low pools), in the remainder of the Quoddy Region and also in the remainder of Charlotte and Saint John Counties.

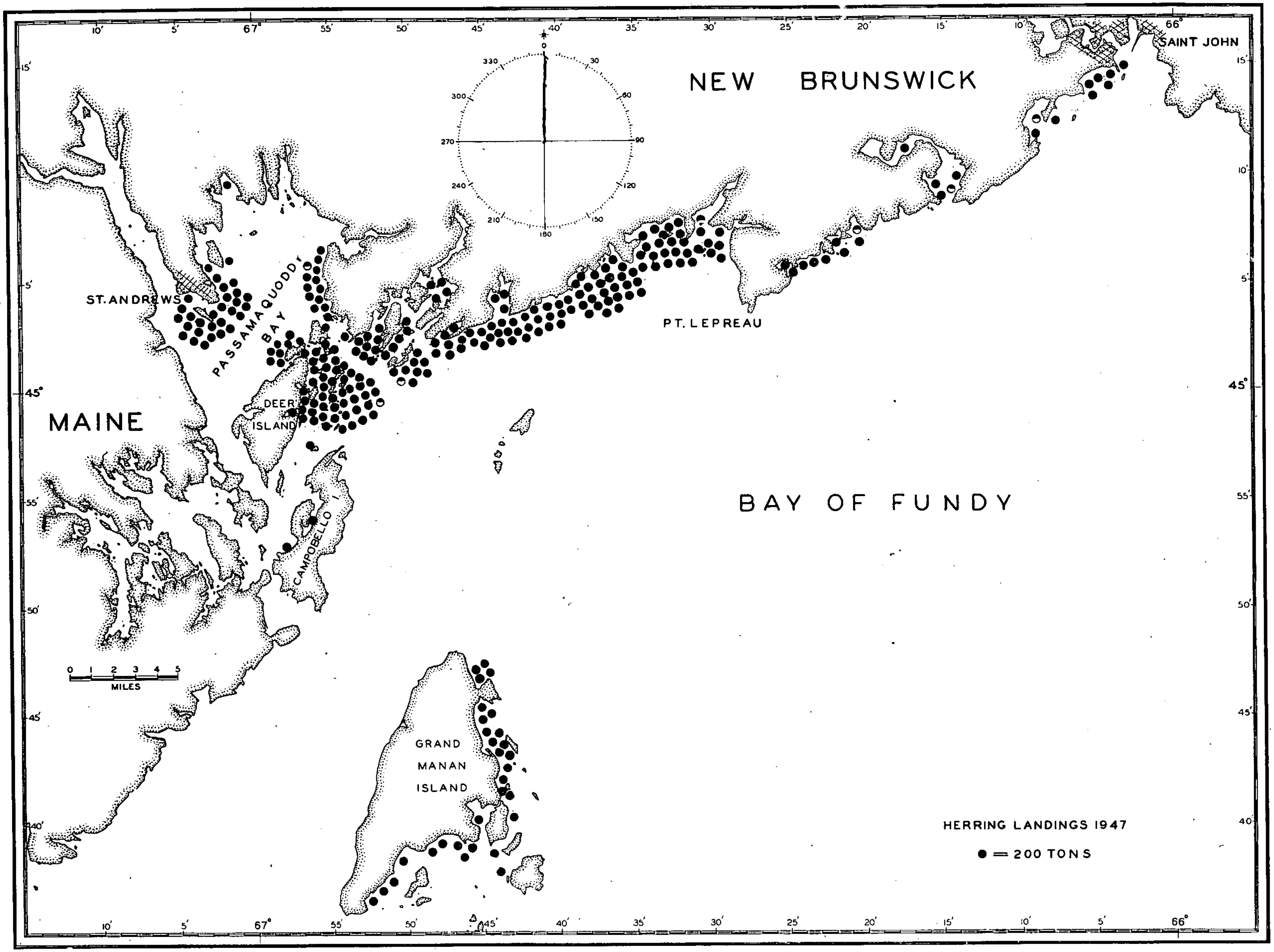

Figure 5. Distribution of herring landings in Charlotte and Saint John Counties, 1947.

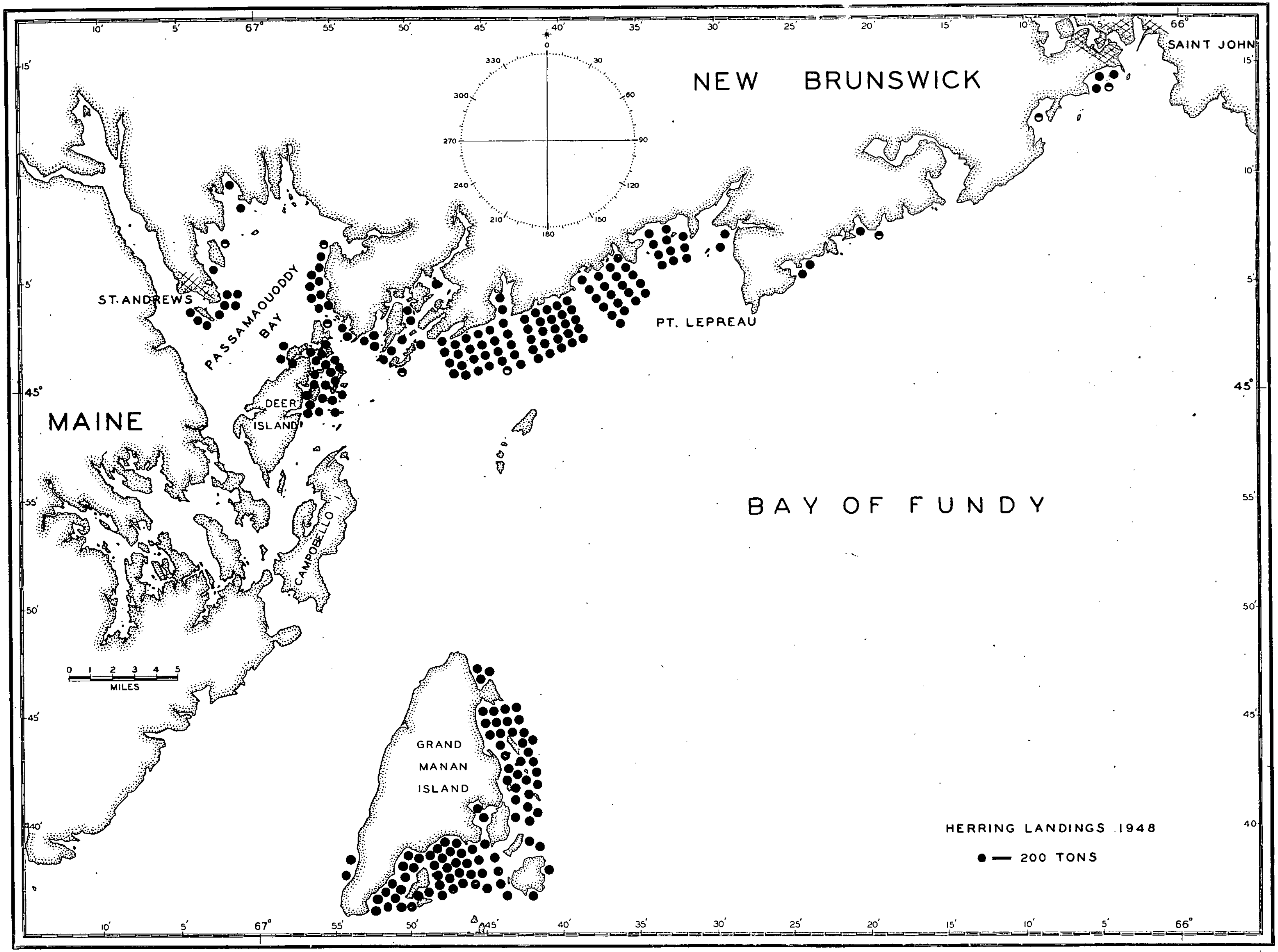

Figure 6. Distribution of herring landings in Charlotte and Saint John Counties, 1948.

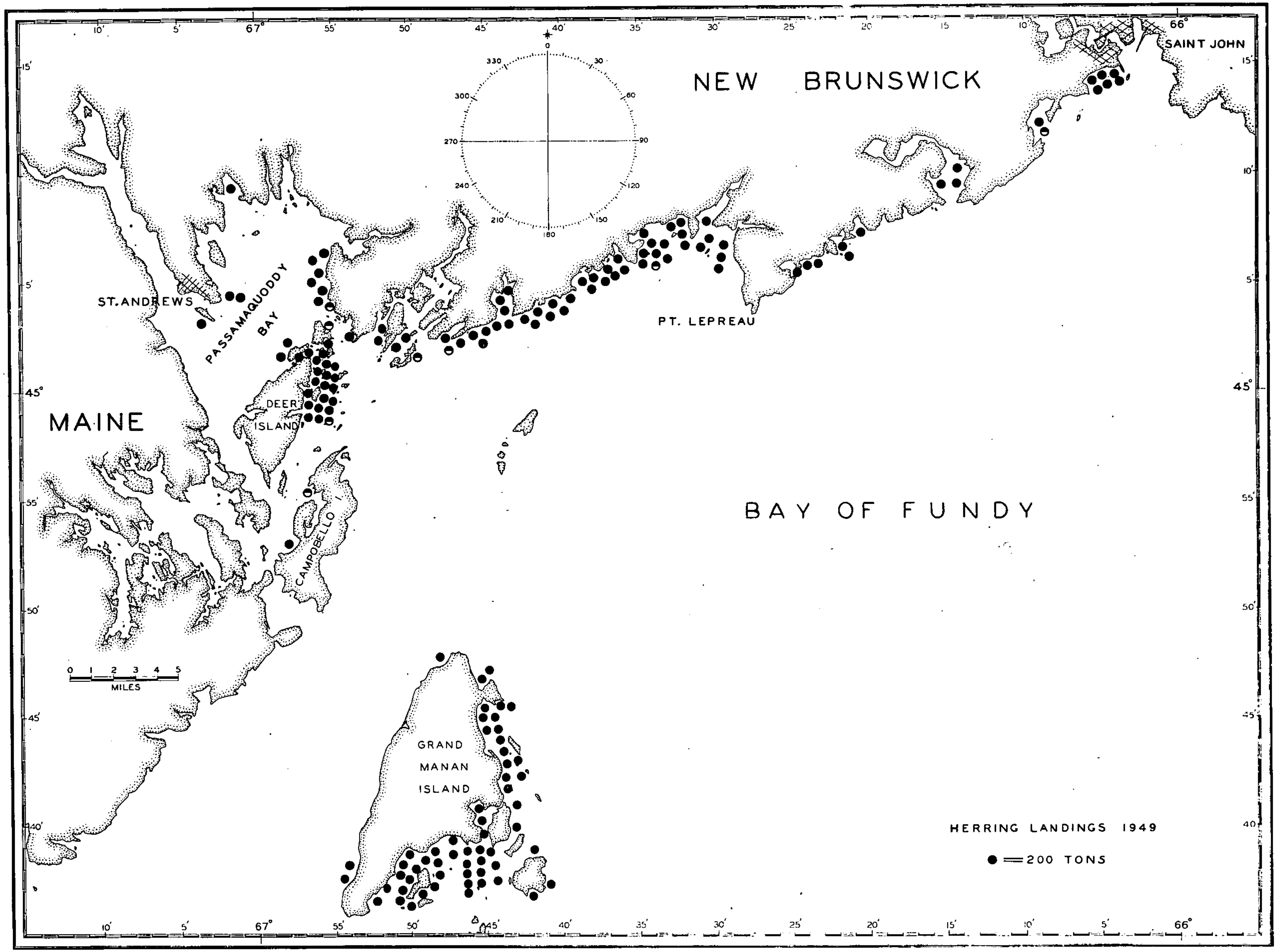

Figure 7. Distribution of herring landings in Charlotte and Saint John Counties, 1949.

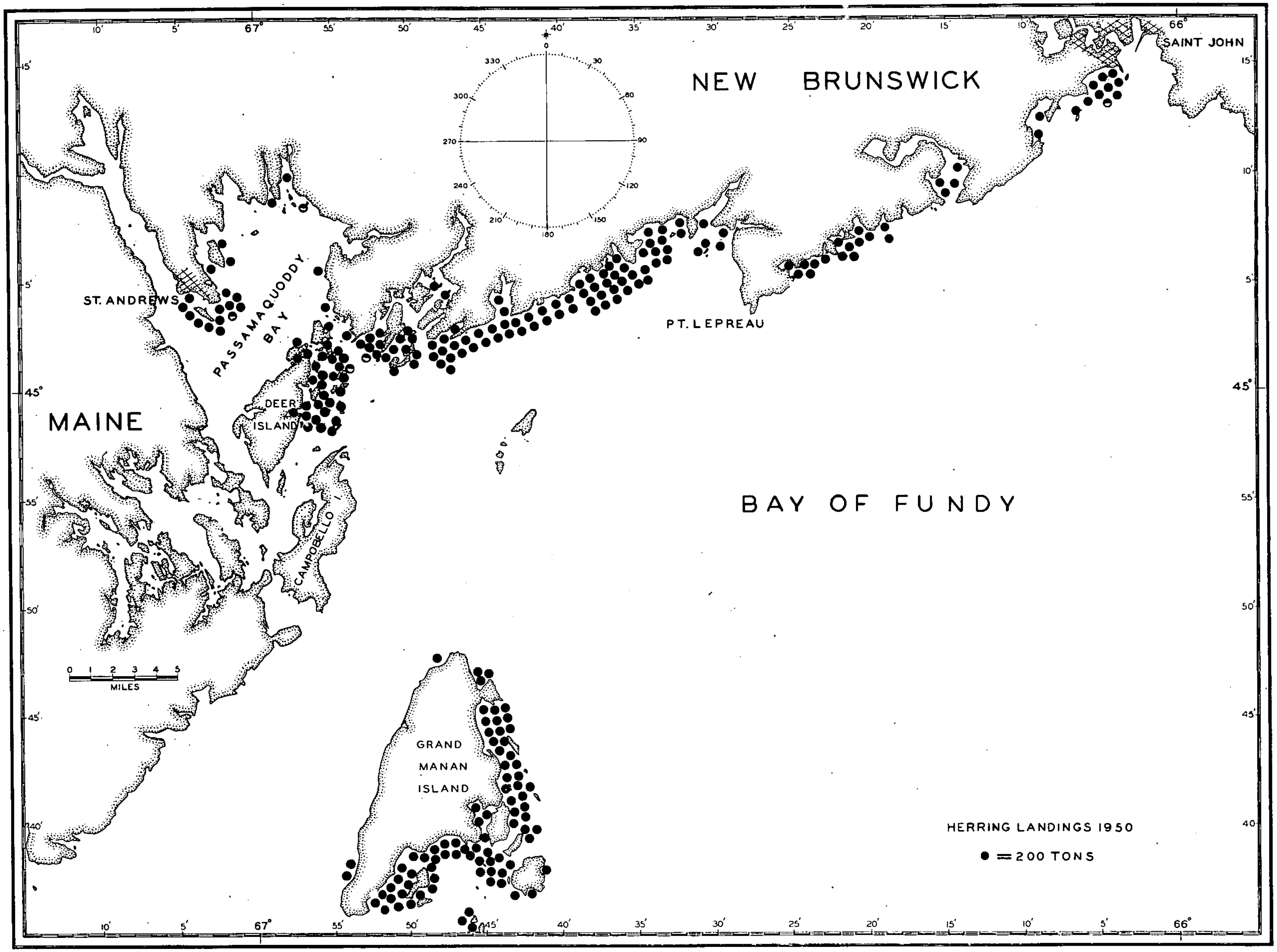

Figure 8. Distribution of herring landings in Charlotte and Saint John Counties, 1950.

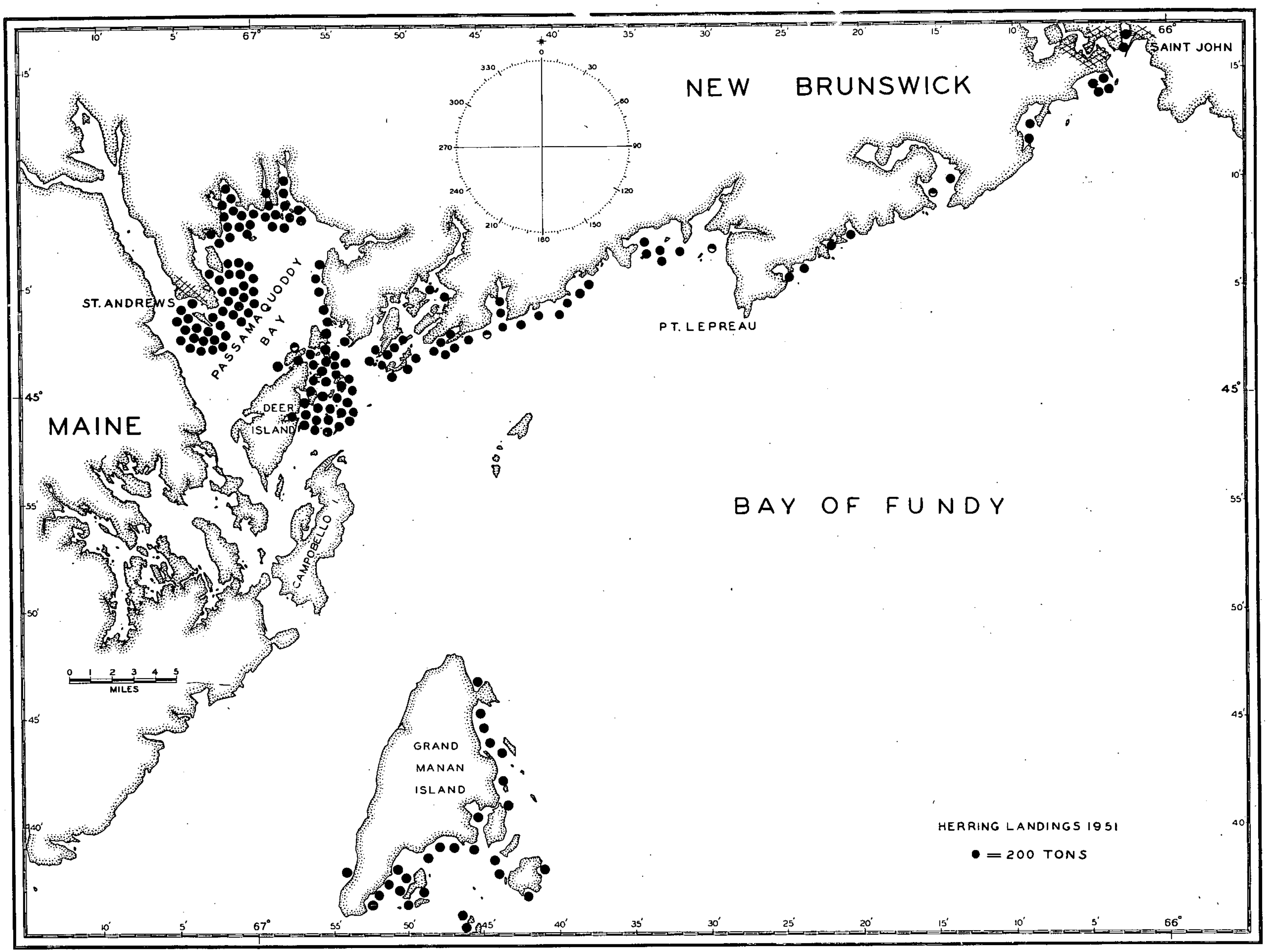

Figure 9. Distribution of herring landings in Charlotte and Saint John Counties, 1951.

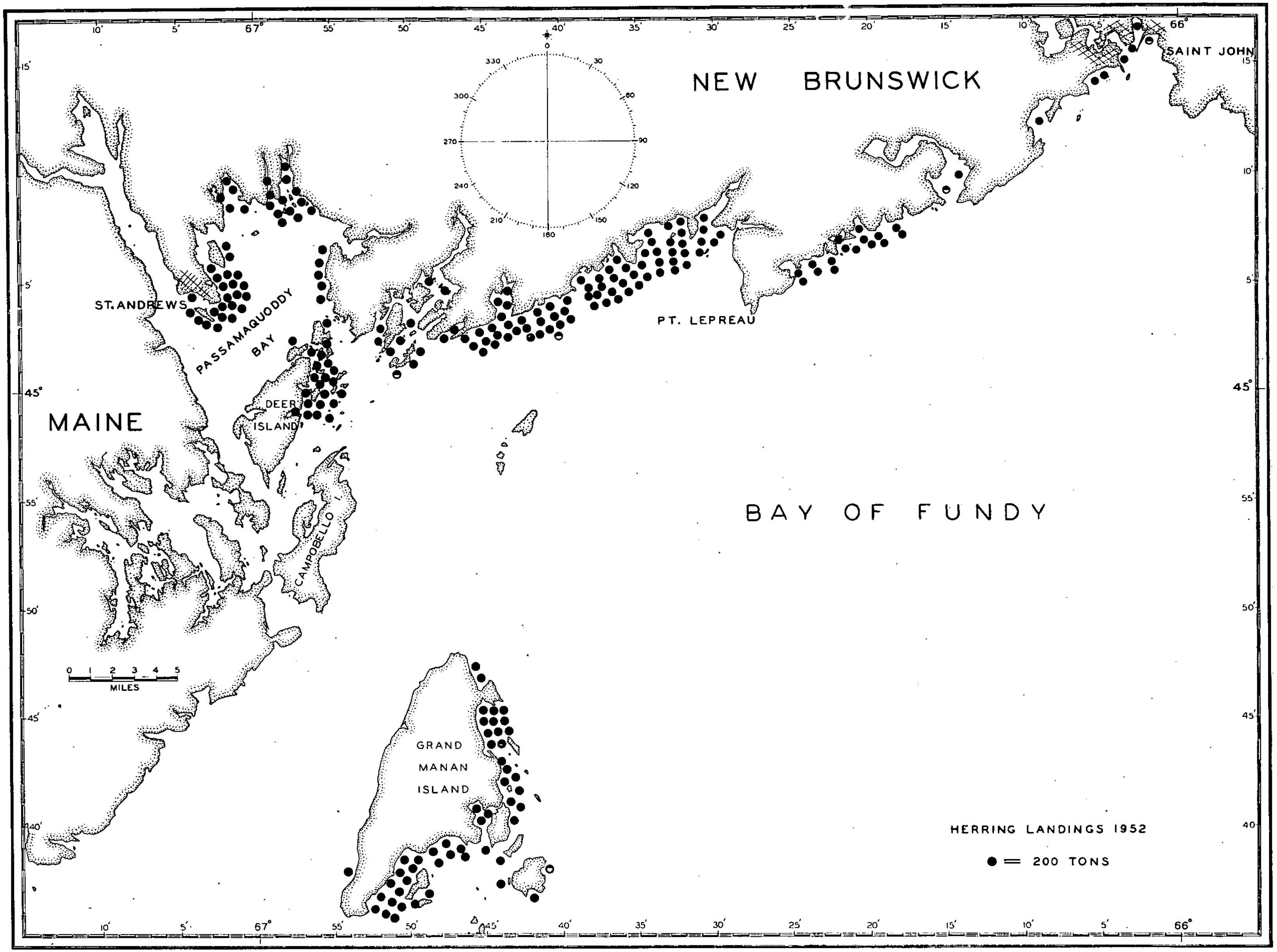

Figure 10. Distribution of herring landings in Charlotte and Saint John Counties, 1952.

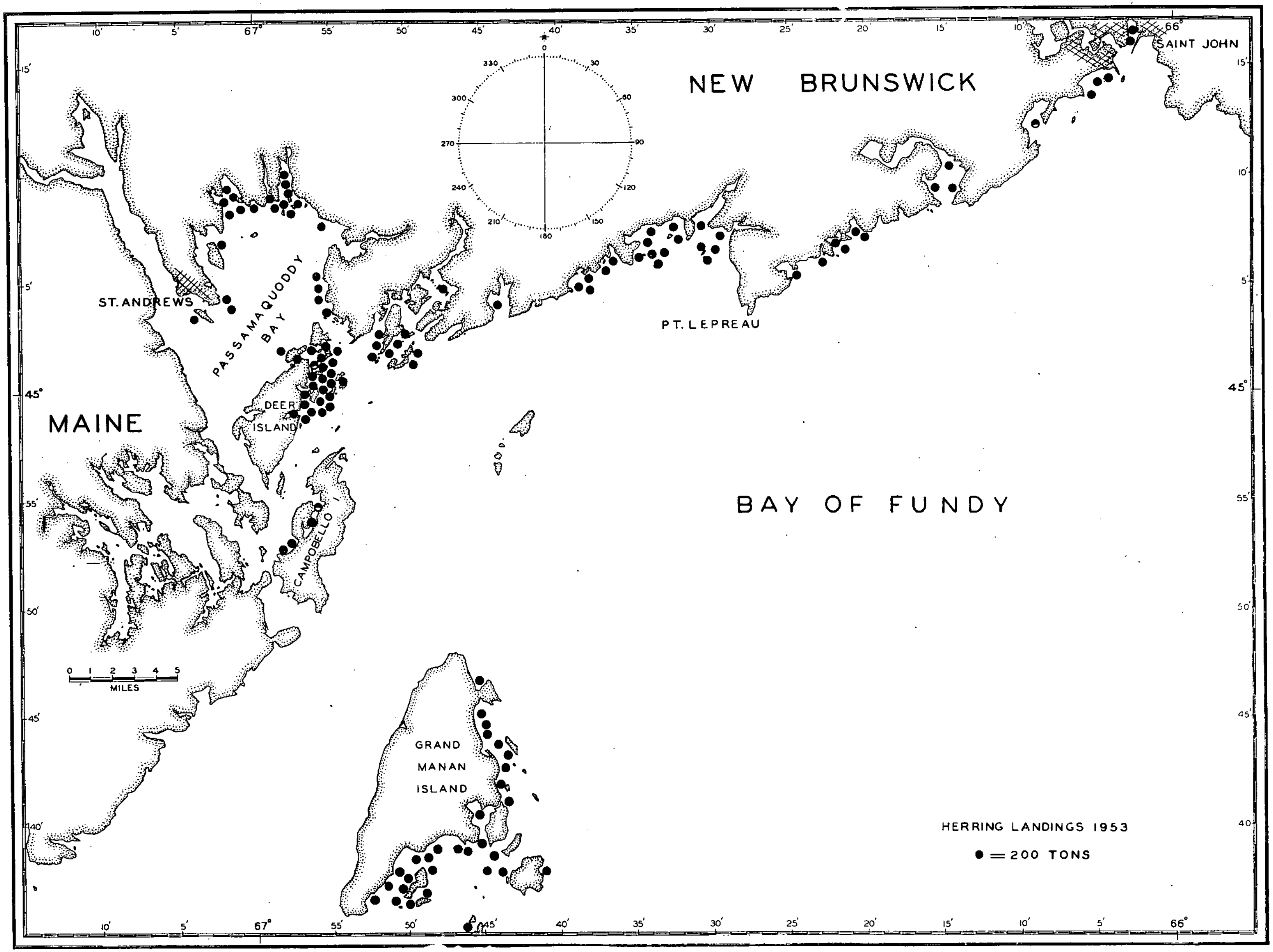

Figure 11. Distribution of herring landings in Charlotte and Saint John Counties, 1953.

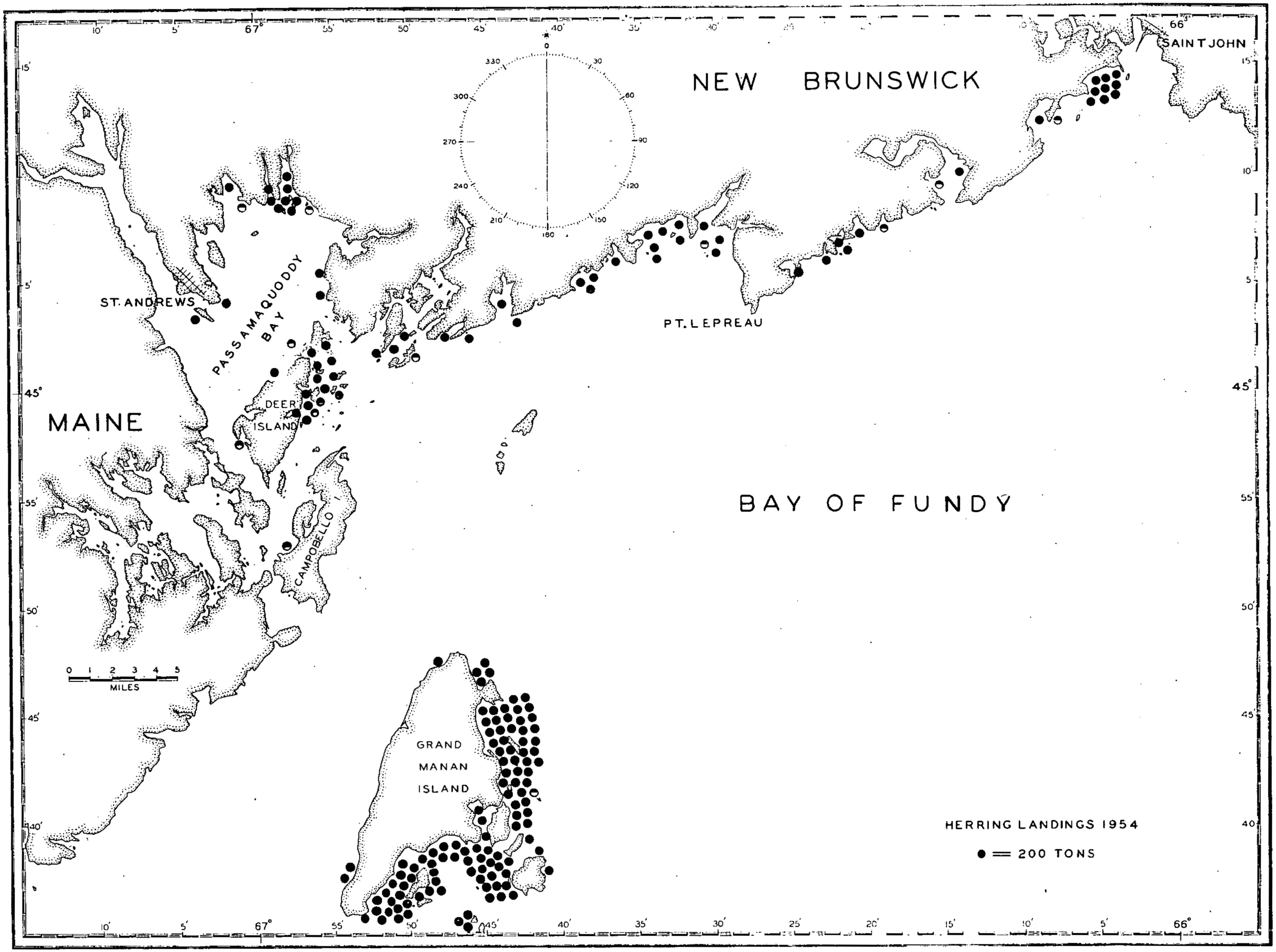

Figure 12. Distribution of herring landings in Charlotte and Saint John Counties, 1954.

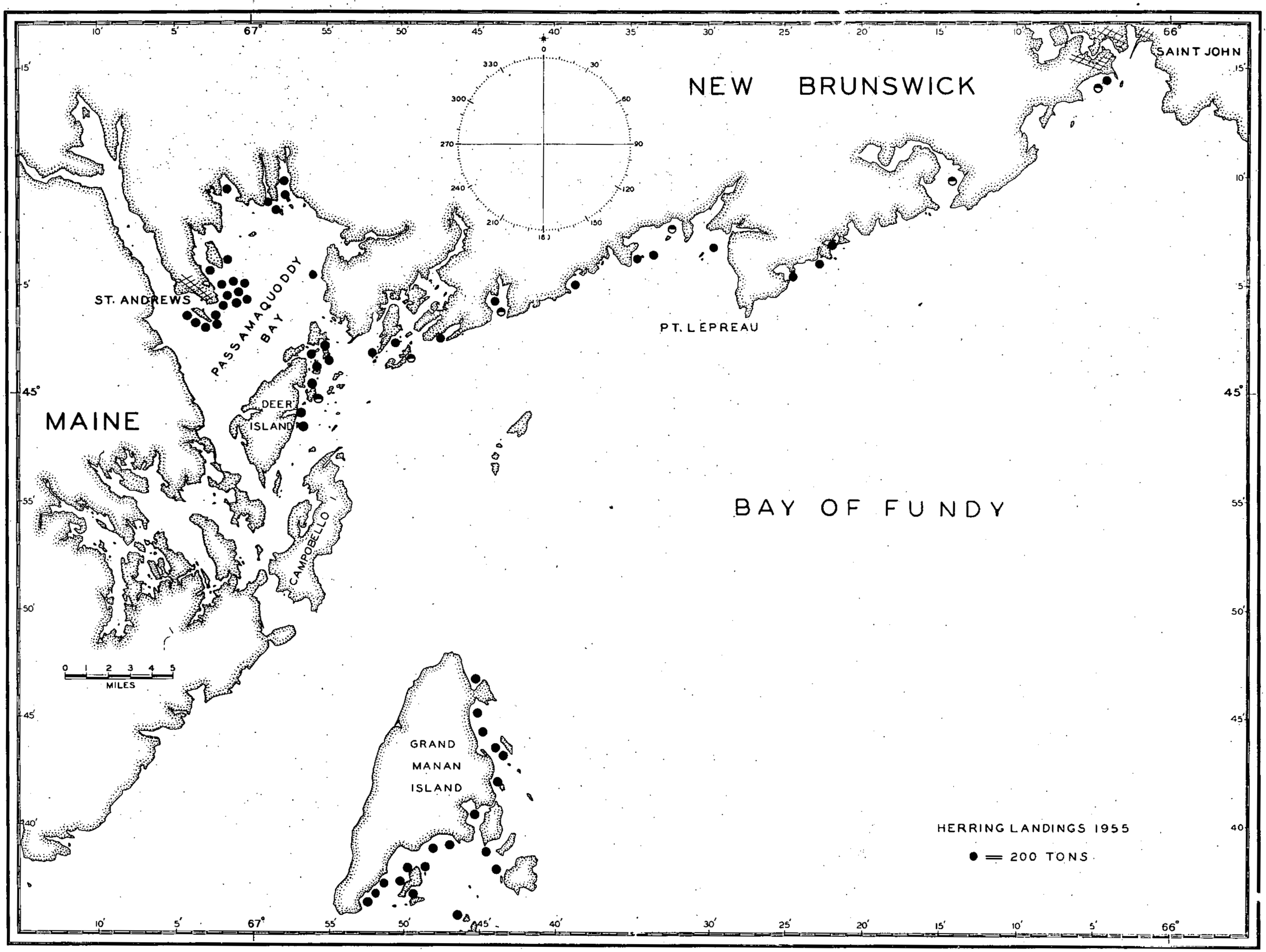

Figure 13. Distribution of herring landings in Charlotte and Saint John Counties, 1955.

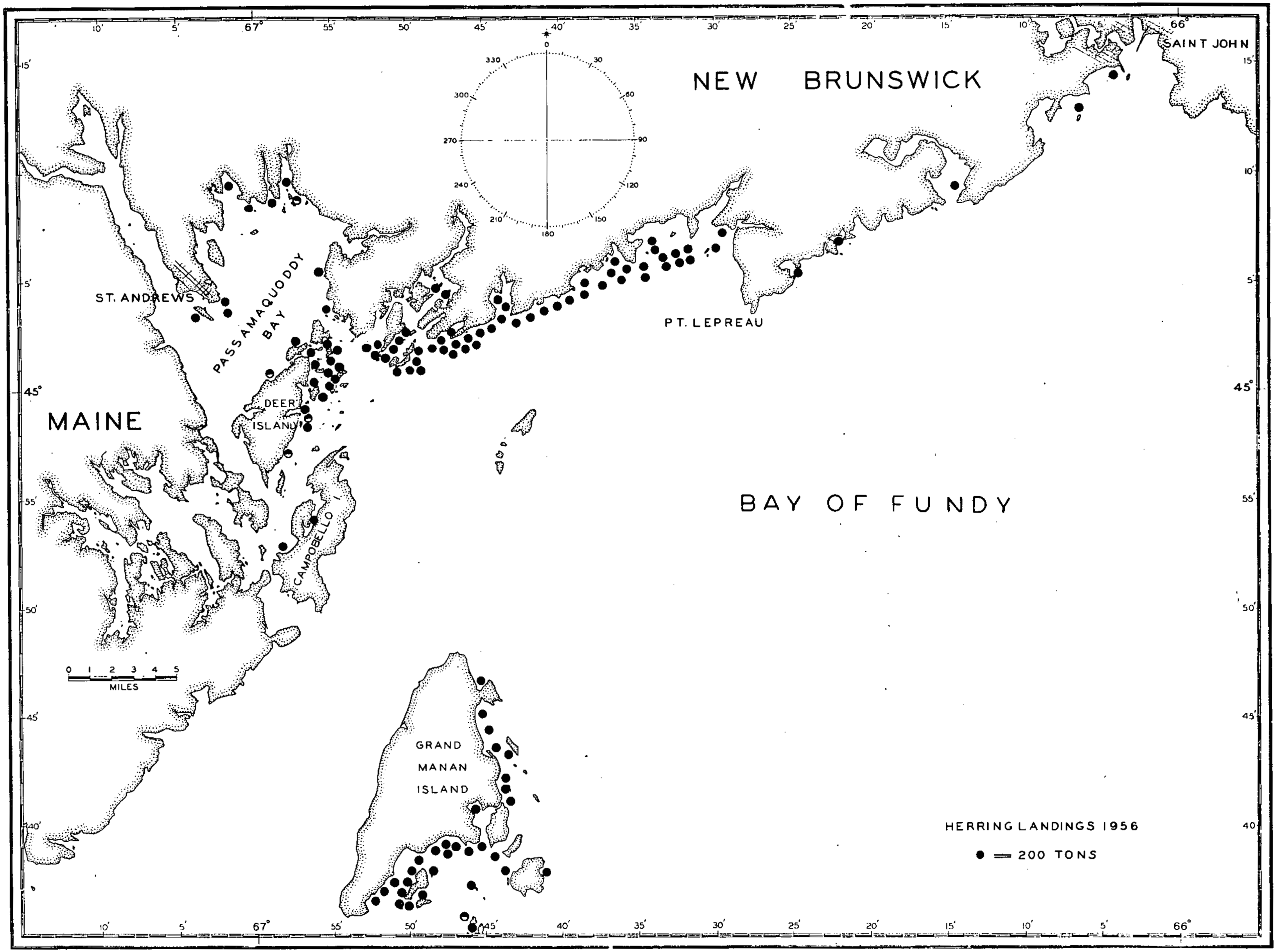

Figure 14. Distribution of herring landings in Charlotte and Saint John Counties, 1956.

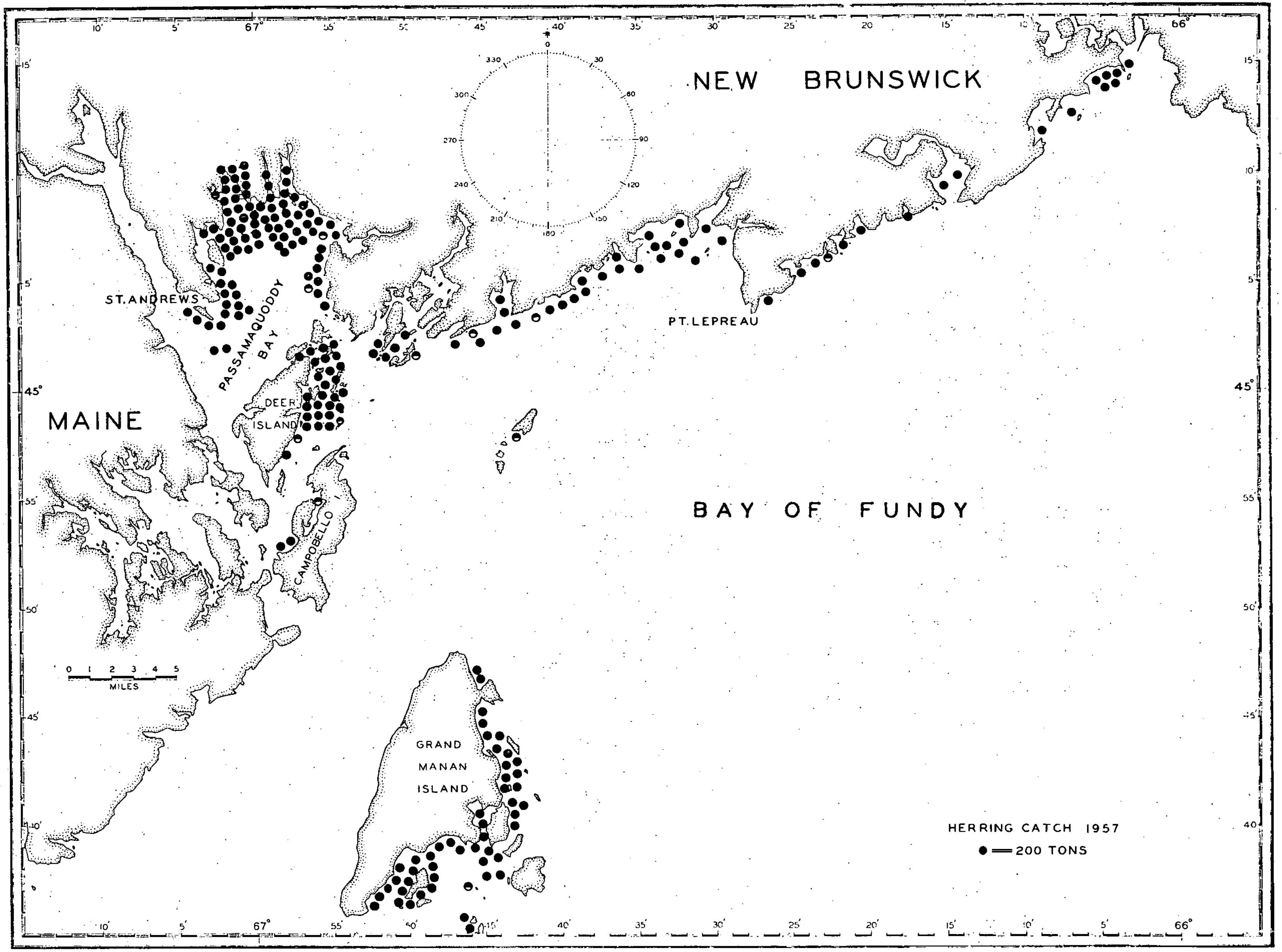

Figure 15. Distribution of herring landings in Charlotte and Saint John Counties, 1957.

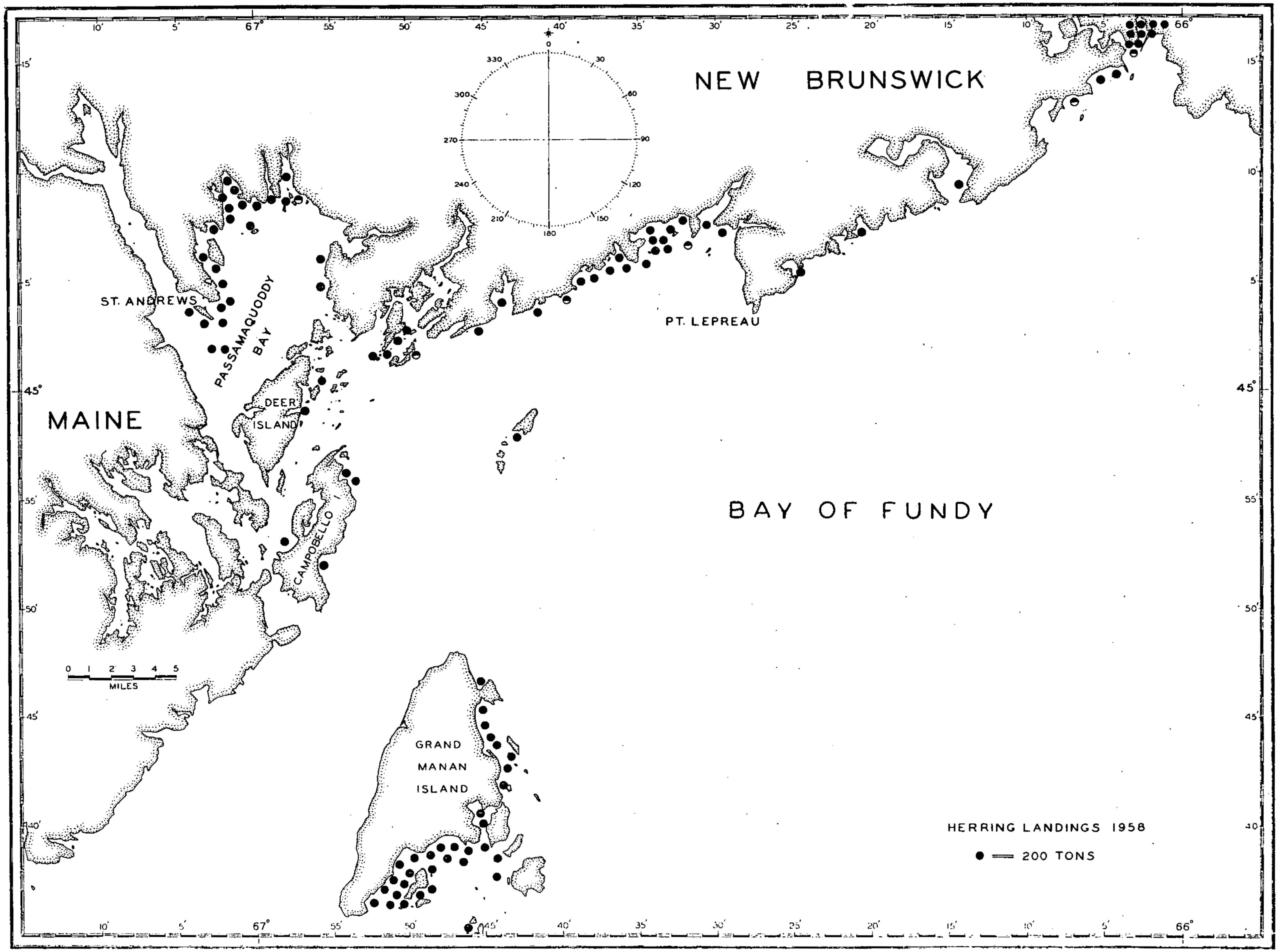

Figure 16. Distribution of herring landings in Charlotte and Saint John Counties, 1958.

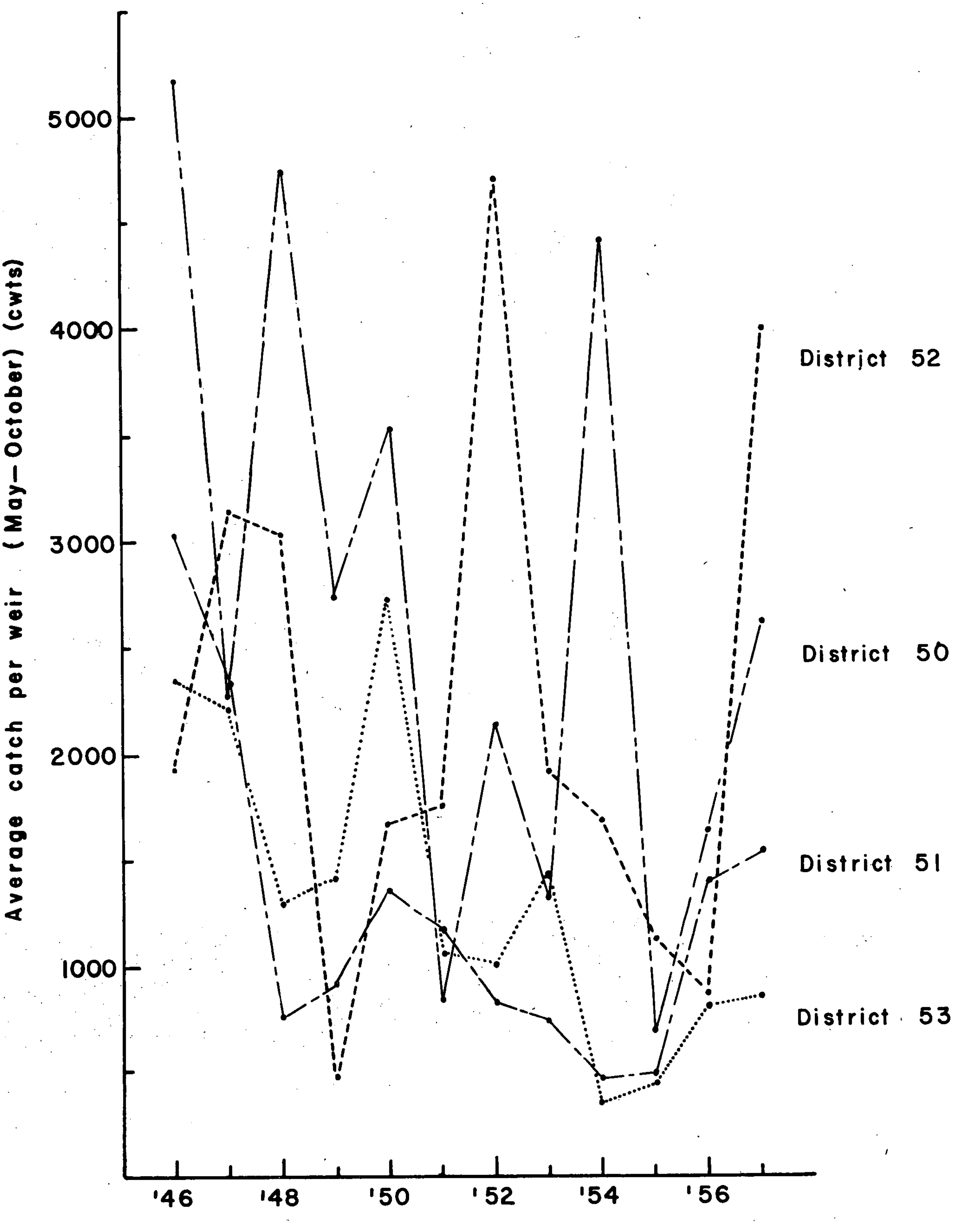

Figure 17. Variations in weir catches, 1946-1957, calculated on basis of number of weirs licensed.

Table A-I

Record of Weirs and Shut-off Operations in Charlotte and Saint John Counties 1947 to 1958 (Shut-off licenses discontinued after 1954)

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
A	Dover Hill Cove	S	S	S	S		S	S	S				
B	Axe Factory	1	S	S	S								
C	Lower Wharf	1	S	S	S								
D	Todds Point			S	S		S	S	S				
E	Ferson						S						
1	McAdam	1	1	1	1	1	1	1	1	1			1
1A	Bedford Creek	1	S	S	S								
2	McCoubrey	1											
2A	Sand Point Cove			S	S								
2B	Curry Cove			S	S								
2C	Octopus			S	S								
2D	Stag					S							
2E	Broken Coin	1	S										
3	Potato Bug	X	S		S		S	1	1	1			1
3A	McCullough		S		S		S	S					
4	Pottery	1	1		1	1			1			1	X
4A	Block	1					S						
4B	Barbara Ann						S						
4C	Boat House	S					S						
5	Shulee	X				1	1	1	1		1		X
6	Outer Niger	X				1		1	1				
7	Niger Reef	1	1	1				1	1	1	1	X	X
8	Benson	1		1	1	1	1	1	1	1	1	1	1
9	Merchant	1	1	1	1	1	1	1	1	1	1	1	1
10	Navy Island	1	1	1	1	1	1	1	1	1	1	1	1
11	Atlantic	1	1	1	1	1	1	1	1	1	1	1	1
12	Bauld Rock	1	1	1	1	1	1	1	1	1	1	1	1
13	Grab All	1	1	1	1	1	1	1	1	1	1	1	1
14	Eastern Light	X	1	1	1	1			1	1	1	1	1
15	Billy's Bar					1	1	1				X	X
16	Union Jack					1	1	1	1	1	X	1	X
17	Beacon Bar			1	1	1	1						
18	Restless	1	1	1	1	1			1				X
19	Granite Rock	X		1	1	1	1	1	1	1	X	X	X
20	Fish Hawk			1	1	1	1	1					
21	Short Bar	X	1	1	1	1	1	1	1	1	1	1	1
21A	Failure	X											
22	Long Bar	1	1		1	1	1	1	1	1	1	1	1
23	Protection	1	1	1	1	1			1	1	1	1	1
24	O'Neill	1	1	1	1	1			1	1	1	1	1
25	Birch Trees	1	1	1	1	1		1	1			1	1
25A	Farroom												X
26	Lamb	X		1	1	1		1		1	1	1	X
27	Robinson	X	1	1	1	1		1		1	1	1	X
28	Cemetery							1	1	1	1	1	1

1 = Weirs licensed and built.
X = Weirs licensed only.
S = Shut-off licensed.

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
29	Rollins	X			S	1			1			1	1
30	Millionaire	1	1	1	1	1	1	1	1	1	1	1	1
30A	McGrath						S						
30B	Greenhouse												1
30C	Pulpit												X
31	Black Point	X			S								
32	Fir Tree	X	1	1	1	1	1	1	1	1	1	1	1
33	Andrews	X	1	1	1	1	1	1	1	1	1	1	1
33A	Sheep Pen				S	S	S	S	S				
33B	James Brook	X			S		S		1				X
33C	Culvert	S			S		S						
33D	Can Plant				S		S						
34	Compromise									1	1	1	1
35	Boyd	X	S		S		S		1	1			X
35A	Craig Point	X											
36	Gows Ledge	1	1	1	1	1				1		1	1
37	McCann's Cove	1	1	1	1	1	1	1	1	1		1	1
38	McColls Head	X				S					1	1	1
38A	McCanns Head		S		S	S	S	S					
38B	Linton		S	S	S								
38C	Miller Point	X											
39	Miller	1	1	1	1	1			1	1	1	1	1
39A	Ox-Bow												X
40	Rocky Beach	1											
40A	Bocabec Pride	X											X
41	Berry Point	1	1	1	1	1	1	1	1		1	1	1
41A	Gut		S	S	S			S	S				
42	Anderson Point	1	1	1	1	1			1	1	1	1	1
43	Apple Tree	1	1	1	1	1	1	1	1	1	1	1	1
44	Foster	X		1	1	1		1		1	1	1	X
45	Orr	1	1	1	1	1	1	1	1	1	1	1	1
45A	Camp		S		S								
46	Chain Ledge	X	S	S	S	S	S	1	1		1	1	1
46A	Ravens Ledge	S					S	S					
47	Square Face	X	1	1	1	1	1	1	1	1	1	1	1
47A	Barney		S		S		S	S					
47B	Hum Bug	X											
48	Northeast	1	1	1	1	1	1	1	1	1	1	1	1
48A	A.B.	S			S		S	S					
49	Black Rock No. 2	X	1	1	1	1	1	1	1	1	1	1	1
50	McWilliam	1	1	1		1	1	1	1	1	1	1	1
51	Red Ledge	X	1	1	1	1	1	1	1	1	1	1	1
51A	Mill Cove		S			S	S						
52	Roy	X		1	1	1	1	1	1	1	1	1	1
53	Holt	1	1	1	1	1	1	1	1	1	1	1	1
54	Vardons Ledge	1	1	1	1	1	1	1	1	1	1	1	1
55	Early Bird	X		1	1	1	1	1	1	1	1	1	1
55A	Bluff												X
56	Ada	X			S	S	S	1	1	1	1	1	1
57	Muir					1	1	1	1	1	1	1	1
58	Union	X	1	1	1	1	1	1	1	1	1	1	1
59	Fills Beach										1	1	X
60	Highland	X		1		1	S	S	1		X	1	X

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
61	White Duck	1	1				1	1	1	1	1	1	X
62	Hog Island	X	1			1	1				X		X
62A	Rocking Chair Fund												X
62B	Hog Island Bar						S	S					
62C	Black Duck	S	S		S								
62D	Jumbo		S	S	S			S					
63	McKay-Bennett	X	1		1	1	1	1	1	1	1	1	1
63A	Sandy Beach				S								
63B	Smoky Beach												X
64	Mary P.	X	S		S	S	S	S	S	1	1	1	1
65	Glass	X	S						1				1
66	Hub						1	1					1
67	Seven Foot Hole						S	1	1	1	1	X	X
67A	Owl						S	S	S				
67AA	McCammics Cove		S		S								
67B	Dominion	1	S				S	S	1	X	X		
67C	Bridge	S	S		S		S	S	S	X			
67D	Ladel Island		S		S								
68	Mink Island	X			1	1					1		1
68A	Flyn												1
69	Carson	X	S	1	1	1	1	1	1	1		1	1
70	Old Mill					1	1	1	1	1	1	X	1
71	Holland Cove				1	1	1	1			1		1
72	Channel	X		1	1	1							X
72A	Dempsey		S		1	1	1	1	1				X
72B	Cedar Point		S	S	S		S	S					X
72C	Struggle						S	S	S				
72D	Long Island		S	S	S		S	S					
73	Deep Cove	X	S		S	S	S	S	1	1		1	1
74	Big Chair	X	S		S	S	S	S				1	
75	Conley	X	1		1	1	1	1	1	1		1	1
76	Timber Creek	X	S		1	1	1	1					1
76A	Simassie		S					S	S				
77	Cove No. 150	1	1	1	1	1	1	1	1	1		1	1
77A	Oven Head		S	S									
78	Huckleberry		S	1	1	1	1						X
79	McElroy	X	S		1	1	1	1	1	1	1	1	1
80	McDougals Island	X	1	1	1	1	1	1	1	1	1	1	1
80A	Gilmore Point		S	S			S						
80B	Dewars Cove	S	S	S	S	S	S	S					
81	Anderson Cove	X	S	S	S	S	S	S		1			
82	Scotchman	X	1	1	1	1	1	1	1	1	1	1	1
82A	Popal Point	1	S	S	S	S	S	S	S				
82B	Pulp Mill		S		S								
82C	Red Store		S										
82D	Basin	S	S	S	S	S	S	S	S				
82E	Leland Creek		S										
82F	Granite		S										
82G	McKenzie's Cove	1				S	S	S					
82H	Seal Ledge		S										
82I	Lone Rover							S					
82II	Silver Island							S					
82J	Betsy's Cove				S			S					

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
82K	Cameron's Cove			S		S	S	S					
82L	Dick		S										
83	Midjic		S	S	S	S	S						
84	Henderson	X	S	1	1	1	1	1	1	1	1	1	1
84A	Red Rock	S	S										
85	Cameron Beach	1	1	1	1	1	1	1	1	1	1	1	1
85A	Homestead		S										
85B	Farm	X											
86	Low's Beach	X		1	1	1	1	1		1	1		1
87	Lot No. 12	X	1	1	1	1	1	1			1	1	1
88	John's Rock	X	S									X	X
89	Cove No. 2	1	1	1	1	1	1	1	1		1	1	1
90	Mascarene	1	1	1	1	1	1	1	1	1		1	1
91	Glass Hill	1	1	1	1	1		1	1				
91A	Catherines Cove	S	S										
92	Hoyts Island	1	1	1	1	1	1	1					
92A	Goose Point	X											
93	Ripp	X		1	1	1							
94	Imperial	X	S	S	S	S	S	S	S	1	1	1	1
94A	McNichols Cove		S	S	S	S	S	S	S				
95	Fog Alarm	1	1	1	1	1	1	1	1				1
96	Green Point	X	1										
96A	Tucker			S									
96B	Pollock Cove	1	S	S	S			S					
97	Crow Island	1	1	1	1	1	1	1	1	1		X	1
98	Crow Point	X	1	1	1	1	1	1					
98A	Big Bear	1	S			S	S	S					
99	Plunder	1	1	1	1	1	1		1				
99A	Cooks Ledge No. 2	1	1	1									
99B	Half Tide Ledge	1											
100	Sweetheart	1	1	1	1								
101	Nickel	1	1	1	1	1	1	X	1	1			
102	Archie's Ledge	1	1	1	1	1	1						
102A	Betty	X											
103	Straw Hat	1	1	1	S	1	1	X	S	1	1	X	X
103A	Leavitt's Cove							S	S				
103B	Monsoon	S	S				S	S	S				
103C	Hard Struggle							S					
104	Perseverence	X	1		S			S					
104A	Granite Rocks	X	X	S	S	S	S	S	S				
105	Gooseberry Bar	1	1	1	1	1	1	1	1	X	1	1	1
106	Leavitt's Head	1	1	1	1	1	1	1					
106A	White Rocks	1	1	S	S	S	S	S	S				
106B	Morrison Point	X											
107	Silver Dollar	1	1	1	1	1	1	1	1	1	1	1	
108	President	1	1	1	1	1	S	S	S				
108A	Gold Dollar	1	1	1									
109	Romulus	1	1	1	1	1	1	1	1	1			
110	Poor House	1	1	1	1	1	1	X	1	1	X		
111	Caucus	1	1	1	1	1	1	1	1	1	1	1	1
112	Mill Cove	1	1	1	1	1	1	1	1	1	1	1	1
113	Charlies Cove	1	1	1	S	S	1	S	S		1	1	1
113A	Big Ledge	X											

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
114	Eagle Island	1	1	1	1	1	1	1	1	1	1	1	1
115	Spruce Island	1	1	1	S	S	S	1	1				
116	Chowder Cove	1	S	S	S	S	S	S	S	1	1	1	X
117	Mackerel Beach	1	1	1	1	1	1	1	1		1	1	1
117A	Lucky Strike	X											
118	Man-O-War Island Ledge	1	1	1	1	1	1	1		1	1	X	1
119	Man-O-War Island	1	1	1	1	1	1	1	1	1	1	1	1
120	Cumberland Shore	1	1	1	1	1	1	1	1	1	1	1	1
121	Tar Pot	1	1	1	1	1	1	1	1	1	1	1	1
122	Califf's Island Beach	1	1	1	1	1	1	1	1	1	1	1	1
123	Laskey Point	1	1	1	1	1	S	1	1	1	X		
124	Bar Island	1	1	1	1	1	1	1	1	1	1	1	1
125	Fox Island	1	1	1	1	1	1	1	1	1	1	1	1
125A	Morans Island	X	1	S	S	S	S	S	S				
125B	Howards Island	S		S	S	S	S	S	S				
125C	Hills Island Cove	S	S	S	S	S	1	S	S				
125D	Four Leaf Clover	S		S	S	S							
126	McCanns	1	1	1	1	1	1	X	S				
126A	McCanns Head	1	1	1	1	1	1	1					
126B	International	X		S	S	S	S	S	S				
127	St. Nicholas	X	1	1	1	1	1	S	S			1	1
128	Pig Rock	1	1	1	1	1	1	S	S	1	1	1	X
128A	Connors Beach	X											
129	Lime Kiln	1	1	1	1	1	1	1	1	1	1		
129A	Raye's Cove	S	S	S	S	S	S	S	S				
129B	Granger Cove	S	S	S	S	S	S	S	S				
129C	Goss Cove					S		S	S				
129D	Enterprise	X			S		1	S					
130	Finger Bay	1	1	1	1	1	1	X		1	1	1	
131	Wild Cat	1	1		1	1	1	1				1	1
131A	Nanny Cove	1	1	S	S		S	S					
132	Fox	1			S		S						
133	Watt's Head	1	1	1	1	1	1	1	1				
133A	Goldfish	X											
134	Speed Bar	1	1	1	1	1	1	X		1	1	X	
135	Goldfinder	1											
136	Tub Island	1	1	1	1	1	1	X	1	1	1	X	
137	Rose Rock	X	1	1	1	1	1	X		1	X	X	X
138	Den	1	1	1	1	1	1	1	1	1	X	X	1
139	Shaw Island	1											
140	Bay View	1											
141	North Star	1	S	1	S	S	S	S	S	1	X	1	1
141A	Triumph	X						S	S				
141B	Preference	X						S	S				
141C	Cochran Island												X
142	Thomsons Cove	1											
143	Hamilton Point	1											
143A	Indian Beach	S	S	S	S	S	S	S	S				
143B	Huttons Cove	1	S	S	S		S	S					
144	Greenlaw Point	1											
145	Singing Seal	X	1	1	1	1		X					
146	Garden of Eden	1	1	1	1	1	1	X					
147	Egg Rock	1	1	1	1	1	1	1	1	1	1	X	X

Cont'd.

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
147A	Freeman Brook	S	S	S	S	S	S	S					
148	Money Cove	1	1	1	1	1	1	1	1	1	1	X	X
148A	Howard's Ledge	S	S	S	S	S	S	S	S				
149	Pentlo Cove	S		S		S				1		X	X
150	Ship's Ledge	X	1	1	1	1	1	1	1				
151	Mitten	1	1	1	1	1	1		1	1	1	1	1
152	Crab Rock	1	1	1	1	1	1		1	1	1	X	X
153	James	1	1	1	1	1	1	1	1	1	1	X	X
153A	Bliss Point	S	S	S	S	S	S	S	S				
154	Outer Lighthouse Cove	S	S	S	S	S	S	S	S	1		1	X
154A	Tree Cove			S	S	S	S	S	1				
154B	Lumber Yard	S	S	S	S	S	S	S	S				
154C	Hole in the Rock			S									
155	Deep Cove No. 2	S	S	S	S	S	S	S	S				
155A	Rock Pile			S	S	S							
156	Trial	1	1	1	1	1	1	1	1	1	1	1	1
157	Manhadden Cove	1	1	1	1	1	1	1	1	1	X	X	X
157A	Fisherman's Cove	S	S	S	S	S	S	S	S				
157B	Try Again	X											
157C	Horse Cove	X	S		S	S	S	S	1				
157D	Pea Point	X	X	S	S	S	S	S	S				
157E	Leo	S	S	S	S	S	S	S	S				
158	Deep Cove No. 1	S	S	S	S	S	S	S	S				
159	Smuggler's Beach	1		1	1	1	1	X	1	1		X	
160	Call's Beach	1	1	1	1	1	1	1	1	1		1	
161	Daisy	1	1	1	1	1	1	1	1	1		X	
162	Hope	1	1	1	1	1	1						
163	Flower Pot	1	1	1	1	1	1	1	1	1	1	1	1
163A	Johnsons Point	X											
164	Deadmans Head No. 1	X		1	1	1	1		1	1	1		
165	Moose Island	1	1	1	1	1	1	1	1	1	1	1	1
165A	Ira's Beach	S	S										
165B	Whales Back		S										
165C	Beaver Light	1	1	1	1	S	S	S	S				
166	Drew's Cove	1	1	1	1	1	1	1	1	1	1	1	1
167	Breakwater	1	1	1	1	S	S	X	1		1	1	1
167A	Eastern Light	1	1	1	1	1							
167B	Jail Rock	X											
167C	Northern Light	1	1	1	1								
167D	Klondyke	S	S	1	1	1	1	X	S				
167E	Beaver Beach		S	S	S	S	S	S	S				
167F	Ina	1											
168	Combination	1	1	1	1		1	S	1		1	1	1
169	Barry Head	1	1	1	1	1	1	1	1		1	1	
170	Elliott	1	1	1	1	1	1	X	1	1	1		
171	Sunrise	1	1	1			S	S	S				
171A	Andy's Cove	S	S	S	S	S		S	S				
171B	Woodpile					S	S	S	S				
172	Foley's Cove	1	1	1	1	1	1	1	1	1	1	1	1
172A	South Beach					S	S						
173	Sand Cove	1	1	1	1	1	1	1	1	1	1	1	1
173A	Orange Pond	S	S	S	S	S	S	S	S				
173B	Three Camps Cove	S	S	S	S	S	S	S	S				

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
173C	Jackies Beach	S	S			S	S		S				
173D	Goldmine							S					
174	Comet	1	1	1	1	1	1	1	1	1	1	1	1
175	Charles Edward	1	1	1	1	1	1	1	1	1	1	1	1
176	Quahaug	1	1	1	1	1	1	1	1	1	1	1	1
176A	Seeley's Point	X		S		S	S						
176B	Stonewall							S	S				
177	Seeley's Basin	1	1	1	1	1	1	1	1	1	1		1
178	Ward's Creek	S	S	S	S	S	S	S	S		X	X	X
179	Success	S	S	1	S	S	S	S	S		X	X	X
180	Crow	S	1	S		S	S	S	S		1		
181	Red Head Cove	1	1	1	1	1	1	1	1	1	1	1	X
181A	Mill Beach			S		S		S					
181B	Maggie	X											
181C	Dougherty's Cove	S	S	S	S	S	1	S	S				
181D	Cocoanut Cove		S	S									
182	McCarron Cove	1	1	1	1	1	1	1	1	1	1	1	1
182A	Bluebell	X											
183	Synagogue	1	1	1	1	1	1	1	1	1	1	1	1
184	Indian Chief					1	1	1	1	1	1	1	
184A	Churchill	X											
184B	Pocologan	X											
185	French	1	1	1	1	1	1	1	1	1	1	X	1
186	Joffre	1	1	1	1	1	1	1	1	1	1	1	1
187	Kitchener	X	1	1	1	1	1	1	1	1	1	1	1
187A	Exchange	X											
188	McCarthy's Point	1	1	1	1	1	1	1	1	1	1	1	1
189	Golden Rod						1	1	1	1	1	1	X
190	Blunder			1	1	1	1	1	1	1	1	1	1
190A	Chamberlain	X											
190B	Davis Cove	S	S	S	S	S		S	S				
191	Bartlett	1	1	1	1	1		1	1		1	1	1
191A	Blackland	X											
192	Harvester	1	1	1	1	1	1	1	1	1	1	1	1
192A	Morale B	1	1	1									
193	Millstream	X			1		1		1	1	1	1	1
193A	Bessie K	X											
193B	Grit	X						X					
194	Curlew	1	1	1	1	1	1			1	1	1	X
194A	Chittick's Beach					S	S	S	S				
194B	Barnaby Head	S	S	S	S	S	S	S	S				
194C	Fowlers Point	1											
195	McCallum	1	1	1	1	1	1	1	1	X	1	1	1
196	Banker	1	1	1	1	1	1	1	1	X	1	1	1
197	Lily	X	X		1	1	1	X	1	1	1		X
198	Otter	1	1	1	1	1	1	1	1	1		1	
198A	Carlow	S	S										
198B	Molly	X		S	S								
199	Ellis					1	1	1	1	1	1	1	1
200	Banshee	1	1	1	1	1	1	1	1	1	1	1	1
201	Gertrude		1		1	1	1	1	1	1	1	1	1
202	Mayflower	1	1	1	1	1	1	1	1		1	X	
202A	Grab All	X											

Cont'd.

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
203	Lomax	X		S	S	S	1	1	1	X	1	1	X
204	Nighthawk	1		S	1	1	1	1	1	X	1	1	1
205	Halibut							1	1	1	1	1	
206	Basin Point	1		S	S	S	1	1	1	X	X	1	1
206A	Gidd's Island						S	S					
206B	Barren	S	S	S	S	S	S	S					
206C	Gem	X		S	1	S	S	1					
207	Forrester	X			1	1	1	1	1	1		1	1
208	Knave		1	1	1	1	1	1		X	1	1	1
209	Roosevelt	X	1	1	1	1	1	1	1		1	1	X
210	Mason	1	1	1	1	1	1	1	1	1	1		
211	Salked Island	1	1	S	S	1	1	S	S				
212	Shag	X				1	1	1	1				
213	Swifter	1	1	1	1	1	1	1	1	1	1	1	1
214	Gold Mine	1	1	S			1	1	1	1	1	1	1
215	Pup No. 2	1	1	1	1	1	1	1	1	X	1	1	1
216	Lena						1	1	1	1	1	1	1
217	Flounder		1	1	1	1	1	1	1	1	1	1	1
218	Councillor					1	1	1	1				
218A	Dry Ledge							S	S				
218B	Jardine	S			S	S	S	S	S				
218C	Welch Cove	S	S	S	S	S							
218D	Cafferty Cove							S	S				
219	Shoal Cove	S	S	S	S	S	S	S	S				
219A	Buttermilk Rock	S	S	S	S	S	S	S	S				
219B	Rocky Beach	S	S	S	S	S	S	S	S				
219C	Coates Cove	S	S	S	S	S	S	S	S				
219D	McKenzies Cove	S	S	S	S	S	S	S	S				
220	Welcome	S	S	S	S	S	S	S	S		X	1	1
221	Little Beach	1	1	1	1	1	1	1	1	1	1	1	1
221A	Gooseberry Beach	S	S	S	S	S	S		S				
221B	Hay Point	S	S	S	S	S	S	S	S				
221C	Spruce Island			S	S	S	S	S	S				
221D	Bills Luck	S	S	S	S	S	S	S	S				
221E	Mariner	S	S	S	S	S	S	S	S				
221F	Ghost Hollow	S	S	S	S	S	S	S	S				
221G	Southern Wolf Light	S		S	S	S	S	S	S				
221H	Deadman's Beach	S	S	S	S	S	S	S	S				
221I	Grovenor's Notch	S		S	S	S	S	S	S				
221J	Wolf	S	S	S	S	S	S	S	S				
222	Southern Cove	1	1	1	1	1	1	1	1	1	1	1	1
222A	Brandy Cove	S	S	S	S	S	S	S	S				
222B	Ships Beach	S	S	S	S	S	S	S	S				
222C	Net Point	S	S	S	S	S	S	S	S				
222D	Eastern End Cove	S	S	S	S	S	S		S				
223	Plumper	1	1	1	1	1	1	1	1	1	1	1	1
224	Long Beach	1	1	1	1	1	1	1	1	1	X	1	1
225	Reef	X	1	1	1	1	1	1	1	X	X		
226	Island Point	1	1	1	1	1	1	1		1	1	1	1
227	Lighthouse	1	1	1	1	1	1	1	1	1	1	1	1
228	Molly Brown	1	1	1	1	1	1	1	1	1	1	1	1
228A	Burn's Cove	X											
229	Round Meadows				1	1	1	1	1	1	1	1	X

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
230	Lobster Cove	1	1	1	1	1	1	1	1	1	1	1	1
231	Pond Hole	X	1	1	1	1	1	1	1		X		
232	Try Again	1	1	1	1	1	1	1	1	1	1	1	1
233	Ledge				1	1	1						
233A	Deep Cove	X											
234	Horseshoe	X	1	1	1	1	1	1	1	1	1	1	X
234A	Adventure	S	S	S	S		1	1	1	X			
235	Pal	X											
235A	Haleys Cove	S	S	S									
235B	Western Head	X											
236	Little Musquash	S	S	S	S					X	1	1	1
237	D and C No. 1	X											
238	D and C No. 2	X											
239	Grab All	X											X
240	D and C No. 3	1	1	1	1	1	1	1	1	1	1	1	1
241	White Rocks									X			X
242	Cameron's Cove	X											
243	Buck	X	1										
244	Five Fathom Hole								1	1	X	X	X
245	Last Chance									X			
246	Rose									X			
247	Osprey								1	1			
248	Connors Cove									X			
249	Musquash Island	X							1	1	X		
250	Black Beach	X								1	1	1	1
251	Silver Dollar	1	1	1	1	1	1	1		X	X		1
252	Kingfisher	1	1	1	1	1	1	1	1	1	1	1	1
253	Seeleys Point		1	1						X	1		
253A	Taylors Island	X											
253B	Fish Camp Cove												X
253C	Island View												X
254	Victory	1	1	1	1	1	1	1	1	X	X	1	1
255	C.F.B.C.						1	1	1	1	1	X	X
256	Sand Cove		1	1						1			X
256A	Duck Cove				1	1							
257	Hamm	1	1	1	1	1	1	1	1	1	1	1	1
258	Seaside Park	1	1	1	1	1	1	1	1	1	1	1	1
259	Surf	1	1	1	1	1	1	1	1	1	1	1	1
260	Fort Dufferin							1		1	X		
261	Shag Rocks	1	1	1	1	1	1	1	1	1	1	1	1
262	Falcon						1						
262A	Lot J.	1	1	1	1	1	1	1	1	1	1	1	1
263	Red Bank				1		1	1					
264	Grass Point Cove	1	1	1	1	1	1		1				
265	King William	1	1	1	1	1	1	1	1	1	1	1	X
266	Britton	X	1	1	1	1	1	1	1		1		
267	Salvation Army	1											
267A	Bald Rock Beach					S		S	S				
267B	Bay View				S	S		S	S				
267C	Back Beach					S		S	S				
268	No. 1	1	1										
268A	Pill					S							
269	Beater	X											

Cont'd.

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
269A	Vernon	X											
270	Home Again	1	1	1	1	1	1	1	1	1	1	1	1
271	Stuart	1	1	1	1	1	1	1		X	X	X	X
272	Wards Beach	X	1	1					S			X	X
272A	Pond Hole	S	1			S		S	S				
272B	Stealer	S											
273	Hooper	1	1	1	1	1							
274	New Spectacle No. 2	X		1	1	1	1	1					
274A	Flat Rock	1				S		S	S				
275	Frog	1											
276	Queen Mary	X	1	1	1	1	1	1	1	1	X		
277	Gardner	1	1	1	1	1	1	1	1	1			
278	Two Hour Bar			1	1	1	1						
279	Eureka	1	1	1	1	1	1	1	1	X			
280	Doughty Beach	X	1	1	1	1			1		1		
281	Red Beach Point	1											
282	Independence	X		1	1	1	1		1			X	1
283	Haven										1	1	1
284	Cummings Point	X			1	1	1	1	1	1			
285	Round Marsh	1	1	1	1	1	1		1	1	1	1	
285A	Cable Beach									X			X
285B	Stephens	X		1		1						X	X
285C	Marble					X							
285D	Gold Seeker	X											
286	Chance		1	1					S				
286A	Hurleys Cove					S			S				
286B	Black Ball								S		X		
286C	Long Beach					S							
287	Indian Cove				S	S				1	X	X	
287A	Richardson	X							S				
287B	Leggins							S	S		X		
288	Doctor		1	1	1	1	1	1	1	1	1	1	1
289	Black Prince	1	1	1	1	1	1	1	1	1	1	1	1
290	McKinney's Cove	1		1	1	1	1			X	X	1	
291	Kidney			1							X	1	X
291A	Amazon										X		
292	Sandy Ledge	X								X		X	
293	Dogfish Hole	1	1	1	1	1	1	1	1	1	1	1	1
294	Hibernia Cove	1	1	1	1	1	1	1	1	1	1	1	1
295	Rocky Point No. 2	1	1	1	1	1	1	1	1	1	1	1	1
296	Rattle Rock	1	1	1	1	1	1	1	1	1	1	1	1
297	Eddy Beach	1	1	1	1	1	1					X	
298	Lighthouse			1	1	1	1	1	1	1	1	1	X
298A	Grave Yard							S	S				
299	Sea Gull	1	1	1	1	1	1	1	1	1	1	1	X
300	Mackerel Beach	1	1	1	1	1	1	1	1	1	1	1	1
301	Hilts Beach	1	1	1	1	1	1	1	1		1	1	1
302	Cline	1	1	1	1	1	1	1	1	1	1	1	1
303	Britt	1	1	1	1	1	1	1	1	1	1	1	1
304	Dreadnaught	1	1	1	1	1	1	1	1	1	1	1	1
305	Barteau	X	1	1	1	1	1	1	1	X			
305A	Lucky	X											
306	Dinner Island	1	1	1		1	1	1	1	1	1	1	1

Cont'd.

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
307	Conqueror	1	1	1	1	1	1	1	1	1	1	1	1
308	Noddens Beach				1	1	1	1	1	X	X	X	X
309	Absentee	1	1	1	1	1	1		1	1	1	1	1
310	Iris	1	1	1	1	1	1		1	1	1	1	1
311	Benjamin	1	1	1	1	1	1				X	1	X
312	Marshall	1	1	1	1	1	1	1	1	1	1	1	1
313	Anderson	1	1	1	1	1	1	1	1	1	1	1	1
314	Ledges										X	X	X
315	Bluenose	1	1	1		1	1			X	1	X	X
316	Bean's Island	1	1	1	1	1	1	1	1	1	1	1	1
317	Peace Maker	X	1	1	1	1	1	1	1	1	1	1	1
318	Deep Cove	1	1	1	1	1	1	1	1	1	1	1	1
318A	Gypsy	X											
319	Cook's Island	1	1	1	1	1	1	1	1	1	1	1	1
320	Catnap	1	1	1	1	1	1	1	1	1	1	1	1
320A	Goldmine	X											
321	Giller	1	1	1	1	1	1	1	1	1	1	1	1
321A	Boom Cove												X
321B	Three Dogs	S		S		S			S				
322	Growler	1	1	1	1	1	1	1	1	X	1	1	1
323	St. Helena	1	1	1	1	1	1	1	1	1	1	1	1
324	Dawn							S	S	X	X	X	X
325	Johnston's Brook	1	1	1	1	1	1	1	1	1	1	1	1
326	Johnston's Bar	S	1					S	S				
327	Bread Pan				S	S	S	S	S		X	X	X
327A	Far Away				S	S		S	S				
328	Uncle Sam	X	1	1	1	1	1	1	1	1	1	1	1
328A	Ned	S			S	S	S						
329	Look Out	1	1	1	1	1	1	1	1	1	1	1	1
329A	Paispearl	X											
330	Hathaway	X		S	S	1					1	X	
331	Ferry	X			1	1	1	1		X			
332	La Canadienne	1	1	1	1	1	1	1	1	1	1	1	1
333	Twilight	1	1	1	1	1	1	1	1	1	1	1	X
334	Little Island				1	1	1	1	1	1	1	1	1
334A	Surprise	1											
335	Golden Rod	1					1	1	1	1	1		
336	Sunshine			1									
337	Centennial	1	1	1	1	1	1	1	1	1	1	1	1
338	Radio	X	1	1	1	1	1	1					
339	Fish Island	1	1	1	1	1	1	1					
340	Dream	1	1	1	1	1	1	1	1	1	1	1	1
341	Huba Huba	1	1	1	1	1	1	1	1		X	1	1
342	Pinafore	1	1	1	1	1	1	1	1	1	1	X	
343	Gleaner	1	1	1		1	1	1	1				
344	Sand Reef	1	1	1	1	1	1	1	1	1	X	X	
345	Golden Press	1	1	1	1	1	1	1	1	1	1	1	X
346	Little Island Ledge	1	1	1	1	1	1	1	1	1	1	1	1
347	C.C.F.	1	1	1	1	1	1	1					
348	Crow Island	1	1	1	1	1	1						
349	Old Crow	1	1	1	1	1	1	1	1		X	X	
350	Hard Times	1	1	1	1	1	1	1	1	1	1	1	1
351	Seal Rock No. 1	1	1	1	1	1	1	1	1	1	1	1	1

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
352	Two Boys			1									
353	Pendleton	1		1	1	1							
354	Butler	X	1	1	1	X							X
355	Little Hog	1	1	1	1	1	1	1	1	1	X		1
356	Fox Passage	1	1	1	1	1	1	1	1	1	1	1	1
356A	New Ireland	X											
357	Roggins Pot	1	1	1	1	1	1	1	1	1	X	X	X
357A	Rival Rock	1	1		1								
358	Otter	X	1	1	1	1	1	1	1	1	1	1	1
358A	Black Duck	S											
359	McLaughlin	1	1	1	1	1	1	1	1	1	X	X	1
360	Brunswicker				1	1	1	1	1	1	1	1	1
360A	Kingfisher	X											
360B	New Lucky	X											
361	Fert						1	1	1				
362	Vigilant	1	1	1	1	1	1	1	1	1	1	1	1
363	Parkers Bar	1	1	1	1	1	1	1	1	1	1	1	1
364	Chatties Point	1	1	1	1	1	1	1	1	1	1	1	1
364A	Combine					S							
364B	Yellow Rock	X											
365	Jack's Tooth	X			S	S		S	S	X	X	X	X
366	Buttercup	1	1	1	1	1	1	1	1	1	1	1	1
366A	Nelson Eddy					S							
366B	Squaw Ledge	X											
366C	Empire	X			S	S		S	S				
367	Dead Horse	1	1	1						X			
368	Sand Beach	X	1	1	1	1	1	1		X	X	X	X
368A	Currie Rock	X											
369	Poplar Cove	X		1	1	1	1	1	1	1	1	1	1
370	McVicar	1	1	1	1	1	1	1	1	1	1	1	1
370A	Mine House	X											
371	Bar	1	1	1	1	1	1	1	1	1		X	X
372	Half Yoke	1	1	1	1	1	1						
373	Illsley	X				S		S	S		X	X	X
374	Adventure	1	1	1	1	1	1		1	1	1	1	
374A	Gidds Point	X											
375	Grass Point	1	1	1	1	1	1						
376	Spectacle	1	1	1	1	1	1	1		X	X	X	X
377	New Spectacle	X	1										
378	Argument	1			1	1							
378A	White Island	X											
379	Pup	1	1	1	1	1	1	1	1	X	X		
379A	Cod Rock					X							
380	Back	1	1	1	1	1	1	1	1	1	1	1	1
380A	Tinkers Island	X											
381	Spruce Island	X			1	1	1	1	1	1	X	X	
382	Young	1	1	1	1	1	1	1	1	1	1	1	1
382A	Casco		1			S							
382B	Melancy					S							
382C	Northeast Cove					S							
383	Little Beach	1	1										
383A	Ballast Beach	X											
383B	Pollock Cove	1	1										

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
383C	Wind Mill										X		
384	Mallock's Beach No. 1	1	1	1	1	1	1	1	1	1	1	1	1
384A	Peter	X											
385	Gun Rock	1	1	1									
386	John's Cove	1	1	1	1	1	1	1	1	1	1	1	1
387	Half-tide	1	1	1	1	1	1	1	1	1		1	1
388	Gilligan	1	1	1	1	1	1	1	1	1	1	1	1
389	Gallagher	1		1						X			
390	Seal Rock No. 2	1	1	1	1	1	1	1	1	1	1	1	1
391	Nubble	1	1	1	1	1	1	1	1				
392	Man-of-War Garden	1	1	1	1	1	1		1				
392A	Mitchill	X											
393	Boyd	X	1	1	1								
394	Calder	X		1									
395	Townsend		1	1	1	1	1	1		1	1		1
396	Good Luck	X	1	1		1							X
396A	Owen Pier	X											
397	Bake										X		
398	Rocky Point No. 1	1		1	1	1	1	1	1	1	1	1	1
399	Envy	1	1	1	1	1	1	1	1	1	1	1	1
400	Friars Bay	1	1	1	1	1	1	1	1	1	1	1	1
401	Defiance	1	1	1	1	1	1	1		1	1	1	
402	Friars Head	1	1	1	1	1	1	1	1	1		1	1
403	Snug Cove	1	1	1		1		S	S	X			X
404	Godfrey									1			
404A	Lobster Hole				S	S			S				
405	Duck Pond	X	1			1	1	1	1	X			
405A	Yellow Bank				S	S			S				
405B	Liberty Cove				S	S		S	S				
406	Racoon Beach	1	1	1	1	1	1	1		X			
407	Five Spikes	1	1	1	1	1		1			1	1	
408	Old	1	1	1	1	1	1	1	1	1		1	1
409	Mahaska	1	1	1	1								
410	Soco	1	1	1	1	1	1	1	1	1	1		
411	North	1	1	1	1								
412	Eastern Pond	1	1	1	1	1	1	1	1	1	1	X	
413	Eastern Head	1	1	1									
414	Meadow Brook	1	1	1	1	1	1	1	1	1	1	1	X
414A	Whale Beach	1				S			S				
414B	Little Whale Beach	X											
414C	Castle Rock	X											
415	Schooner Cove	1	1	1	1	1	1					X	X
416	Dog Fish Hole No. 2	1	1	1									
417	White Rocks	1	1	1									
418	Point	1	1										
419	Mill Cove	1	1	1	1	1	1	1	1	1	1	1	1
420	Fitz No. 1	1	1	1	1	1	1						
421	Anthony	1	1	1	1	1							
422	Fitz No. 2	1	1	1	1	1	1						
423	Birch Head	X		1									
423A	McEwing									X			
424	Cub No. 2	X	1	1					1				
425	Greenwood	1	1	1									

Cont'd.

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
425A	Sawyer	X											
426	Galley	1	1	1	1	1	1						
427	Deadmans	1	1	1	1	1							
428	Buzzer	X	1										
428A	Punk	X											
429	Indian Beach	1	1	1	1								
430	Gulley Hole	1	1									X	
431	Money Cove	1	1	1	1	1	1	1	1			1	1
431A	Shadow		S										
432	Dream		1										
432A	Herring Cove		S										
432B	Battle Head Cove		S										
432C	Joe's Chopping Cove		S	S									
432D	Pandora Cove		S										
432E	Big Head Cove		S										
433	Bradford's Cove			1	1	1	1	1	1	1	1	1	1
433A	Upper Hay Point		S	S									
433B	Lower Hay Point Cove		S	S									
433C	Upper Old Maid Cove		S				S						
433D	Lower Old Maid Cove		S	S									
433E	Little Island		S	S									
433F	Lighthouse Cove		S	S	S	S	S						
433G	Beach		S	S	S								
434	Pat	1	1	1	1	1	1	1	1	1	1	1	1
434A	Gale							S					
435	Tom Stones	1	1	1	1	1	1	1	1	1	1	1	1
436	North Cliff							S			X		
436A	Trees												X
437	Commando		1	1	1	1	1	1	1	1	1	1	1
437A	Navijo							S					
438	Falias Gap		1	1	X	1	1	1	1	1	1	1	1
439	Admiral	1	1	1	1	1	1	1	1	1	1	1	1
440	Jack Tar	1	1	1	1	1	1	1	1	1	1	1	1
441	Harvey Point		1	1	1	1	1			X	1	1	1
441A	Greens Landing							S					
441B	Fitzgerald												X
442	Grassy Point		1	1	1	1	1	1	1	1	1	1	X
443	No. 2 C		1		1	1	1	1	1	1	1	1	1
444	Whale Cove	1	1	1	1	1	1	1	1	1	1	1	1
444A	No. 7 C		S	S	S	S	S						
445	Little Wood Island	1	1	1	1	1	1	1	1	1	1	1	1
446	Shag Rock	1	1		1	1	1	1	1	1	1	1	1
446A	Ram Rock		S		S								
447	Breaker										X	X	X
447A	Back Beach Cove		S		S	S							
448	Venture		1	1	1	1	1	1	1	1	1	1	1
449	Gully		1	1	1	1	1	1	1	1	1	1	1
450	Gulls Egg	1	1	1	1	1	1	1	1	1	1	1	1
451	Good Luck			1	1	1	1	1	1	1	1	1	1
452	Wild Goose			1	1	1	1		1	1	X		
453	Sheep Yard		1	1	1	1		S		1	X	X	X
454	Last Chance			1	1								
455	Wonder		S							1	1	1	1

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
456	Pond Point		1	1	1	1	1	1	1	1	1	1	1
457	Sonny			1	1	1	1	1	1	1	1	X	X
457A	Carpet		S										
458	Seattle		1	1	1	1	1	1	1	1	1	1	1
459	Trout Brook	1	1	1	1	1	1	1	1	1	1	1	1
460	Laurier				1	1	1	1					
461	Turnip Patch		1	1	1	1	1	1	1	1	1	1	1
462	Defender		1	1	1	1	1	1	1	1	X	1	1
463	Hector		1	1	1	1	1	1	1	1	1	1	1
464	Louise		1	1	1	1	1	1	1	1	1	1	1
465	Sand Flea							S	1				X
466	Martha			1	1	1	1						
467	Bonanza		1	1		1	1	1	1	1		X	
468	Senator				S	S		S	1				1
469	Gold Seeker		1	1	1	1	1	1	1	1	1	1	1
470	Eureka	1	1	1	1	1	1	1	1	1	1	1	1
471	Tom Thumb									1		X	
472	Welcome Bend		S		S	1	1	1	1	1	X	X	X
473	Gold King		1	1	1	1	1	1	1	1		1	1
474	Prince Albert						1	1	1	1	1	1	1
474A	Bonny Brook							S					
475	Lobster								1	1	X	X	
476	Zandike			1	X	X			1	1	X	X	
476A	Tom Cod		S	S	S	S	S	S					
476B	Chalk Island Cove		S										
477	Cow Rock									1	1	X	
478	Bluebell			1	1	1	1		1	1	1	X	X
479	John Ross		1	1	1	1	1	1	1	1	1	1	1
480	Acorn			1						1	1	1	1
481	Try Again		1	1	1	1		1	1	1	1	1	1
482	Uncle Bill			1	1	1	1	1	1	1	1		1
483	Solomon		1	1	1	1	1	1	1	1	1	1	1
484	Victoria		1	1	1	1	1	1	1	1	1	1	1
485	Protest			1									
486	Benson				1	X							
487	Salt Point			1	1	1	1	1	1			X	X
488	Standard Time									1	1	X	
488A	Bill's Island			S									
489	Fresh Point		S	S	S		1	1	1	X	X	X	X
490	Round Shoal			1	1	1	1	1	1				
491	Minto				1	1	1	1	1				
492	Polly				1	1	1	X					
493	Eatonia			1	1	1	1						
494	Toothpick		1	1	1	1	1	1	1	1	1	1	
495	Progressive		1	1	1	1	1	1	1	1			
496	Sand Beach		1	1	1	1	1	1			1		
497	Judy		1										
498	Eastern Green Island										1	1	1
499	Bar No. 1				1	1	1	1	1	1	1	1	1
499A	Surplus												X
500	Sheep Island		S		S		1	1	1	1	1	1	1
500A	Minor		S	S		S	S	S					
500B	Blondie			1		S	S						

Cont'd.

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
500C	Southern Cove		S	S	S								
501	Eastern Ledge		1	1	1	1	1	S	1	1	1	1	1
501A	Long Point		S	S									
502	Sandy Cove		S	S	S	S	S	S		1	1	X	
502A	Langwedge		S	S	S								
503	Barnacle Bill		1	1	1	1							
504	Old House		S	1	1	1	1	1	1				
505	Shrimp		1	1	1	1	1	1	1	1	1	1	X
505A	Wilson's Cove		S	S									
505B	Seaduck Beach		S	S	S	S	S	S					
505C	Lily		S	S		S	S	S					
506	Mermaid			1	1	1	1	1	1	1	1	1	1
507	Southern Cross		1	1		1	1	1	1	1	1	1	X
508	Sunny South		1	1	1	1	1	1	1	1	1	1	1
509*	Andy's Ledge												
510	Black Prince			1	1	1	1	1	1		X	X	X
511	Black Ledge			1	1	1	1		1	1	1	1	
512	Duck Pond			1	1	1	1	1	1				1
512A	The Bar		S										
513	Lion's Ledge	1	1	1	1	1	1	1	1			X	
514	Last Ditch	1	1	1	X	1	1	1	1			X	
515	Turkish Empire			1	1	1	1		1				
516	Two B's										X		
517	Conqueror		1										
518	Bessie Beach		1	1	1	1	1	1	1	1	1	1	1
519	Experiment			1	1	1	1	1	1	1	1	1	1
520	Goose Rock							S	1	1	1	1	X
521	Buttermilk									X			
522	Pot		1	1	1	1		1	1	1			X
523	Skinner								1	1	X	X	
524	Deep Hole			1	1	1		1					
524A	Billy's Cove							S					
524B	Nantucket		S	S	S								
525	Pirate										X		
526	Lime Kiln		1	1	1			1		1	1	1	
527	North Star		1	1	1	1	1	1	1	1	1	1	X
528	Sog							S	1	1	1	1	X
529	Split Rock		1	1	1	1	1	1	1	1	1	1	X
530	Prescription	1	1	1	1	1	1	1	1	1	1	1	1
530A	Snapper		S	S	S								
530B	Gleaner		S	S	S								
531	Gold Mark	1	1	1	1	1	1		1			X	
531A	Isabelle							S					
532	Seal Rock		1	1	1	1	1	1	1	1		1	
533	National	1	1	1	1	1	1	1	1	1	1	1	
534	Lode Stone		1	1	1								
535	Mistake				1	1	1						
536	Captain Kidd	1		1	1	1	1	1	1	1	1	1	1
537	Tel-el-Keber	1	1	1	1	1	1	1	1	1	1	1	1
537A	Whet Stone				S								

*Andy's Ledge weir numbered in error, licensed only prior to 1947.

Code	Name	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57	'58
538	Envy	1	1	1	1	1	1	1	1	1	1	1	1
539	Ruin				1	1	1		1	1	1	1	
539A	Fishermans Beach		S	S	S								
540	King George	1	1	1	1	1	1	1	1	1	1	1	X
540A	North End		S	S									
541	Sol Jacobs	1	1	1	1	1	1	1				1	
542	Dutchman	1	1	1	1	1	1	1	1	1	1	1	1
543	June Bug									1	1	1	X
544	Marsh								1	1	1	1	1
545	Lue	1	1	1	1	1	1	1	1	1	1	1	1
546	Oddfellow		1	1	1	1	1	1	1	1	1	1	1
547	Spite											X	
548	Busy East				1	1	1	1	1				
549	War-of-Hope				1	1	1	1			X		
550	Coquitelam	1						S		1	X		X
551	Ottoman	1	1	1	1	1	1	1	1	1		1	1
552	Drakes Dock	1	X			1	1	1	1	1	1	1	1
553	Stanley Beach	1			1	1	1	1	1	1	X	X	X
554	Andrew				S				1		X		1
554A	Atlas				S								
555	Cora Bell	1	1	1	1	1	1	1	1	1		1	1
555A	Saw-Pit		S	S									
556	Jubilee No. 31A	1	1	1	1	1	1	1	1	1	1	1	
557	Star-of-Hope	1	1		1	1	1	1	1		1	1	1
558	Winner	1	1		1	1	1	1	1		1	1	1
559	Mystery	1	1	1	1	1	1	1	1	1	1	1	1
	Weirs licensed and built	322	375	399	398	410	391	349	366	326	300	296	267
	Weirs licensed only	170	4	0	3	5	0	17	0	44	67	75	110
	Shut-offs licensed	72	148	124	149	128	123	149	110	0	0	0	0

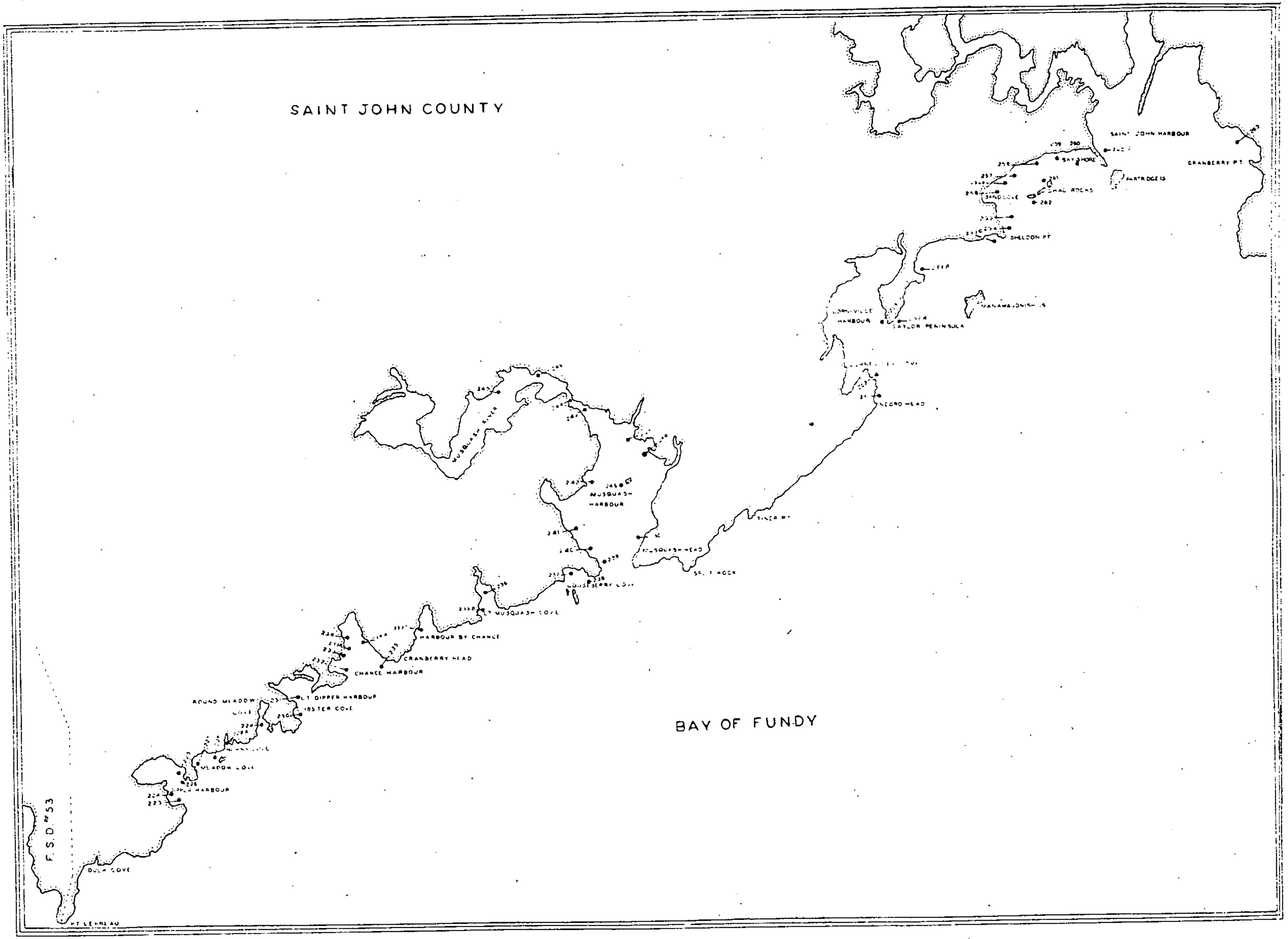

Figure A1. Map of weir locations (#223-263), fisheries statistical districts # 48 and 49, Saint John County.

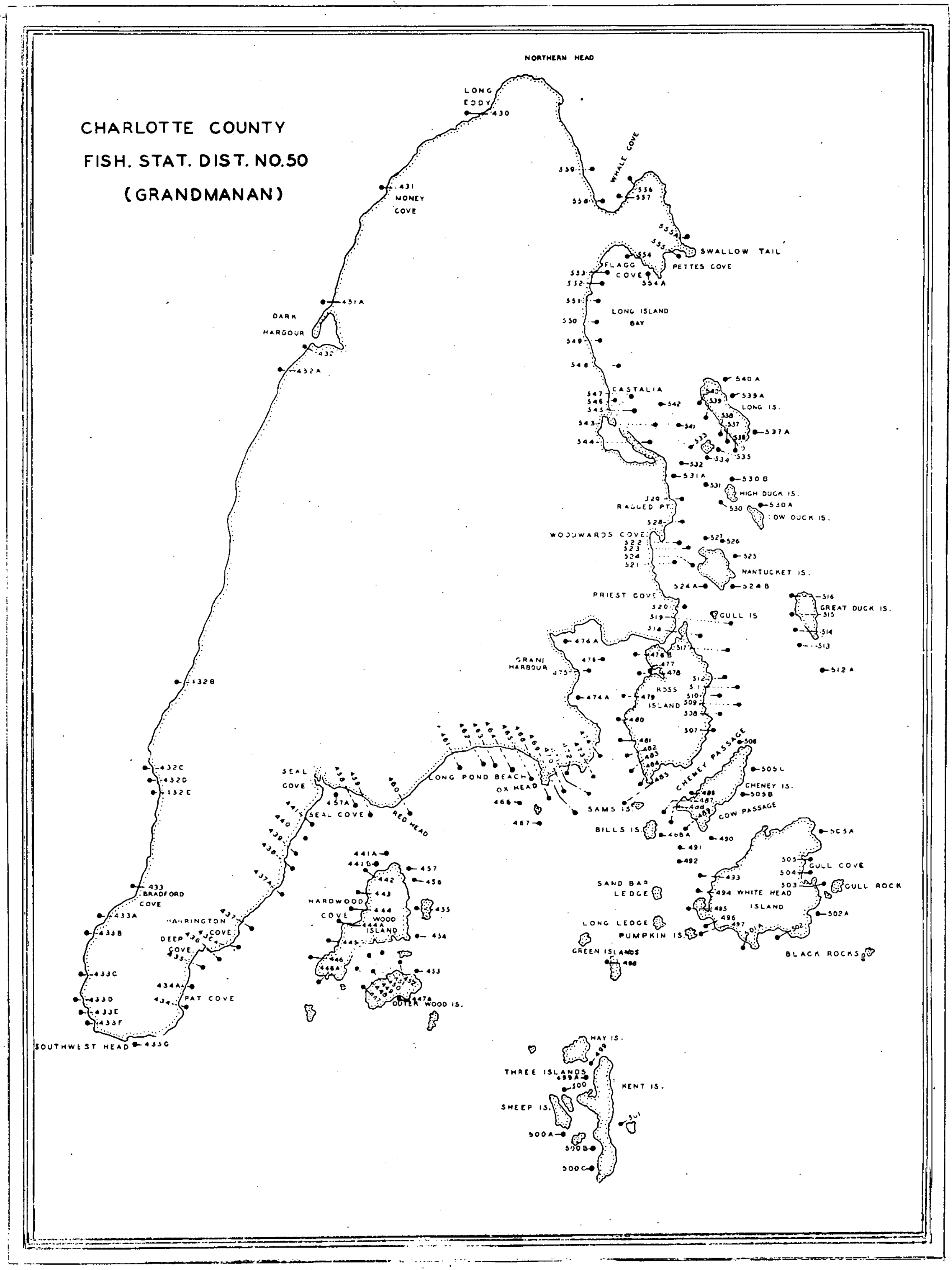

Figure A2. Map of weir locations (#430-559), fisheries statistical district # 50, Grand Manan, Charlotte County.

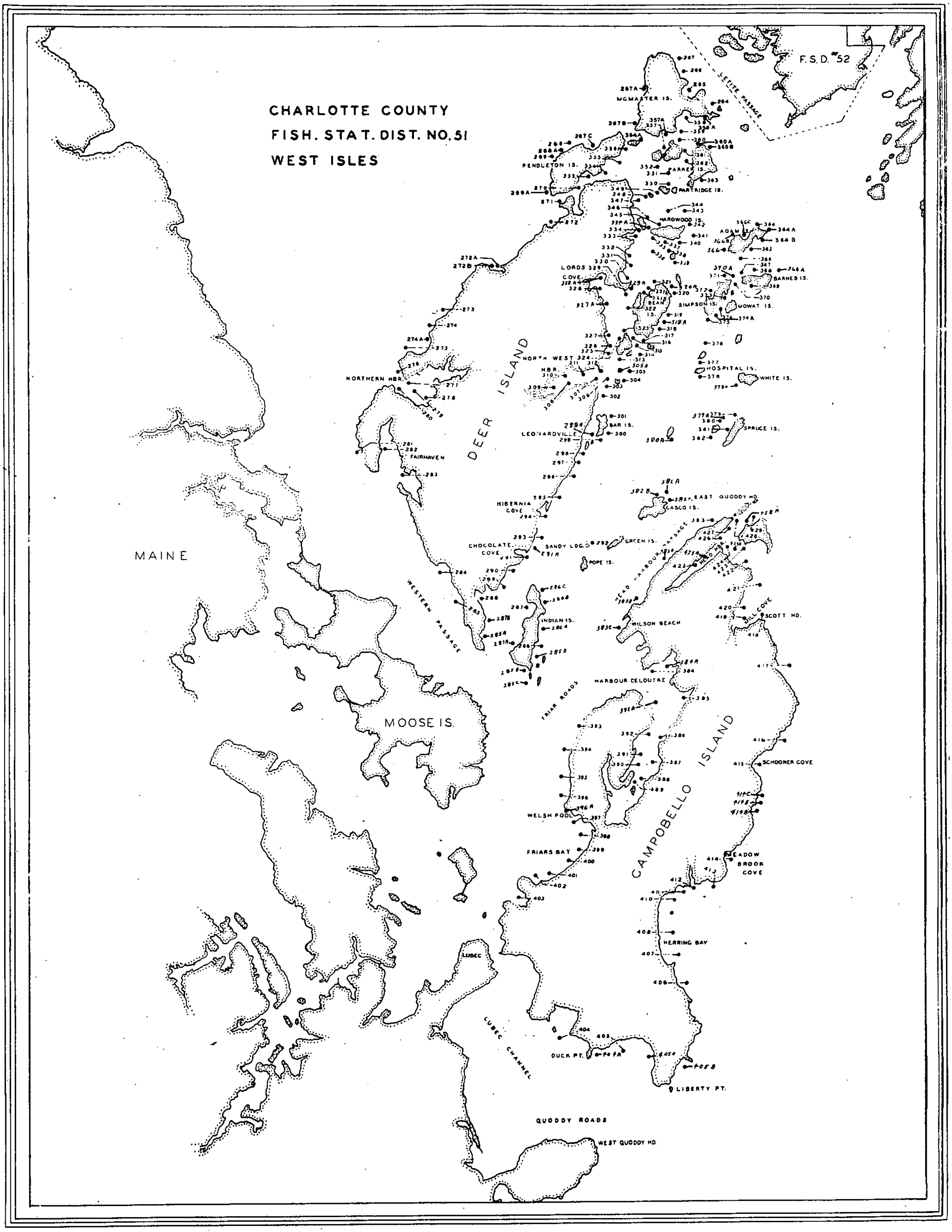

Figure A3. Map of weir locations (#264-429), fisheries statistical district # 51, West Isles, Charlotte County.

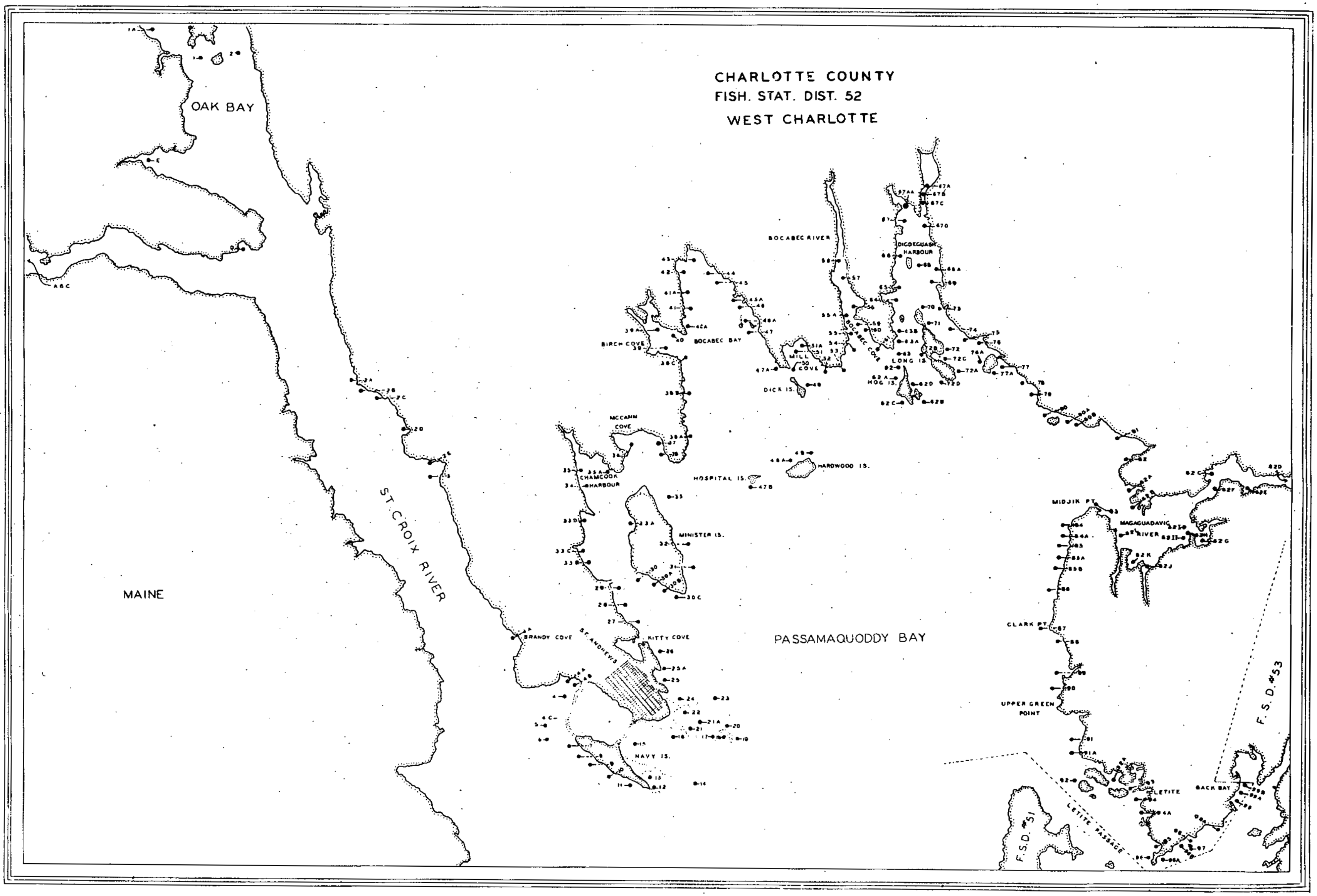

Figure A4. Map of weir locations (#A-99B), fisheries statistical district # 52, West Charlotte, Charlotte County.

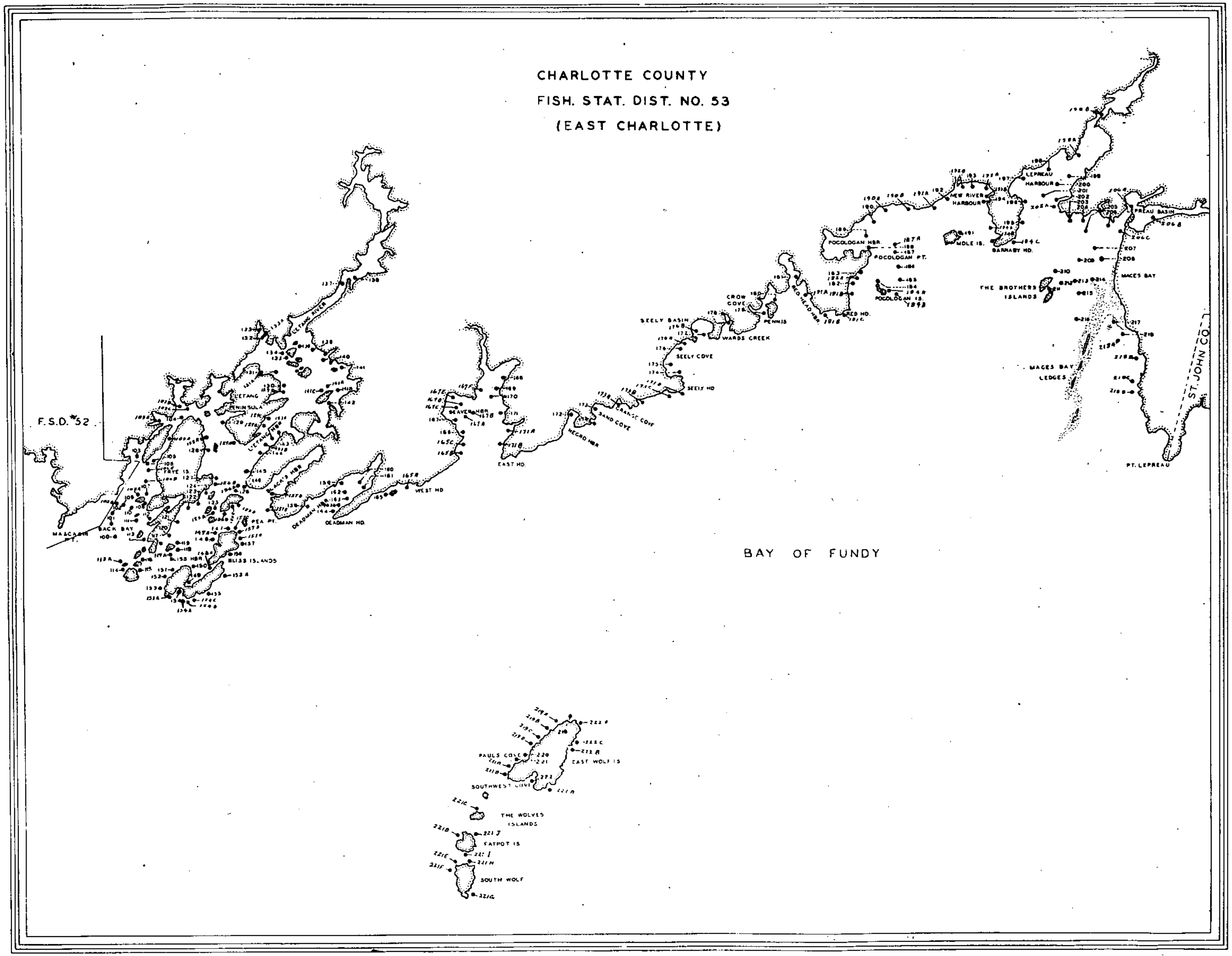

Figure A5. Map of weir locations (#100-222D), fisheries statistical district # 53, East Charlotte, Charlotte County.

HERRING BEHAVIOUR AND PHYSIOLOGICAL STUDIES

by

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ABSTRACT

Herring survived brief exposure to -1.0°C and had an upper lethal temperature between 19 and 21°C. They survived for four weeks in water of 5 °/oo salinity but died in fresh water. Changes in pressure from 0 to 67 lb/in^2 and from 20 to 0 lb/in^2 were shown to have no adverse effect on herring. Herring lowered to 100 feet from the surface behaved normally under artificial light. It was also found that herring orientated into a current and swam upstream at a rate in excess of the current speed until their maximum swimming speed was reached. This orientation was dependent on the presence of visual stimuli from stationary objects. The maximum swimming speed for exercised herring averaged over one minute was found to vary from 3.0 ft/sec for 15 cm fish to 4.7 ft/sec for 27 cm herring. It was found that from May to October at least 60% of the herring population in Passamaquoddy Bay was between the surface and 40 feet. At night during this period at least 50% of the herring population came within 23 feet of the surface.

A project to develop tidal power involves damming Passamaquoddy and Cobscook Bays in such a way that the former is open to the Bay of Fundy only during high tide periods, and the latter only during low tides. Water flows continually from the high pool in Passamaquoddy Bay through turbines into the low pool in Cobscook Bay. From the observations, it is predicted that herring will continue to enter the high pool in approximately the same quantity as at present. In the high and low pools, they will be able to survive the changed oceanographic conditions except for occasional heavy mortality when temperatures in localized areas of the high pool exceed 20°C. It is expected that herring will pass through the turbines to populate the low pool with some mortality among herring that are abraded during their passage through the turbine. Herring will be lost from the low pool through the emptying gates.

INTRODUCTION

At present herring enter and remain in Passamaquoddy and Cobscook Bays in sufficient numbers to support a weir fishery. Their presence is the result of a complicated variety of responses to environmental stimuli. In this report the results of studies on herring behaviour are applied to predicting the effects on herring occurrence of installing structures to develop tidal power (Appendix I, Chapter 7).

For a successful fishery it is not only necessary that fish shall enter a region. They also have to survive in good condition in the environment that they have entered. Under the proposed Passamaquoddy project, the environment of herring in the high and low pools would differ in some respects from present conditions. In order to predict the effect of the scheme on the herring fishery it was necessary to determine the tolerance limits of herring to temperature and lowered salinity. Because herring might pass through the turbines it was also necessary to determine their tolerance of pressure changes. The resistance of herring to environmental extremes varies slightly from one individual to the next, depending partly on its age, size, and previous environment. In the present investigation, it was sufficient to know in general terms the temperature and salinity limits of the herring as the variations due to individual differences are small compared with seasonal variations about the mean predicted oceanographic conditions.

This investigation was carried out at the Atlantic Biological Station, St. Andrews, during the years 1957 to 1959. It was based on herring (Clupea harengus) of sizes important to the weir fishery obtained from the Passamaquoddy region.

In the following pages the various experiments are described separately, each one being followed immediately by an interpretation of the results in terms of the effect of the power project on the herring population. Starting on page 41 the predicted effects of the project on the herring are discussed on the basis of all the results obtained.

EXPERIMENTAL METHODS AND RESULTS

The vertical distribution of herring in Passamaquoddy Bay

The distribution of herring between a depth of 10 ft and the bottom was studied by the use of echo sounders. An analysis of the records showed both diurnal and seasonal changes in vertical distribution in Passamaquoddy Bay.

Diurnal changes in depth are a well known feature of the behaviour of herring shoals on both sides of the Atlantic. In the North Sea, it appears that the upward movement at night is more extensive among small immature herring than in the large herring (Lucas, 1936). Richardson (1952) followed the movements of herring shoals in the North Sea by echo-sounder and found there was a correlation between light penetration and the depth of the top of the herring shoals. In the North Shield fishery the herring were deepest in the water by day, averaging 144 ft from the top of the shoals to the surface, and rose towards the surface at night to an average depth of 94 feet. Richardson also found that a thermocline did not restrict the herring shoals in the course of their diurnal movements.

For the Passamaquoddy Bay region, Moore (1898) records that all but the "brit" (5-10 cm herring) are in deep water and offshore during the day and approach the surface at night. He also remarks that during the winter the herring apparently stay in deep water. Johnson (1939) gives the vertical distribution of herring in the top 10 feet of water in the Passamaquoddy region. His results are of special value in supplementing the present investigation as they fix the upper limit of the herring's distribution when this falls in the upper 10 feet, a zone which could not be investigated by echo-sounder as it was above transducer. Johnson's results only cover the months from June to September and many of the observations were made on fish confined in weirs. He showed for these months that herring of the sizes found in Passamaquoddy Bay occur in the upper 10 feet at sunrise and sunset and, if the sky were overcast, for several hours before sunset and after sunrise. In direct sunlight at midday only 8 to 10 cm herring occur in this zone; herring from 14 cm upwards have their upper limit at 10 feet or deeper. On moonlight or starlight nights herring of all sizes were seen breaking the surface.

Material: Echo sounder records from 1947 to 1958 inclusive relating to Passamaquoddy Bay on file at the St. Andrews Biological Station were examined. Additional records were obtained from cruises made in the Bay for this purpose during the Passamaquoddy project.

Methods: The recording paper from the echo sounders bore a grid which, at the setting used, divided the water column vertically into 10 foot intervals and horizontally into one minute intervals. At 9 knots, the usual cruising speed of the boat from which most of the records were obtained, the horizontal divisions of one minute would correspond to a distance of 912 feet. The record was examined for traces between 10 feet and the bottom. Traces were assumed to be due to turbulence and discarded if they occurred only in the upper 30 feet, and continued upwards until they were lost in the 0 to 10 foot zone giving a triangular shape with the base upwards. These traces were most likely to be due to turbulence if they occurred over an irregular bottom or near the passages to Passamaquoddy Bay. All dubious traces were omitted. It was assumed that most of the remaining traces were due to herring as this is the only schooling fish present in quantity in Passamaquoddy Bay. Herring are plentiful enough to support a weir fishery from May until October but there are also herring in the Bay at other times of the year as they are caught in January and March by seining. A few fishing records taken at the same time as the sounder records were available for March, August and November and these confirmed that herring were present in the area in which the traces were seen. Mr. B. B. Parrish, in charge of herring investigations at the Marine Laboratory, Aberdeen, kindly looked at typical traces from Passamaquoddy Bay and found them similar to herring traces recorded round the coasts of Great Britain.

The records were divided into sections in which fish traces were present. For single fish traces these sections were only one minute wide but where groups of fish occurred,one section was made to cover the whole group even though this included some minutes in which there were no fish traces. By this means the absence of fish was only accorded significance when it occurred close to water which contained fish and the large areas devoid of fish were removed from further consideration. The sections were further arranged so that each fell inside a one hour period and the results were recorded according to the hour and month.

In each section a count was made of the number of squares one minute wide and 10 feet deep representing the amount of water which occurred in each 10 foot zone. As the record went down to 200 feet and most of Passamaquoddy Bay is shallower than this there was usually a decreasing number of squares with depth. For the same section a count was made of the number of squares in each depth zone in which there were fish traces. No account was taken of the size of the fish trace in each square but as large traces commonly occupied more than one square they gave a higher count. Notes were made on the size, appearance and distance from the bottom of the traces.

When analysis of the records was to be on an hour to hour basis all the results relating to the same hour in the month were first added together. To bring out the diurnal changes in depth more clearly the day was sometimes divided into four periods, day, sunset, night, and sunrise, all the results within each period were summed before being treated further. The predicted times of sunrise and sunset within each month were obtained and corrected for the latitude of St. Andrews. These predicted times often fell into more than one hour. As the data of depth distribution was collected on a full hour basis it was decided to include in the sunrise and sunset periods not only the hours into which the predicted times of sunrise and sunset fell but also a full hour on either side. Thus all results within at the greatest three hours and the least one hour of sunrise and sunset are included in these periods. The remaining hours were assigned to the day or night periods.

Data are recorded in two ways: viz. the depth distribution of squares showing fish, and, the percentage of squares showing fish at each depth expressed as a percentage of all the squares showing fish. The unweighted data give the actual distribution found for fish in Passamaquoddy Bay. Weighing the data compensates for the decreasing volume of water with depth so that the results are more generally applicable. Median depths were determined by linear interpolation so that 50% of the fish lie above and 50% below the median depth. In a similar manner the upper and lower quartiles were determined, these marking the upper and lower depth limits of the central 50% of the fish recorded.

Results: As the information was taken from records made for other purposes there was an unequal coverage of day and night hours and of the various months with more records for the daylight hours and the summer and autumn months when boat work was at its peak. The number of squares containing fish traces which were obtained for each month are shown in Table I.

Table I. Number of squares of echo-sounder record containing traces of fish which were used for the determination of the depth distribution of herring.

Month	Day	Sunset	Night	Sunrise	Total
January	46	11	--	--	57
February	19	--	30	--	49
March	127	14	--	10	151
April	65	--	--	--	65
May	1,218	28	27	2	1,275
June	1,487	14	--	52	1,553
July	2,268	79	320	70	2,737
August	1,588	261	572	--	2,421
September	2,534	203	119	317	3,173
October	190	141	510	--	840
November	554	426	--	238	1,218
December	87	88	363	--	538.

The records showed that there was a well defined diurnal change in depth distribution of the herring in Passamaquoddy Bay. From the graph of median depth of fish shoals for each month (Fig. 1) it can be seen that the herring are deeper in the water by day, rise at dusk, are nearer the surface by night and descend at dawn. The hourly distribution of fish in September, a month typical of the May to December period, and in March, a month typical of the remainder of the year is given in Figure 2. In September, the herring descend to their greatest depth 4 to 5 hours after sunrise when the median depth is 56 feet. During the day they rise slowly except for a second depression at 1200 and 1300 hours when the sun is at its highest. By 1800 hours, which is within one hour before sunset, the herring are near the surface and remain there with minor fluctuations until at sunrise they begin to descend. The median depth during the night calculated from the sounder records was 20 feet but it was obvious when studying the records that the fish extended upwards into the 0 to 10 feet zone where they were not recorded. For all records therefore where the median appraoches within 20 feet or so of the surface it is probable that the median depth should be nearer to the surface than is actually shown. For example, assuming for night in September that there are as many fish in the 0 to 10 foot zone as in the 10 to 20 foot zone below it, the median depth should be 15 feet instead of 20 feet.

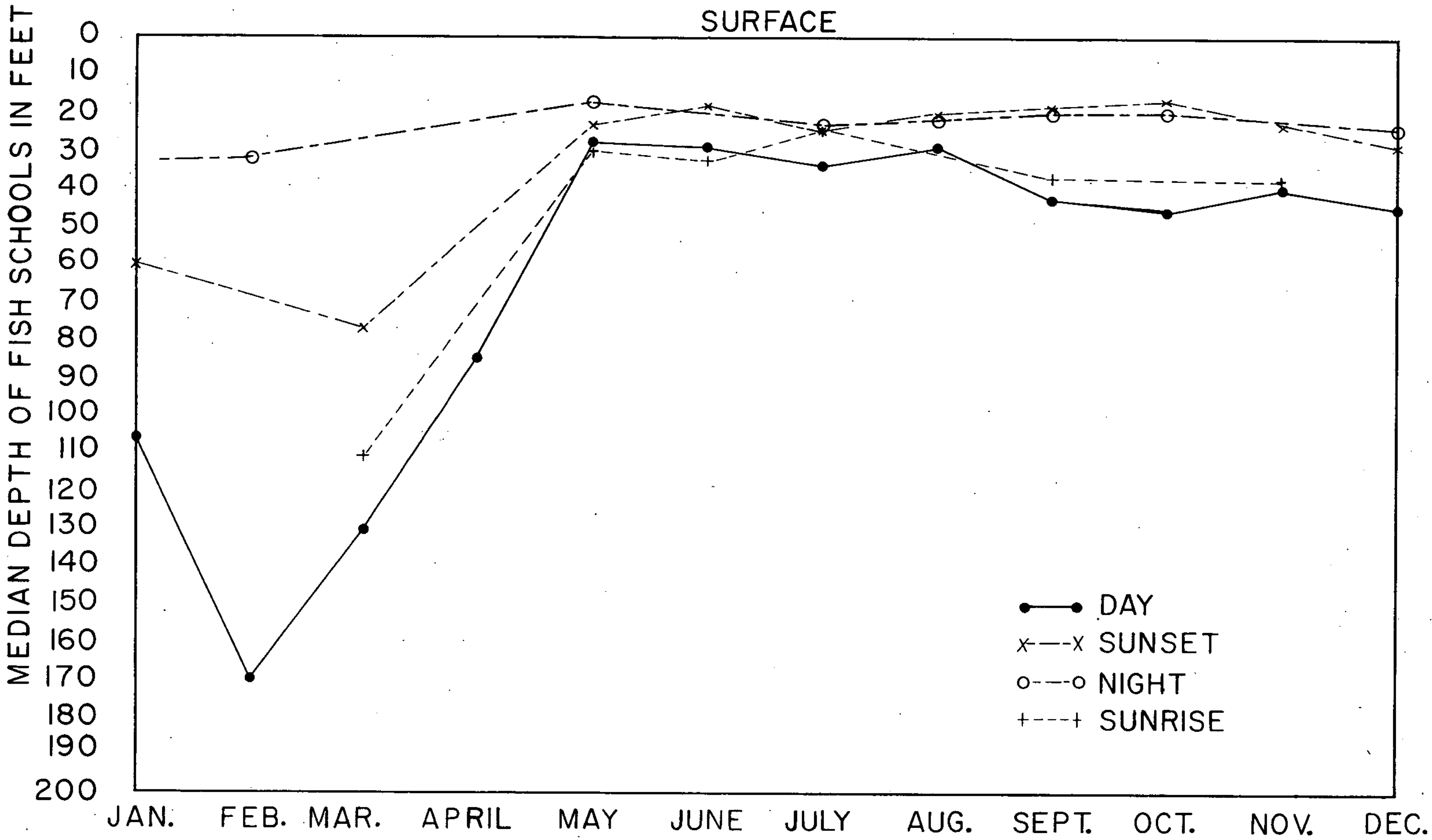

Figure 1. Median depth of fish in Passamaquoddy Bay during the year based on weighted data.

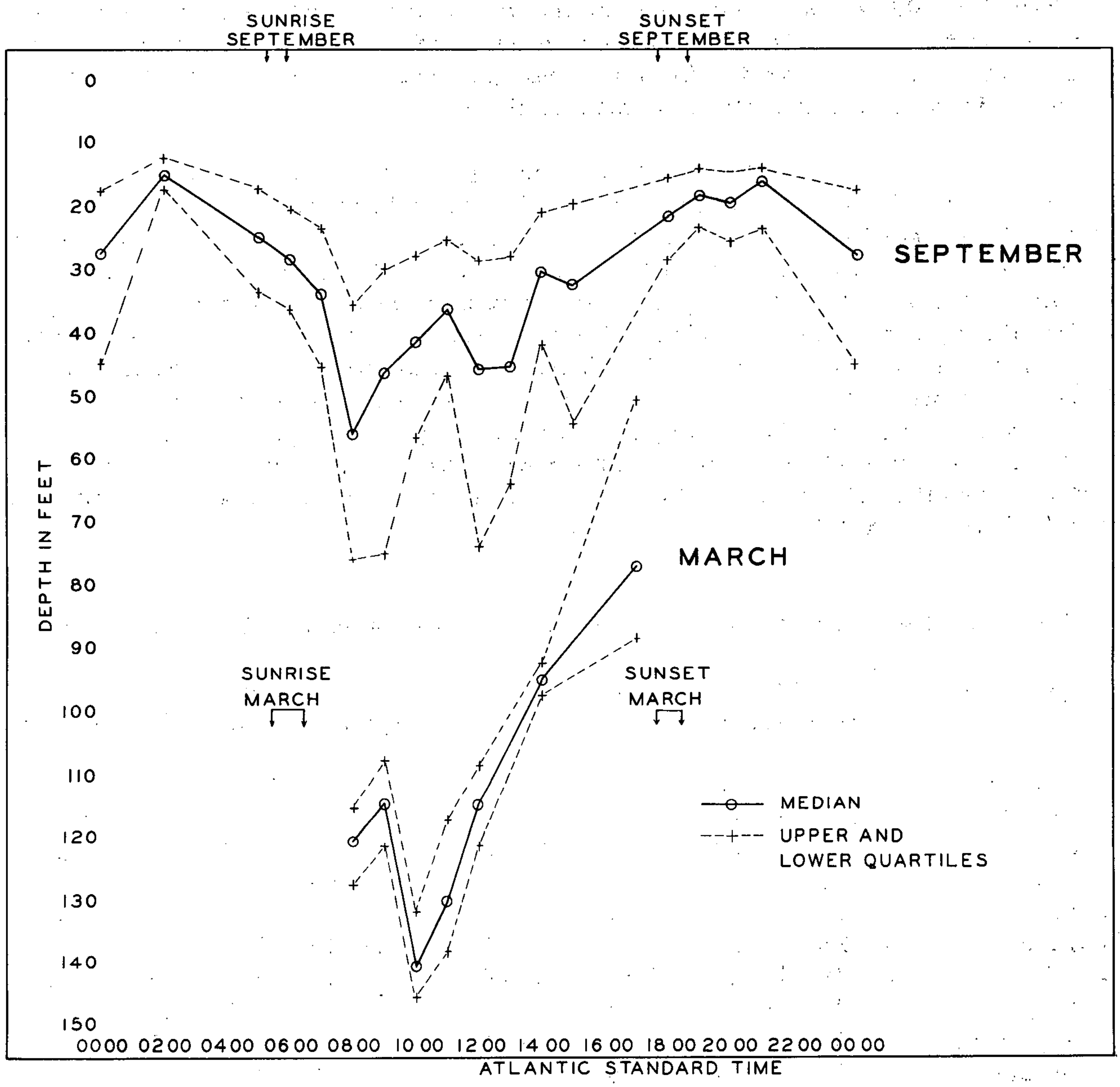

Figure 2. The hourly depth distribution of fish in Passamaquoddy Bay in March and September, based on weighted data.

The record for March is incomplete but it shows that the greatest depth during the daylight hours is reached one or two hours after sunrise, The herring then rise slowly in the water during the day but do not show a depression when the sun is on the meridian. The fish traces obtained during the day in March were shown to be made by herring as simultaneous bottom trawling caught about 20 lb of herring between 0920 and 1020 hours and 3,000 lb between 1115 and 1220 hours. There are no night echo-sounder records for March but in the previous month, February, when the fish are also very deep in the water during the day, the herring rise in the water at night showing a median depth of 32 feet. In the months January to April inclusive the herring undergo more extensive diurnal vertical migrations than in the other months of the year.

In addition to diurnal changes in depth distribution there was found to be a considerable seasonal change in the depth of the herring shoals during the day and a less pronounced one at night. These changes are reflected in changes in the median depth shown in Figure 1, and in the distribution of herring for the day and night periods shown in Figures 3 and 4. From May until December inclusive the vertical distribution is very similar from one month to the next. The median depth during the day for this period varies from 26 to 40 feet based on the unweighted data and from 28 to 47 feet using the weighted data (Table II). From January to April inclusive the herring are much deeper in the water by day than in other months. The median depth then varies between 79 and 122 feet for the unweighted data and 85 to 170 for the weighted data.

Table II. Median depth in feet of herring in Passamaquoddy Bay.

Month	Unweighted data				Weighted data			
	Day	Sunset	Night	Sunrise	Day	Sunset	Night	Sunrise
January	85	60	--	--	106	60	--	--
February	100	--	32	--	170	--	32	--
March	122	60	--	118	131	77	--	121
April	79	--	--	--	85	--	--	--
May	26	23	17	30	28	23	17	30
June	26	17	--	33	29	18	--	33
July	29	23	23	20	34	24	23	24
August	28	21	22	--	29	21	22	--
September	35	19	19	35	43	19	20	36
October	34	17	18	--	47	17	20	--
November	34	21	--	32	40	23	--	38
December	40	23	22	--	45	30	24	--

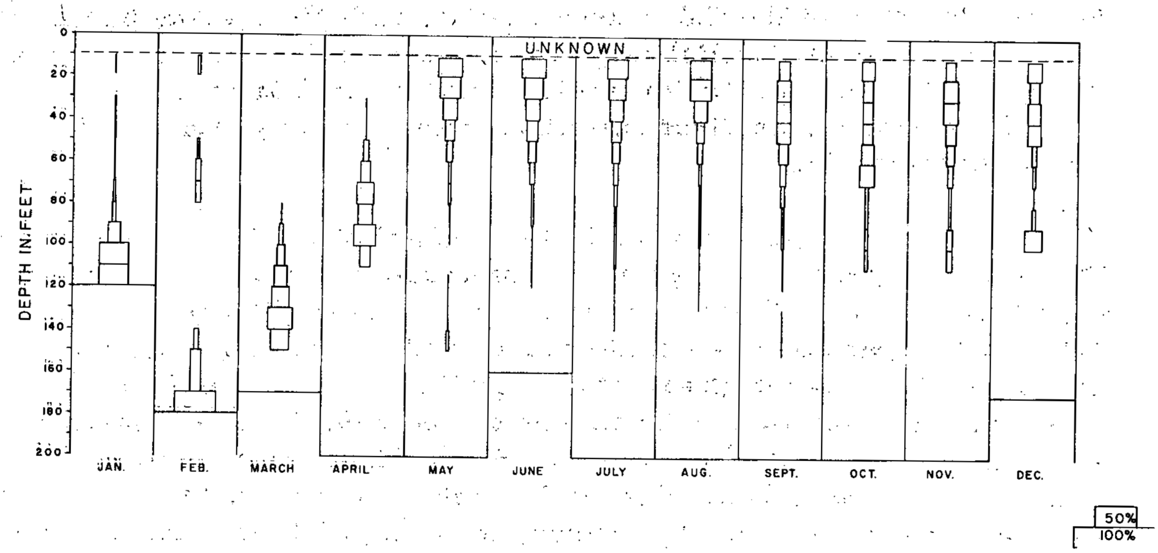

Figure 3. Vertical distribution of fish by day in Passamaquoddy Bay based on weighted data.

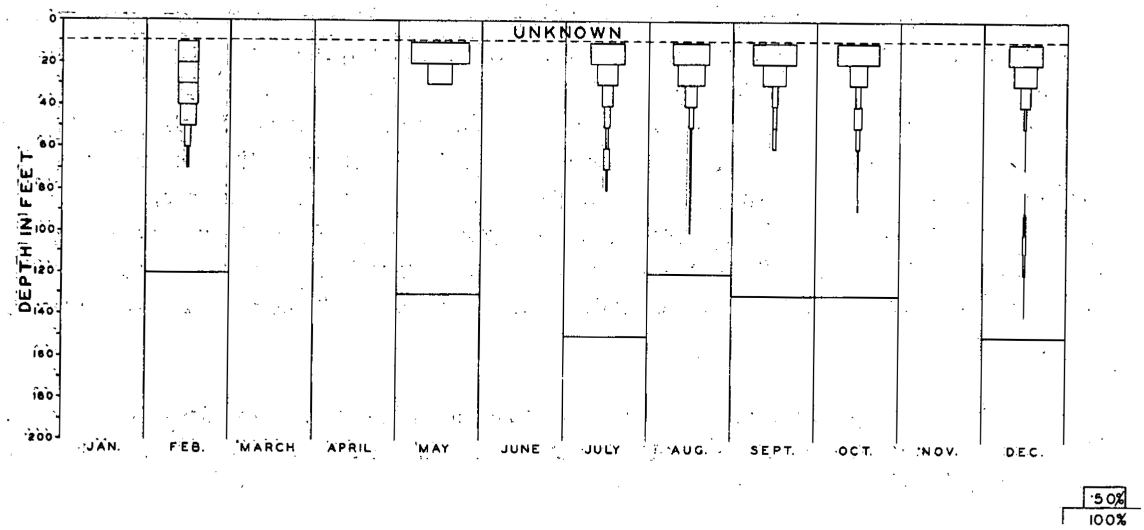

Figure 4. Vertical distribution of fish by night in Passamaquoddy Bay based on weighted data. The transverse line across each column indicates the grestest depth examined.

There are few records for the January to May period obtained during the night but the fact that seiners can catch herring in these months shows that some of the fish must come within 50 feet of the surface in the evening or at night. In February the median depth at night was found to be 32 feet. This does not differ greatly from the median depths of 17 to 23 or 17 to 24 feet calculated from the unweighted and weighted data for the June to December period.

During the period of the weir fishery from May until October the median depth of the herring shoals varied from 26 to 35 feet during the day and from 17 to 23 feet at night. Thus at least 50% of the fish come within 23 feet of the surface in each 24 hour period. As Johnson (1939) has shown herring of all sizes are present at night in the 0 to 10 foot zone during June to September. As these fish were excluded from the calculation of the median depth it is certain that more than 50% of the herring actually come closer to the surface than 23 feet during the night. Assuming that there are as many herring in the 0 to 10 foot zone as at 10 to 20 feet during the night then it would appear that at least 50% of the herring came within 17 feet of the surface during the 24 hours within these months.

During this same period, May to October, the herring although showing diurnal changes in depth are never far from the surface. The position of the median depth based on unweighted data shows that at least 50% of the herring are always within 35 feet of the surface during this time.

In Table III, the percentage of herring occurring between the surface and various depths from May until October has been given, based on calculations from the unweighted data. These percentages are in every sense minimum ones. No correction was applied for fish possibly present but unrecorded in the 0 to 10 foot zone. Also the table is based on the daytime distribution when herring are deepest in the water. For the sunrise, sunset and night periods the herring are higher in the water and thus these percentages are exceeded during the greater part of each 24 hour period. As this is a minimum value it can be stated that from May until October, according to month, at least 60 to 81% of the herring are always within 40 feet of the surface.

Table III. Percentage of total herring recorded occurring between the surface and various depths by day during the months of the weir fishery. Based on unweighted data.

Depth zone (ft)	May	June	July	August	September	October
0-20	34	33	28	26	19	25
0-30	62	60	53	57	40	44
0-40	80	78	81	75	60	60
0-50	91	89	92	85	76	84

In Passamaquoddy Bay herring schools which on the echo-sounder paper exceeded one square in area, were rare. The schools recorded seldom exceeded 230 feet in length or 30 feet in thickness. At night the schools broke up, first into smaller units and then more finely until the whole zone of the echo sounder record occupied by the fish was peppered with small dots, presumably from individual fish. This change occurred 3-1/2 hours after sunset in August and September; 2-1/2 hours after sunset in November and 2 hours after sunset in December. A mid-water trawl fished at this time in November caught herring. It is probable that the change in the nature of the trace is a reflection of the herring's inability to school visually with its neighbours below a certain light intensity. Records taken just before dawn are few but one for September shows the schools re-forming half an hour before sunrise. Verheijen (1953) reports for captive herring that with decreasing light intensity the shoal breaks up while feeding continues, then eating stops while obstacles are still avoided visually.

Conclusions: The herring in Passamaquoddy Bay show both diurnal and seasonal changes in depth distribution. In all months the herring are deeper in the water by day than at night. The daytime depth varies with the season there being a median depth from January to April of 79 to 122 feet(unweighted data) compared with 26 to 40 feet during the remaining months of the year. At night in all seasons the herring approach the surface and from May to October, the period of the herring fishery, at least 50% of the herring come within 23 feet of the surface and probably within 17 feet of it. From May until October at least 60 to 81% of the herring are always between 40 feet and the surface.

Discussion: If the same vertical distribution holds for herring in the entrance passages, the filling gates, which extend from 10 to 40 feet below mean sea level, would not prove an obstacle to the passage of fish into the high pool. The water that passed through the filling gates into Passamaquoddy Bay would be drawn from those levels in which the herring are to be found. Similarly, it is from these levels that the 45 foot passage to the turbine intake draws, so that it is likely that some herring would enter the low pool through the turbines. The emptying gates extend from 18 to 48 feet below the mean water level in the low pool. It is thus likely that some of the herring in the low pool would pass out through the emptying gates.

It has been shown that in Passamaquoddy Bay from May until October that at least 50% of the herring come within 23 feet of the surface at night and probably within 17 feet of it. During at least the last part of this period it is predicted that, if dams were built, Passamaquoddy Bay would be stratified with a less saline and warmer surface layer reaching a thickness of 10 to 16 feet (3 to 5 metres). Although this surface layer is thin it lies at a depth which during the night is entered by a considerable percentage of the herring population. Unless these fish altered their present distribution they would come under the influence of the reduced salinity and warmer temperatures of the upper layer. In the sections on temperature and salinity tolerance reasons have been given for supposing that herring do not avoid water of 20 ‰ salinity or 18°C. Herring shoals have also been observed by echo sounder to pass through a thermocline during their normal vertical migrations (Richardson, 1952). Thus it seems likely that a considerable percentage of the herring population in the high pool would be subjected to the altered hydrographic conditions. To a lesser extent, because stratification there would be less marked, this conclusion applies to herring present in the low pool.

The echo-sounder records showed that the herring schools broke up several hours after sunset and did not reform until shortly before dawn. If this breakdown of the schooling habit was caused by the low light intensity it seems logical to assume that at these light intensities the herring would not be able to perceive details of the bottom when it was more than a few feet away. Underwater television experiments suggest that it was necessary for the herring to receive visual stimuli from stationary objects in order to orientate into a current. It thus appears probable that during most of the night herring, being at too low a light intensity to school with each other, are also at too low an intensity to receive visual stimuli from distant fixed objects and so would be displaced by currents instead of swimming upstream. During these hours it seems likely that most of the herring present in water that is being drawn towards the filling gates, turbines or emptying gates will be carried passively with the water.

The temperature tolerance of herring

Herring have been caught in surface gill nets in water of temperatures up to 18°C in the summer and have been seined in the winter after being present for at least five days in water that was close to 0°C from top to bottom (Leim, et al, 1957). Thus herring occur naturally in a wide temperature range. Battle et al (1936) have shown that captive herring subjected to natural seasonal variation in temperature continued to feed in water of 0.75°C. In the present investigation herring were seen through a crack in the ice to be swimming actively 6 to 9 inches above the bottom in water of -0.3°C in a large pen which communicated with the sea at high tide.

Several determinations of the upper lethal temperature were made and are described here together with notes on the survival of herring after brief exposure to low, naturally produced temperatures. Most recent lethal temperature determinations have been based on results obtained with fish previously acclimated by prolonged exposure to constant temperatures. Only in this way can consistent results be obtained. These experiments have shown that the temperature tolerance of some fish increases with an increase in the acclimation temperature (Fry, et al, 1942).

In the present investigation an attempt was made to acclimate herring at 5, 10, and 15°C. After four weeks mortalities ranged from 14 to 30% leaving a selected stock which was unsuitable for further work. Consequently, the determinations of the upper lethal temperature were made on unacclimated fish most of which were captured immediately prior to being tested. Although the past temperature history of these fish was unknown it should more closely resemble that of the "typical" herring entering Passamaquoddy Bay. Thus the results obtained are more relevant when considering whether herring from the sea entering the high level pool would be able to survive the temperatures that they encountered there. Using recently-caught herring had the additional advantage that the fish were tested in their natural condition of fatness and had fed only on natural food. This latter point is of importance as it has been shown that the temperature tolerance of some fish can be altered by changes in the nature of the oils fed to them in captivity (Hoar and Dorchester, 1949).

In the present investigation the upper lethal temperature was defined as the temperature that would cause 50% mortality in 48 hours.

Procedure used when transporting herring required for experimental purposes: Herring were obtained for lethal temperature and other experimental work from weirs in Passamaquoddy Bay or its approaches during normal fishing operations. While there was still enough water in the seine for the fish to swim freely, some of the herring were surrounded by a dip net. A plastic bucket was used to carry herring in water from the dip net to galvanized tubs in a rowboat. The tubs were later submerged in water in the carrying tank on M. B. *Mallotus* and tipped to liberate the fish. At no time were the herring removed from the water. In the carrying tank the herring were held in water which was constantly renewed by water pumped in from the sea. At the Biological Station, St. Andrews, the herring were once more surrounded by the dip net, scooped out with water in the bucket and carried in a tub in small numbers to the experimental or holding tanks where they were released by immersing the tub. Herring handled in this way did not appear to be unduly distrubed and on most occasions there was no mortality between the weir and the final holding tank.

Material: The first determination of the upper lethal temperature in June 1958 was made on fish held for eight days at 8.7° to 11.2°C before testing. In October 1958 and June and July 1959 herring were used on the same day caught from weirs in Passamaquoddy Bay or its approaches. The June 1959 determination was made on fish which differed from the rest in being obtained outside Passamaquoddy Bay (at Califf Island) and held on board for 8 hours before testing. In July and October, herring were placed in experimental tanks within 3 hours of removal from the weir. In all experiments the size composition of the groups of herring tested at different temperatures was made as similar as possible by estimation.

Apparatus and methods: Changes were made in both the apparatus and handling method between one determination and the next. In June 1958 herring were tested in groups of 14 or 15 in wooden tanks 2 feet square, holding 6 inches of water. The herring were handled as described above until they were beside the test tanks. They were then flipped on a taut net from the carrying tank into the test tank. The temperature of the inflowing water was continuously adjusted to maintain the desired temperature in the test tank.

In October 1958 the herring were tested in part of a rectangular wooden tank 3 feet square and in water 1 1/2 feet deep. In this and all subsequent experiments the herring were introduced into the test tank by immersing the carrying tub and tipping it to release the fish. The cold water that was introduced with the fish lowered the temperature in the experimental tanks slightly (average depression 0.3°C) but the experimental temperature was always restored within the hour. Temperature was controlled in the October experiment by adjusting the inflowing water.

In June 1959 the same wooden tanks were used. Temperature control maintained the desired temperature within ± 0.1°C by pumping in cold sea water when the temperature rose. In July 1959 circular fibre glass tanks, 3 feet in diameter and with water 20 inches deep were used as test tanks. Temperatures in these tanks were also thermostatically controlled.

In all determinations the herring were tested in water which was being constantly renewed and aerated. In the deeper wooden tanks and circular tanks a cylindrical aerator which caused a continuous overturn of water in the tank prevented vertical stratification. A diagram of the apparatus is given in Figure 5.

In June 1958 the temperatures and number of dead fish were recorded every 15 minutes. In later experiments mortality and temperatures were recorded at 6, 12, 24, 36 and 48 hours. Dead herring were removed from the tanks and measured.

Results: The percentage mortality with time has been given for the four experiments in Tables IV to VII. From these results, the temperature at which 50% of the fish would have died at 48 hours was found by linear interpolation and taken as the upper lethal temperature. In June 1958 the lethal temperature for 10 to 18 cm herring was found to be 19.6°C. It was below 19°C for 10 to 22 cm herring taken in June 1959 but this determination was made on herring that were held on board for eight hours before testing and this experience may have lowered the resistance of the fish. In July 1959 an upper lethal temperature of 19.6°C was found for 12 to 22 cm herring.

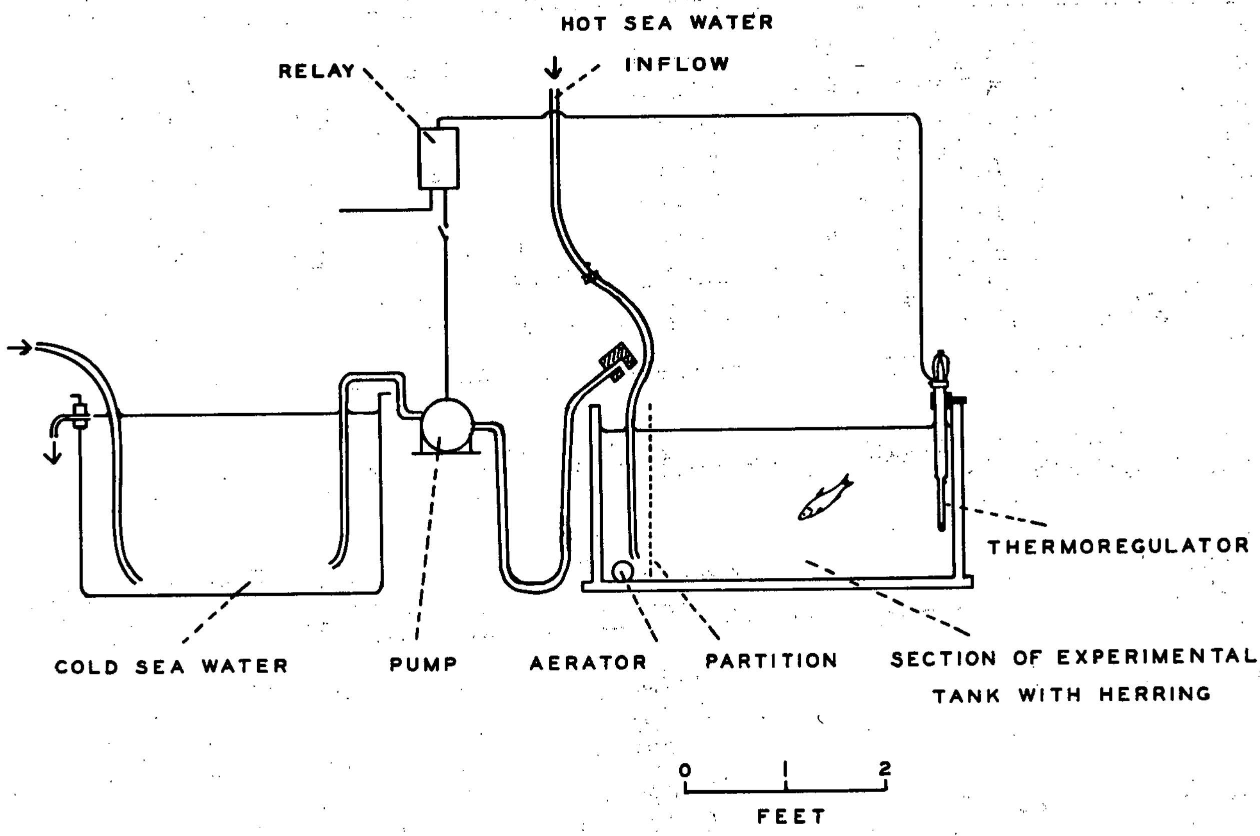

Figure 5. Diagramatic vertical section through the apparatus used to determine the upper lethal temperature of herring.

Herring used in the October determination fell into two distinct size groups 9 to 12 and 17 to 30 cm, and six to ten of the larger fish were included in each test group of 28 to 31. When the mortalities at 23° and 21°C were considered, it was found that there was a significant difference between the mean length of the first 10 and the second 10 that died in each tank. In a group of herring ranging from 9.5 to 30.4 cm, there is thus a differential mortality with size; the larger fish dying more quickly at high temperatures than the smaller ones. In Table VII the results for the 9 to 12 cm and the 17 to 30 cm herring which formed the two distinct groups are given separately. The upper lethal temperature for the 9 to 12 cm herring was 21.2°C compared with 19.5°C for the 17 to 30 cm herring.

Table IV. Percentage mortality of herring of mean length 13.6 cm held in captivity at 8.7° to 11.2°C for eight days before testing in June 1958.

Temperature °C	Temperature variation	No.	size range cm	% mortality 6hr	12hr	24hr	36hr	48hr
24	+0.1 - 0.3	29	10-18	100	100	100	100	100
23	+0.2 - 0.4	28	11-16	96	100	100	100	100
22	+0.6 - 0.4	29	10-15	38	90	97	100	100
21	+0.5 - 0.3	27	11-17	4	44	63	70	70
20	+0.6 - 0.3	26	11-17	4	27	46	54	54
19	+0.3 - 0.3	32	12-17	0	6	22	41	44
19	+0.4 - 0.3	15	12-14	13	20	27	33	40
9.4 (control)	+0.4 - 0.4	15	12-17	0	0	0	0	7

Table V. Percentage mortality of herring of mean length 15.3 cm taken from a weir in June 1959.

Temperature ± 0.1°C	No.	Size range cm	% mortality 6 hr	12hr	24hr	48hr
22	20	10-22	95	100	100	100
21	20	12-23	40	90	100	100
20	20	11-22	20	90	100	100
19	20	10-23	0	5	25	80
9.8 (control)	20	10-22	0	0	0	0

Table VI. Percentage mertality of herring of mean length 17.6 cm taken from a weir at 9.9°C in July 1959.

Temperature ± 0.1°C	No.	Size range cm	% mortality 6hr	12hr	24hr	36hr	48hr
21	31	16-20	3	6	61	77	81
20	29	16-22	0	7	48	52	62
19	30	12-21	0	0	13	17	30
18	29	16-21	0	0	3	3	7
12.5-15.1 (control)	30	16-22	0	0	0	0	0

Table VII. Percentage mortality of herring taken from a weir at 9.6°C in October 1958.

Temperature °C	Temperature variation	9-12 cm herring No.	% mortality 6hr	12hr	24hr	36hr	48hr	17-30 cm herring No.	% mortality 48hr
23	+0.2-0.5	29	76	90	100	100	100	10	100
21	+0.2-0.9	31	13	23	39	45	45	10	100
19	+0.3-0.3	30	0	0	0	10	17	6	33
17	+0.3-0.3	29	0	0	0	7	31	9	33
15	0.0-0.0	28	0	0	0	0	11	9	22
10 (control)	+0.4-0.7	28	0	0	0	0	0	10	0

The upper lethal temperatures for herring of various size-groups for the various months are given in Table VIII

Table VIII. Summary of upper lethal temperature experiments.

Date	Length of test fish Range, cm	Mean, cm	Upper lethal temperature °C
June 1958	10-18	13.6	19.6
June 1959	10-22	17.6	<19.0
July 1959	12-22	15.3	19.6
October 1959	17-30	21.9	19.5
October 1959	9-12	11.1	21.2

There is not sufficient evidence to show whether herring show seasonal changes in their resistance to high temperatures.

Resistance of herring to low temperatures: No experimental determination of the lower lethal temperature of herring was made. However, an accidental occurrence suggests that herring can survive low temperatures. In December 1958 an outside stock tank was found to have an 1/8 inch covering of ice. The surface temperature was -1.1°C and the bottom -1.4°C. Out of at least 210 herring in this tank only 27 were dead. The herring were transferred to water of 7°C and 50 died during the next week giving a survival rate of more than 60% for herring which were exposed to these low temperatures and held for one week after the exposure.

Conclusions: Herring from Passamaquoddy Bay or its approaches in June, July, and October show a 50% mortality over 48 hours at between 19 and 21°C. In October the upper lethal temperature is associated with size, being 21.2°C for herring of mean length 11.1 cm and 19.5°C for herring of 21.9 cm mean length. Herring can survive a brief exposure to -1°C.

Discussion: It is predicted by Trites (Appendix I, Chapter 7) that the mean monthly maximum surface temperature averaged over the entire surface layer of the high pool will be in the vicinity of 19°C. The maximum daily temperature will probably reach 20°C for the surface layer. Maximum temperatures can be expected to exceed 20°C in sheltered coves. A combination of neap tides, high air temperatures, high insolation and low wind speeds at the time of the maximum could elevate the temperature by several degrees in localized areas. The maximum depth of the warmer surface layer will be 10 to 15 metres (33 to 49 feet) but will often be only a few metres.

These predicted temperatures are close to the temperatures which caused considerable mortality among the herring after 48 hours exposure. However, these are maximum values and the temperatures below these maxima which will prevail for the greater part of the herring fishing season from May until October should not be injurious to the fish. Under certain conditions temperature may rise high enough in limited localities and for short periods to cause heavy mortality among herring.

Herring have been caught in nature in water of 18°C (Leim et al, 1957) which makes it unlikely that herring avoid water of this temperature. They also pass through a thermocline in the course of their diurnal vertical movements (Richardson, 1952). It thus seems unlikely that the presence of an upper warmer surface layer in the high pool will disrupt the normal vertical movements of the herring. It has been shown by echo sounding that from May until October at least 50% of the herring in Passamaquoddy Bay come within 23 feet of the surface at night and probably within 17 feet of it. Thus a considerable proportion of the population would come under the influence of the higher temperatures. In the daytime only 19 to 34 per cent of the fish were found in the 0 to 20 feet zone. Thus the exposure time for many herring to the high temperatures would lie between 12 and 18 hours in each 24 hours. Except for the dubious June 1959 determination the experiments showed that 24 hours exposure to temperatures up to 19°C did not cause immediate mortality in more than a small percentage of the herring tested. For this reason, as well as the limited occurrence of temperatures above the upper lethal temperature of the herring, it is likely that mortality among the herring stocks caused by high temperatures in the high pool will be slight.

In the low pool the summer maximum of the surface may reach 20°C in the inner part of Cobscook Bay but in the outer part will not greatly exceed 15°C. As these temperatures are lower than those predicted for the high pool the mortality of herring due to high temperature should be even more limited in time and extent.

In winter it is predicted that there will be ice cover over part of the high and low pools. At this time of the year the herring are in deep water which is not expected to cool below 0°C. As a considerable proportion of a herring group can survive short exposure to -1.1°C there should not be widespread mortality among herring which may overwinter in the high or low pools.

The sallinity tolerance of herring:

A decrease in the salinity of the upper water layers of Passamaquoddy and Cobscook Bays has been predicted as one of the changes which would occur if dams were built. Although limited in vertical extent, this less saline water would occur in part of the normal vertical range of the herring during the summer months so that it could have considerable influence on the herring stocks. If herring avoided the less saline water they could only do so by disrupting their normal vertical migrations, a disruption that could exclude them from part of their food supply and which might keep them offshore, away from the weirs. If, on the other hand, herring entered the upper layer the reduced salinity might itself prove lethal to the fish, a possibility that was investigated in this experiment.

Herring are occasionally caught in large numbers far up the estuaries of rivers. They have been taken in the St. Croix River as far inland as St. Stephen (Tibbo, personal communication). Bigelow and Schroeder (1953) give 28 o/oo as about the lower salinity tolerance of these fish but their occurrence in estuaries suggests that they enter and live for at least short periods in water of lower salinity than this. McKenzie (personal communication) recorded the taking of herring from the Miramichi estuary from water of 20o/oo.

Rosenfield (unpublished work) kept herring in running water whose salinity was reduced 5°/oo at the end of each week. Ten herring of brit size (small 1st year fish) were originally present; two died at 20°/oo, two at 15°/oo, four at 10°/oo, and two at 5°/oo. It is difficult to interpret these results further than to say that exposure to water of 25°/oo for one week does not cause immediate mortality in these fish but exposure to water of 20°/oo may do. However, a few fish could survive one week's exposure to 10°/oo. Rosenfield notes that at 10°/oo the herring did not feed as well as they did previously and their actions seemed relatively sluggish.

In the present experiment herring were taken from sea water and immediately placed in water of various lowered salinities which were then kept constant. This removed any delayed effects of other salinities on the mortality, a difficulty that arises when the salinity is reduced in a series of steps.

Material: Herring that had been held over winter in tanks supplied with sea water whose salinity usually varies between 28 and 32°/oo were tested in February to June. These fish ranged in size from 10.2 to 24.2 cm with a mean length of 14 cm and were distributed as evenly as possible with respect to size among the test tanks. Twenty fish were tested at each salinity except the sea water control which accidently had nineteen. In the stock tank the herring appeared in good condition and fed readily.

Apparatus: The herring were tested in circular fibreglass tanks 3 feet across and containing 332 litres of water. Fresh water for the dilution of sea water to 10°/oo and 25°/oo came from melted snow; other dilutions and the fresh water tank used filtered pond water. The water was aerated but not renewed and its temperature was kept between 4 and 8°C except on two days when the temperatures in the 20°/oo and fresh water tanks rose to 14°C. All these temperatures are within the temperature tolerance limits of herring.

Method: The herring were transferred to the test tanks without removing them from the water. For most test salinities the herring were carried in a bucket of sea water the addition of which to the tank produced the correct salinity and volume. For the fresh water determination the herring were first placed in a tub to which fresh water was added for five minutes to reduce the salinity to 1.4°/oo. The volume of this water was reduced to a minimum and then fish and water were added to a tank of fresh water.

Water samples were removed from the tanks for salinity determination. A rough measure of the salinity was made using a hydrometer. At 24-hour intervals, the dead fish were removed from the tanks, weighed and measured and the water temperature was taken. The fish were fed occasionally on chopped *Gammarus*.

Results: The number of fish dying in each week of the 4 week test period is shown in Table IX.

In fresh water the herring swam continuously. After several hours scales along the flanks of the fish were standing out from the body. Half of the herring died during the first 4 1/2 hours in fresh water and all died before the end of the first 24 hours.

In water of 5‰ or greater the herring appeared to be able to osmoregulate so that deaths over the four week test period were few and irregularly distributed with respect to salinity. This irregular distribution suggests that the mortality might be caused by incidental factors, such as the failure of a few fish to feed under experimental conditions or some undetected injury, rather than a direct effect of the low salinity. Even at 5‰ most of the smaller herring would take food, though not quite so readily as fish at higher salinities.

Table IX. The mortality of 10-24 cm herring at different salinities over a four-week period.

Number of fish	Average temperature °C	Average salinity ‰ (± 0.6‰)	Deaths in each week 1st	2nd	3rd	4th	% dead at 4 weeks
19	6.1	31.9	0	0	0	0	0
20	5.7	25.6	0	0	0	0	0
20	6.8	20.1	1	1	1	1	20
20	5.5	10.2	0	0	0	1	5
20	5.9	5.2	0	1	1	1	15
20	9.1	0.1 below	20	-	-	-	100

Conclusions and discussions: The experiment showed that herring of the size most commonly taken commercially in the Passamaquoddy area are very resistant to lowered salinity, being able to withstand a salinity of 5‰ for four weeks with only a low mortality. The salinity of the surface layer of both the high and low pools is predicted to fall within the 20 to 30‰ range except during freshet conditions when it may drop below 20‰. Thus if herring enter the less saline surface waters this should not affect them adversely.

The second possibility, that herring might avoid the less saline surface waters has not been investigated experimentally. However, McKenzie's observation, mentioned earlier, that herring in nature will enter water of 20‰ suggest that herring will not avoid the surface layers of the high and low pools because of their low salinity. Thus the altered salinity conditions in the two pools should not in any way adversely affect the herring or its fishery.

The ability of herring to withstand rapid changes in pressure

Herring are known to move vertically through considerable distances. Runnstrom (1941), for example, describes a herring shoal that changed its depth by 100 metres (330 feet) in about an hour. Such movements subject the herring to considerable changes in pressure. A fish adjusts to pressure at depth by secreting gas into the swim bladder until the normal buoyancy of the fish is restored. If this fish then rises in the water the gas in the swim bladder expands as the pressure decreases and may rupture the walls or blood vessels of the swim bladder unless the fish is able to remove the excess volume of gas quickly. Structurally the herring and a few close allies are uniquely well adapted for the quick removal of this excess gas as their swim bladders open, not only into the gut, but also directly to the exterior through a posterior duct (de Beaufort, 1909). The working of the swim bladder in relation to the general physiology of the fish and its environment are fully discussed by Jones and Marshall (1953).

After descending, the herring, like other fish, would have to secrete gas into the swim bladder before it was again in equilibrium with its surroundings. During the underwater television cruises described elsewhere in this appendix it was found that herring lowered in six minutes (from the surface) to 100 feet had no difficulty in maintaining a constant level in the water, presumably overcoming the tendency to sink further by compensatory fin movements until more swim bladder gas could be secreted.

Blaxter and Parrish (1958) working on the attraction of herring to artificial lights calculated the percentage pressure change and the vertical swimming speeds of herring shoals recorded on their echo sounder. The fastest vertical swimming speed recorded for 16 to 25 cm herring was 36 metres per minute during descent and 13.5 metres per minute during ascent. Expressing this in terms of rate of pressure change, the herring were experiencing an increase of pressure of 0.9 $lb/in^2/sec$ and a decrease in pressure of 0.4 $lb/in^2/sec$ while moving vertically through 59 feet of water or less.

In the first of the present experiments herring were subjected to changes in depth of 150 feet by confining them in a cage which could be raised or lowered in the water. This experiment was primarily designed to show if herring adjusted to surface pressures could withstand sudden compression and decompression of this magnitude without affecting their behaviour or viability.

In the second experiment herring were held for 16 hours at a pressure corresponding to a depth of 45 feet and then subjected to sudden decompression. Such pressure changes would be expected to place the greatest strain on the fish as, under such conditions, gas secreted into the swim bladder under pressure will expand when the pressure is released and might rupture the swim bladder wall.

Combining the information obtained in both experiments allows prediction of the effect on herring of rapid pressure changes which it would encounter during a passage through the turbines of the proposed Passamaquoddy power project.

I. The ability of herring accustomed to pressure near the surface to withstand increase in pressure to 67 lb/in^2 followed by decompression.

Material: One hundred and ninety eight herring of 14 to 21 cm were used in the experiment. The herring were taken from a weir whose maximum water depth at low tide was 20 ft and were held in 2 ft of water for 1 1/2 to 4 hours before testing.

Apparatus: A cage in which water movement was reduced to a minimum was designed to hold herring during rapid changes in depth. The cage consisted of two parts which fitted one inside the other (Fig. 6). The outer part was a cube with 3-foot sides in which the top and bottom faces were drawn out into a pyramid. It was covered with a woven cotton mesh which offered considerable resistance to the passage of water. Round the middle of the cage this fine mesh was replaced by a six-inch band of half-inch mesh to allow some interchange of water between the inside and outside of the cage. Several inner cages of half-inch mesh were made and the fish were held in these. The outer cage was hung from ropes above and was weighted below so that it sank rapidly and remained upright. The cage was fished over the side of the M. B. Mallotus, being allowed to descend as quickly as it could strip wire off the winch and being hauled by the winch.

Method: The outer cage with its inner lining in place was held at the surface while herring were put into the inner cage. The lid was closed and the cage was allowed to drop to 145 or 150 ft. After five minutes at this depth the cage was hauled to the surface. The lid was raised, the inner cage secured and the outer cage lowered until it was free of the inner cage. The inner cage containing the fish was then hung from the side of a row boat. By this method the herring were tested and held for their subsequent mortality and behaviour to be observed without transferring them to another container. Two groups of herring were tested. The first, of 86 fish, descended to 150 ft in 1 minute, 27 seconds giving an average rate of pressure increase of 0.8 lb/in^2/sec. After 5 minutes they were raised to the surface in 57 seconds; a rate of pressure decrease of 1.2 lb/in^2/sec. The second group, of 58 fish, were lowered to 145 feet, held there for 5

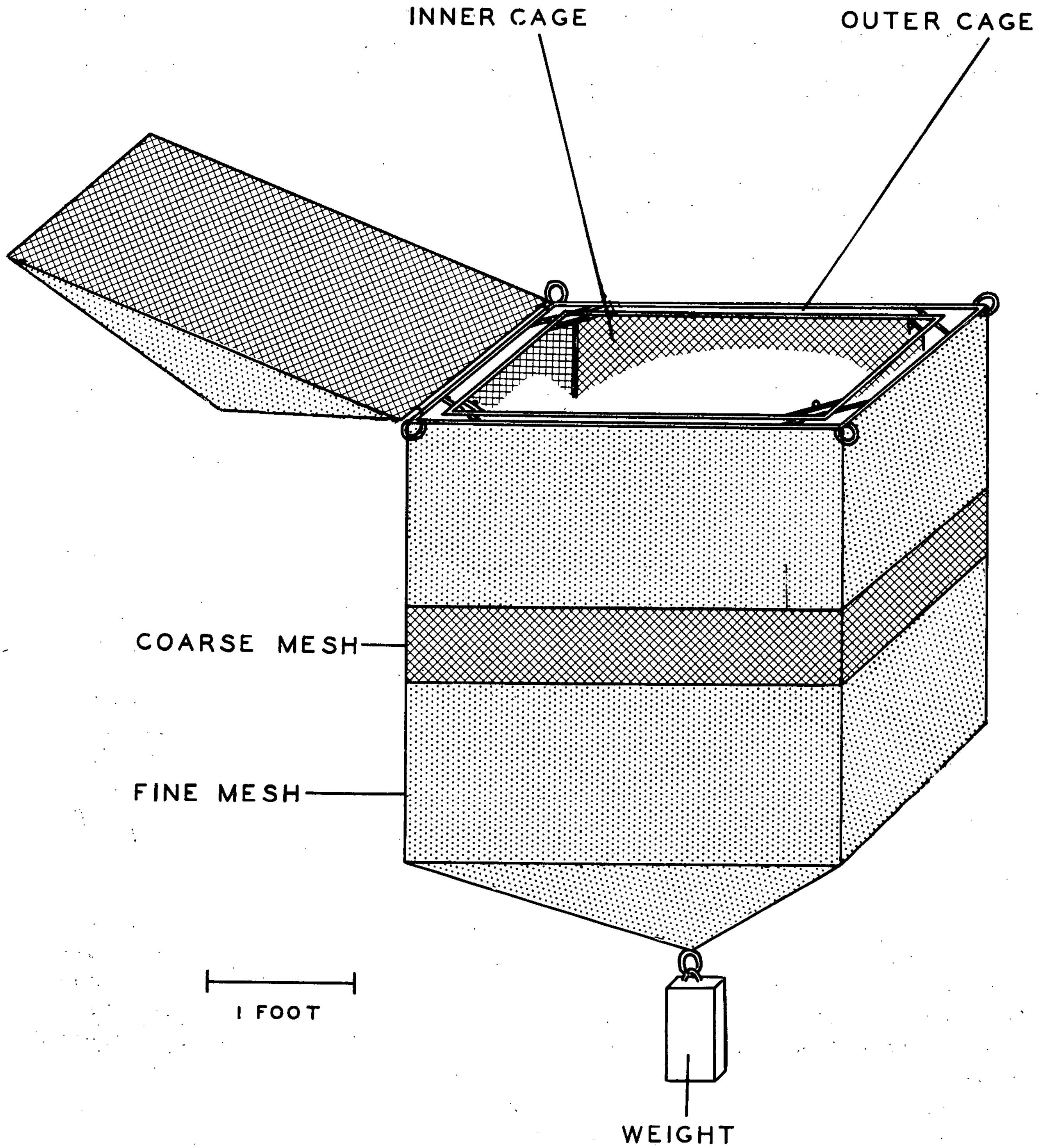

Figure 6. Cage used to hold herring during rapid changes in depth.

minutes and then raised to the surface. The average rates of pressure change for the second group were 0.8 lb/in^2/sec, during descent and 1.0 lb/in^2/sec, when raised. The two groups were kept under observation for two hours and one hour respectively after this experience.

As a control 54 herring were placed in the inner cage and the unit modified so that it could be towed horizontally about 5 feet below the surface with the former upper surface leading. The cage was towed for 1 minute 27 seconds, held for 5 minutes and towed again for 1 minute 57 seconds. The inner cage with its fish was then removed as before and the herring kept for three hours under observation.

Results: No deaths occurred in any of the groups of fish during the periods of observation. From the moment that they returned to the surface the herring were active, appeared healthy and swam normally.

Conclusions: From this experiment it was concluded that herring that have been several hours at the surface can survive a descent to 150 feet involving an increase in pressure from 0 to 67 lb/in^2, at an average rate of 0.8 lb/in^2/sec. After 5 minutes at this depth they can survive a return to the surface which involves a decompression at the rate of 1.0 to 1.2 lb/in^2/sec. After such an experience herring can swim normally from the moment that they return to the surface.

II. The ability of herring accustomed to pressure of 20 lb/in^2 to withstand rapid decompression.

Material: Thirty herring, 11 to 18 cm long with an average length of 14.5 cm were tested one to two weeks after capture. Between capture and use in the experiment these fish were held in 2 to 3 ft of water.

Apparatus: A steam sterilizer was modified to hold herring under pressure (Fig. 7). The sterilizer was fitted with a pressure control valve and an inflow of sea water from the laboratory supply at 22 lb/in^2. This sea water came from a reservoir open to the atmosphere and came to the experimental vessel in a closed system. Its pressure was due solely to the hydrostatic head. The gaseous content of this water could not exceed the saturation value at atmospheric pressure and thus in this respect the experimental conditions were exactly comparable to those at this pressure in the sea.

Once the pressure inside the sterilizer had reached the setting of 20 lb/in^2 on the pressure release valve a steady leakage through the valve of about one litre per minute occurred maintaining the pressure between 19 and 20 lb/in^2. This leakage allowed a continuous flow of sea water to pass through the vessel bringing oxygen to the fish, removing waste products and maintaining a temperature of about 10°C.

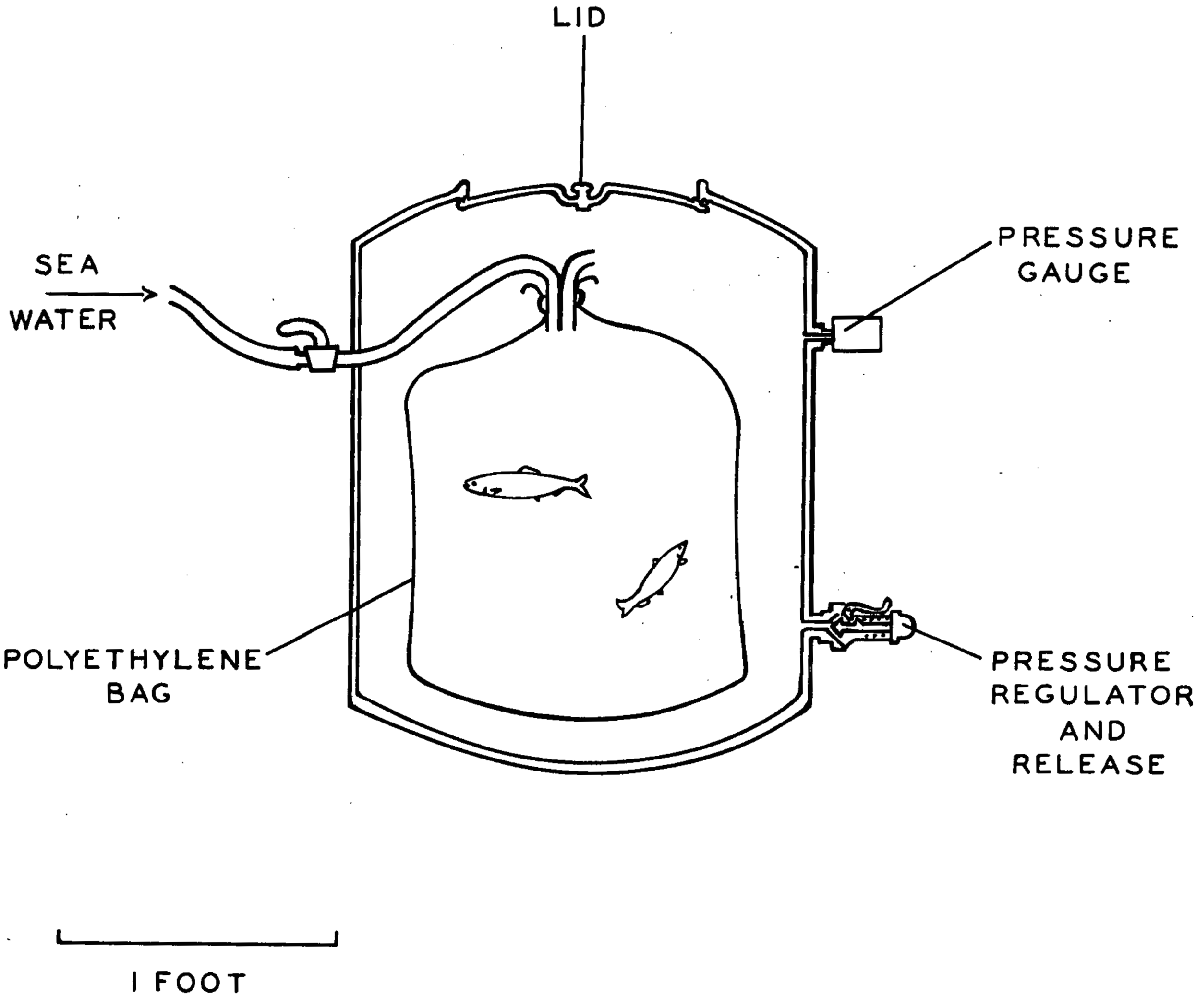

Figure 7. Apparatus used to investigate the effect of sudden pressure changes on herring.

The herring were held in a large polyethylene bag into which the inflowing sea water discharged. The bag could be brought to the surface of the water in the sterilizer and being transparent it allowed the behaviour of the fish to be observed immediately after decompression.

Method: Six herring were placed in the polyethylene bag and the neck of the bag was tied leaving as little air in the bag as possible. The sterilizer was filled with sea water, sealed and the pressure inside it increased. The time taken for the pressure gauge to move from 0 to 19 or 20 lb/in^2 was noted. The herring were left for 16 hours at this pressure and then rapidly decompressed. In less than 2 seconds the pressure gauge registered 0 and at 4 or 5 seconds the lid of the sterilizer fell in allowing the herring to be seen. The fish were observed continuously for five minutes after decompression and then transferred to a holding tank for further observation.

Results: The results of these experiments and details of the rates of pressure change for each experimental group of 6 fish are given in Table X. None of the herring held for 16 hours at 19 to 20 lb/in^2 and decompressed at a rate of between 10.5 and 12.5 $lb/in^2/sec$ died during the following 48 hours. In Group E, however, where the rate of decompression was 23.8 $lb/in^2/sec$ two of the herring were swimming on their sides immediately after decompression. One recovered, the other 13.8 cm long, died within two hours. During the five minutes after decompression at the slower rate herring of groups A, C and D swam very actively, often in a downward direction, pushing at the bottom of the bag. The tendency to swim downwards could have been a response to the sudden increase in light. The fish in Group B could not be seen because the water was cloudy. On no occasion was a herring seen to float upwards against the top of the bag; an expected result if the herring had become too buoyant by the expansion of gas in the swim bladder. No bubbles were observed to leave the fish by mouth or posterior opening during the five minute observation period.

The herring before testing had been held for one to two weeks in sea water 2 to 3 feet deep. They were thus accustomed to surface pressures. As none of the fish were dead on decompression it follows that these herring withstood an increase in pressure at the rate of at least 1.1 $lb/in^2/sec$ to 20 lb/in^2 without injury which would cause their death within 16 hours.

Conclusions: Herring which for 16 hours have been accustomed to a pressure of 19 to 20 lb/in^2, corresponding to a depth of 42 to 44 ft, can survive decompression at a rate of 12.5 $lb/in^2/sec$ to surface pressure. These fish show no disturbance of their swimming ability immediately after decompression. The disturbed swimming and subsequent death of one fish out of six decompressed at a rate of 23.8 $lb/in^2/sec$ suggests that there may be some mortality if herring are subjected to such a rapid decrease in pressure.

Table X. Survival of herring kept for 16 hours at 19 to 20 lb/in^2 after decompression to 0 lb/in^2.

Fish group	Number of fish	Average rate of compression $lb/in^2/sec$	Average rate of decompression $lb/in^2/sec$	Fish dead Time after decompression 0-5min	0-24hr	24-48hr
A	6	0.4	12.5	0	0	0
B	6	1.0	10.5	0	0	0
C	6	0.4	12.2	0	0	0
D	6	0.5	11.1	0	0	0
E	6	1.1	23.8	0	1	0

This experiment also showed that herring held for one to two weeks in 2 to 3 feet of water can survive an increase in pressure to 20 lb/in^2 at an average rate of 0.4 to 1.1 $lb/in^2/sec$.

Discussion: The pressure changes that would affect a herring passing through the turbines on the centerline under conditions of mean water level in the two pools may be considered first. If the herring came in at the average depth of the channel to the power house it would not be subjected to a change in pressure on entering the intake tube. In passing through the turbines the herring would pass from a pressure of 13 lb/in^2 in the intake to 0 lb/in^2 at the top of the draft tube with a maximum rate of pressure decrease of about 7 $lb/in^2/sec$. If the herring can be assumed to have been adjusted to the depth of about 20 feet at which it approached the intake, the conditions closely resemble those of the second experiment in which herring were shown to survive decompression of greater magnitude and at a greater rate than at this point in the turbine.

The second experiment showed that if herring adjust roughly to a decrease in pressure by liberating excess gas from the swim bladder this process is complete within two or three seconds of the end of decompression. Although the time taken for decompression when passing through the turbine is only a matter of seconds this may be long enough for the herring to lose the excess gas from the swim bladder and so be roughly in equilibruim with the pressure of 0 lb/in^2 at the top of the draft tube.

From the top of the draft tube to the mid line at its lowest point the herring would experience an increase in pressure from 0 to 29 lb/in^2. The first experiment showed herring adjusted to surface pressures could withstand pressure increases of more than twice that value. The rate of pressure increase of 2 $lb/in^2/sec$ averaged over the whole distance with a maximum transitory rate of about 7 $lb/in^2/sec$ was not matched in the experiments but as a compression is involved resulting in a decrease in the volume of swim bladder gas and the rest of the fish is virtually incompressible no ill effects on the herring would be expected. The herring would be deprived of part of the buoyancy provided by the swim bladder gas but observations on herring at 100 ft using the underwater television camera have shown that herring can compensate for this with their fin movements.

From the lower part of the draft tube to its exit into the low pool a herring on the centreline would again be subjected to decompression, this time from 28 to 19 lb/in^2 at a rate of about 0.6 $lb/in^2/sec$. The experiments showed that herring could withstand decompression of this magnitude and at this rate whether or not they had become adjusted to the greater pressure.

If a herring, instead of keeping to the centreline followed a course that would subject it to the greatest pressure changes, both the magnitude of the changes and the rate still fall within the values that herring have been shown to survive. The only exception, as with the centreline path, lies between the top of the draft tube and its lowest point, where changes occur which were not investigated experimentally. For the same reasons given before, the compression in this region is not thought likely to injure the fish.

It thus seems that pressure changes alone will not cause mortality among herring schools that pass through the turbines. However, the herring is readily abraded if it comes into contact with rough surfaces and some mortality may be expected from those fish which come into contact with hard surfaces as they pass through the power house.

The behaviour of herring in currents and a determination of their maximum swimming speed

Herring in nature have been reported by several observers to orientate upstream when in a current. Balls (1951) noticed that young herring usually stemmed a current. Huntsman (1953) concluded that herring lead along the shore when they are quite near it and that they also head and swim upstream when in a current and close to the bottom. Jones (1957) followed the movements of a herring school at 5 to 10 fathoms over a bottom at 14 fathoms on an echo sounder. His observations suggested that the herring were being carried with the current over the ground but were swimming into it at a rate of 1 or 2 knots. Moore (1898) after observing herring in the Passamaquoddy region reported that he had never seen any evidence that herring feeding at the surface keep facing the current. If their food drifted with the current then he found that the fish also drifted with the current; if the food organisms stemmed the tide the fish followed them.

Although there appears to be a discrepancy between Moore's results and the others, there are two reasons why the herring might sometimes orientate into a current and at other times not do so. It is possible that even when conditions are favourable for the current response to be shown that internal or external factors cause the herring to show another type of behaviour. Herring kept in a pen which was in communication with the sea at high tide were seen to swim into the tidal flow entering the pen and remain near the netting through which the water entered the pen. When natural food coming in with the tide drew near to a fish, the herring stopped swimming into the current and drifted downstream at the same rate as the food for a distance of one or two feet before springing forward to seize it. As soon as the food was taken the fish again responded to the current and swam upstream to its former position. Thus during the act of feeding the herring responds to the food rather than to the current which is one reason why Moore may not have found any evidence of a response to current in fish feeding at the surface.

A second reason is that the term "response to current" is a misleading one, although it is a convenient way to refer to an animal's behaviour in currents when other conditions necessary for a response to be shown are present. Animals being carried along in current at a steady rate and in a straight line are stimulated only if this movement results in a change in the relationship between the animals and their environment. Unless there is such stimulation there can be no response to the displacement. This point is discussed fully by Lyons (1904). The result of these complex underlying factors is that the presence of a current alone is not sufficient to cause a response. Only when secondary stimuli are present which indicate the displacement caused by the current can a response be shown. Thus Moore's observation that herring near the surface failed to face into a current could have been caused by the absence of the necessary fixed points of reference. The same fish in shallow water where they could receive visual, tactile or other stimuli from their environment when displaced by a current might show a clear response.

Although currents of uniform velocity cannot by themselves be a stimulus yet when velocity increases it subjects the animals carried with it to acceleration which persists only so long as the speed of the current continues to change. No fish has yet been shown to respond to this possible means of stimulation by changes in current speed although Gray (1937) subjected blinded goldfish to linear acceleration along all the three main axes of the body.

If herring are swimming against a current the effectiveness of their response will depend on their swimming speed compared with the current speed. Fridricksson and Aasen (1950) found that large herring left undisturbed in live nets swam constantly in an anticlockwise direction at a speed of about 6 to 8 metres a minute (0.3 to 0.4 feet per second). Jones (1957) suggests that a school of herring followed by echo sounder may have been swimming at 1 to 2 knots (1.7 to 3.4 feet per second). In the present investigation the maximum swimming speed of exercised herring swimming in a school was determined.

Cruises: Two cruises using under water television equipment were made during 1958. The first, from May 16 to May 28, used equipment belonging to the United States Bureau of Commercial Fisheries, Woods Hole supervised by Mr. R. Livingstone. The second, from September 18 to October 1, used the National Research Council of Canada's unit developed by Mr. W. M. Cameron.

Equipment: During the latter part of the first cruise and the whole of the second cruise observations were made on groups of herring confined in a mesh-covered cage, 6 ft long, 4 ft wide, and 4 ft deep. The camera was attached to one end of the cage so that a clear view of most of the interior of the cage was obtained on the monitor screen. Both cameras were cylindrical in shape with a diameter of 10 and 14 1/2 inches. They were mounted with their long axes parallel to the water flow when the cage was being towed and with the lens in the centre of the end wall of the cage. This left 1 1/2 feet of mesh between the base of the camera and the bottom of the cage. As the fish took up a position in the front end of the cage and within about one foot of the bottom while the cage was being towed they were in water not disturbed greatly by the passage of the camera. The cage with its attached frame supporting the camera, was slung from above and in front from booms on M. V. *Harengus* so that it could be lowered, held or towed at any depth. When towing the unit the cage acted as a fin so that the camera end of the cage always moved first through the water. Thus the camera looked "downstream" and fish swimming into the apparent current faced the camera. For convenience in description the end of the cage with the camera will be called the front end, the opposite end the back and the long walls the side.

A Gurley current meter was suspended from a cross bar inside the cage, half way back and 10 inches from the top. At first it was placed in the centre of the cross bar but after September 26 was suspended from a point 14 inches from one side. A small streamer of white string in the centre of the cage where it was easily seen on the television screen gave visual indication of the direction of minor currents through the cage.

The equipment is illustrated in Figure 8.

Methods: Herring were obtained from weirs in Passamaquoddy Bay using the handling technique described in the section on temperature tolerance and tested on the same day. The fish were held in a tank until required and then were placed in the partially submerged cage through a door in its upper wall. From the weir to the cage these fish were never out of water.

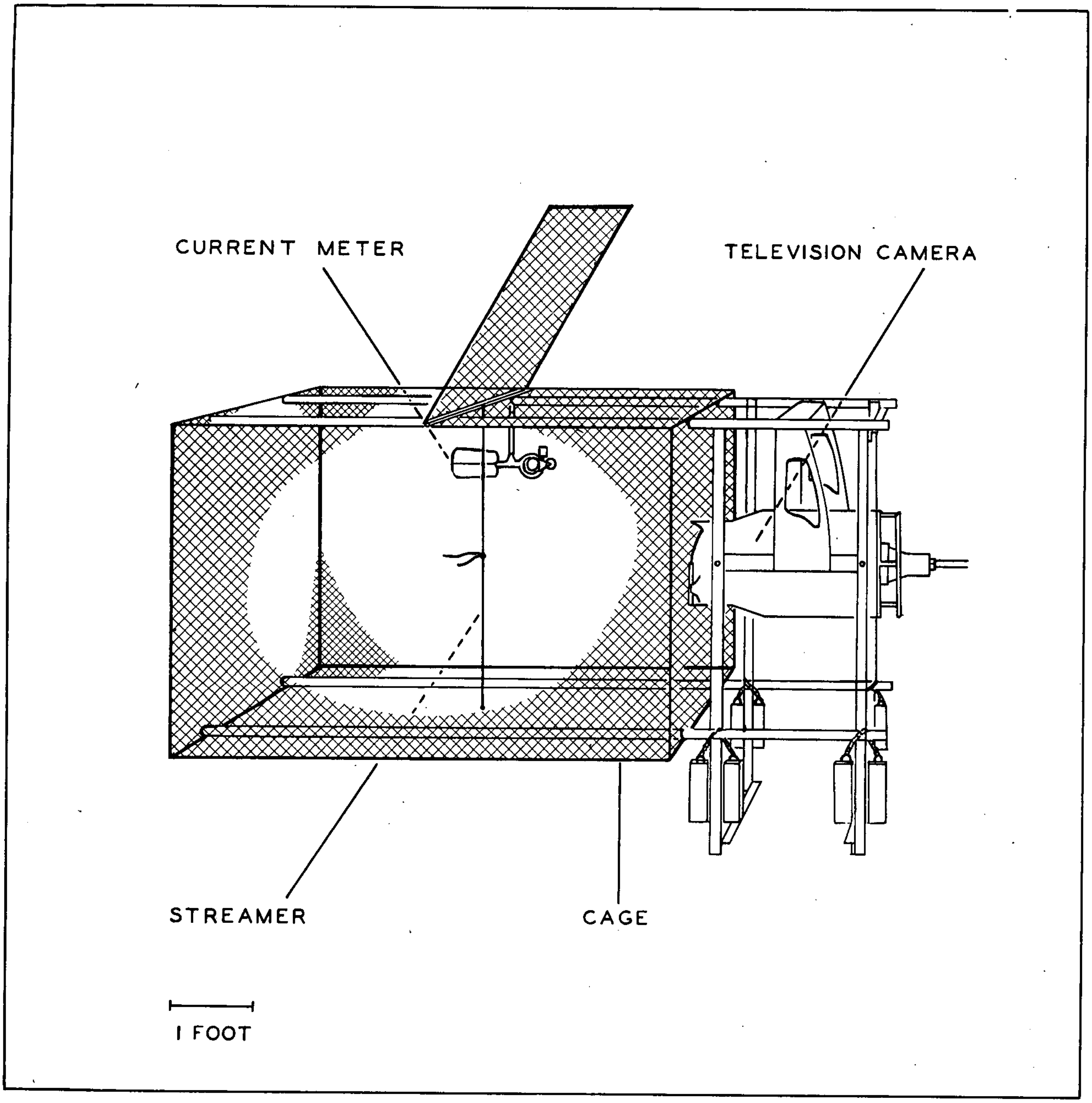

Figure 8. Cage and camera used during the second television cruise.

The behaviour of herring in natural currents was observed by anchoring the boat in a tidal flow and lowering the cage to 20 ft where it was clear of the hull. Only the response to low current speeds could be investigated in this way. Using the smaller M. B. Mallotus to tow the larger M.V. Harengus the cage was drawn at a gradually increasing speed through the water. The behaviour of the herring in the flow of water through the cage was observed and the speed of the current was increased until all fish failed to keep pace with the cage. From these results the maximum swimming speed of herring of various sizes was calculated as described under that section. A new group of herring was placed in the cage after each determination of the swimming speed. The apparatus was also used to observe the fish at various depths down to 100 feet. During all these observations records of the current velocity and of the herring behaviour were kept on a minute by minute basis. The water temperature at 20 ft was taken before and after each test period. After the depth experiments a series of readings of light intensity with depth were taken.

As the current meter was placed near the top of the cage away from the fish it was necessary to calibrate it in terms of the water flow past the fish. A second current meter was mounted in the cage 10 inches from the bottom and in three positions in the area which had been occupied by the fish during the experiment. Two positions were on the midline at 1 1/2 and 3 ft from the front end and the other 1 1/2 ft back and 1 ft from the side. Simultaneous readings of the original and second meter were taken over the range of current speeds used in the experiments. The results obtained from the three positions were used to construct a graph from which current velocities recorded by the original meter could be expressed in terms of the rate of water movement past the fish. This corrected current speed value was used when calculating the maximum swimming speed of the herring.

The behaviour of herring in currents: The behaviour of herring in natural currents was studied during the television cruises by holding the herring in the cage with the boat at anchor in a tidal flow. This was supplemented later by observations without the use of television made on herring held in the cage which was buoyed and tied to a wharf in a tidal current.

It was found that in natural currents from 0.1 to 0.5 ft/sec the herring remained in the upstream half of the cage, usually within a foot of the bottom. There they swam continuously from one side wall to the other, appearing at these current speeds to be swimming directly across the current but as they maintained a constant distance from the front mesh there must even here have been a component of their path in the upstream direction, compensating for the displacement by the current. The response to the current was most clearly seen when the herring reached the side wall where they always turned into the current before swimming across the cage again. At these low current speeds the cage did not always swing round so that it was downstream of the camera. However, the direction of the current could be judged by the position of the streamer and it was found that the herring's response was always related to the current despite differences in the direction of the water flow through the cage.

When there was no flow of water through the cage or its speed was less than 0.1 ft/sec the herring followed the walls of the cage, sometimes turning back at a corner, but usually turning to follow the next wall.

When the cage was towed some water passed through the front (camera) end of the cage. Although this water may have been stationary in relation to the earth's surface yet relative to the cage it was moving and it was found that the herring responded to this apparent current in exactly the same manner as they responded to the real, natural currents of the same velocities. As the speed of the current increased the herring inclined their bodies more nearly into the current as they moved from one side wall to the other. The extent of the side to side movements also decreased with increasing current speed until near the maximum swimming speed the herring were facing directly upstream and showing only occasional deviations of a few inches to one side or another. The existence of these side to side deviations in the path of the fish showed that the herring at all but the fastest of these current speeds were swimming at a faster rate than the current. Herring from the back of the cage used this excess swimming over current speed to come to the front of the cage but there further progress in the upstream direction was prevented by the front mesh of the cage and the side to side movements began. Herring never remained in the downstream half of the cage making side to side movements which shows that there were due solely to the presence of a barrier to movements upstream. Thus it is expected that herring near enough to fixed objects to perceive their displacement by a current yet free to move in all directions would swim upstream and make way against the current unless the current speed exceeded their swimming speed.

<u>The maximum swimming speed of herring:</u> As the speed of the current through the cage was increased a point was reached for each fish at which it could no longer keep pace with the cage. Still facing upstream and swimming vigorously the herring was then displaced downstream until it was held against the back mesh of the cage. The greatest current speed against which the fish could swim was taken as its maximum swimming speed. Although the speed of the water was gradually increased when making a determination of the maximum swimming speed yet the swimming speed of the fish before failing did not increase in the same manner. In the determinations described below the herring groups had been swimming for 9 to 30 minutes before 50% failed to keep pace with the cage. During this time the herring determined their own swimming speed as this was, until just before the maximum swimming speed was reached, in excess of the current speed. The maximum swimming speed obtained under these conditions is thus the greatest speed that the fish can swim averaged over one minute after swimming

for 9 to 30 minutes at the rate shown by these fish when in an excited state.

The maximum swimming speed was determined for groups of herring made up as nearly as possible by eye, of fish of uniform size. These fish were placed in the cage, which was then lowered to 20 feet and held there for 15 minutes. Tides or wind drift of the boat usually caused a minor current to pass through the cage under these conditions but the flow remained below 1.2 ft/sec. After 15 minutes the cage was towed at a gradually increased speed. A record was kept of the behaviour of the fish and of the number of fish that had failed to keep pace and were on the back of the cage at the end of each minute. A second observer recorded the current velocity on a minute to minute basis. The increase in speed continued until all the fish had failed, when the cage was raised, placed on deck, and the fish removed for measuring. A temperature reading at 20 feet was taken between each tow.

From graphs of the percentage of fish on the back mesh and current speeds plotted against time the current speed at which 25%, 50% and 75% of the fish failed has been determined and is shown in Table XI. The speed at which 50% of the herring failed to keep pace with the cage may be taken as the maximum swimming speed which may be maintained over one minute by exercised fish of these sizes at these temperatures.

In the second and third columns across the table results have been given for two groups of herring of the same mean length and of the same stock which were tested at the beginning and end of the day. Strong winds at the end of the day, making handling difficult and necessitating an increase in speed before the tow and not just the increased holding times are likely to be the cause of the difference in swimming speed of the two groups.

The results in the table have been arranged according to the mean length of the fish. When treated statistically there was found to be a significant positive correlation between mean length and the maximum swimming speed; the larger herring overcoming higher current velocities before 50% failed to keep pace with the cage.

<u>The behaviour of herring at various depths</u>: It was found that herring lowered from the surface to 20, 40, 60, and 100 ft could still swim normally when illuminated by artificial light. This shows that the herring were able to compensate for the decrease in buoyancy which must have occurred as the gas in the swim bladder was compressed. Herring at these depths under artificial light continued to school and behave in currents in the typical manner, except that at 40 feet or below they were found more commonly at all depths in the cage instead of in the lower foot as at 20 ft.

When the cage was being lowered in the water the herring swam horizontally with occasional excursions up or down. There was no

Table XI. Details and results of experiments to determine the maximum swimming speed of herring.

Date 1958	No. of experiments	No. of fish	Mean length cm	Size range cm	Hours after capture	Temperature °C	Average increase in speed ft/sec	Time to 50% failure min	Current speed at which fish failed ft/sec** 25%	50%	75%
Sept. 26	4	31	15.2	12.2-17.5	7 3/4	12.2	0.16*	9	2.8	3.0	3.2
Sept. 26	2	50	18.5	15.5-21.5	3 3/4	12.1	0.10	25	3.8	4.0	4.1
Sept. 26	5	43	18.5	15.9-21.1	9	12.4	0.11	12	2.5	3.1	3.1
Sept. 29	3	35	20.7	18.7-23.3	6	11.7	0.12	18	2.9	4.0	4.1
Sept. 26	3	30	22.0	19.6-27.1	5 3/4	11.6	0.11	24	3.3	3.7	4.0
Sept. 30	1	46	25.8	23.5-29.3	1 3/4	11.7	0.11*	26	4.0	4.4	4.5
Sept. 29	2	22	26.7	24.9-30.0	3 3/4	11.7	0.08	30	4.4	4.7	4.7

* To 75% failure only.

** 2.5 to 4.7 ft/sec equals 1.6 to 2.8 knots.

constant swimming downwards on a spiral course as herring sometimes use to approach food from below. It has also been noticed that captive herring, when swimming very slowly, sink slightly in the water between each swimming movement suggesting that their density is greater than that of the sea water even after they have been held for weeks in shallow water. On one occasion during the television cruises all the fish in a cage held at a constant depth were seen to stop swimming and rapidly sink in the water when the main engines were started. These observations suggest that the herring may descend mainly by sinking in the water. For the descent to be made rapidly the herring initially would need to be denser than sea water but once the descent had begun it would be accelerated as the increase of pressure reduced the volume of gas in the swim-bladder and the buoyancy of the fish. It is interesting to note that Magnan (1929) reported a sinking factor of 1034 for the herring, which is high for a marine fish with a swim-bladder and was queried on this account by Jones and Marshall (1953).

While the cage was being raised the herring swam with heads inclined upwards. They swam normally and vigorously with their bodies quite vertical when the rate of hauling increased. The downward position of the streamer showed that these fish were swimming into the current which entered through the top of the cage.

<u>The stimulus necessary for the response to currents:</u> It was shown earlier that herring in the cage behave in the same manner in natural currents and in the flow of water through the cage which occurs when the cage is towed. In natural currents the water displaces the fish relative to the earth and the fish could sense this displacement as a change in any one of the stimuli which characterize one point on the earth's surface. Using this information the fish could orientate and swim at such a rate that it counteracted the change and so maintained a stationary position relative to the earth. When the cage was being towed the movement of water through it only displaced the herring relative to the cage, yet the herring still responded to this displacement. Thus they must have been receiving stimuli from the cage on which to base their response. This stimulus could not be a tactile one as herring showing the current response did not come into contact with the walls of the cage. The stimulus could have been a visual one or perhaps some change in the characteristics of the water streaming through the meshes to the fish, such as smell or the presence of turbulence, allowed the fish to orientate in that direction. However, it was found under two different conditions that a decrease in the visual stimuli from the cage was followed by a failure of the response to current by the fish although all other stimuli were still present. A group of herring lowered from the surface to 100 ft swam normally, schooled and responded to the current under artificial light. The light was switched off for 5 to 10 seconds on several occasions. When it was turned on again the herring were seen to be further downstream and motionless. They began to swim immediately after the light was turned on, advancing to the upstream end of the cage and responding to the current

in the normal manner. These observations were few and could not be repeated because the camera case leaked at these depths but they do suggest that the herring were using visual stimuli from the cage to orientate to the current. If sudden changes in light intensity caused a startle reaction which interfered with the normal behaviour in currents then this must only be effective when the light was switched off as the fish immediately responded to the current when the light came on. The short periods of darkness gave little time for light adaption so these observations cannot be interpreted to mean that the light intensity at 100 ft during the day is too low for visual orientation into a current.

On the second occasion a group of herring were being towed in the cage at 20 ft. The speed had increased until 4 out of 104 fish failed to keep pace and then was decreased. One minute elapsed after this maximum speed, during which no more fish failed, then there was a sudden change in the water from clear to very muddy. Although the speed was still decreasing herring in large numbers failed to keep their position in the upstream part of the cage and 66 were later found to have been swept back against the back mesh. These herring did not turn away from the dirt-laden water but were displaced downstream tail first suggesting that they were losing their upstream position because they were no longer receiving clear visual stimuli from the cage.

Conclusions: The experiments with groups of herring held in a large mesh covered cage showed that herring given a well defined visual field will respond to currents greater than 0.1 ft/sec by turning and swimming upstream. As the swimming speed of the herring exceeds the current speed until the maximum swimming speed of the herring is nearly reached, this upstream swimming is masked in the cage by side to side movements at the upstream end of the cage. Herring do not turn downstream when the current speed exceeds their swimming speed but are forced backwards tail first. It seems probable that the response to current is based on visual stimuli which indicate the displacement of the herring by the water relative to fixed objects in its environment.

The maximum swimming speed of herring was found to increase with fish length. At 12°C the maximum swimming speed ranged from 3.0 to 4.7 ft/sec for herring groups of mean length 15.2 and 26.7 cm respectively when these fish had been exercised for 9 to 30 minutes.

When taken from the surface to depths down to 100 ft the herring show no disturbance of their behaviour but swim normally, school and respond to currents in the presence of artificial light. Herring descend in the water mainly, if not wholly, by sinking. They rise by swimming with their heads inclined towards the surface and are able to swim vertically upward.

Discussion: The results obtained during these cruises when applied to wild fish, suggest that herring near the bottom or near any object which gives a fixed visual reference point will move upstream in a current. However, herring that are far from the bottom or at such low light intensities that they lose their visual reference points will not have their direction of swimming determined by the current although they will be displaced downstream by it. Assuming that herring schools far from the bottom were swimming randomly in direction, an increasing number of these schools would be moved downstream in a given time as the current increased until, when the current exceeded the normal swimming speed of the herring, all the schools would be displaced downstream. Whether a herring school is responding to a current or not, whenever the current speed exceeds the maximum swimming speed the school will be displaced downstream. For herring of the sizes caught in the Passamaquoddy fishery, it can be said that any current which exceeds 5 ft/sec will carry all the herring with it.

Applying these findings to the Passamaquoddy area and combining them with the data on the depth distribution described previously gives the following explanation for the occurrence of herring in Passamaquoddy Bay. During the months of the fishery at least 50% of the herring population are between 23 ft and the surface by night and between 35 ft and the surface by day. Except for shallow regions along each bank, the floor of the passages into the Bay is far below most of the fish making up such a population, and almost certainly too deep, dark and featureless to provide fixed visual reference points for them. It is thus to be expected that during the months of the fishery most herring in water being drawn towards the passages pass in and out with the tide. A small proportion of the herring population that happened to be in shallow water would move counter to the current flow in each instance. At completely slack water the movement of fish through the passages would be slight as it depends entirely on the random movements of herring to take the fish through.

With such a system the loss or gain of herring through the passages would depend on the concentrations of fish at the two ends of each passage. So long as herring were in greater concentration immediately outside the Bay than they were in the Bay greater numbers would pass in than out. The continuous removal of herring from the Bay by the weir fishery would contribute to a lack of balance between the Bay and the sea tending to draw more herring into the Bay. It was shown on the echo-sounder records that the herring shoals broke up several hours after sunset and reformed just before sunrise. Minor fluctuations in the concentrations of herring inside and outside the Bay could be caused as the period during which the shoals had disintegrated fell to a greater or lesser extent into one tidal flow. During these hours the herring are not only nearest to the surface but at the lowest light intensities so that they are both furthest removed from fixed objects and least able to see objects at a distance. Under these conditions the greatest proportion of the herring would be carried in the tidal flow.

The building of dams across Passamaquoddy Bay would not prevent herring entering the high pool by the same mechanism. The depth of the filling gates, from 10 to 40 ft below mean sea level coincided with the depth distribution of most of the herring population. The flow would increase in velocity to a maximum of about 24 ft/sec at the throat of the filling gates. Herring being drawn towards the filling gates would be in water that exceeded 5 ft/sec at some distance from the gates. Thus even if the herring used the gates as visual reference points and turned into the current they would still be swept into the high pool as the current velocity exceeds their maximum swimming speed. As before some herring in shallow water in the passages or those whose random movements took them against the current when current velocities were still low would be lost to the fishery. These should not amount to a greater proportion of the population than before.

In the high pool a slow drift towards the powerhouse would be expected to carry some of the herring with it. The channel leading to the intakes being 33 to 50 ft deep and 1800 to 2400 ft across is large enough to enable some of these fish to be carried along it without coming near the sides or the bottom. At the end of the channel would be turbine intakes 40 ft deep and 65 ft broad. The mean velocity in both the channel and intakes would be about 3 ft/sec, low enough so that herring swimming continuously against the current could escape from the channel. Thus some herring could return to the high pool but in order to do this they would have to be able to see the bottom almost continuously so the proportion returning would probably be small.

The observations on the behaviour of herring lowered to depths of 100 feet suggest that the changes in pressure which would accompany the passage of herring through the turbines would not have a detrimental effect on their behaviour. The successful passage of herring through the turbines would allow herring to populate the low pool.

The emptying gates from the low pool extend from 23 to 53 ft below mean sea level so that they also coincide with the depth distribution of a large proportion of the herring population. The maximum velocity of 24 ft/sec in the gates is well above the maximum swimming speed of the fish and it is expected that some of the herring in the low pool would pass out with the water through the emptying gates. The velocity is too high to allow herring to enter the low pool through the emptying gates once the flow has been established.

DISCUSSION OF THE EFFECT OF THE PASSAMAQUODDY POWER PROJECT ON THE HERRING POPULATION OF THE AREA, BASED ON EXPERIMENTAL RESULTS

The entry of herring into the high pool

Herring have been found in nature in sea water of temperatures up to 18°C and they move up estuaries into water whose salinity has been reduced to 20°/oo by the admixture of river water (Leim et al, 1957) (McKenzie - unpublished data). This suggests that herring do not avoid water of these salinities and temperatures. It is predicted (Appendix I, Chapter 7) that the temperature and salinities outside the dams will show little change from present conditions except in the immediate vicinity of the dams where there will be a somewhat greater seasonal variation. It is not expected that the slight change in these properties will cause herring to avoid the Passamaquoddy area as they fall well within the range in which herring are found in nature.

During the months of the weir fishery echo-sounder records show that at least 60 to 81% of the herring population are always within 40 ft of the surface in Passamaquoddy Bay. If the same vertical distribution is true of herring in the passages leading to Passamaquoddy Bay then the filling gates which extend from 10 to 40 ft below mean sea level, would not prove an obstacle to the passage of herring into the high pool. The water that passed through the filling gates into the high pool would be drawn from those levels in which the herring are to be found. The depth distribution of the herring is such that a large proportion of the population will be far above the floor of the passages into the high pool. Except for shallow regions along each bank the sea bed will be too far below most of the herring to provide them with fixed visual reference points. Thus, as herring have been shown to require visual stimuli from their environment in order to turn and swim against a current it is expected that most herring will not respond to currents in the passages. Instead, if the population is made up of herring schools swimming randomly in direction an increasing number of herring schools would be displaced downstream in the current as the current speed increased. Herring being drawn towards the filling gates in the current would be in water that exceeded 5 ft/sec, which is greater than their maximum swimming speed, at some distance from the gates. Thus even if the herring used the gates as visual reference points and turned into the current they would still be swept into the high pool. Herring which were in shallow water in the passages or those whose random movements took them against the current when current velocities were still low would be lost to the fishery. These should not amount to greater proportion of the population than are lost under the same circumstances at present.

Herring passing through the filling gates would be subjected to a maximum change of pressure of 4 lb/in^2. As herring have been shown to withstand both increases and decreases in pressure of 20 lb/in^2, this pressure change is not expected to cause injury to the fish.

Once the flow had been established no herring could leave the high pool through the filling gates as the maximum swimming speed of the herring is below 5 ft/sec while the flow inwards through the gates will sometimes exceed 24 ft/sec.

The survival of herring in the high and low pools

From May until October an examination of echo-sounder records have shown that at least 50% of the herring in Passamaquoddy Bay come within 23 ft of the surface at night and probably within 17 ft of it. Thus a considerable proportion of the population would enter the surface layer of warmer, brackish water in the high pool and a smaller number in the low pool. It is thought unlikely that herring will modify their vertical movements to avoid this layer as at most times its temperature and salinity are within the natural range of the fish. Herring have been shown to have an upper lethal temperature between 19 and 21°C which is close to the predicted maximum daily temperature of 20°C for the surface layer in the high pool. However, as this is a maximum figure the temperature will be for most of the summer below that which proved lethal to the herring. It is expected that mortality in the herring in the high pool will occur only over a limited period of time. In sheltered coves where the maximum may be exceeded by several degrees, heavy mortality might occur but this would only affect a limited area of the high pool.

In the low pool the predicted surface summer maximum of 15°C for the outer part and 20°C for the inner part should not cause mortality among the herring.

Except in estuaries of rivers discharging into the pools, the salinity of the surface layer of both pools is not expected to drop below 20‰. As herring at salinities of 5‰ or above, show only slight mortality over a four-week period it is expected that there will be no mortality caused by reduced salinity in either pool. Throughout the summer the water below the surface layer will be suitable both in temperature and salinity for the survival of herring in the high and low pools.

During the winter ice will cover part of the high and low pools. At this time of the year herring are in deep water which is not expected to cool below 0°C. As herring can survive brief exposure to -1°C, there should not be widespread mortality among herring which may overwinter in the high or low pools.

The entry of herring into the low pool

As the outward flow through the emptying gates from the low pool will reach a maximum of 24 ft/sec, which is well above the maximum swimming speed of herring, no herring will be able to enter the low pool through these gates once the flow has been established. However herring could populate the low pool if they could pass uninjured through the turbines.

In the high pool a slow drift of water towards the powerhouse is expected to carry some of the herring with it. The channel leading to the powerhouse, being 33 to 50 ft deep and 1800 to 2400 ft across is large enough to enable some of these herring to be carried along it without coming near to the sides or bottom. Most of these fish would also be far from the sides and bottom when entering the intakes at the end of the channel which will have a depth of 40 ft and be 65 ft broad. The mean velocity in both the channels and intakes will be about 3 ft/sec, which is low enough so that herring swimming continuously against the current could escape from the channel. The behaviour of herring in currents showed that herring would only swim against the current so long as they could see objects that were not moving at the same velocity as the water. In order to escape from the channel back into the high pool herring would have to see the bottom almost continuously and so it is thought that the number returning would probably be small.

Herring that are drawn into the intake and pass through the turbine would be subjected to a pressure change from 13 to 0 lb/in^2, from 0 to 28 lb/in^2 and then from 28 to 19 lb/in^2. Herring have been shown to survive pressure changes of this magnitude. Herring have also been shown to withstand the rates of pressure change involved except for the momentary rate of pressure increase of 7 $lb/in^2/sec$ which occurs between the top and deepest part of the draft tube. As compression is involved it is expected on theoretical grounds that this will not injure the herring. Compression would deprive the herring of part of the buoyancy provided by the swim-bladder gas but observations on herring taken down to 100 ft have shown that herring can compensate for this with their fin movements and still swim normally. It is expected that herring will be able to survive a passage through the turbines and so populate the low pool. However, herring are readily abraded and some mortality is expected among fish which come into contact with hard surfaces as they pass through the turbines.

The loss of herring from the low pool

The emptying gates from the low pool extend from 23 to 53 ft below mean sea level so that they coincide with the depth distribution of most of the herring population. The maximum velocity of 24 ft/sec in the gates is well above the maximum swimming speed of the fish. It is expected, therefore, that some of the herring in the low pool will pass out with the water through the emptying gates.

SUMMARY AND CONCLUSIONS

It is expected that herring will continue to enter Passamaquoddy Bay if dams are built across the entrances. During the months of the herring fishery at least 60% of the herring population was found to be between the surface and 40 ft. Thus, they are at the right depth to pass through the filling gates. Herring were found to swim against the current only when within sight of fixed objects. It is expected that most herring in the passages will be too far from the bottom to swim against the current so that herring schools will be drawn in the inflow towards the filling gates. Some distance from the gates the current velocity exceeds the maximum swimming speed of less than 5 ft/sec for herring which provide the basis of the weir fishery and this current flow will carry all the herring in it through the filling gates. The maximum pressure change of 4 lb/in^2 encountered by fish passing through the gates was shown to have no ill effect on the herring. Herring in nature occur in water of lower salinity and higher temperature than that in the approaches to the dams suggesting that these areas will not be avoided by herring. Thus it is expected that the supply of fish to the fishery in the high pool will remain unaltered.

In the high and low pools herring should be able to survive the altered conditions of temperature and salinity except for occasional heavy mortality in small enclosed areas of the high pool if water temperatures exceed 20°C. The upper lethal temperature of herring was found to lie between 19 and 21°C. They could withstand salinities as low as 5‰ but died in fresh water. The surface layer of the two pools is predicted to have a salinity between 20 and 30‰ which will not be injurious to herring. The predicted temperature and salinity of the lower layers at all times falls within the tolerance limits of the herring.

Herring can enter the low pool by passing through the turbines. Their dependence on visual clues to orientate into current makes it likely that some fish will be carried in the slow drift of water across the high pool, up the channel leading to the powerhouse and through the turbines to the low pool. Herring have been shown to withstand the pressure changes from 13 to 0 lb/in^2; from 0 to 29 lb/in^2 and from 28 to 19 lb/in^2 which would be encountered as a herring moved through the turbines along the midline. Pressure changes of this magnitude were also shown to have no adverse effects on the behaviour of herring. It is expected that there will be some mortality among herring that come into contact with hard surfaces and are abraded as they pass through the turbines. It is expected that enough herring will pass through the turbines to populate the low pool.

Herring will be lost from the low pool through the emptying gates as these correspond in depth to the distribution of most of the herring population. As in the passage of herring through the filling gates, the behaviour of herring in currents and their low swimming speed compared with the current velocity will cause herring to be carried through the gates and these will be lost to the fishery in the low pool.

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THE MIGRATIONS OF HERRING IN THE PASSAMAQUODDY AREA

by

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ABSTRACT

From June 20, 1957, to October 17, 1958, 137,469 herring were tagged in the Bay of Fundy and the Gulf of Maine. These fish were immature and ranged in mean total length from 98.9 to 199.0 mm and in age from 1 to 3 years. Recovery of 3,582 (2.6%) tagged individuals showed that herring moved in and out of Passamaquoddy Bay irregularly throughout the summer and autumn. In both years many fish concentrated at the head of this Bay. Outward movement reached a peak in July, especially in 1958 when there was a considerable movement eastward towards Point Lepreau. Herring moved into Passamaquoddy Bay from as far south as Grand Manan and from as far east as Point Lepreau. Little interchange of herring took place between the Passamaquoddy area and the coasts of Maine and Nova Scotia. The greatest straight-line distance moved was 55 miles. More than half of the recaptures were made within 2 miles of the tagging sites and nearly two-thirds within 5 miles. About 30% of the recaptures were made within 1 week after tagging and 63% within 2 weeks. The mean time before recapture was 12 days in 1957 and 17 days in 1958, and the longest time between release and recapture for both years was 165 days. Drift bottles released with the tagged herring showed that the tagged fish did not always move in the same direction as the surface currents.

INTRODUCTION

The Passamaquoddy area, located on the southwestern shore of the Bay of Fundy, is the centre of a large fishery for young "sardine" herring. Average annual landings from 1937 to 1956 exceeded 50,000,000 lb. Primary landings are used primarily in the production of canned sardines. Fish meal and oil as well as pet food and bait are also produced.

There is no evidence of major spawnings within the Passamaquoddy area and the origin of the young herring supporting this fishery is unknown.

Huntsman (1933, 1934) emphasized the importance of hydrographic conditions in determining the abundance and movements of herring in this area. As herring were taken in stationary brush weirs, he considered capture as evidence of movement and suggested that herring "be treated as a planktonic form". He concluded that water movements were responsible for carrying the herring into the region and effecting their distribution there.

To provide specific details of movements of young herring, tagging experiments were carried out in 1957 and 1958 as part of the International Passamaquoddy Fisheries Board's research program. Major responsibility for the project was assumed by the Fisheries Research Board of Canada and 49 of the 59 taggings reported here were done from the St. Andrews Biological Station. The Boothbay Harbor laboratory of the U. S. Bureau of Commercial Fisheries carried out 10 taggings independently and provided technical assistance for 20 other taggings. This paper presents the results of all experiments and discusses the significance of herring movements in relation to time, direction, and distance. Preliminary reports were published by McKenzie and Tibbo (1958) and McKenzie and Skud (1958).

MATERIALS AND METHODS

The tag: To study the movements of young herring, the following requirements were considered: (1) tags had to be external and attached to the head or tail (parts of the body which are not canned); (2) tags had to be small and very light in weight because of the size of the fish; (3) tags had to be quickly and readily made in the laboratory; (4) tags had to be conspicuous. The tag used by McKenzie (1950) for smelt fulfilled these requirements. It was made of scarlet "celluloid" 0.01 (0.25 mm) thick. Tags of various shapes were cut out and marked so that different taggings could be identified. Figure 1 shows the method of attaching a tag to the operculum of a herring.

Preliminary experiments: To test the suitability of this tag for herring, an experiment was carried out in the laboratory at St. Andrews, New Brunswick, beginning in November 1956 by S. N. Tibbo (unpublished data). Thirty-four herring were tagged and an equal number were held in the same tank as controls. At the end of the first week, 10 tagged fish (29%) and 4 controls had died. At the end of the first month, 23 tagged fish (68%) and 11 controls were dead. The experiment was concluded at the end of the second month when 4 tagged fish and 9 controls were still alive. There was no evidence of a live fish having shed its tag.

At St. Andrews late in 1958, 84 herring were tagged with opercular tags. Mortality was heavy (44%) during the first 2 weeks but only 4 tags were shed by live fish. The loss of tags increased to a maximum in the sixth week and by the end of the eighth week, a total of 37 tags had been lost. Only 2 fish died after the second week.

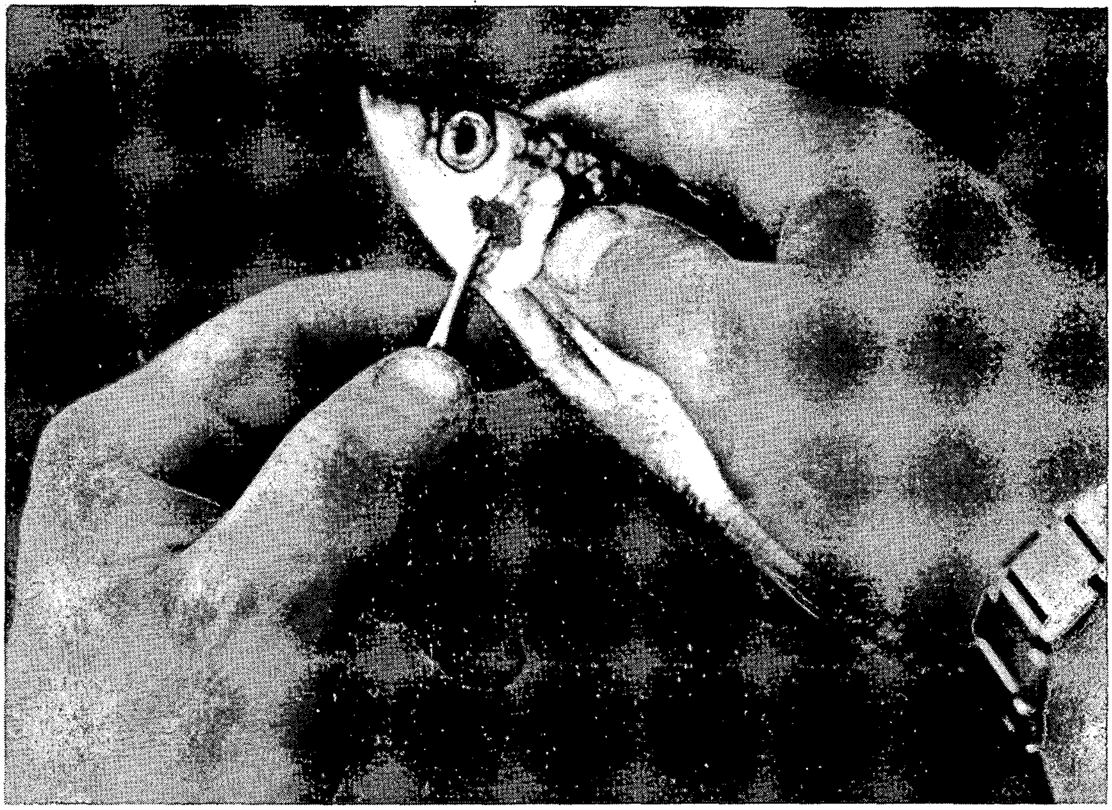

Figure 1. Attaching a tag to the operculum of a herring. (From McKenzie and Tibbo, 1958.)

At Boothbay Harbor, Maine, B. E. Skud and H. C. Boyar (unpublished data) found that cumulative mortalities, including loss of tags, of 51 tagged fish were 8%, 55%, 84%, and 90%, in 12, 24, 36, and 48 days respectively. During the same period, cumulative mortalities of 53 controls were 0%, 20%, 30%, and 30%. No records were kept of tags shed by the live fish in the tank.

To test recovery, S. N. Tibbo and R. A. McKenzie (unpublished data) tagged 350 fish entering Connors Bros., sardine canning plant in Blacks Harbour on June 5, 1957. With plant personnel alerted, 268 (77%) were recovered in 3 days, 206 (59%) in the first 2 hours.

To determine the colour of tags that would yield the best returns, 220 scarlet and 250 maroon tags were attached to fish entering Connors Bros., sardine plant on June 17, 1958. Returns of 165 (75%)

scarlet and 128 (51%) maroon tags showed that scarlet was a more conspicuous colour. A similar experiment was carried out in a field tagging at Navy Island, St. Andrews Point on July 25, 1958, when 968 sardines were tagged with scarlet tags, 986 with maroon tags, and 964 with yellow tags. Returns of 13 (1.3%) scarlet, 0 (0.0%) maroon, and 6 (0.6%) yellow again showed scarlet to be the best colour to use.

Field experiments: Fish for tagging were obtained from commercial fishing operations. Great care was taken in handling the fish to ensure their return to the water in the best condition possible. Brails and retainers of smooth nylon netting were used to reduce injury from loss of scales. Fish were out of the water for only a few seconds during actual tagging then quickly returned to a net retainer until about 500 had accumulated. Injured fish were removed and the remainder released as small schools.

During most of the taggings, samples of fish were also taken for age and length analyses. Samples taken within the Passamaquoddy area varied in mean total length (calculated on the basis of 10 mm groupings) from 98.9 to 199.0 mm, and in age from 1 to 3 years. The overall mean for all 1957 samples was 155.5 mm and for 1958, 141.2 mm. Table I shows the size distribution and mean lengths of each sample obtained. There was no indication that the size of the tagged fish influenced the results.

TAGGINGS AND RECAPTURES, 1957

From June 20 to November 21, inclusive, 37,495 "sardine" herring were tagged at 12 locations on 17 occasions (Table II). Eight locations were in or at the mouth of Passamaquoddy Bay, 2 were 25 and 125 miles westward along the coast of Maine, 1 about 12 miles eastward along the New Brunswick shore, 2 off southern Grand Manan and 2 off western Nova Scotia. A total of 792 or 2.1% were recovered, 738 with complete and 54 with incomplete data concerning time and place of recapture. Only those with complete information are shown in the figures or considered later in this account. Distances from tagging sites to recapture positions were measured in straight lines.

Moat Island tagging (Fig. 2): On June 20, 1,452 herring were tagged at the McVicar (Zig Zag) weir. No recaptures were made within the first 10 days following tagging. Of the 13 recaptures with complete information, 11 (85%) were made more than 2 miles from the tagging site. The recaptures show a movement to the head of the eastern part of Passamaquoddy Bay and along the shore towards Saint John.

Table I. Size distribution of herring tagged in 1957 and 1958.

Date	Locality	Size range cm	Mean length cm
1957			
June 20	Moat Island, N. B.	15-25	18.7
June 21	Harbour de Loutre, N. B.	12-19	15.4
July 9	Bocabec, N. B.	11-20	15.3
July 23	New River Beach, N. B.	10-20	14.2
Aug. 22	Lords Cove, N. B.	12-23	16.0
Sept. 4	Frost Cove, Me.	9-25	15.5
Sept. 5	McDougal's Island, N. B.	11-24	15.1
Sept. 13	Bucks Harbor, Me.	12-24	18.0
Oct. 24	Harmon Harbor, Me.	10-18	13.0
Oct. 30	Harmon Harbor, Me.	10-21	13.6
Nov. 21	White Head Island, N. B.	16-24	20.0
1958			
Mar. 3	Long Island Bay, N. B.	8-17	12.4
Mar. 11	Red Head Harbour, N. B.	7-16	11.4
Mar. 18	East Wolf Island, N. B.	9-17	13.3
Mar. 20	Seely Cove, N. B.	8-19	12.3
Apr. 9	Maces Bay, N. B.	8-16	11.6
Apr. 10	Crow Cove, N. B.	7-16	9.9
May 2	Fox Island, N. B.	9-21	12.5
May 9	Loring Cove, Me.	9-18	13.1
May 16	Birch Cove, N. B.	10-20	15.1
May 16	Little Kennebec, Me.	9-14	10.9
May 22	Mascarene Shore, N. B.	9-19	12.7
June 4	New River Island, N. B.	8-16	9.9
June 10	Bean Island, N. B.	10-21	14.0
June 19	Bean Island, N. B.	11-20	14.0
July 2	Spider Cove, N. B.	12-20	15.7
July 3	St. Andrews Point, N. B.	11-26	16.2
July 4	Bocabec Bay, N. B.	11-20	15.0
July 8	Chandler Bay, Me.	12-20	14.1
July 9	Sprucehead Island, Me.	14-20	16.8
July 10	East Bay, Me.	14-24	16.8
July 11	Great Chebeague Is., Me.	9-25	17.9
July 17	Linekin Bay, Me.	13-19	15.9
July 25	St. Andrews Point, N. B.	12-20	15.2
Aug. 1	New River Beach, N. B.	11-28	15.8
Aug. 19	Cedar & Laireys Is., Me.	9-22	18.0
Aug. 20	Seely Cove, N. B.	15-28	19.8
Aug. 20	Sprucehead Is., Me.	14-23	17.5
Sept. 4	Holt Point, N. B.	15-25	18.7
Sept. 5	Passamaquoddy Bay, N. B.	15-24	18.3
Oct. 15	Lobster Cove, Me.	9-18	12.1
Oct. 17	Capitol Island, Me.	9-17	13.4

Table II. Recaptures from herring taggings, June 20 to November 21, 1957.

Location	Fish tagged		Recaptures		Total recaptures	
	Date	Number	Complete data	Incomplete data	Number	Percent
Moat Island, N. B.	June 20	1,452	13	1	14	0.9
Harbour de Loutre, N. B.	June 21	1,460	23	7	30	2.1
Bocabec, N. B.	July 9	2,974	128	22	150	5.0
New River Beach, N. B.	July 23	2,183	48	10	58	2.7
Pats Cove, N. B.	Aug. 16	2,000	33	3	36	1.8
Lords Cove, N. B.	Aug. 21	1,360	39	2	41	3.0
Frost Cove, Me.	Sept. 4	2,989	32	1	33	1.1
McDougal's Island, N. B.	Sept. 5	2,993	61	5	66	2.2
Bucks Harbor, Me.	Sept. 13	2,959	2	0	2	0.1
Digby Basin, N.S.	Sept. 18	1,985	0	0	0	0.0
Johnson Bay, Me.	Oct. 1	2,860	104	3	107	3.7
Bocabec, N. B.	Oct. 2	2,963	3	0	3	0.1
Cumberland Shore, N. B.	Oct. 3	2,965	2	0	2	0.1
Harmon Harbor, Me.	Oct. 24	461	0	0	0	0.0
Harmon Harbor, Me.	Oct. 30	1,967	250	0	250	12.7
Lear Island, N. S.	Oct. 30	2,951	0	0	0	0.0
White Head Island, N. B.	Nov. 21	973	0	0	0	0.0
Totals		37,495	738	54	792	2.1

Harbour de Loutre tagging (Fig. 3): On June 21, 1,460 herring were tagged at the Half Tide (Biddy Brook) weir. The 8 recaptures during the first 10 days were all made within 2 miles of the tagging site. Thereafter 11 out of 15 (73%) of the recaptures were made away from the tagging site. The recaptures from this tagging also show a movement to the head of the eastern part of Passamaquoddy Bay and along the Bay of Fundy shore towards Saint John.

Bocabec tagging (Fig. 4): On July 9, 2,974 herring were tagged at the Apple Tree weir. During the first 10 days, 92 out of 101 recaptures were within the tagging area. Of the 27 recaptures made subsequently, 12 were made within the tagging area. The high proportion (81%) of recaptures within the tagging area suggests much less movement away from the area than in the tagging described above.

New River tagging (Fig. 5): On July 23, 2,183 herring were tagged at the Harvester weir. Twenty-four of the 33 recaptures in the first 10 days were made in the tagging area. Altogether there were 48 recaptures with complete information and of these, 18 (38%) were taken away from the tagging area. Four of these tagged herring had moved eastward, 1 as far as Saint John, while 14 went westward as far as Bocabec Cove in Passamaquoddy Bay.

Pats Cove tagging (Fig. 6): On August 16, 2,000 herring were tagged at the Tom Stones (Nubbles) weir at Pats Cove near the southern tip of Grand Manan. Thirteen of the 20 recaptures in the first 10 days were made from 2 to 35 miles away from the tagging area as were all of the 13 tags recovered afterwards. There was some evidence of movement to the coast of Maine (3 recaptures were made near Jonesport, Maine) but generally the movement appears to have been eastward around Grand Manan to the eastern end of Deer Island and to the head of Passamaquoddy Bay.

Lords Cove tagging (Fig. 7): On August 21, 1,360 herring were tagged at the Growler weir. Twenty-seven of the recaptures were taken during the first 10 days, 11 within 2 miles of the tagging site; 14 around St. Andrews peninsula and at the head of Passamaquoddy Bay and 2 from Pats Cove, Grand Manan. The remaining 12 recaptures were taken within the next 6 weeks, 2 in the tagging area and 9 at the head of Passamaquoddy Bay. A fairly rapid movement away from the tagging area to the inner part of Passamaquoddy Bay was indicated by these recaptures.

Frost Cove tagging (Fig. 8): On September 4, 2,989 herring were tagged at the Edgar Ritchie weir in Frost Cove, Maine. All recaptures were made more than 2 miles from the tagging site. During the first 10 days following tagging, 20 were recaptured, 16 around St. Andrews peninsula and the St. Croix River west of St. Andrews, 3 on the east side of Passamaquoddy Bay and 1 near Lepreau. Of the remainder, 11 were recaptured within another month in the regions indicated above, while 1 was recaptured in Cobscook Bay. Here again, the movement was chiefly to the head of Passamaquoddy Bay with many returns from the St. Andrews peninsula.

McDougal's Island tagging (Fig. 9): On September 5, 2,993 herring were tagged at the McDougal's Island weir. Thirty-eight were recaught in the first 10-day period; 16 within 2 miles of the tagging site, and 22 up to 20 miles away. Fifteen of the 22 were recaptured westward as far at St. Andrews Point and 7 along the shore towards Point Lepreau. The other 23 recaptures were taken during the next 3 weeks, 5 within the tagging region, and 18 outside of it, all westward around the head of Passamaquoddy Bay as far as St. Andrews. While most of the recaptures were thus from the head of the Bay, a few were from the Bay of Fundy shore almost to Point Lepreau.

Bucks Harbor tagging (Fig. 10): On September 13, 2,959 herring were tagged on the southwest side of Bar Island in Bucks Harbor, Maine, about 25 miles west of Passamaquoddy Bay. Only 2 recaptures were made, 1 not far from the tagging site, while the other was retaken about 50 miles eastward towards Saint John in Lepreau Harbour.

Johnson Bay tagging (Fig. 11): On October 1, 2,860 herring were tagged at the Jesse Tucker weir, in Johnson Bay, Lubec, Maine. Of the 92 recaptured during the first 10 days, 87 were taken at the tagging site, the other 5 in Cobscook Bay, 6 to 7 miles away. The remaining 12 recaptures were made in the next 2 weeks, 4 at the tagging site, 1 in Cobscook Bay, 6 at the head of Passamaquoddy Bay, and 1 in Musquash Harbour to the eastward near Saint John. In this tagging also, the movement was mainly into Cobscook and Passamaquoddy Bays.

Bocabec tagging (Fig. 12): On October 2, 2,963 herring were tagged at the Apple Tree weir in the head of Bocabec or Big Bay. The 3 recoveries were within 2 days of tagging and in adjacent weirs.

Cumberland Shore tagging (Fig. 12): On October 3, 2,965 herring were tagged at the Cumberland Shore weir off Frye or Cailiff Island. Only 2 recaptures were made, both in Musquash Harbour near Saint John, about 25 miles from the tagging site.

Harmon Harbor tagging: No recoveries were made from 461 tagged herring released at Harmon Harbour, Maine, on October 24. However, 250 recoveries were made after a second tagging of 1,967 fish on October 30 (Fig. 10). All recoveries were made on November 6 within a mile of the point of release. Local fishermen believed that strong on-shore winds held fish of the latter tagging in the Bay, whereas off-shore winds after the first tagging did not prevent movement out of the Bay. Two tag patterns were used in the second tagging and 792 and 995 fish were released. Fish tagged with one pattern were held for at least an hour and released in lots of about 500; fish tagged with the other pattern were held for not more than 10 minutes and released in lots of 25. The number of recoveries was 125 for each pattern and indicated no difference in rate of recapture.

Additional taggings (Fig. 13): No recaptures were recorded for 1,985 herring tagged at Digby Basin, N. S., September 18; 461 at Harmon Harbor, Maine, October 24; 2,951 at Lear Island, N. S., near Pubnico, October 30; and 973 at White Head Island, Grand Manan, November 21. The fact that herring fishing ended in each of these localities soon after tagging probably accounted for the lack of recoveries.

TAGGINGS AND RECAPTURES, 1958

From March 3 to October 17 inclusive, 99,974 "sardine" herring were tagged in 39 locations on 42 occasions (Table III). Sixteen locations were in or at the mouth of Passamaquoddy Bay, 10 were located westward along the coast of Maine as far as Great Chebeague Island, 8 were eastward along the New Brunswick shore as far as Dipper Harbour, 3 were off Grand Manan and 2 off Digby Neck, Nova Scotia. A total of 2,790 (2.8%) tags were recovered, 2,688 with complete and 102 with incomplete data concerning time and place of recapture.

Table III. Recaptures from herring taggings, March 3 to October 17, 1958

Location	Fish tagged		Recaptures		Total recaptures	
	Date	Number	Complete data	Incomplete data	Number	Percent
Long Island Bay, N. B.	Mar. 3	1,951	7	0	7	.4
Red Head Harbour, N. B.	Mar. 11	1,965	54	1	55	2.8
East Wolf Island, N. B.	Mar. 18	2,966	143	0	143	4.9
Seely Cove, N. B.	Mar. 20	1,913	10	0	10	.5
Maces Bay, N. B.	Apr. 9	1,913	4	0	4	.2
Crow Cove, N. B.	Apr. 10	971	1	0	1	.1
Fox Island, N. B.	May 2	2,863	43	1	44	1.5
Loring Cove, Me.	May 9	2,970	234	0	234	7.9
Birch Cove, N. B.	May 16	2,974	708	6	714	24.0
Hope Island, Me.	May 16	2,992	41	2	43	1.4
Mascarene Shore, N. B.	May 22	2,479	91	5	96	3.9
St. Andrews Point, N. B.	May 29	2,956	144	5	149	5.0
New River Island, N. B.	June 4	1,937	14	0	14	.7
Bean Island, N. B.	June 10	1,889	67	3	70	3.7
Mill Cove, N. B.	June 17	1,399	180	6	186	13.3
Moose River Cove, Me.	June 17	2,959	30	2	32	1.1
Bean Island, N. B.	June 19	2,960	112	18	130	4.4
Griffin Cove, N.S.	June 24	2,405	3	0	3	.1
Sandy Cove, N. S.	June 25	1,126	0	0	0	0.0
Spider Cove, N. B.	July 2	2,984	335	27	362	12.1
St. Andrews Point, N. B.	July 3	2,945	31	1	32	1.1
Bocabec, Bay, N. B.	July 4	2,993	112	23	135	4.5
Chandler Bay, Me.	July 8	1,480	0	1	1	.1
Sprucehead Island, Me.	July 9	1,970	1	0	1	.1
East Bay, Me.	July 10	2,976	63	0	63	2.1
Great Chebeague Is., Me.	July 11	2,104	1	0	1	.04
Linekin Bay, Me.	July 17	2,933	1	0	1	.03
Navy Island, N. B.	July 25	2,918	19	0	19	.7
Dipper Harbour, N. B.	July 31	2,959	19	0	19	.6
New River Beach, N. B.	Aug. 1	2,970	59	0	59	2.0
Eagle Island, N. B.	Aug. 6	1,472	2	0	2	.1
Cedar and Laireys Is., Me.	Aug. 19	2,128	0	0	0	0.0
Seely Cove, N. B.	Aug. 20	2,531	11	0	11	.4
Sprucehead Island, Me.	Aug. 20	2,949	1	0	1	.03
Gleason Cove, Me.	Aug. 26	2,623	44	0	44	1.6
McCann Cove, N. B.	Aug. 29	2,951	24	0	24	.8
Holt Point, N. B.	Sept. 4	1,494	23	0	23	1.5
Passamaquoddy Bay, N. B.	Sept. 5	2,982	50	1	51	1.7
Long Pond Bay, N. B.	Sept. 23	1,460	0	0	0	0.0
Two Island Harbour, N. B.	Sept. 24	1,460	3	0	3	.2
Lobster Cove, Me.	Oct. 15	2,169	2	0	2	.09
Capitol Island, Me.	Oct. 17	2,935	1	0	1	.03
Totals		99,974	2,688	102	2,790	2.8

As in 1957, only recaptures with complete information are shown in the figures or considered in the text and as before distances from the tagging sites to the recapture positions were measured in straight lines.

Long Island Bay tagging (Fig. 14): Tagging in 1958 began on March 3 with 1,951 herring tagged at Lat. 44°44'27"N., Long. 66°43'05"W. The fish were obtained from a purse-seine catch. Of the 7 recaptures, 4 were made in the tagging locality within 2 days. The other 3 were recaptured 3 weeks later on May 24 near Red Head, 20-25 miles northeast of the tagging location.

Red Head Harbor tagging (Fig. 15): On March 11, 1,965 purse-seined herring were tagged at Lat. 45°05'00"N., Long. 66°35'19"W. Forty-four of the 54 recaptures were made within 2 miles of the tagging site and distributed fairly evenly over a 5-week period. None of the recaptures were made beyond 10 miles from the tagging site. Five recaptures were made eastward in the Pocologan region; 26 westward, chiefly in Seely Cove and Beaver Harbour; 1 at The Wolves Islands; and the remainder (22) at the tagging site.

East Wolf Island tagging (Fig. 16): On March 18, 2,966 herring were tagged from a shut-off seine in Southern Cove on East Wolf Island. Out of a total of 143 recaptures, 90 were made at the tagging site; 52 from April 7-9; 33 on April 19; 3 on April 24; and 2 on May 8. Forty-eight recaptures were made along the mainland shore from Point Lepreau to Beaver Harbour, chiefly within the first 9 weeks, though two recaptures were made on July 19 (18 weeks after tagging). Four recaptures were made 9 weeks and one 12 weeks after tagging at the head of Passamaquoddy Bay.

This tagging indicates that a body of herring lay off The Wolves Islands during March and April, moving in close to shore at irregular intervals. Some of them moved in along the mainland shore from Point Lepreau to Beaver Harbour where they were taken chiefly by purse seiners. Absence of weirs may account for none of the tags showing up in catches in Passamaquoddy Bay before May 20.

Seely Cove tagging (Fig. 17): On March 20, herring were obtained in Seely Cove from a purse seiner and 1,913 were tagged and released at the mouth of this Cove (Lat. 45°05'15"N., Long. 66°38'15"W.). Ten recaptures were made, 3 in the first week, 3 in the third, 3 in the fifth, and 1 in the sixth. Only 1 was recaptured within 2 miles of the tagging site, 6 were retaken 2 to 6 miles eastward along the shore and 2 the same distance westward. One was recaught at The Wolves on April 24.

Maces Bay tagging (Fig. 18): On April 9, herring were obtained in Maces Bay from a purse seiner and 1,913 were tagged and released at Lat. 45°07'10"N., Long. 66°29'42"W. Only 4 tags were recovered, 3 within 2 miles of the tagging site (2 on April 15 and 1 on the 19th) and 1 in Bocabec Bay on May 20.

Crow Cove tagging (Fig. 18): On April 10, 971 purse-seined herring were tagged and released at Lat. 45°06'06"N., Long 66°36'44"W. The single recovery from this tagging was at Mill Cove, Campobello, 15 to 16 miles away on July 7, 13 weeks after tagging.

Fox Island tagging (Fig. 19): On May 2, 2,863 herring were tagged at the Fox Island weir. The 43 recaptures were spread over a 12-week period. Only 1 was retaken within 2 miles of the tagging site and that was in the 11th week following tagging. All 11 recaptures during the first week were made eastward, 3 in Beaver Harbour, 3 off Seely Head and 5 off Pocologan. During the third week, 4 were retaken at Pocologan and 7 in Bocabec Bay. The recaptures in the weeks that followed were made in the same general areas except 1 near the tagging site on July 15 and 1 at Dipper Harbour on July 18.

Loring Cove, Maine, tagging (Fig. 20): On May 9, 2,970 herring were tagged from George Johnson's weir in Loring Cove. None were recovered in United States waters or within 2 miles of the tagging site. All 234 recaptures were made in a 19-week period following tagging. Most (227) of the recaptures were made at the head of Passamaquoddy Bay. One was recaptured at Seely Cove, 1 at St. Andrews Point, and 4 near Pocologan, 1 at Mill Cove, Campobello, and 1off eastern Grand Manan.

The majority of these fish thus appeared to move to the head of Passamaquoddy Bay where they remained for the rest of the season. A few, however, wandered eastward as far as Seely Cove and Pocologan.

Birch Cove tagging (Fig. 21): On May 16, 2,974 herring were tagged and released at the Miller weir in Birch Cove. Of the 708 recaptures, 631 were made within 2 miles of the tagging site. Only 8 recoveries were made outside Passamaquoddy Bay although others were made among the islands at the entrance to the Bay.

The results suggest that these fish remained almost entirely in the inner part of Passamaquoddy Bay throughout the season, although a few appeared to wander away to the islands at the entrance to Passamaquoddy Bay and eastward almost to Point Lepreau.

Hope Island, Maine, tagging (Fig. 22): On May 16, 2,992 herring were tagged and released off Hope Island, Little Kennebec, Maine, about 25 miles southwest of Passamaquoddy Bay. Of the 41 recaptures, 9 were taken the first week and 32 the second week after tagging. All were recaptured within 2 miles of the tagging site.

Mascarene Shore tagging (Fig. 23): On May 22, 2,479 herring were tagged and released from the Mascarene weir on the east side of Passamaquoddy Bay. As at Loring Cove on the west side of Passamaquoddy Bay no recaptures were made within 2 miles of the tagging site. The pattern of movement was similar in that 81 (89%) of the 91 recaptures were made at the head of Passamaquoddy Bay. Seven recaptures were made in other parts of Passamaquoddy Bay, 1 near the northeast end of Campobello Island and 2 eastward as far as New River Beach.

St. Andrews Point tagging (Fig. 24): On May 29, 2,956 herring were tagged and released from the Protection weir. Of the 144 recoveries, 124 (86%) were made at the head of Passamaquoddy Bay. Four recaptures were made at the tagging site, 4 at other points in Passamaquoddy Bay, 9 among the islands at the mouth of this Bay, and 3 near Pocologan.

Here, as in the case of the Loring Cove and Mascarene Shore taggings, the majority of the fish moved to the head of the Bay and remained there most of the season.

New River Island tagging (Fig. 25): On June 4, 1,937 herring were tagged and released from the Bartlett weir off New River Island just west of Point Lepreau. Fourteen recaptures were made over an 8-week period. Eleven of these were recovered within 2 miles of the tagging site, 1 near Saint John about 20 miles eastward, and 2 about 20 miles westward--1 in Bocabec Bay and the other in Mill Cove, Campobello.

Bean Island tagging (Fig. 26): On June 10, 1,889 herring were tagged and released from the Giller weir off Bean Island. Sixty-seven recaptures were made over a 21-week period following this tagging. Here again most of the fish moved to the head of Passamaquoddy Bay where 47 (70%) of the recaptures were made. Six recaptures were made at other points in Passamaquoddy Bay, 2 were recaught at the tagging site and 12 along the shore eastward towards Point Lepreau.

Mill Cove, Campobello, tagging (Fig. 27): On June 17, 1,399 herring were tagged and released from the Mill Cove weir on the eastern end of Campobello Island. Of the 180 recaptures, 163 (91%) were recaptured at the tagging site. The other 17 recaptures were made at various locations in the Passamaquoddy region and eastward as far as Saint John.

Moose River Cove, Maine, tagging (Fig. 28): On June 17, 2,959 herring were tagged and released in the outer part of Moose River Cove, about 8 miles westward from West Quoddy Head. There were 30 recaptures altogether, 1 at and 1 just east of the tagging site. Westward there were 16 recaptured at Cutler and 1 at Jonesport and eastward there was 1 from Grand Manan, 2 from Passamaquoddy Bay and 8 along the New Brunswick shore from Letite to Dipper Harbour.

Bean Island tagging (Fig. 29): On June 19, 2,960 herring were tagged and released from the Giller weir located off Bean Island. Of the 112 recaptures, only 17 were made at the tagging site. Most of the movement was into Passamaquoddy Bay and 82 recaptures were made there. Of the remainder 1 was retaken off the western end of Deer Island 2 in Mill Cove, Campobello, and 10 along the shore from Letite to Musquash Harbour, just west of Saint John.

Griffins Cove, N. S., tagging (Fig. 22): On June 24, 2,405 herring were tagged and released from the Sidney Westcott weir, Digby Neck, N. S. Only 3 recaptures were ever recorded from this tagging, 2 at the tagging site during the first week after tagging and 1 off Deer Island the second week.

Spider Cove tagging (Fig. 30): On July 2, 2,984 herring were tagged and released from the Trial weir in Spider Cove, Bliss Island. The majority of the 335 recaptures were made within 3 weeks of tagging, most of them (270) at the tagging site. The remaining 65 were retaken away from the tagging location in various directions, 49 eastward as far as Dipper Harbour, 9 southwestward to Mill Cove, Campobello, 6 northwestward to the head of Passamaquoddy Bay, and 1 northeastward into the Letang River estuary.

St. Andrews Point tagging (Fig. 31): On July 3, 2,945 herring were tagged and released from the Short Bar weir off St. Andrews Point. In general, the fish moved either northeastward towards the head of Passamaquoddy Bay (21 recoveries) or out of the Bay eastward along the New Brunswick shore (7 recoveries). Three recaptures were made at other points in Passamaquoddy Bay.

Bocabec Bay tagging (Fig. 32): On July 4, 2,993 herring were tagged and released from the Orr weir at the head of Big Bay. Of the 112 recaptures, 102 were made in the first 4 weeks after tagging and the other 10 in the following 6 weeks. Eighty-nine recaptures were made close to the tagging site, 20 near the eastern entrance and 2 near the western entrance to Passamaquoddy Bay, and 1 near Point Lepreau.

Sprucehead Island, Maine, tagging (Fig. 22): On July 9, 1,970 herring were tagged and released from the Harold Simmon's weir off Rockland, Maine. Only 1 recapture was ever recorded and that in the Simmon's weir on July 21.

East Bay, Maine, tagging (Fig. 33): On July 10, 2,976 herring were tagged and released from the Tucker-Parker stop seine in

Cobscook Bay, Maine. Sixty of the 63 recaptures were made within 3 weeks of tagging. Fifty-six recaptures were made near the tagging site, 1 at Little Machias Bay, 4 in other parts of Cobscook Bay, and 2 in Passamaquoddy Bay.

Great Chebeague Island, Maine, tagging (Fig. 34): On July 11, 2,104 herring were tagged and released from Henry Dyer's stop seine off Great Chebeague Island, Casco Bay, near Portland, Maine. Only 1 was ever recorded as recaptured and that on July 16 at Little John Island off Yarmouth, Maine, about 2 to 3 miles from the tagging site.

Linekin Bay, Maine, tagging (Fig. 35): On July 17, 2,933 herring were tagged and released from Brink Chapman's stop seine at the head of Linekin Bay, Boothbay Harbor, Maine. There was only 1 recorded recapture and that on July 21 in Linekin Bay.

Navy Island tagging (Fig. 36): On July 25, 2,918 herring were tagged and released from the Navy Island weir. No recaptures were recorded during the first 3 weeks following tagging. There were 19 recaptures altogether, 14 of them within Passamaquoddy Bay. In addition, there was 1 recapture near the eastern and 2 near the western entrances to Passamaquoddy Bay, and 1 at Musquash near Saint John. The final record for this tagging was a recapture in the fifteenth week on the Nova Scotia side of the Bay of Fundy.

Dipper Harbour tagging (Fig. 37): On July 31, 2,959 herring were tagged and released from the Plumper weir at the entrance to Dipper Harbour. During the first week 15 of the 19 recaptures were recorded, 14 in Sand Cove near Saint John about 18 miles east of the tagging site, and 1 off Lorneville about 13 miles eastward. From 2 to 5 weeks later, 3 were recaught in Musquash Harbour and 1 in Sand Cove. No recoveries were made at the tagging site and all the movement was eastward towards Saint John, 14 of the tagged fish moved about 18 miles in 4 days.

New River Beach tagging (Fig. 38): On August 1, 2,970 herring were tagged and released from the Harvester weir at New River Beach. In the first week after tagging, 53 of the total of 59 recaptures were recorded, all within 2 miles of the tagging site. Two more were recaptured in the second and third weeks, both from the tagging area. During the sixth week, 3 were recovered at the head of Passamaquoddy Bay, almost 20 miles in a straight line westward. The final recapture was made off Fairhaven on the west end of Deer Island on November 10, 15 weeks after tagging.

The majority of these recaptures were made near the tagging site. However, some moved to the westward, as shown by the recaptures at the head of Passamaquoddy Bay and off western Deer Island. This is almost the reverse of the movement shown by recaptures from the Dipper Harbour tagging on the previous day.

Eagle Island tagging (Fig. 37): On August 6, 1,472 herring were tagged and released from the Eagle Island weir just outside and to the east of Letite Passage. Only 2 recaptures were recorded, 1 in the first week about a mile away from the tagging site and 1 six weeks after tagging at the head of Passamaquoddy Bay.

Seely Cove tagging (Fig. 39): On August 20, 2,531 herring were tagged and released from the Comet weir at the western entrance to Seely Cove. Of the 11 recaptures, 4 were made west (as far as Passamaquoddy Bay) of the tagging site, and 7 east (as far as Musquash Harbour) of it. In this tagging, unlike that at either Dipper Harbour or New River Beach, recaptures were made nearly 20 miles away both westward and eastward.

Sprucehead Island, Maine, tagging (Fig. 35): On August 20 also, 2,949 herring were tagged and released from the Edgar Post weir off Sprucehead Island, Maine. On August 26, the single recapture from this tagging was made within 2 miles of the tagging site.

Gleason Cove, Maine, tagging (Fig. 40): On August 26, 2,623 herring were tagged and released from Edwin Evan's weir in Gleason Cove, Maine. There were 44 recaptures, 1 at the tagging site, 5 along the Maine shore inside Passamaquoddy Bay, 5 off the north side of Deer Island, and 33 at the head of Passamaquoddy Bay.

McCann Cove tagging (Fig. 41): On August 29, 2,951 herring were tagged and released from the McCann Cove weir. All 24 recaptures were made inside Passamaquoddy Bay from 1 to 6 weeks after tagging.

Holt Point tagging (Fig. 42): On September 4, 1,494 herring were tagged and released from the Holt Point weir. All 23 recaptures were made in the head of Passamaquoddy Bay, 12 in the first week after tagging and 11 during the second week.

Passamaquoddy Bay tagging (Fig. 43): On September 5, 2,982 herring were tagged and released from purse-seine catches at Lat. 45°02'45"N., Long. 66°59'30"W. in Passamaquoddy Bay, about 1 1/2 miles northwest of Pendleton Island. There were 50 recaptures, 23 within the first week after tagging and the remainder within the next 3 weeks. The general movement of these fish tagged in the deeper central waters of the Bay was northeastward towards the head of Passamaquoddy Bay, some going into the shoaler water where they were taken by the weirs and some remaining off in a little deeper water where they were taken by the purse seiners. A few tagged fish, however, remained in the deeper waters of the Bay and were recaptured off North Harbour, Deer Island.

Two Island Harbour tagging (Fig. 42): On September 24, 1,460 herring were tagged and released from the Good Luck weir, Two Island Harbour, Grand Manan. Three recaptures were made, 1 in the first week after tagging, another in the second week (both within 2 miles of the tagging site) and the third during the sixth week at Pats Cove about 3 miles away.

Lobster Cove, Maine, tagging (Fig. 22): On October 15, 2,167 herring were tagged and released from Bradley's stop-seine in Lobster Cove, Boothbay Harbor, Maine. The 2 recaptures were made in Linekin Bay, Boothbay Harbor, Maine, October 20, 5 days after tagging.

Capitol Island, Maine, tagging (Fig. 34): On October 17, 2,935 herring were tagged and released from Swett's stop-seine at Capitol Island, Boothbay Harbor, Maine. The single recapture was made 3 days later in Linekin Bay, Boothbay Harbor, Maine.

Additional tagging (Fig. 13): No recaptures were recorded from 1,126 herring tagged at Sandy Cove, Digby Neck, N. S., on June 25; 1,480 herring tagged at Chandler Bay, Maine, on July 8; 128 herring tagged at Cedar and Laireys Island, Maine, on August 19; and 1,460 herring tagged at Long Pond Bay on September 23.

DRIFT BOTTLE AND TAG RECOVERIES

During 35 of the tagging experiments in 1958, a total of 1,725 drift bottles were released at the same time as the tagged fish in an attempt to discover whether there was a relationship between herring migrations and the drift of surface waters. Usually an attempt was made to tag 3,000 fish and release 48 weighted bottles during a tagging. The bottles were released in direct relation to the numbers of tagged fish released from time to time during the operation. Bottle recoveries varied from 4.2 to 89.7% with an overall average of 31.6% (Table IV).

In some cases, the tagged herring and the drift bottles moved in the same direction (Fig. 23 and 44), in others, in the opposite directions (Fig. 43 and 45). In many cases, there was no apparent relationship between the direction of the tagged fish and bottle movements. In the remainder there were insufficient recoveries of either tags, bottles or both to draw conclusions.

Table IV. Drift bottle releases and recoveries, 1958.

Location	Date 1958	Releases	Recoveries	Percentage
Red Head Harbour, N. B.	Mar. 11	48	14	29.2
East Wolf Island, N. B.	Mar. 18	48	17	35.4
Seely Cove, N. B.	Mar. 20	48	6	12.5
Maces Bay, N. B.	Apr. 9	48	8	16.7
Crow Cove, N. B.	Apr. 10	48	5	10.4
Fox Island, N. B.	May 2	48	18	37.6
Loring Cove, Me.	May 9	48	19	39.6
Hope Island, Me.	May 16	48	16	33.3
Birch Cove, N. B.	May 15	48	43	89.7
Mascarene Shore, N. B.	May 22	48	14	29.2
St. Andrews Point, N. B.	May 29	48	13	27.0
New River Island, N. B.	June 4	48	16	33.3
Bean Island, N. B.	June 10	48	11	22.9
Mill Cove, N. B.	June 17	48	9	18.7
Moose River Cove, Me.	June 17	48	5	10.4
Bean Island, N. B.	June 19	48	17	37.5
Griffin Cove, N. S.	June 24	48	15	31.3
Sandy Cove, N. S.	June 25	48	2	4.2
Spider Cove, N. B.	July 2	48	14	29.2
St. Andrews Point, N. B.	July 3	48	24	50.0
Bocabec Bay, N. B.	July 4	48	38	79.2
Chandler Bay, Me.	July 8	48	6	12.5
East Bay, Me.	July 10	48	23	48.0
Navy Island, N. B.	July 25	48	15	31.3
Dipper Harbour, N. B.	July 31	44	6	13.4
New River Beach, N. B.	Aug. 1	48	8	16.7
Eagle Island, N. B.	Aug. 6	48	22	45.9
Cedar and Laireys Is, Me.	Aug. 19	48	7	14.6
Sprucehead Island, Me.	Aug. 20	48	34	70.8
Seely Cove, N. B.	Aug. 20	48	8	16.7
Gleason Cove, Me.	Aug. 26	48	15	31.3
McCann Cove, N. B.	Aug. 29	48	34	69.5
Holt Point, N. B.	Sept. 4	48	8	16.7
Passamaquoddy Bay, N. B.	Sept. 5-6	49	20	40.8
Long Pond Bay, N. B.	Sept. 23	48	4	8.3
Two Island Harbour, N. B.	Sept. 24	48	9	18.7
Total		1,725	543	31.5

DISCUSSION

During the 1957 and 1958 operations, 137,469 "sardine" herring were tagged with the "celluloid" opercular tags and a total of 3,582, or 2.6%, were recaptured, 3,428 with complete and 154 with incomplete data on time and place of recapture.

In this section the distance and direction that the tagged herring moved and the length of time between tagging and recaptures are considered. In Tables V to X, and in the text of the discussion, 44 recaptures from Johnson Bay and 250 recaptures from Harmon Harbor taggings are not included because the former were recaught in the release area within a day and the latter were recaught where released within a week. Recoveries varied from 0 to 5.0% in 1957 and 0 to 24.0 % in 1958.

Extent of movement: Table V shows that 234 (52.7%) of the recaptures from the 1957 taggings were made within 2 miles of the points of release while 51 were recaught 3-5 miles away. Beyond this distance, the recaptures declined sharply. Only 6.1% were recaptured over 25 miles away. One was taken 55 miles away (Bucks Harbor, Maine, to Lepreau Basin, New Brunswick). Table VI shows that in the first week following the 1957 tagging, 31% of the recaptures were made over 2 miles away from the tagging sites. This percentage increased during the following week until after 4 weeks all the recaptures were made outside of the tagging areas.

Table VII shows that 56.1% of the recaptures from the 1958 taggings were made within 2 miles of the release points and 6.4% made 3-5 miles away. In the 5-10 miles distance, 25.4% were recaptured compared to 16.6% in 1957. However, as in 1957, the 1958 recaptures declined sharply beyond this with 55 miles being about the greatest distance between the points of release and recapture. During the first week 35% (Table VI) were recaptured more than 2 miles away. However, as in 1957, this percentage increased with time, being 59% in the third week and 70% in the 5-to 24-week period. Recaptures within 2 miles of the tagging area were thus similar in the 2 years, 53% in 1957, and 56% in 1958.

Even though the number of recaptures from distant areas increased with time, some herring travelled long distances within short periods (Table VIII). The average rate of movement for these herring was 1.0 miles per day with a range of 0.2 to 11.3 miles per day. Recovery data do not show the amount of wandering between the points of release and recapture. However, it is interesting to note and perhaps significant that this maximum rate of movement is very similar to the calculated speeds for non-tidal surface currents in the same area (Appendix 1, Ch.2).

Table V. Recaptures of tagged herring at various distances from points of release (1957).

Taggings	Distance in miles 0-2	2-5	5-10	10-25	25-55	Totals
Moat Island, N. B.	1	3	7	0	2	13
Harbour de Loutre, N. B.	12	0	3	8	0	23
Bocabec, N. B.	101	7	2	12	6	128
New River Beach, N. B.	20	10	7	11	0	48
Pats Cove, N. B.	7	0	8	4	14	33
Lords Cove, N. B.	13	0	24	2	...	39
Frost Cove, Me.	0	18	4	9	1	32
McDougal's Island, N. B.	29	13	13	6	...	61
Bucks Harbor, Me.	1	0	0	0	1	2
Johnson Bay, Me.	47	0	6	6	1	60
Bocabec, N. B.	3	0	...	...	...	3
Cumberland Shore, N. B.	0	0	0	0	2	2
Totals	234	51	74	58	27	444
Percentage	52.7	11.5	16.6	13.1	6.1	100

Table VI. Percentage recaptures of herring within and outside tagging areas by weekly periods 1957 and 1958.

	1957		1958	
Weekly periods	within (0-2 miles)	outside (2-55 miles)	within (0-2 miles)	outside (2-55 miles)
	%	%	%	%
1st	69	31	65	35
2nd	47	53	67	33
3rd	19	81	41	59
4th	35	65	60	40
5-24th	0	100	30	70
Percent	53	47	56	44

Table VII. Recaptures of tagged herring at various distances from points of release (1958).

Taggings	Distance in miles 0-2	2-5	5-10	10-25	25-55	Totals
Long Island Bay, N. B.	4	0	0	3	..	7
Red Head Harbour, N. B.	44	0	10	..	..	54
East Wolf Island, N. B.	90	0	36	17	..	143
Seely Cove, N. B.	1	7	2	..	..	10
Maces Bay, N. B.	3	0	0	1	..	4
Crow Cove, N. B.	0	0	0	1	..	1
Fox Island, N. B.	1	3	8	31	..	43
Loring Cove, Me.	0	1	227	6	..	234
Birch Cove, N. B.	631	51	11	15	..	708
Hope Island, Me.	41	..	..	..	..	41
Mascarene Shore, N. B.	0	2	88	1	..	91
St. Andrews Point, N. B.	4	20	117	3	..	144
New River Island, N. B.	11	0	0	3	..	14
Bean Island, N. B.	2	7	15	43	..	67
Mill Cove, N. B.	163	2	8	4	3	180
Moose River Cove, Me.	1	1	16	6	6	30
Bean Island, N. B.	17	11	31	52	1	112
Griffin Cove, N.S.	2	0	0	0	1	3
Spider Cove, N. B.	270	1	23	41	..	335
St. Andrews Point, N. B.	2	5	23	1	..	31
Bocabec Bay, N. B.	74	12	3	23	..	112
Sprucehead Island, Me.	1	..	..	..	..	1
East Bay, Me.	56	2	2	3	..	63
Great Chebeague Is., Me.	1	..	..	..	..	1
Linekin Bay, Me.	1	..	..	..	..	1
Navy Island, N. B.	0	4	13	0	2	19
Dipper Harbour, N. B.	0	0	3	16	..	19
New River Beach, N. B.	55	0	0	4	..	59
Eagle Island, N. B.	1	0	0	1	..	2
Seely Cove, N. B.	0	1	7	3	..	11
Sprucehead Island, Me.	1	..	..	..	..	1
Gleason Cove, Me.	4	5	3	32	..	44
McCann Cove, N. B.	3	18	3	..	..	24
Holt Point, N. B.	20	3	..	..	..	23
Passamaquoddy Bay, N. B.	0	16	34	..	..	50
Two Island Harbour, N. B.	2	1	..	..	..	3
Lobster Cove, Me.	2	..	..	..	..	2
Capitol Island, Me.	1	..	..	..	..	1
Totals	1,509	173	683	310	13	2,688
Percentage	56.1	6.4	25.4	11.6	.3	100

Table VIII. Time lapse between release and recapture of tagged herring that moved 20 to 55 miles.

Distance (miles)	No. of fish	Days from release to recapture Min.	Max.	Av.
20-25	48	2	101	32
25-30	15	6	60	20
30-35	11	7	69	22
35-40	8	4	63	26
40-45	3	16	34	26
45-55	3	9	102	43

Days to recapture: There was considerable variation in the length of time between tagging and recapture. Of the recaptures from 1957 taggings (Table IX), 52.2% were made within a week of release, 26.1% in the second week and the percentages declined steadily over the next 10 weeks. The maximum period before recovery was 82 days, while the mean number of days from release to recapture for all 1957 taggings was 12 days.

In 1958, the pattern of recaptures was somewhat different. Only 24.4% were retaken in the first week while 36.5% were recaptured during the second week (Table X). A much larger proportion was retaken in the third week in 1958 than in 1957, 18.8% compared to 9.7%. The percentage retaken declined regularly thereafter until the 24th week. The longest time between release and recapture was 165 days while the average number of days from release to recapture for the 1958 taggings was 17 days.

A comparison of the recaptures shows that in 1957 and 1958 about 97% and 91% respectively were made in the first 5 weeks. However, in 1957 all recaptures were made within 12 weeks with the maximum time at large being 82 days while in 1958 recaptures were made over a 24 week period with the maximum time at large being 165 days.

Direction of movement: Slightly over half the recaptures for 1957 and 1958 showed little movement, that is they were recaptured within 2 miles of the tagging site. Among the other recaptures no regular change in direction of movements was evident. Movements away from the tagging sites were generally in more than one direction. Throughout the season herring moved both into and out of Passamaquoddy Bay.

Movement into Passamaquoddy Bay occurred from as far east as New River (Fig. 5), as far south as southern Grand Manan (Fig. 6), and west as far as Bucks Harbor, Maine (Fig. 10). However, there was

Table IX. Recaptures of tagged herring at weekly intervals following tagging in 1957.

Taggings	Time to recapture									
	1st	2nd	3nd	4th	5th	6th	7th	8th	9-12th	Total
Moat Island, N. B.	0	1	5	4	1	0	0	0	2	13
Harbour de Loutre, N. B.	8	6	6	3	..	..	..	..	..	23
Bocabec, N. B.	72	40	12	0	2	1	1	..	..	128
New River Beach, N. B.	26	12	4	4	0	0	0	0	2	48
Pats Cove, N. B.	14	10	2	3	2	0	0	0	2	33
Lords Cove, N. B.	14	15	1	4	0	1	3	1	..	39
Frost Cove, Me.	11	15	4	1	0	1	..	..	..	32
McDougal's Island, N. B.	34	14	3	10	..	..	..	..	..	61
Bucks Harbor, Me.	0	1	1	..	..	..	..	..	..	2
Johnson Bay, Me.	48	2	5	5	..	..	..	..	..	60
Bocabec, N. B.	3	..	..	..	..	..	..	..	..	3
Cumberland Shore, N. B.	2	..	..	..	..	..	..	..	..	2
Totals	232	116	43	34	5	3	4	1	6	444
Percentage	52.2	26.1	9.7	7.7	1.1	0.7	9.9	0.2	1.4	100

but little movement from the westward (Fig. 10, 22, 28, 34, 35) and only 1 recapture made in New Brunswick from the Nova Scotia tagging (Fig. 22).

Recaptures in Letite and the Western Passages were few, possibly because there were not many weirs in these locations. However, the recoveries indicated a possible preferencefor Letite Passage over Western Passage.

Most recoveries from releases inside Passamaquoddy Bay were made within the Bay itself, but some were retaken in the vicinity of Letite Passage as well as eastward along the mainland shore as far as Saint John. The earliest tagging inside the Bay was at Loring Cove, Maine, on May 9, 1958 (Fig. 20) and three more taggings were carried out during that month at Birch Cove, Mascarene Shore and St. Andrews Point (Table III and Fig. 21, 23, 24). Of 1,177 recaptures from these 4 taggings, 1,140 (96.9%) were retaken inside Passamaquoddy Bay and mainly at its head. Only 1.6% were recaptured among the islands at the mouth of the Bay, 1.5% eastward along shore and none southward or westward along the Maine coast. No taggings were carried out inside the Bay in June in

Table X. Recaptures of tagged herring at weekly intervals following tagging in 1958.

Taggings	Time to recapture									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9-24th	Total
Long Island Bay, N. B.	4	0	3	..	..	..	..	..	..	7
Red Head Harbour, N. B.	11	5	13	5	9	2	1	0	8	54
East Wolf Island, N. B.	16	5	9	53	35	9	3	5	8	143
Seely Cove, N. B.	3	0	3	0	3	1	..	..	..	10
Maces Bay, N. B.	2	1	0	0	0	1	..	..	..	4
Crow Cove, N. B.	0	0	0	0	0	0	0	0	1	1
Fox Island, N. B.	11	0	11	8	4	2	0	0	7	43
Loring Cove, Me.	5	64	136	13	9	0	2	1	4	234
Birch Cove, N. B.	170	399	35	31	5	19	5	6	38	708
Hope Island, Me.	9	32	..	..	..	..	..	..	..	41
Mascarene Shore, N. B.	46	18	9	1	0	6	2	1	8	91
St. Andrews Point, N. B.	56	51	3	2	12	6	5	0	9	144
New River Island, N. B.	2	0	3	3	0	3	2	1	..	14
Bean Island, N. B.	0	2	32	10	8	4	3	3	5	67
Mill Cove, N. B.	54	2	103	10	9	1	0	0	1	180
Moose River Cove, Me.	0	3	2	2	4	17	1	0	1	30
Bean Island, N. B.	23	48	9	14	8	3	4	0	3	112
Griffin Cove, N. S.	2	1	..	..	..	..	..	..	..	3
Spider Cove, N. B.	71	171	77	8	6	0	1	0	1	335
St. Andrews Point, N. B.	7	12	6	2	0	1	1	1	1	31
Bocabec Bay, N. B.	24	63	7	8	0	0	0	6	4	112
Sprucehead Island, Me.	0	1	..	..	..	..	..	..	..	1
East Bay, Me.	11	29	20	1	0	1	0	0	1	63
Great Chebeague Is., Me.	1	..	..	..	..	..	..	..	..	1
Linekin Bay, Me.	1	..	..	..	..	..	..	..	..	1
Navy Island, N. B.	0	0	0	3	2	1	7	1	5	19
Dipper Harbour, N. B.	15	1	1	0	2	..	..	..	..	19
New River Beach, N. B.	53	1	1	0	0	3	0	0	1	59
Eagle Island, N. B.	1	0	0	0	0	1	..	..	..	2
Seely Cove, N. B.	6	2	2	1	..	..	..	..	..	11
Sprucehead Island, Me.	1	..	..	..	..	..	..	..	..	1
Gleason Cove, Me.	7	21	14	1	1	..	..	..	..	44
McCann Cove, N. B.	4	16	3	0	0	1	..	..	..	24
Holt Point, N. B.	12	11	..	..	..	..	..	..	..	23
Passamaquoddy Bay, N. B.	23	22	2	3	..	..	..	..	..	50
Two Island Harbour, N. B.	1	1	0	0	0	1	..	..	..	3
Lobster Cove, N. B.	2	..	..	..	..	..	..	..	..	2
Capitol Island, Me.	1	..	..	..	..	..	..	..	..	1
Totals	655	982	504	179	117	83	37	25	103	2,688
Percentage	24.4	36.5	18.8	6.7	4.4	3.1	1.4	.9	3.8	100

either 1957 or 1958. In July, however, there were some in both years (Fig. 4, 31, 32, 36). In 1957, 85.9% of the recaptures were made inside the Bay and 14.1% among the islands at the mouth of the Bay and eastward as far as Point Lepreau. In 1958, 79.6% were recaught inside the Bay and 20.4% among the islands and eastward to Musquash Harbour. The recaptures from August taggings (Fig. 40, 41, 42) within the Bay were all made inside Passamaquoddy Bay while in September the recaptures inside (Fig. 8, 9, 43) were 88.2 and 98.0% respectively, for the two years. Thus, the taggings inside Passamaquoddy Bay showed that there was more movement out in July than during the other months with slightly more in 1958 than 1957.

Tagging among the islands at the mouth of Passamaquoddy Bay in May showed a tendency for the tagged herring to move rapidly away either into the Bay or eastward towards Point Lepreau (Fig. 19). In June most of the recaptures were either among the islands at the mouth of the Bay (56.5%) or in Passamaquoddy Bay, with few (5.3%) to the eastward (Fig. 26, 27, 29). However, the recaptures from July tagging among the islands were made chiefly near the tagging site (83.6%), with 14.6% taken to the eastward and a few (1.8%) within Passamaquoddy Bay (Fig. 30). In August the recaptures were made either among the islands or in Passamaquoddy Bay, few eastward (Fig. 7, 37). No tagging was done in September. October tagging showed that the majority of the recaptures were made locally (Fig. 11). Thus, the movement shown by the recoveries from taggings among the islands at the mouth of Passamaquoddy Bay in May was into the Bay or eastward along shore, in June it was mainly into the Bay and in July eastward. In August, the movement was again chiefly into the Bay.

As in most other taggings, herring tagged east of Passamaquoddy Bay were chiefly recovered locally. However, in both March and April there was some movement to the westward even into Passamaquoddy Bay (Fig. 15, 17, 18). No tagging was done in May. June tagging gave recaptures to the east and west and in Passamaquoddy (but to a less extent than earlier) (Fig. 25). While one tagging in July at New River just west of Point Lepreau yielded about the same pattern of recaptures as obtained in June, tagging at Dipper Harbour just east of Point Lepreau showed all the recaptures made still farther eastward, some almost to Saint John and none locally or westward. August tagging just west of Point Lepreau showed some movement eastward as well as westward into Passamaquoddy Bay. No taggings were conducted later in the season in the eastern section of the area.

Some taggings were carried out at Grand Manan and at The Wolves Islands, south of Passamaquoddy Bay. Almost two-thirds of the recaptures from the March tagging at Grand Manan (Fig. 14) were made locally (within 2 miles of the tagging site) and the remainder were recaught along the mainland shore between Deadman Head and Point Lepreau. Tagging at The Wolves (Fig. 16) in March resulted in 63% local recaptures, 32% along the mainland shore from Deadman Head to Point Lepreau, 4% among the islands at the mouth of Passamaquoddy Bay and 1% in the Bay. August tagging off southern Grand Manan (Fig. 6) showed that 48% of the recaptures were made locally, 9% along the coast of Maine and the remaining 43% were retaken among the islands at the mouth of Passamaquoddy Bay or in the Bay itself. The 3 recoveries from the September tagging off southern Grand Manan (Fig. 42) were all made locally. In general these taggings showed a movement northward towards Passamaquoddy or immediately east in March and August but not in September. No taggings were carried out in the other months.

Ten percent of the recaptures from the tagging at Moose River (Fig. 28), a few miles west of Passamaquoddy Bay, were made locally, 57% were retaken farther west along the shore of Maine and 33% eastward--7% inside Passamaquoddy Bay and 26% along the shore from Fryes Island to Dipper Harbour. The Bucks Harbor tagging (Fig. 10) yielded 1 recapture to the east, close to Point Lepreau. In the other taggings along the coast of Maine, recoveries were, mainly, local (Fig. 22, 34, and 35). There is thus some movement of herring from the extreme easterly part of the coast of Maine to the Passamaquoddy area and eastward but little or none from the more westerly Maine shore.

Four taggings on the Nova Scotian side of the mouth of the Bay of Fundy (Fig. 13, 22) yielded only 3 recaptures. These were tagged at Griffin Cove, Digby Neck, on June 24, 1958. One was made at Deer Island at the mouth of Passamaquoddy Bay. Thus, only 1 from a total of 8,467 herring tagged in Nova Scotia is known to have crossed to the Passamaquoddy area. Only 2 are known to have crossed from the Passamaquoddy area to Nova Scotia, 1 from the Mill Cove, Campobello, tagging, June 17, 1958, (Fig. 27), and 1 from the Navy Island tagging, July 25, 1958, (Fig. 36).

The taggings showed that in March, April, May, and June the movement of marked herring was in general to Passamaquoddy Bay or the shore as far eastward as Point Lepreau. Little movement out of Passamaquoddy Bay took place at that time of year. However, in July more movement out of the Bay and to the eastward occurred, especially in 1958, even though fish from outside continued to move in. In August the inward movement continued while the outward movement declined. Tagging in September and October showed much less movement in all directions than at other times of the year.

The heavy fishery carried on during most of the summer and autumn in 1957 at the head of Passamaquoddy Bay reflected the concentration of herring there as indicated by the tagging. The movement towards Point Lepreau and Saint John County in July-August 1958 was confirmed by a definite increase in the fishery in this area compared to earlier in 1958 and at any time during 1957.

Drift bottle vs tagged fish movements: These experiments indicated that tagged herring do not always move in the same direction as the surface currents. Sometimes the surface layer may be very shallow and have no effect on the movements of the fish. While there is insufficient evidence to establish a pattern of herring migration, there is a suggestion of random movement with some tendency to swim against the current. There are undoubtedly other factors affecting migration, such as enemies, reaction to light, vertical distribution, etc., and further investigation will be necessary to establish a pattern.

SUMMARY AND CONCLUSIONS

Tagging experiments have provided information on the local movements of immature herring 1 to 3 years old. Tagging 137,469 of these "sardine" herring with opercular tags in the outer part of the Bay of Fundy, especially on the New Brunswick side, and along the Maine coast yielded 3,582 or 2.6% recaptures. About 50% of the recaptures were made within 2 miles of the release area during the first week. Remaining recaptures were spread over distances up to 55 miles. Some recaptures, 20 to 55 miles from the above areas, were made within 2 days, others up to 102 days. Mean time for release to recapture was 12 days in 1957 and 17 days in 1958. The maximum time before recovery was 82 days in 1957 and 165 days in 1958.

The number of recaptures from distant areas increased with time. However, some herring travelled long distances (always measured in straight lines from release to recapture points) within short periods. The average rate of movement for long distance (20-55 miles) travellers was 1.0 miles per day with a range of 0.2 to 11.3 miles per day. It is interesting and perhaps significant that this maximum speed is very close to the calculated speed of the non-tidal surface currents in the same area.

Although about half of the recaptures indicated little movement from the tagging locations, the other half showed movement of distances up to 55 miles. Recaptures from taggings outside the Bay showed movement towards Letite Passage and the head of Passamaquoddy Bay as well as towards Point Lepreau. Recaptures from the Grand Manan taggings indicated a movement along the southeastern coast of Grand Manan to the head of Passamaquoddy Bay as well as a little movement westward to the coast of Maine.

Recaptures from taggings inside Passamaquoddy Bay showed that movements were mainly within the Bay with some towards Western and Letite Passages and as far eastward as Saint John. Movements within Passamaquoddy Bay from both the vicinity of Western Passage and Letite Passage were predominantly to the head of the Bay, especially to Bocabec or Big Bay. Sometimes these movements were along shore as in 1957 (Fig. 8, 9) and sometimes in deeper waters as in 1958 (Fig. 20, 23, 40). Movements out of the Bay reached a peak in July and were greater in 1958 than 1957.

More recaptures were made in the Letite area than the Western Passage area indicating a possible preference for Letite Passage as a means of entering or leaving Passamaquoddy Bay.

Little movement of tagged fish took place between Passamaquoddy Bay and either the Nova Scotian shore of the Bay of Fundy or the coast of Maine.

Drift bottles released during tagging operations showed that the tagged fish did not always move in the same direction as the surface currents.

These tagging experiments in 1957 and 1958 showed that herring moved freely in and out of Passamaquoddy and Cobscook Bays during the fishing season from May to October with some tendency to concentrate at the head of Passamaquoddy Bay. It is expected that the installation and operation of the proposed Passamaquoddy power dams will not affect the movement of herring to the Quoddy Region, nor should it affect the distribution of fish except in the Bays and immediately outside the dams. Herring should arrive outside the dams and filling gates in both Western and Letite Passages as before, but, since the filling gates are only open for about 5 hours each day, the movement of fish into Passamaquoddy Bay will be delayed. This will affect the rate at which herring accumulate inside Passamaquoddy Bay but since the percentage recaptures suggest that fishing mortality is low (probably 2% or less), there should be no reduction in the overall abundance of herring inside the Bay. Herring will not be able to enter Cobscook Bay directly from the outside. Entry into Cobscook Bay and exit from Passamaquoddy Bay will be possible only through the turbines which lead into Cobscook Bay. As a result, movement into Cobscook Bay and away from both bays will be altered both in time and direction.

ACKNOWLEDGMENTS

We wish to acknowledge the co-operation of the sardine fishermen and the various plant operators and employees in the return of the tags. Grateful appreciation is extended to the various Canadian Fisheries Officers, especially K. E. Bates, J. P. Cowie, F. W. Durant, and W. C. Hodges for the purchase and careful recording of tags. Records of returns in the United States were handled by H. C. Boyar, C. Larsen, and J. P. Wentworth, U. S. Bureau of Commercial Fisheries.

Special acknowledgment is made of the co-operation of Mr. L. W. Scattergood, U. S. Bureau of Commercial Fisheries, Boothbay Harbor laboratory, for permission to use the results of ten tagging experiments carried out under his direction and for providing technical assistance in many of the other taggings.

The authors also appreciate the extra time and effort given and the enthusiasm with which the technical personnel of the Pelagic Fish Investigation of the Fisheries Research Board of Canada at St. Andrews, N. B., carried out the field program.

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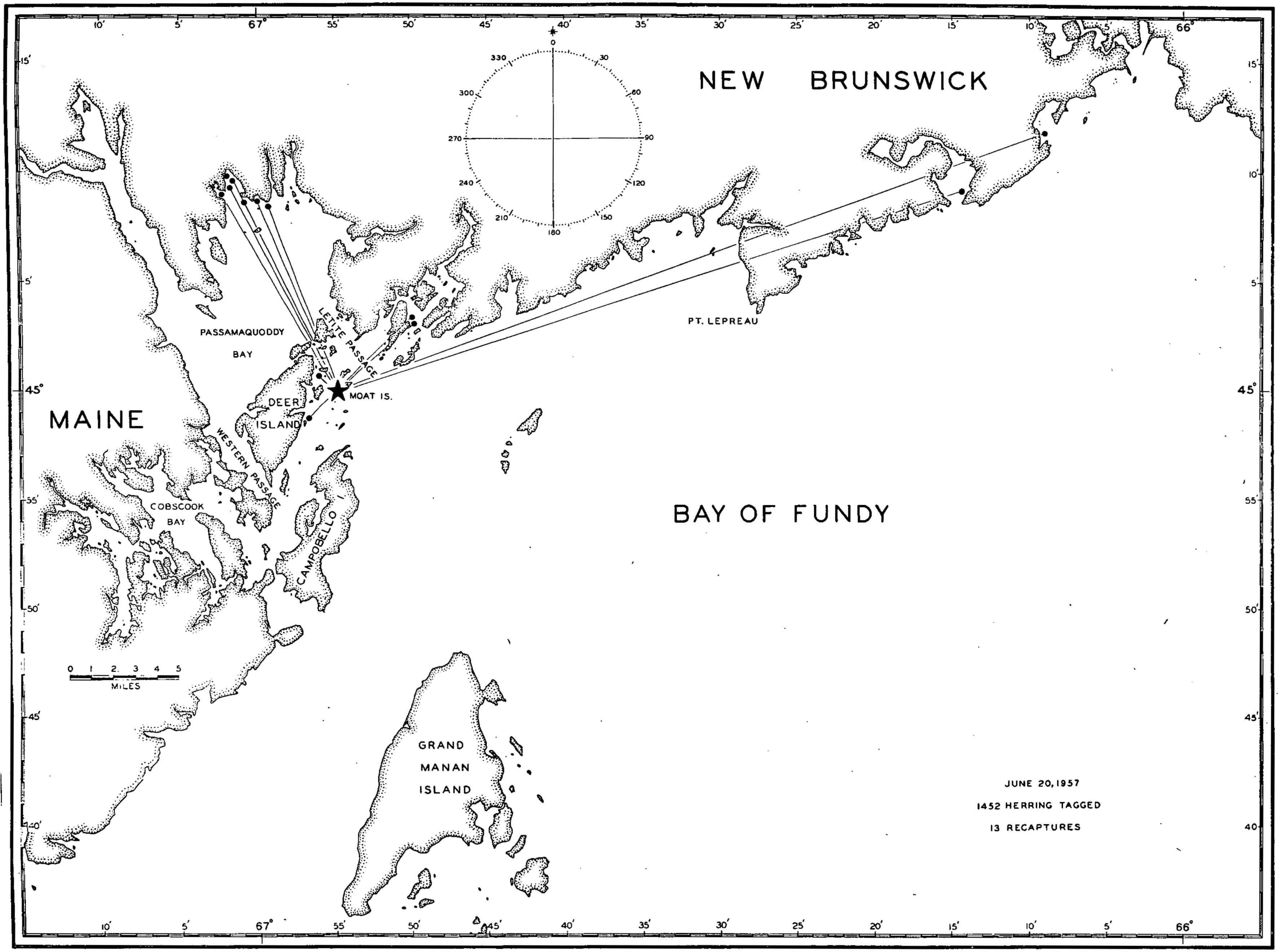


Figure 2. Recaptures of herring tagged at Moat Island, N. B., on June 20, 1957.

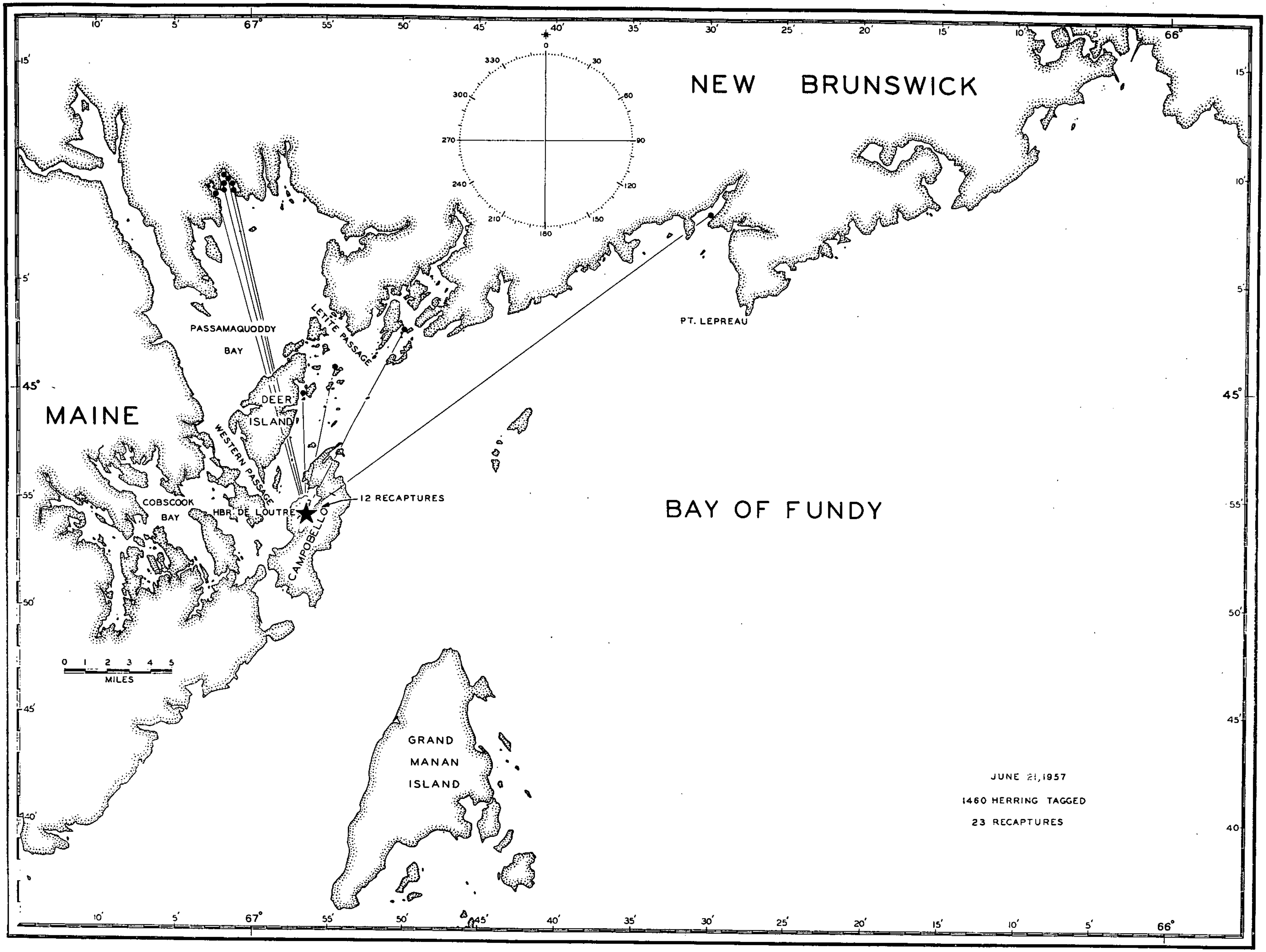


Figure 3. Recaptures of herring tagged at Harbour de Loutre, N. B., on June 21, 1957.

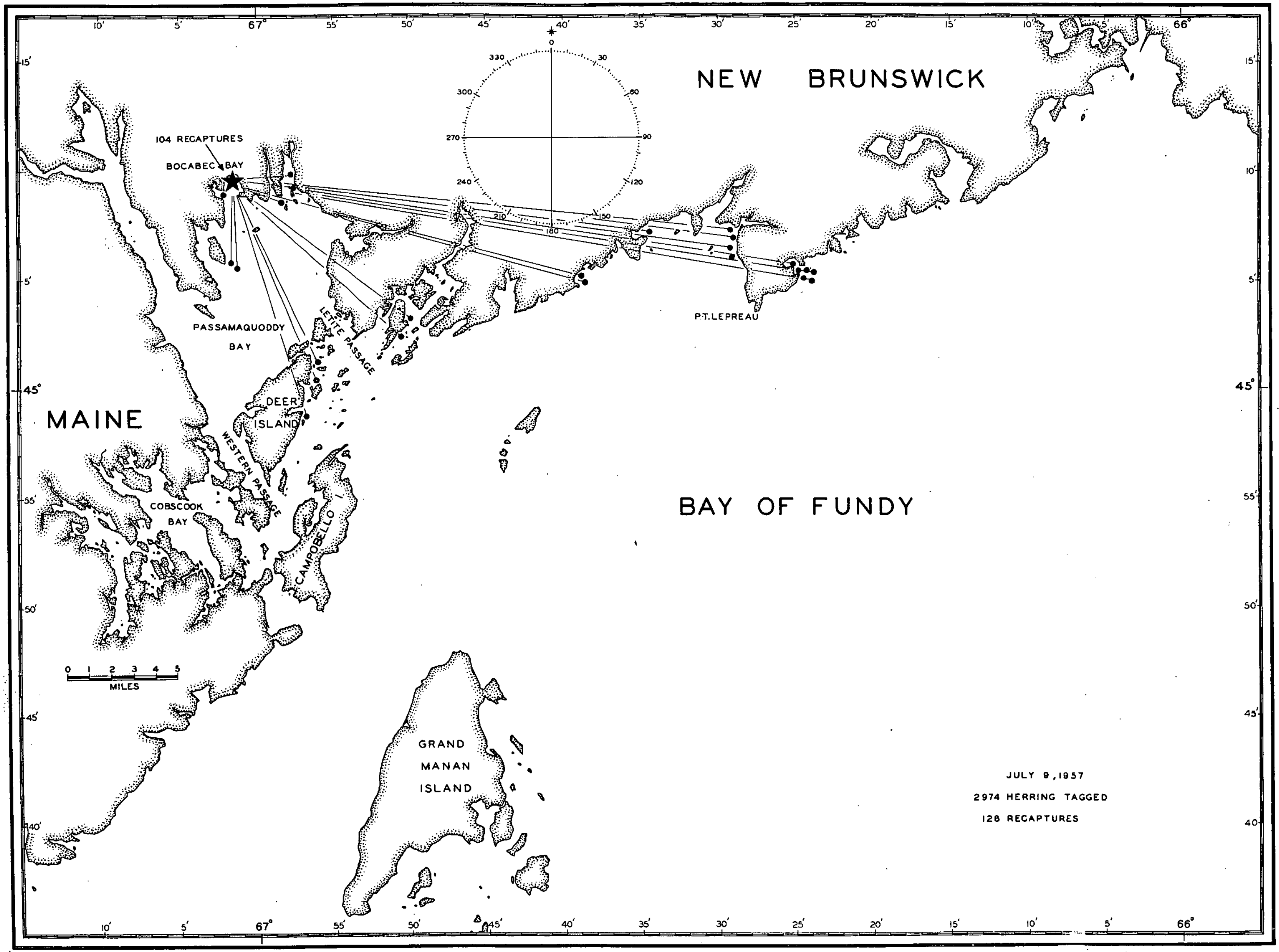


Figure 4. Recaptures of herring tagged at Bocabec, N. B., on July 9, 1957.

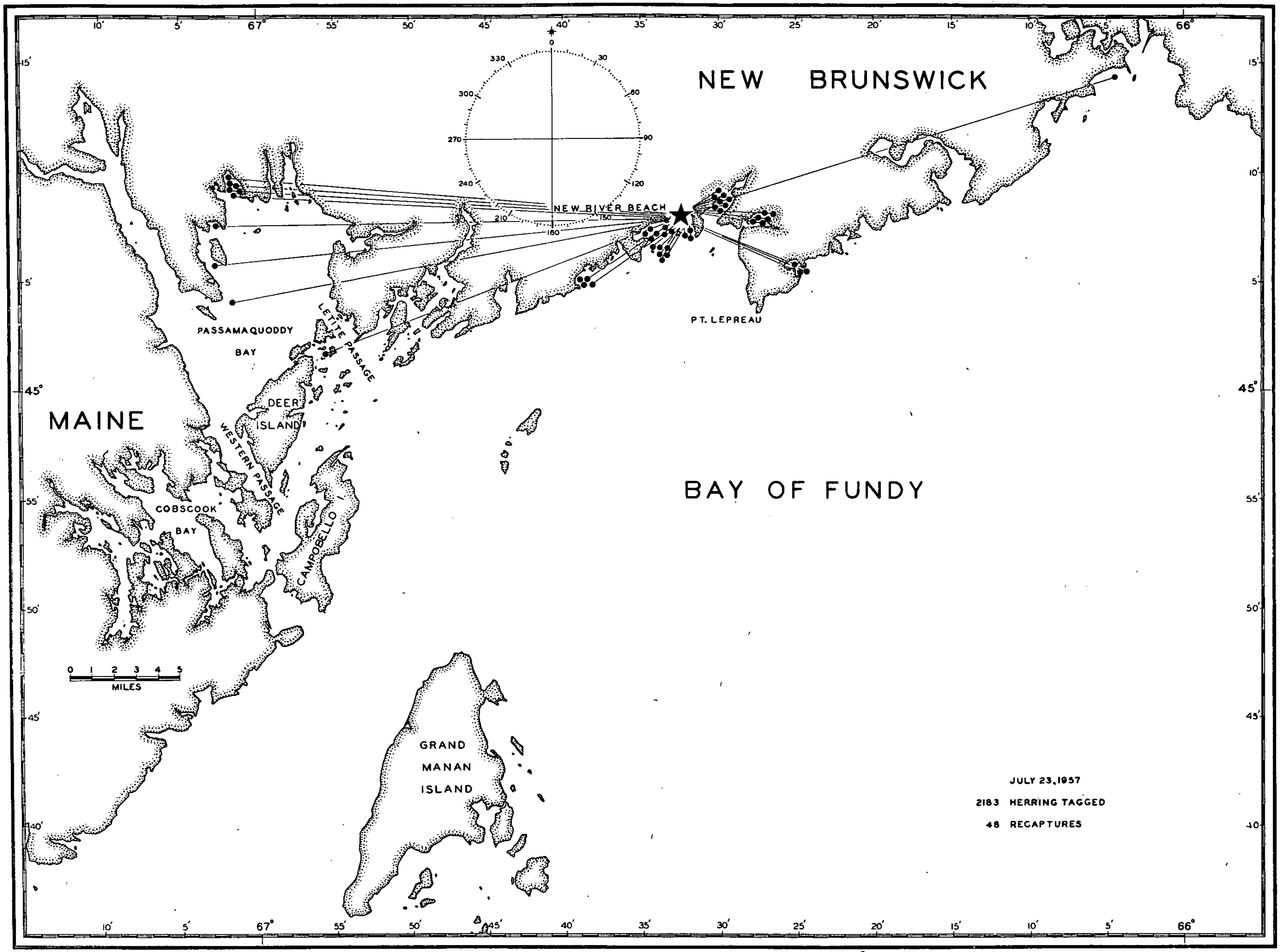


Figure 5. Recaptures of herring tagged at New River Beach, N. B., on July 23, 1957.

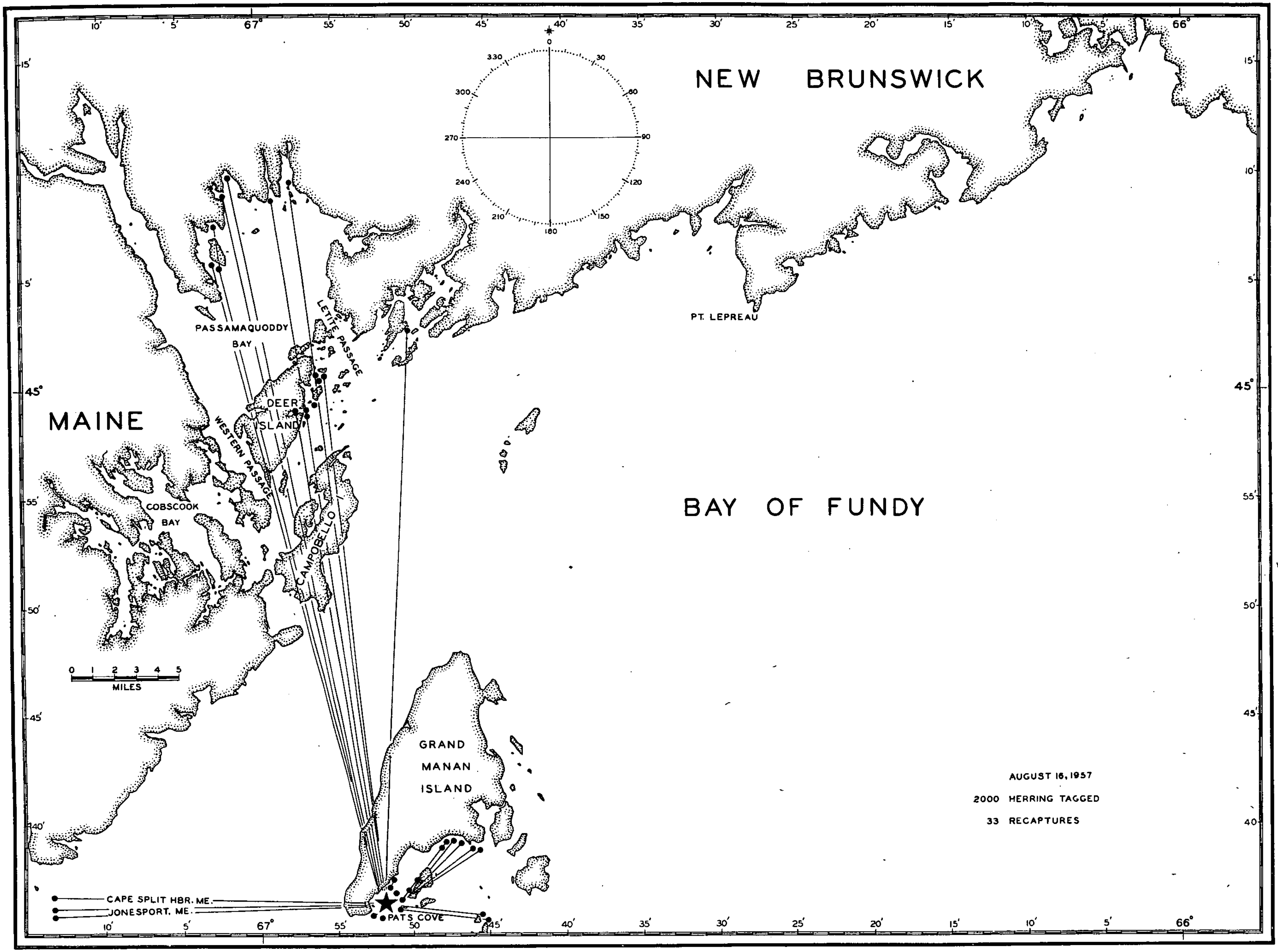


Figure 6. Recaptures of herring tagged at Pats Cove, N. B., on August 16, 1957.

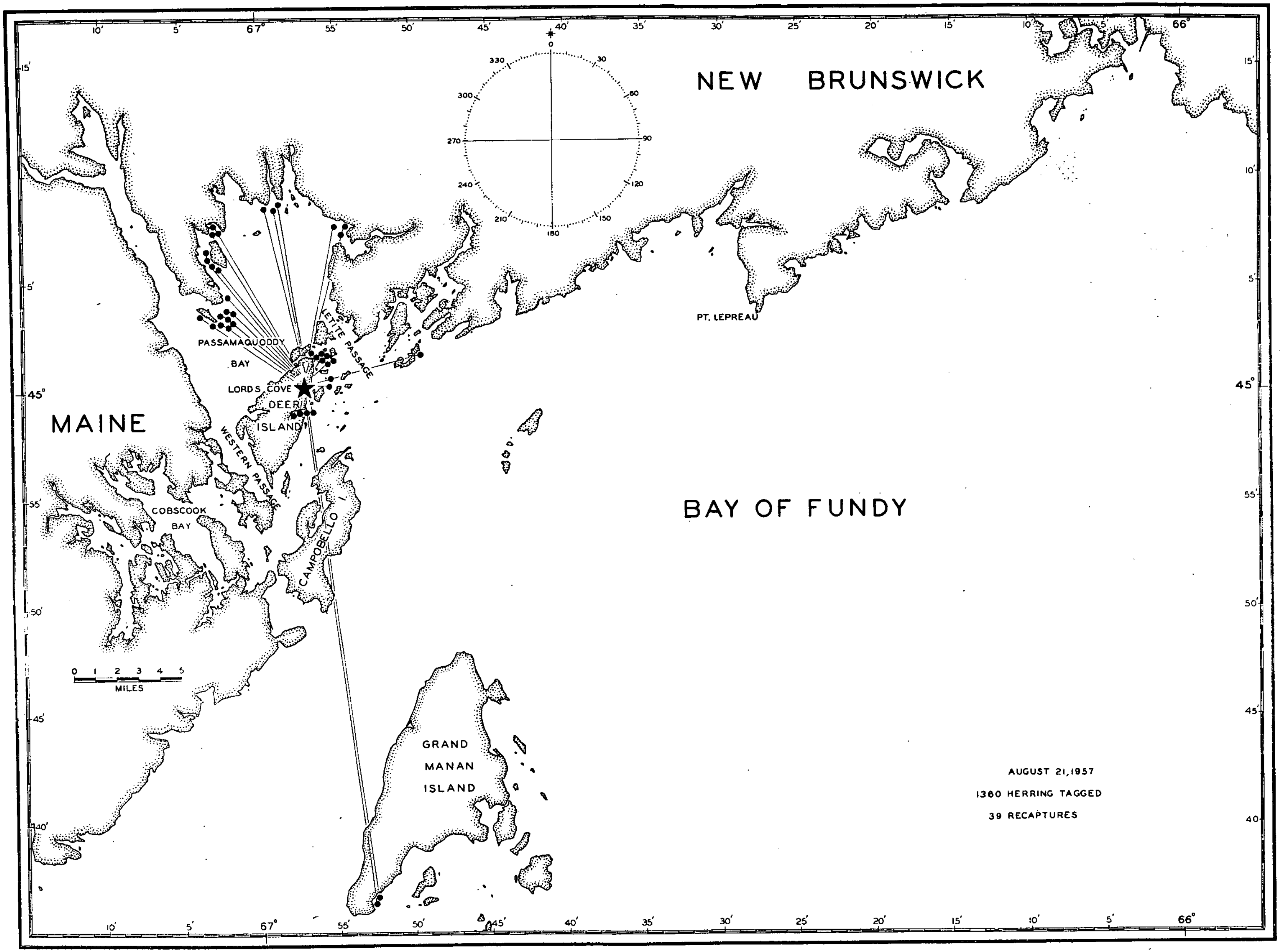


Figure 7. Recaptures of herring tagged at Lords Cove, N. B., on August 21, 1957.

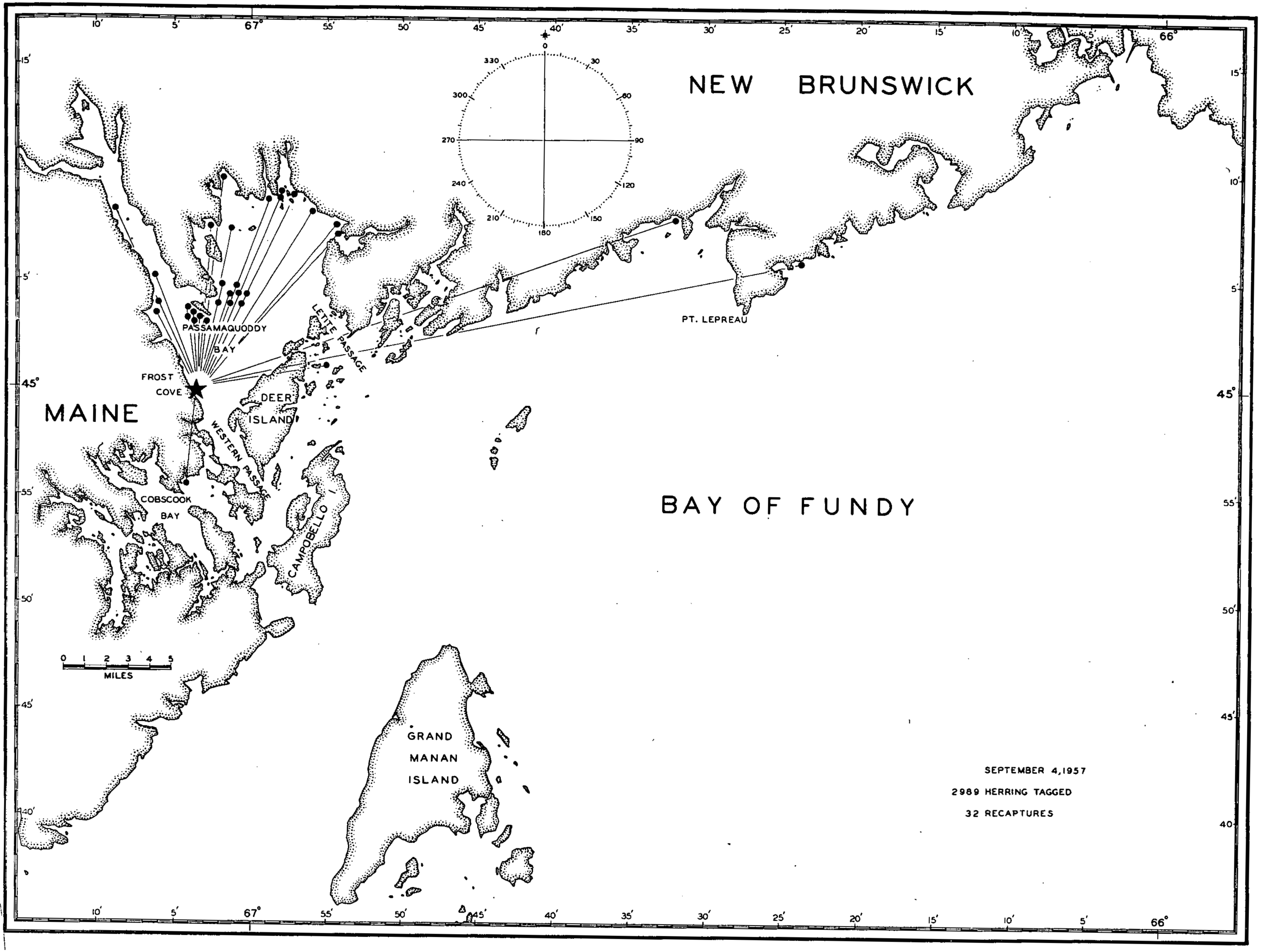


Figure 8. Recaptures of herring tagged at Frost Cove, Me., on September 4, 1957.

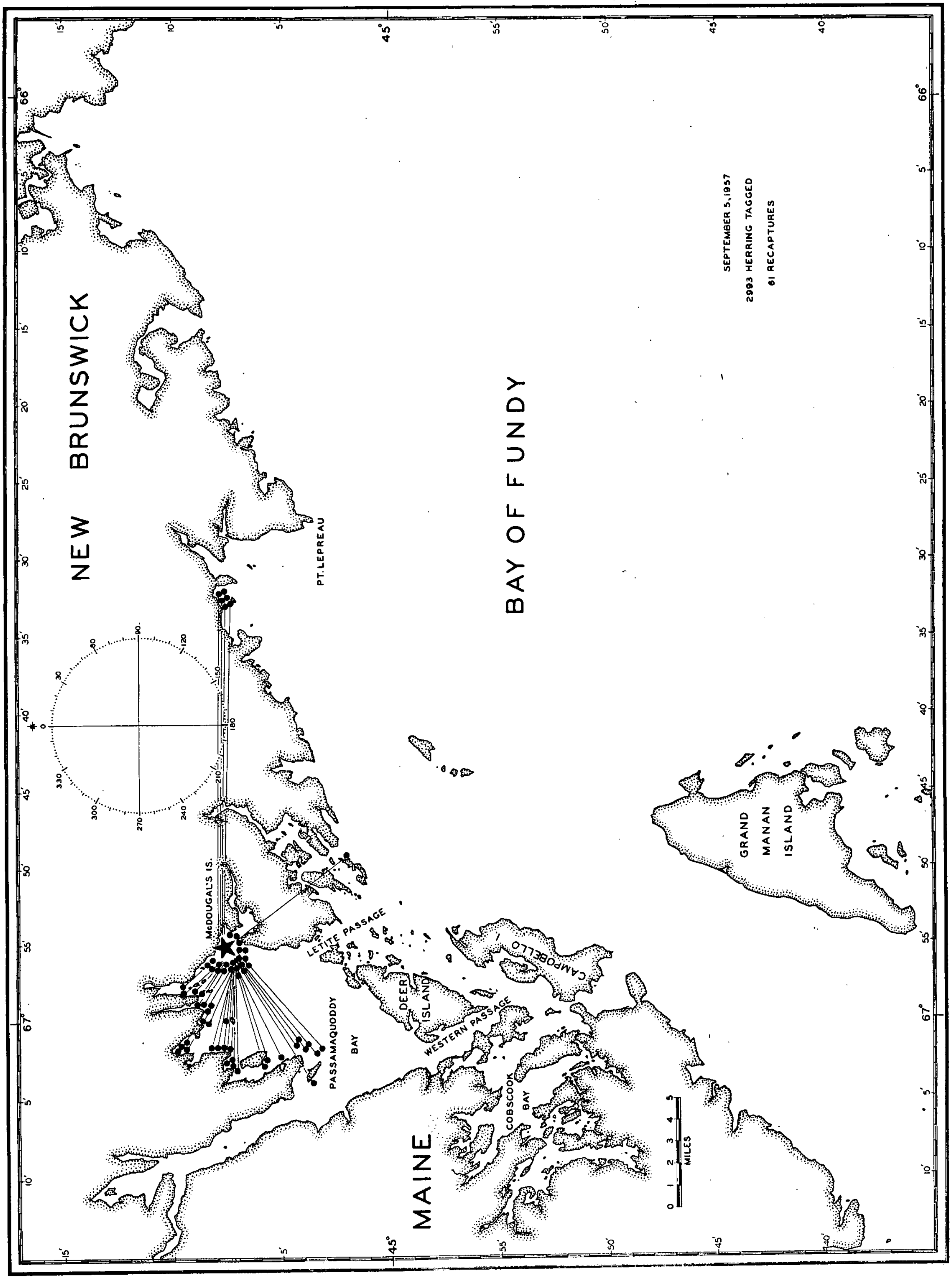


Figure 9. Recaptures of herring tagged at McDougal's Island, N. B., on September 5, 1957.

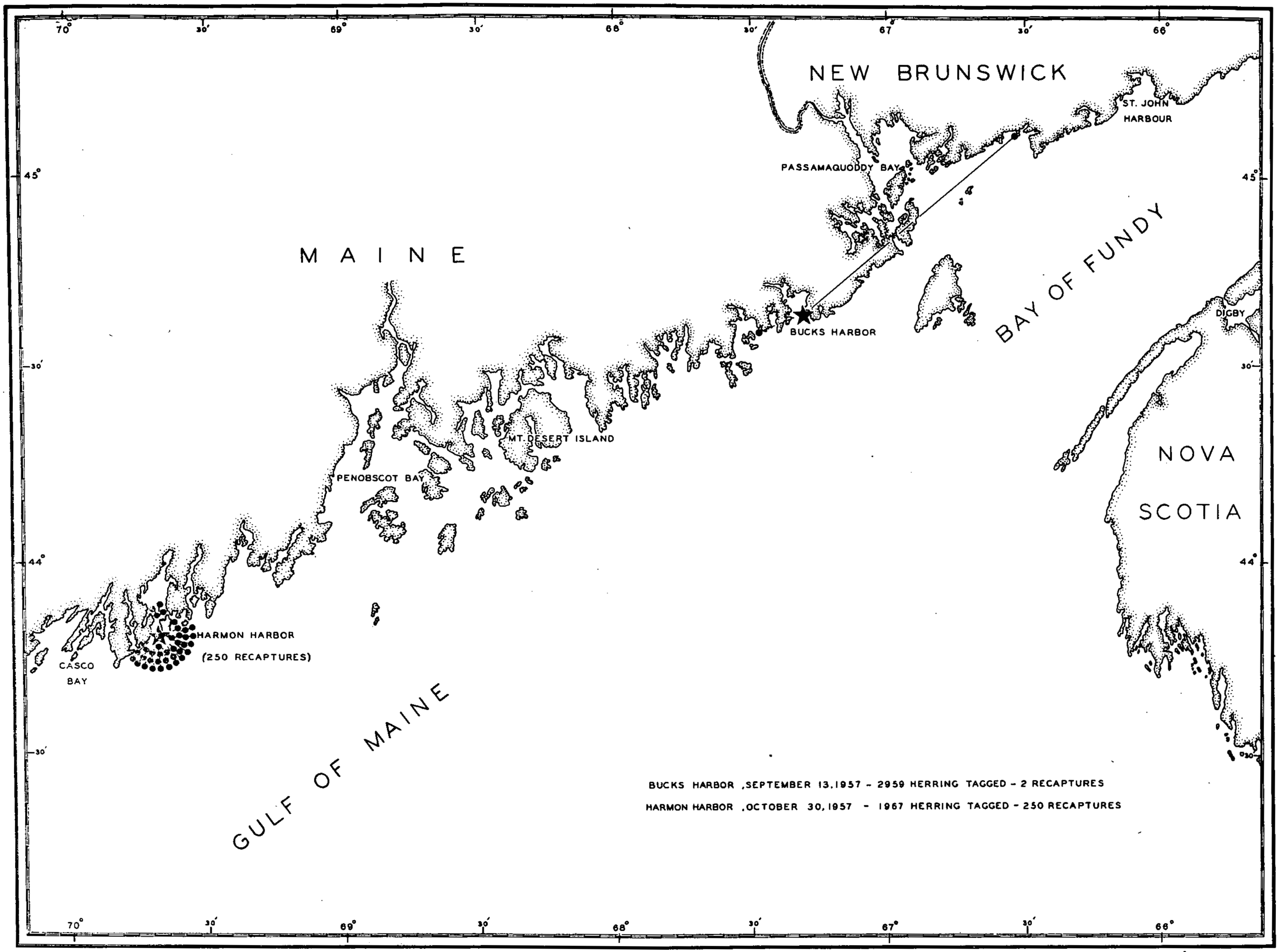


Figure 10. Recaptures of herring tagged at Bucks Harbor, Me., on September 13, 1957; Harmon Harbor, Me., on October 30, 1957.

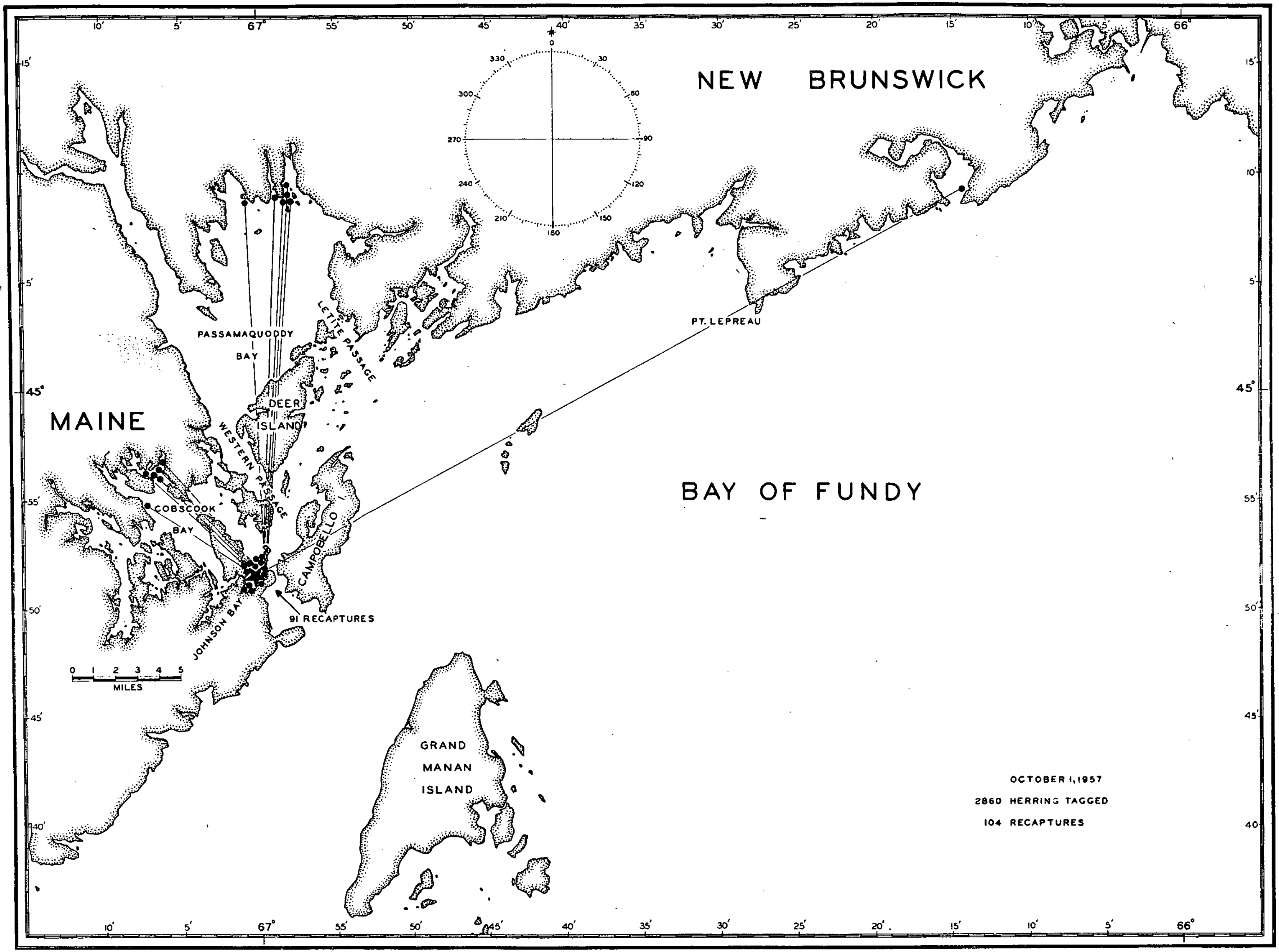


Figure 11. Recaptures of herring tagged at Johnson Bay, Me., on October 1, 1957.

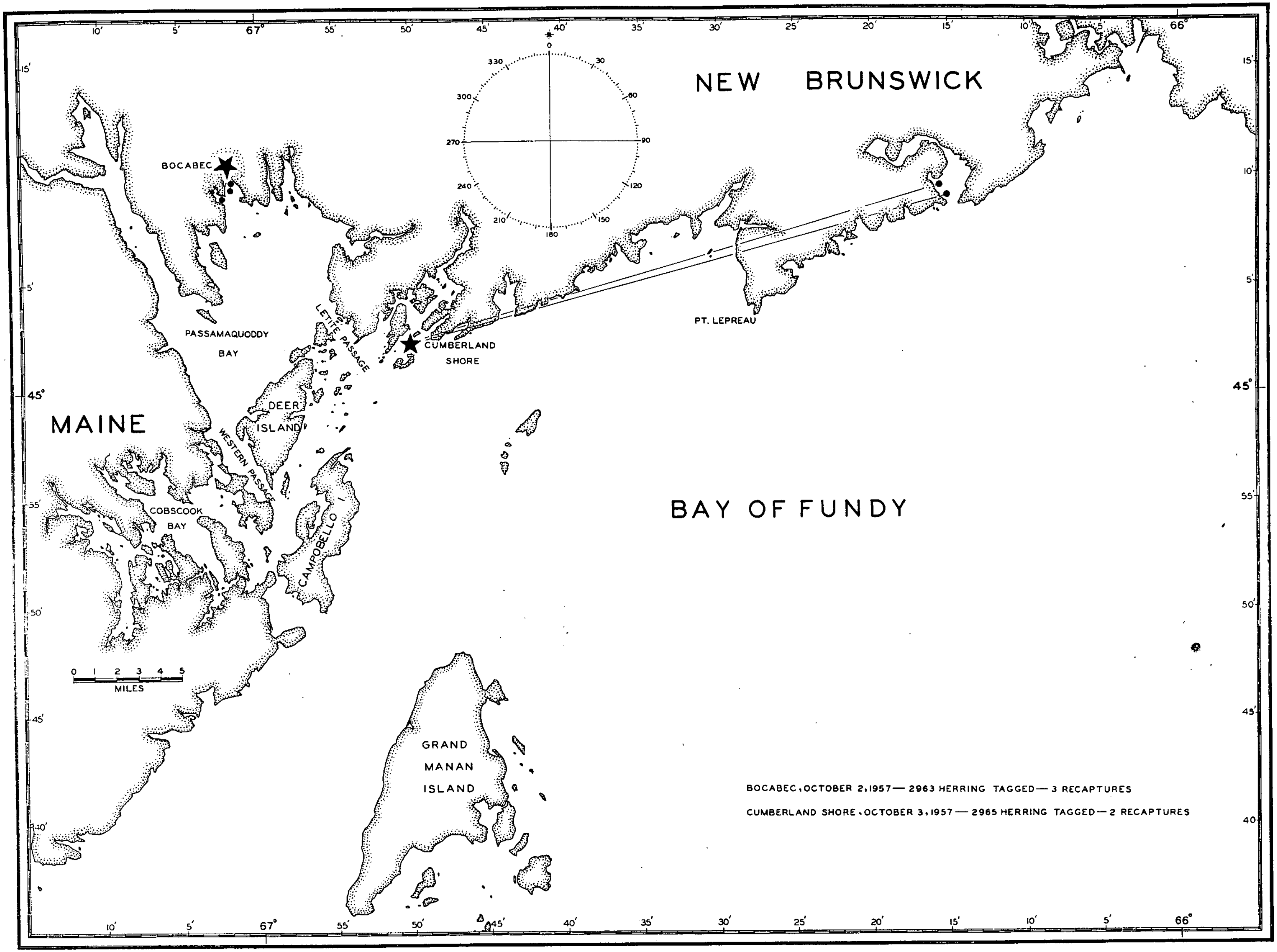


Figure 12. Recaptures of herring tagged at Bocabec, N. B., on October 2, 1957; Cumberland Shore, N. B., on October 3, 1957.

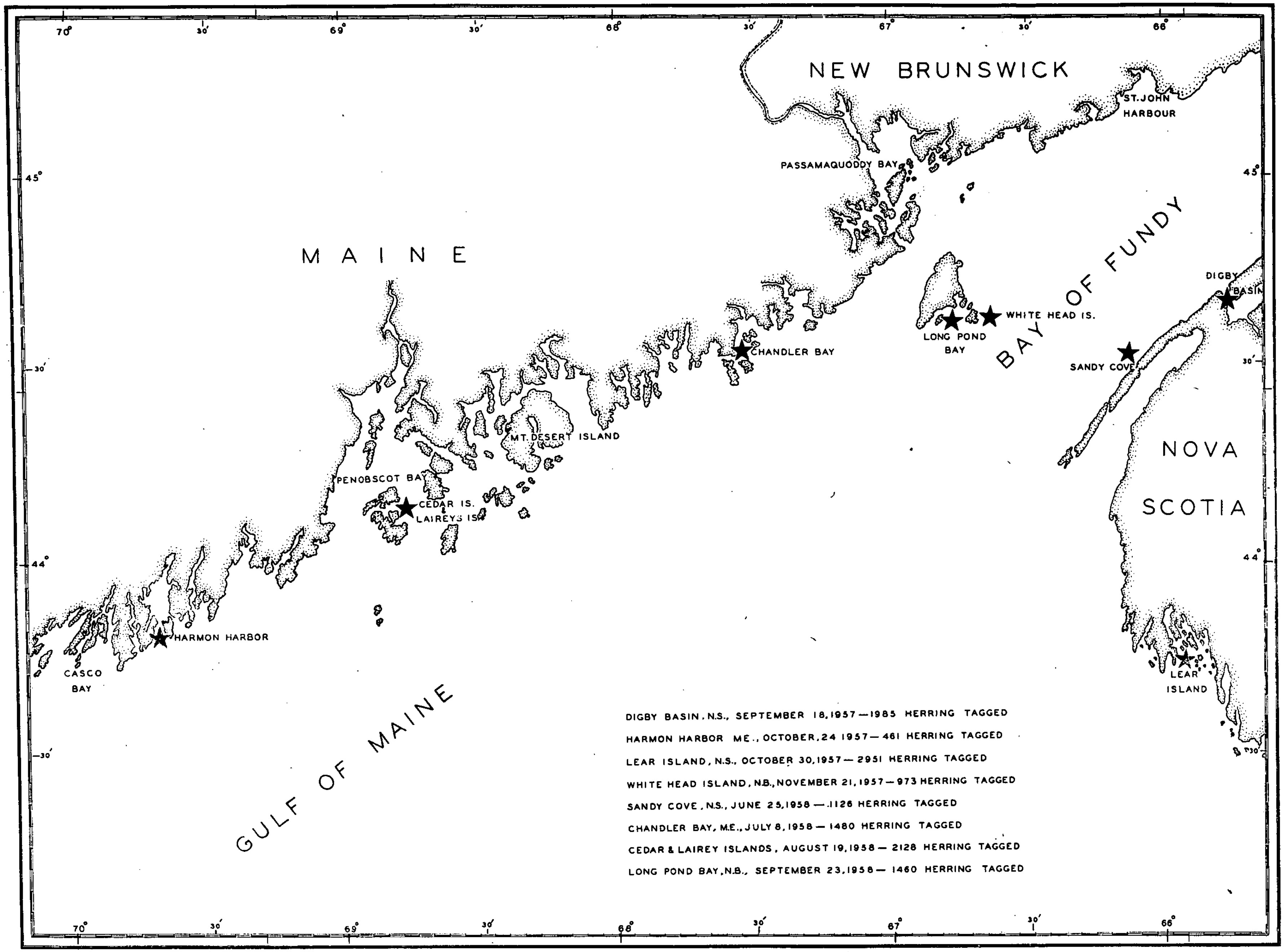


Figure 13. Taggings (1957 and 1958) from which no recaptures were obtained.

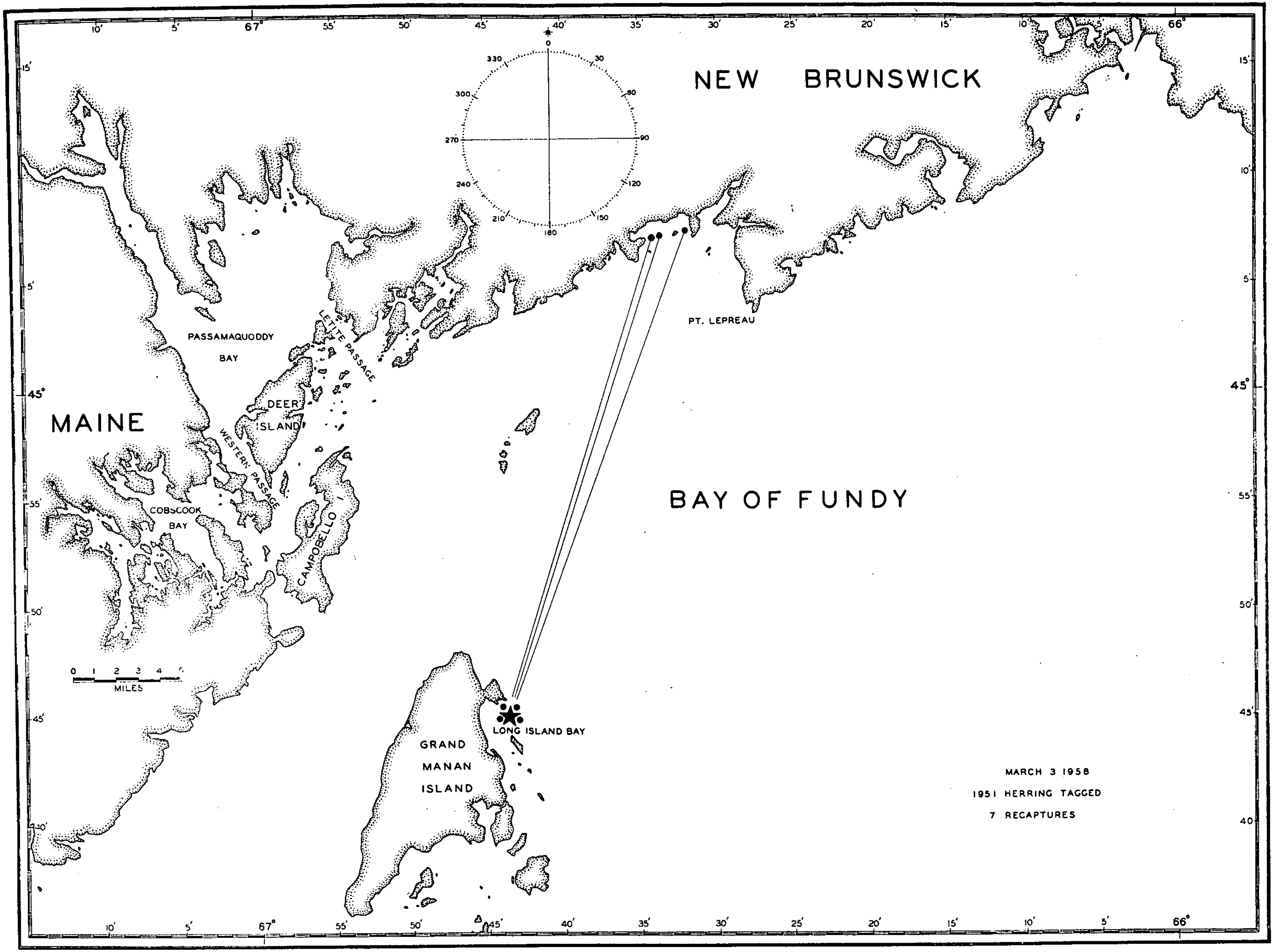


Figure 14. Recaptures from herring tagged at Long Island Bay, N. B., on March 3, 1958.

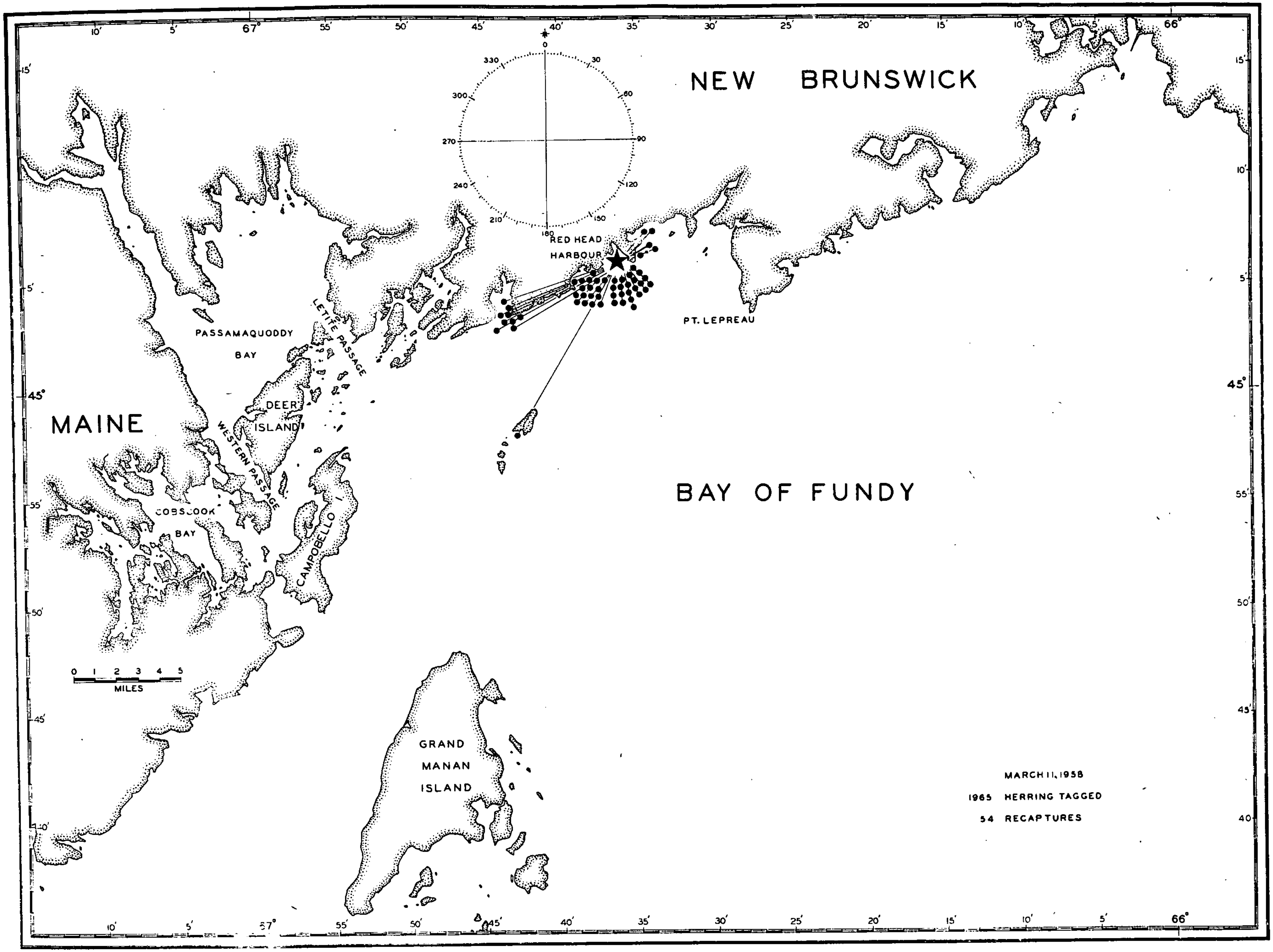


Figure 15. Recaptures from herring tagged at Red Head Harbour, N. B., on March 11, 1958.

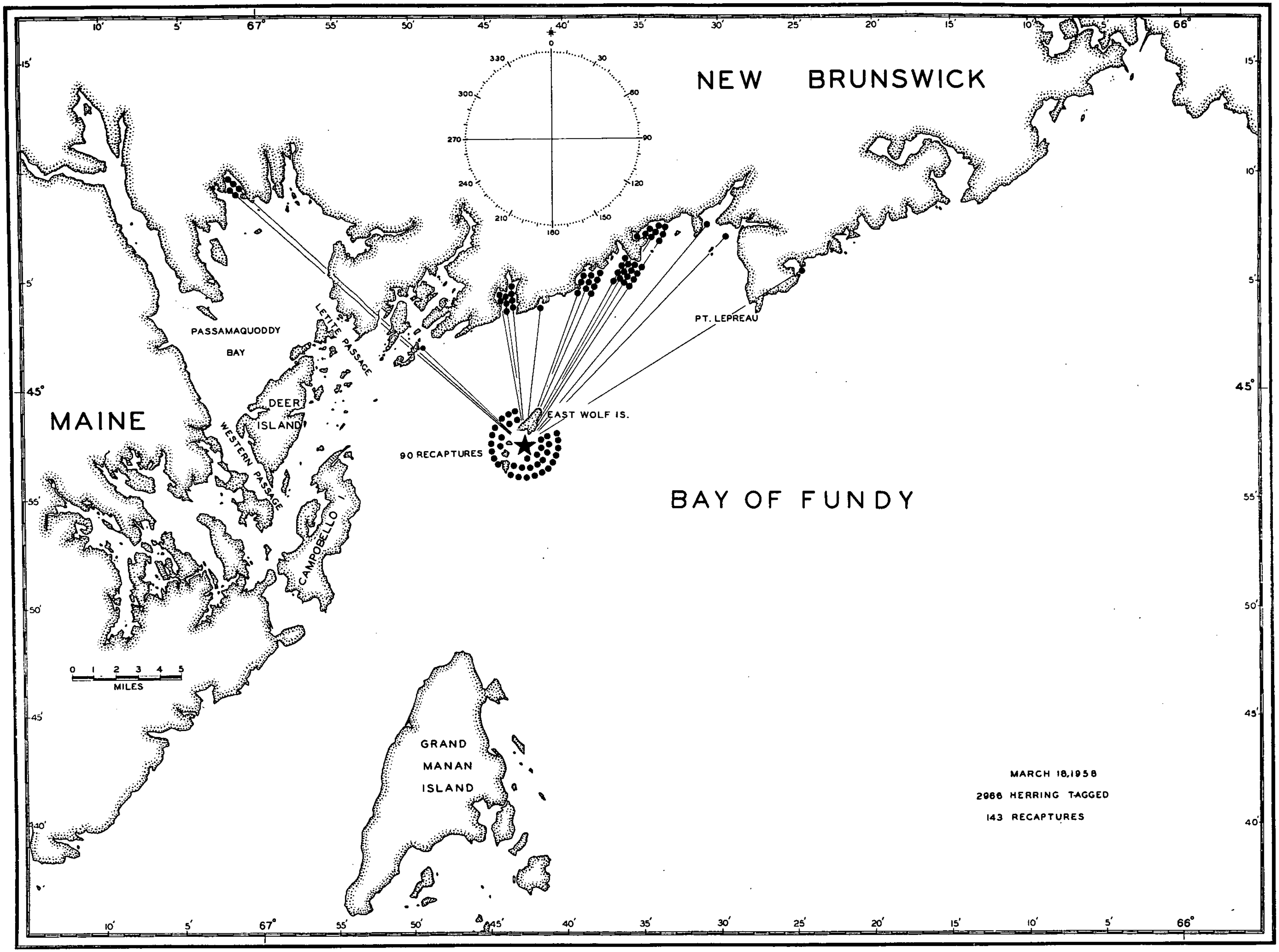


Figure 16. Recaptures from herring tagged at East Wolf Island, N. B., on March 18, 1958.

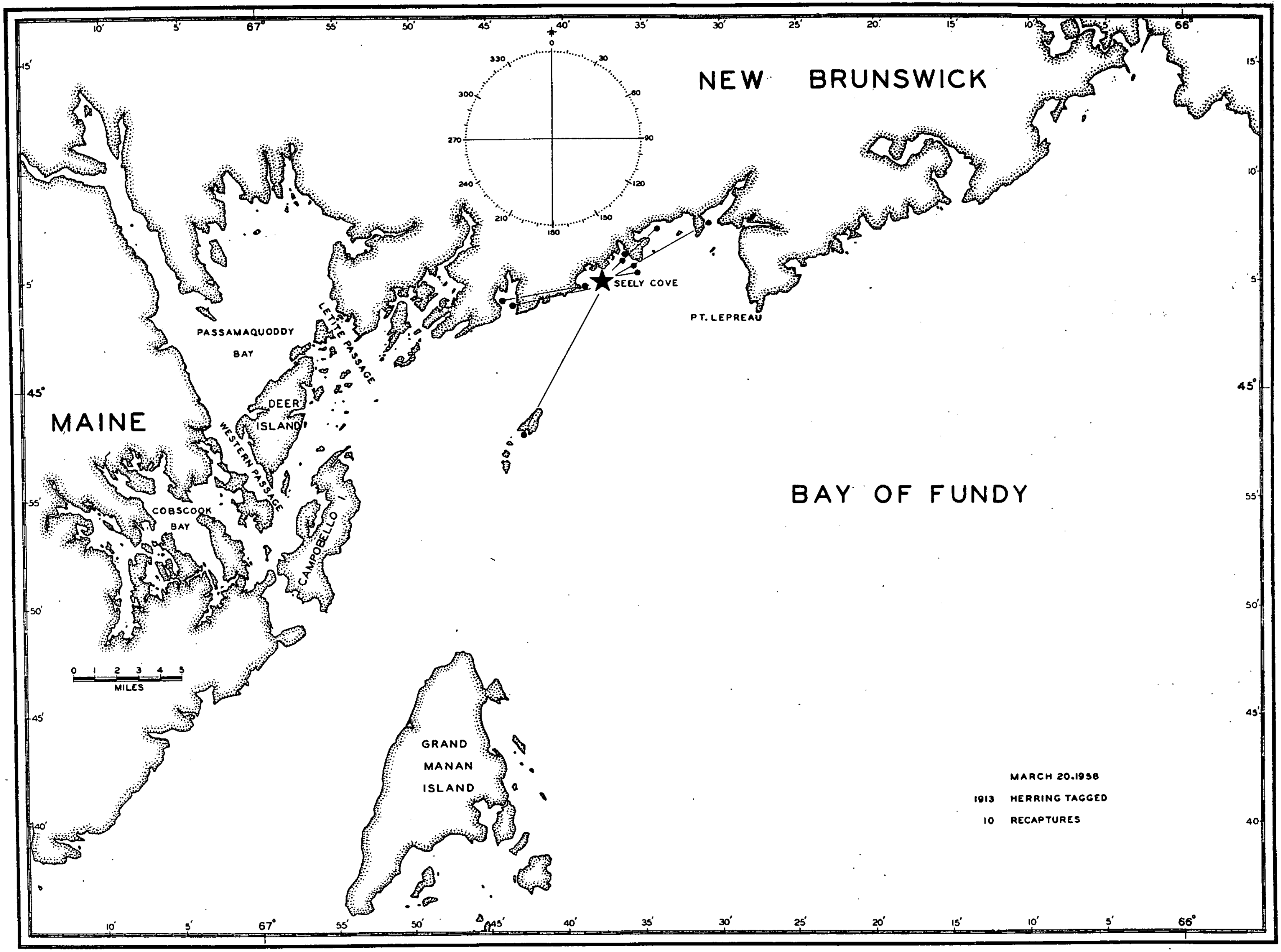


Figure 17. Recaptures from herring tagged at Seely Cove, N. B., on March 20, 1958.

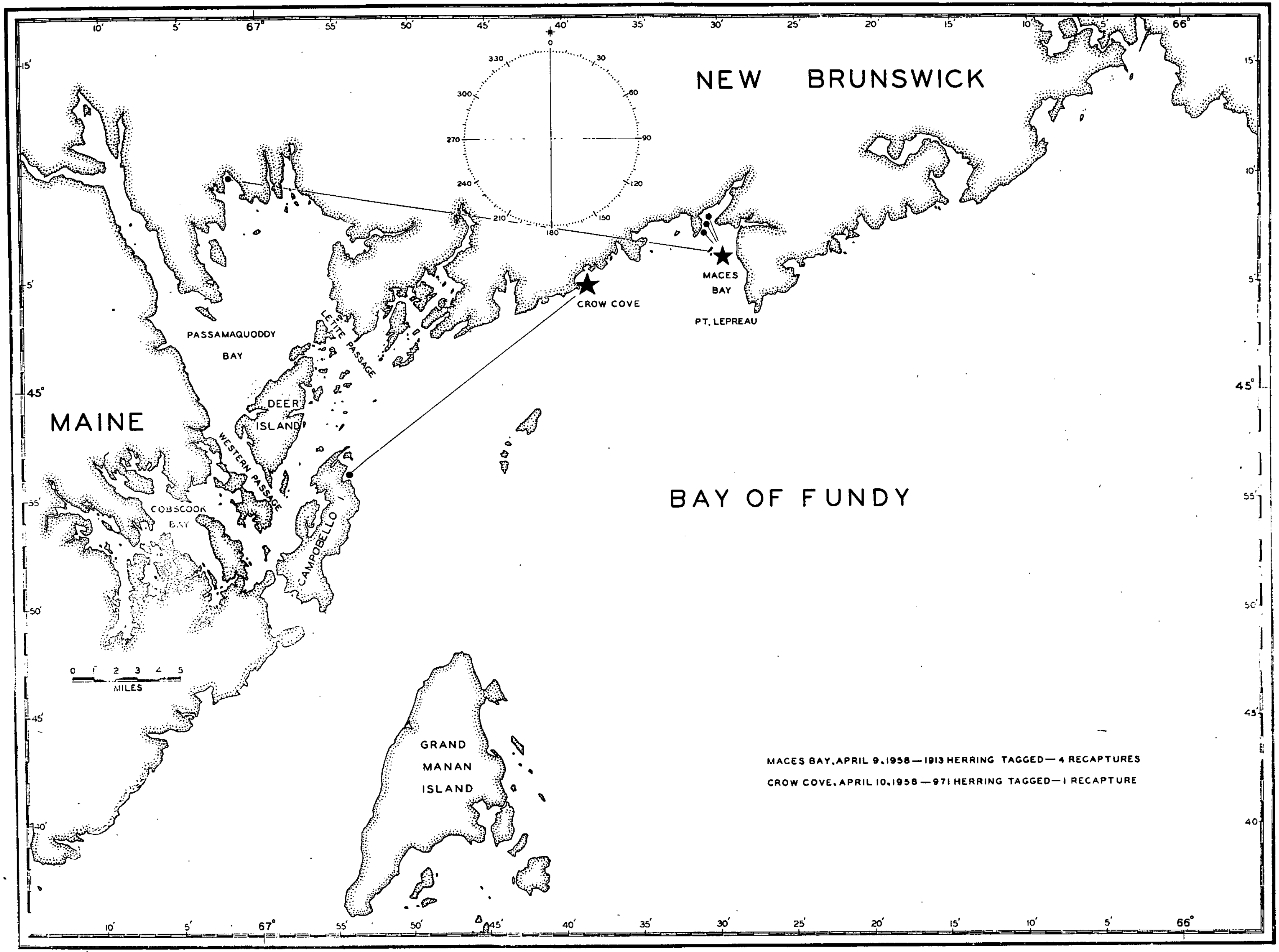


Figure 18. Recaptures from herring tagged at Maces Bay, N. B., on April 9, 1958; Crow Cove, N. B., on April 10, 1958.

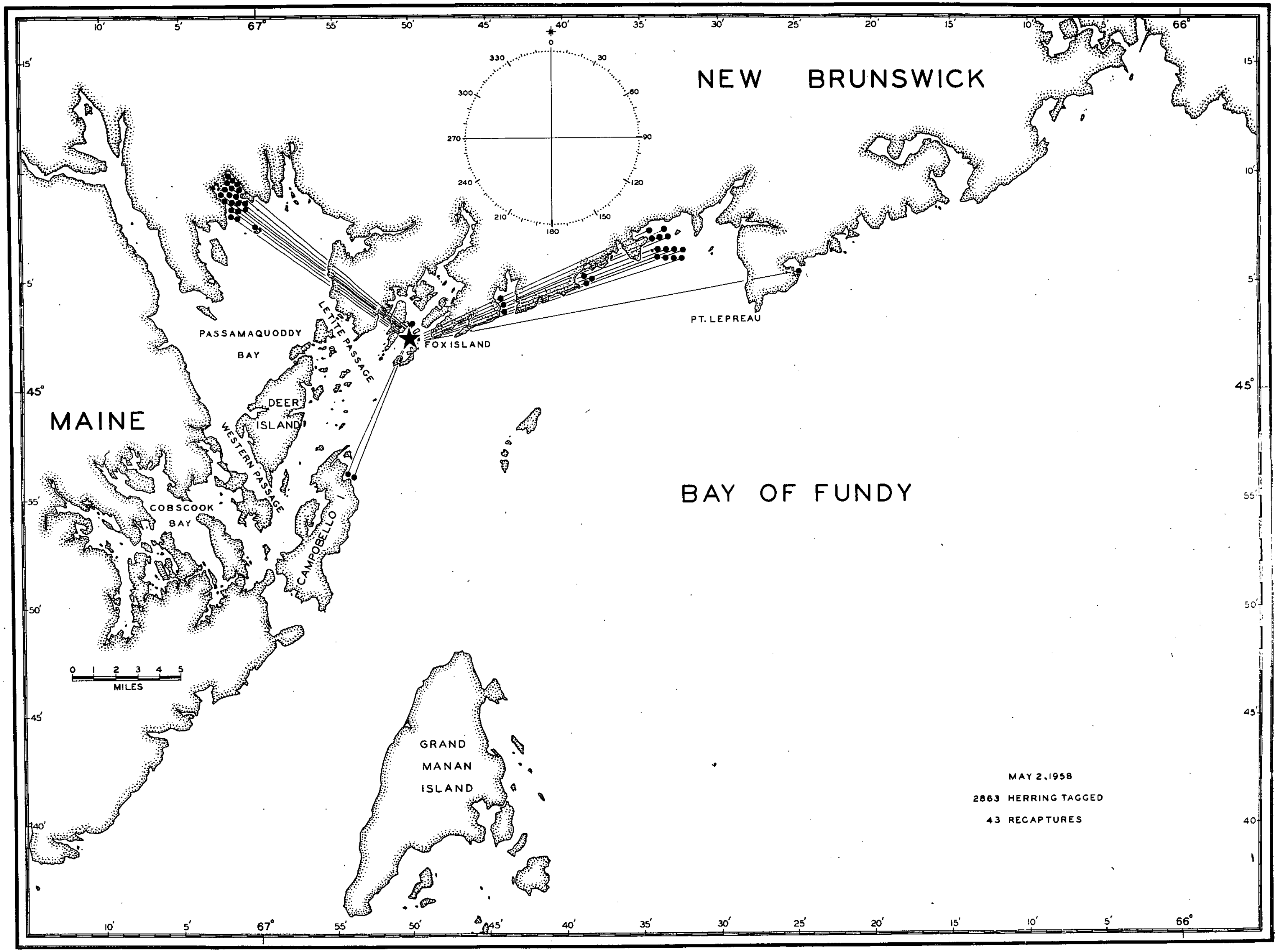


Figure 19. Recaptures from herring tagged at Fox Island, N. B., on May 2, 1958.

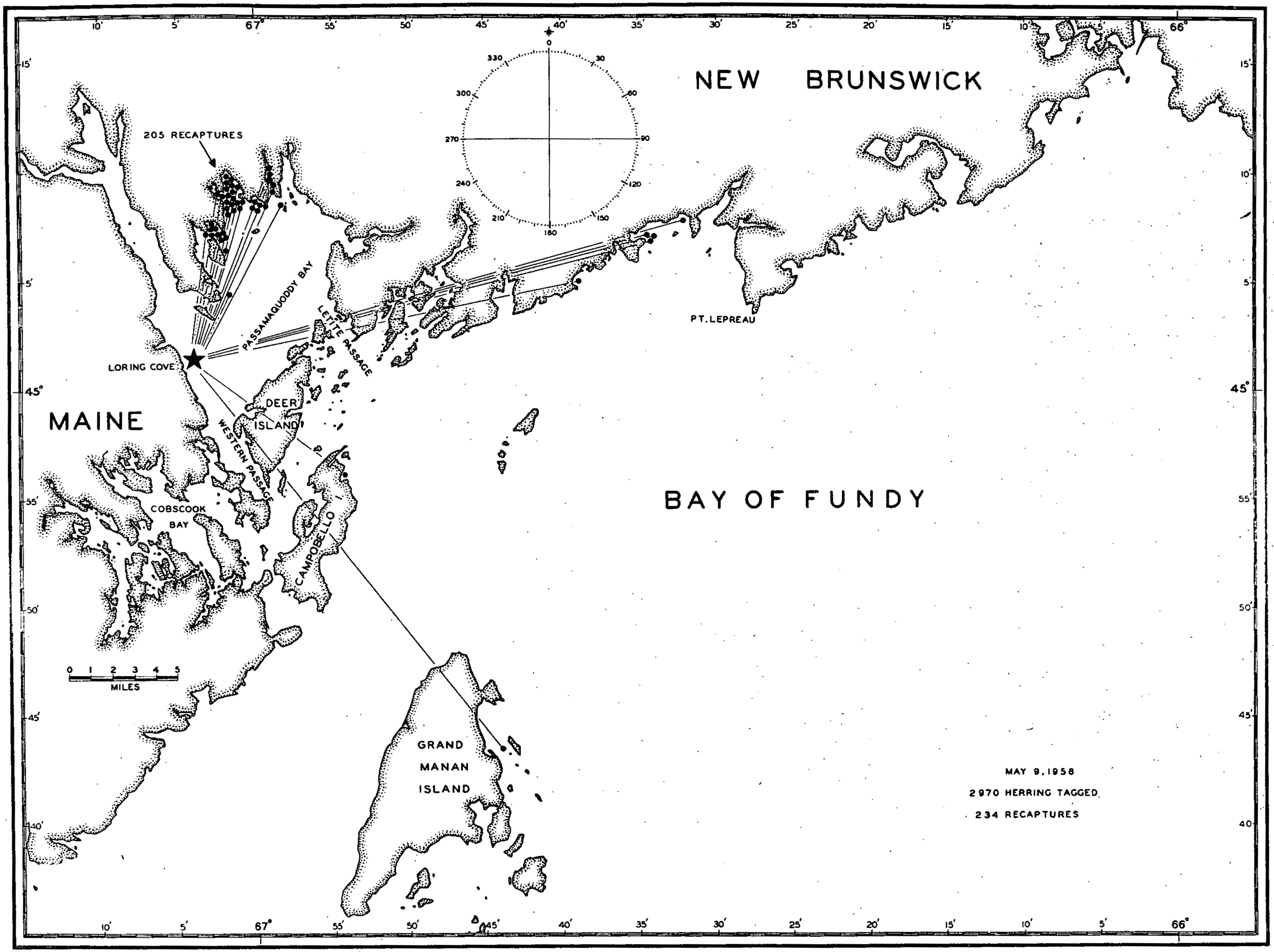


Figure 20. Recaptures from herring tagged at Loring Cove, Me., on May 9, 1958.

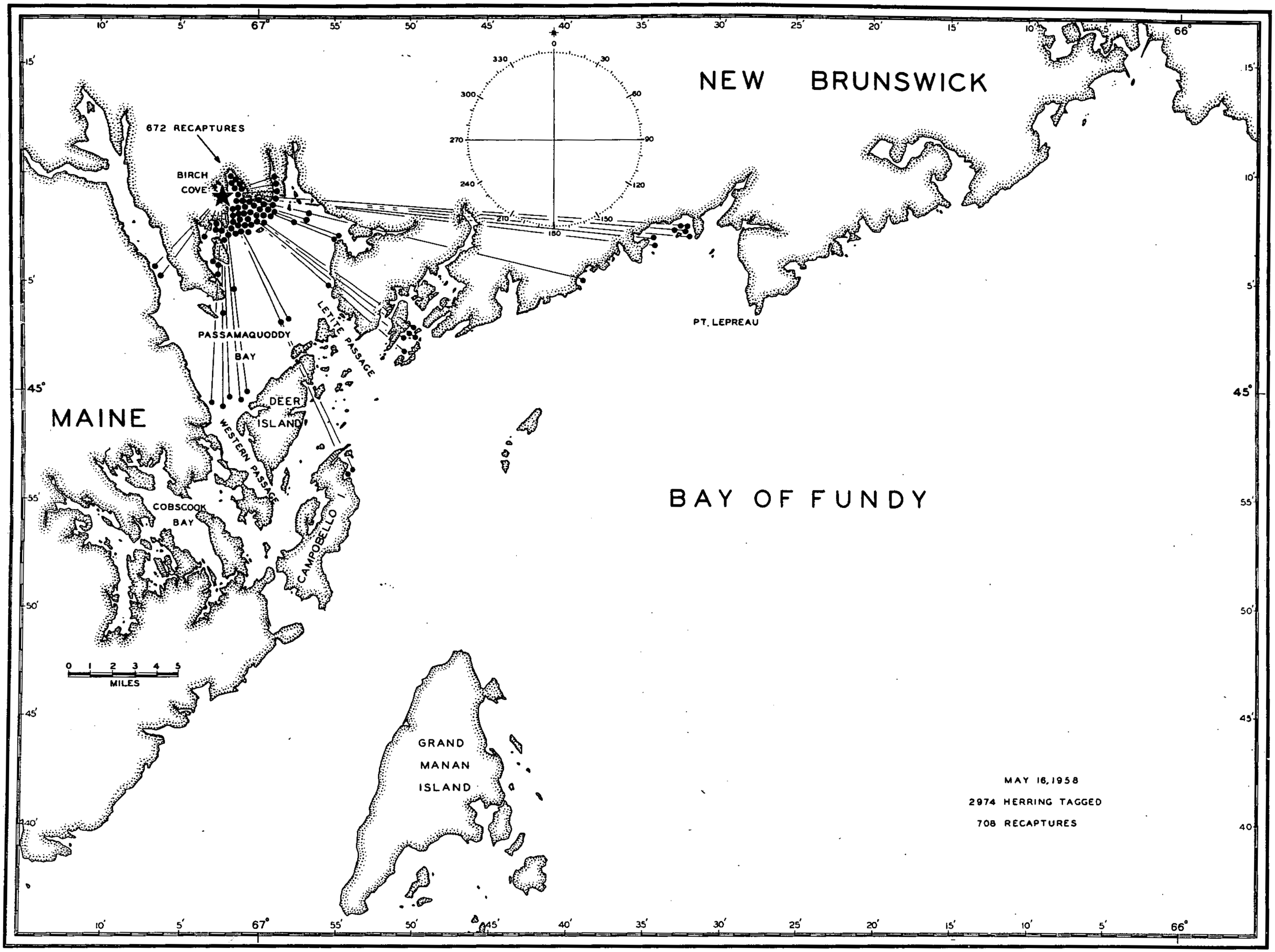


Figure 21. Recaptures from herring tagged at Birch Cove, N. B., on May 16, 1958.

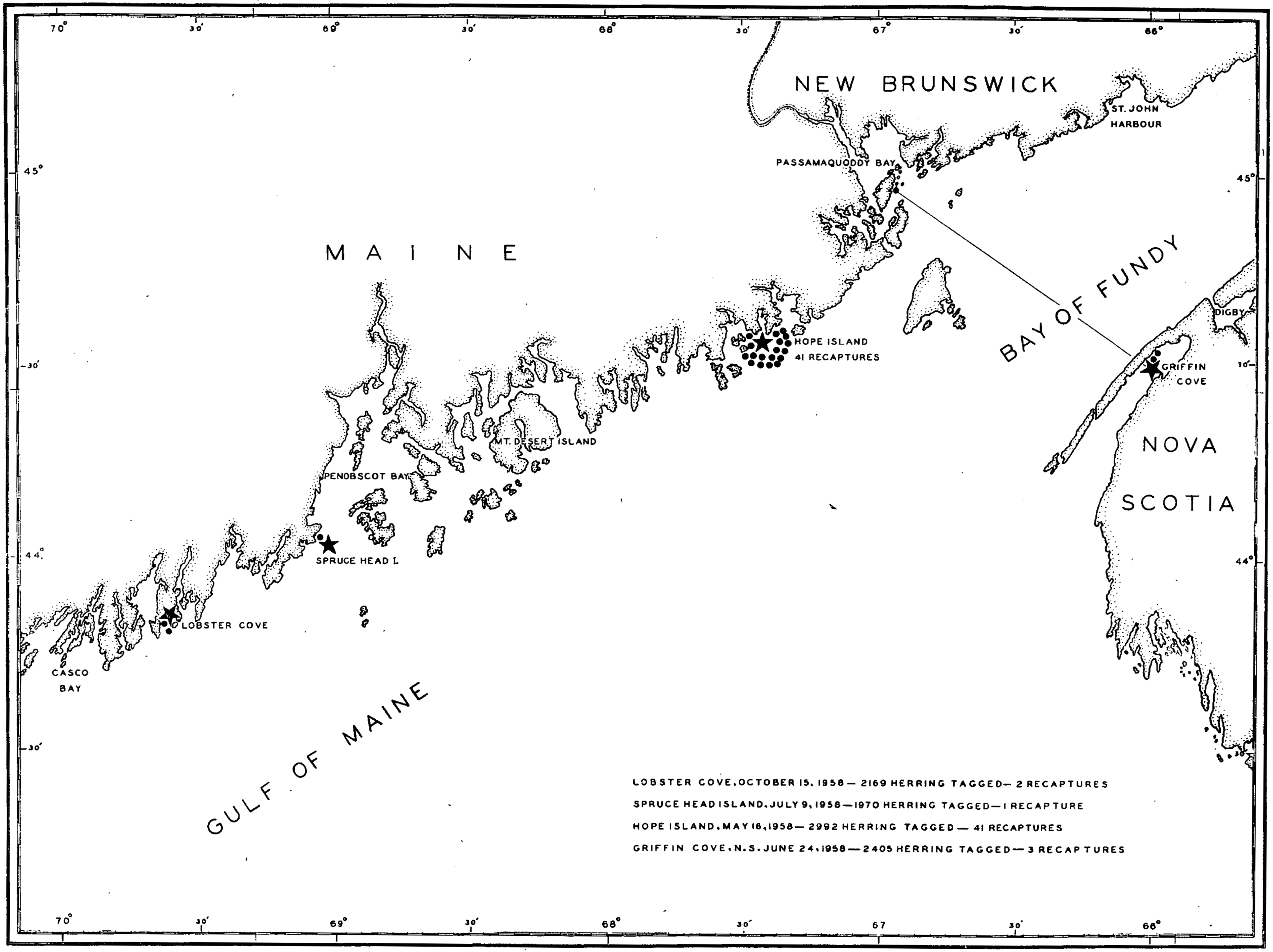


Figure 22. Recaptures from herring tagged at Lobster Cove, Me., on October 15, 1958; Sprucehead Island, Me., on July 9, 1958; Hope Island, Me., on May 16, 1958; Griffin Cove, N. S., on June 24, 1958.

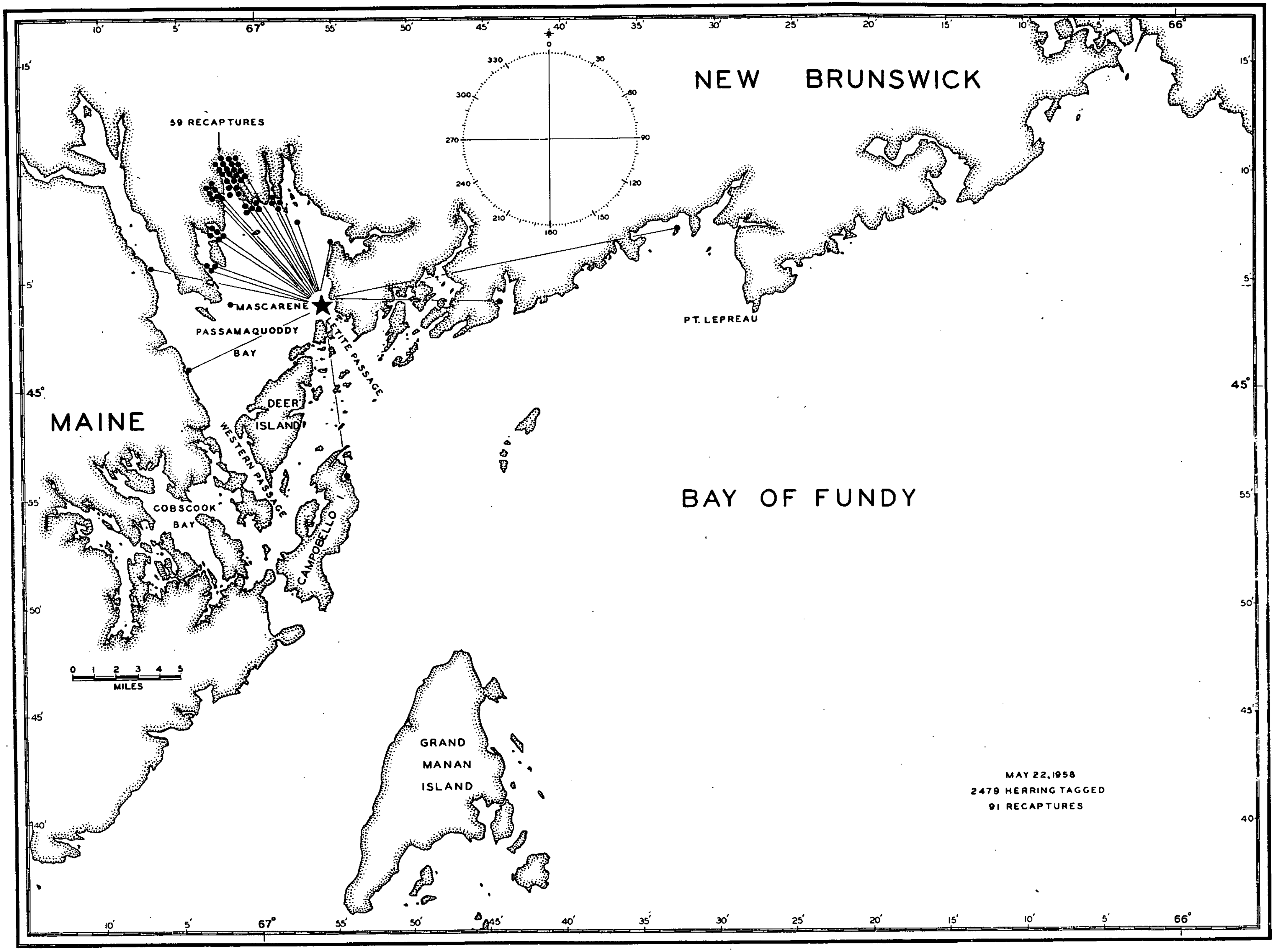


Figure 23. Recaptures from herring tagged at Mascarene Shore, N. B., on May 22, 1958.

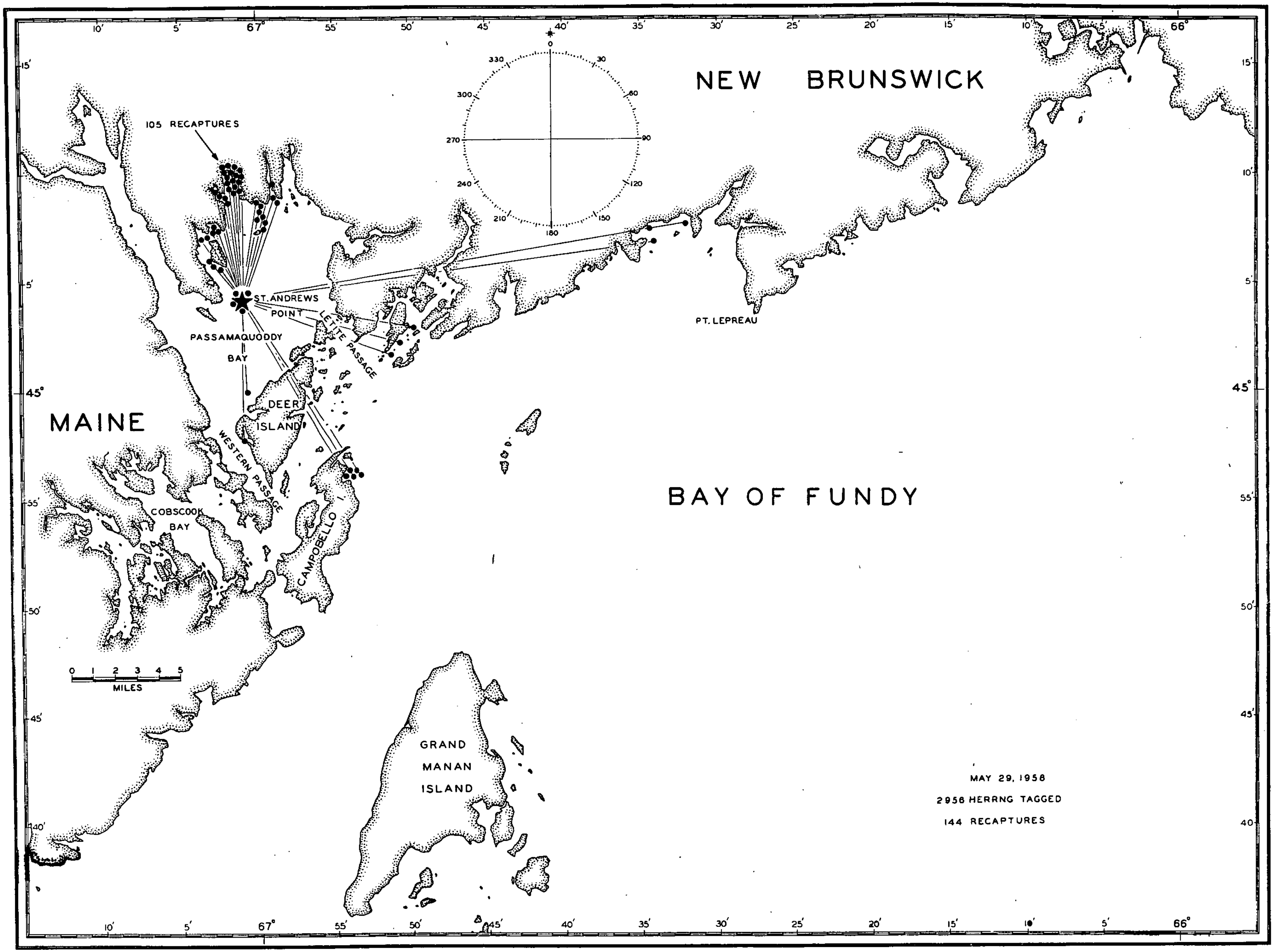


Figure 24. Recaptures from herring tagged at St. Andrews Point, N. B., on May 29, 1958.

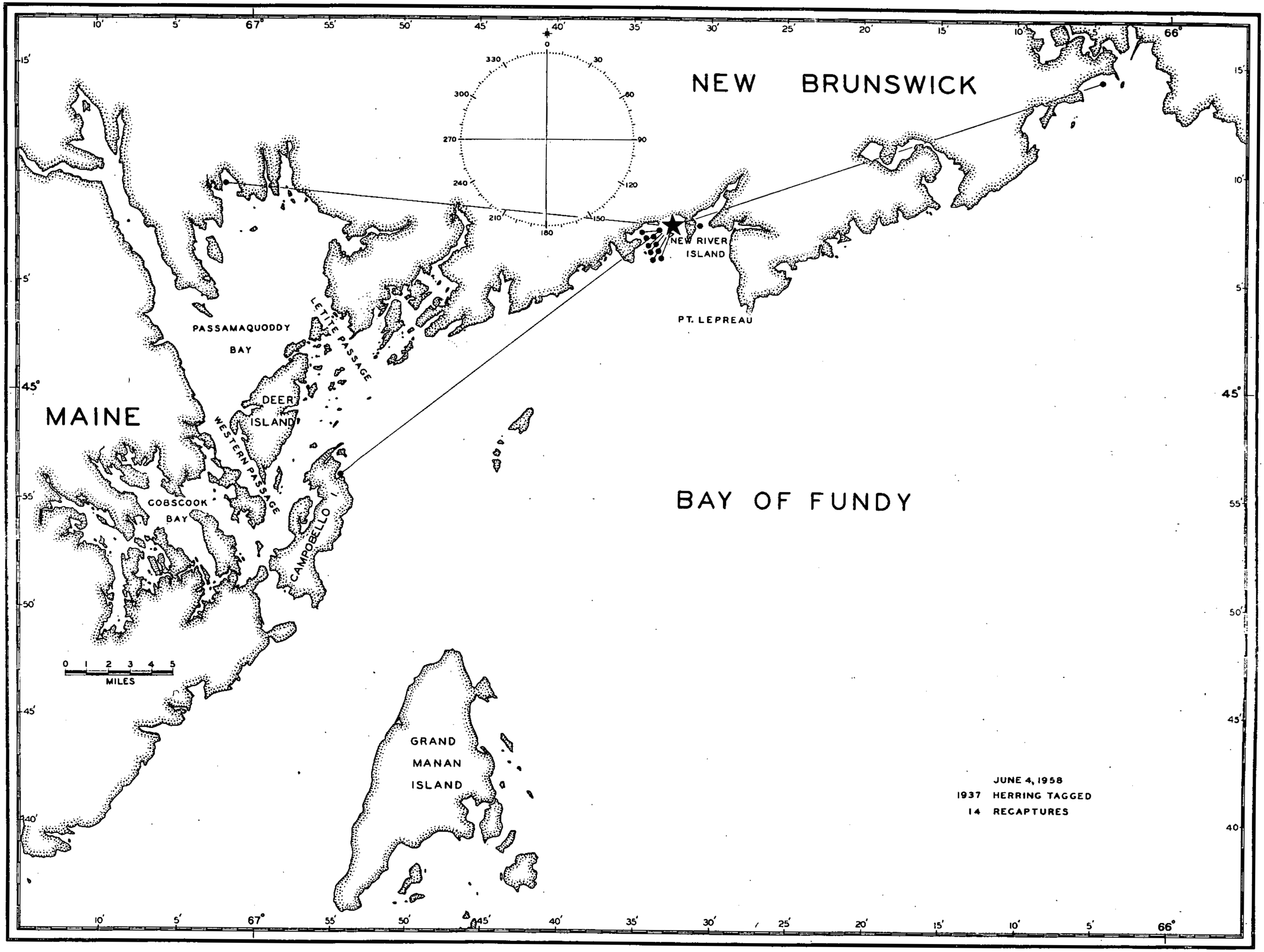


Figure 25. Recaptures from herring tagged at New River Island, N. B., on June 4, 1958.

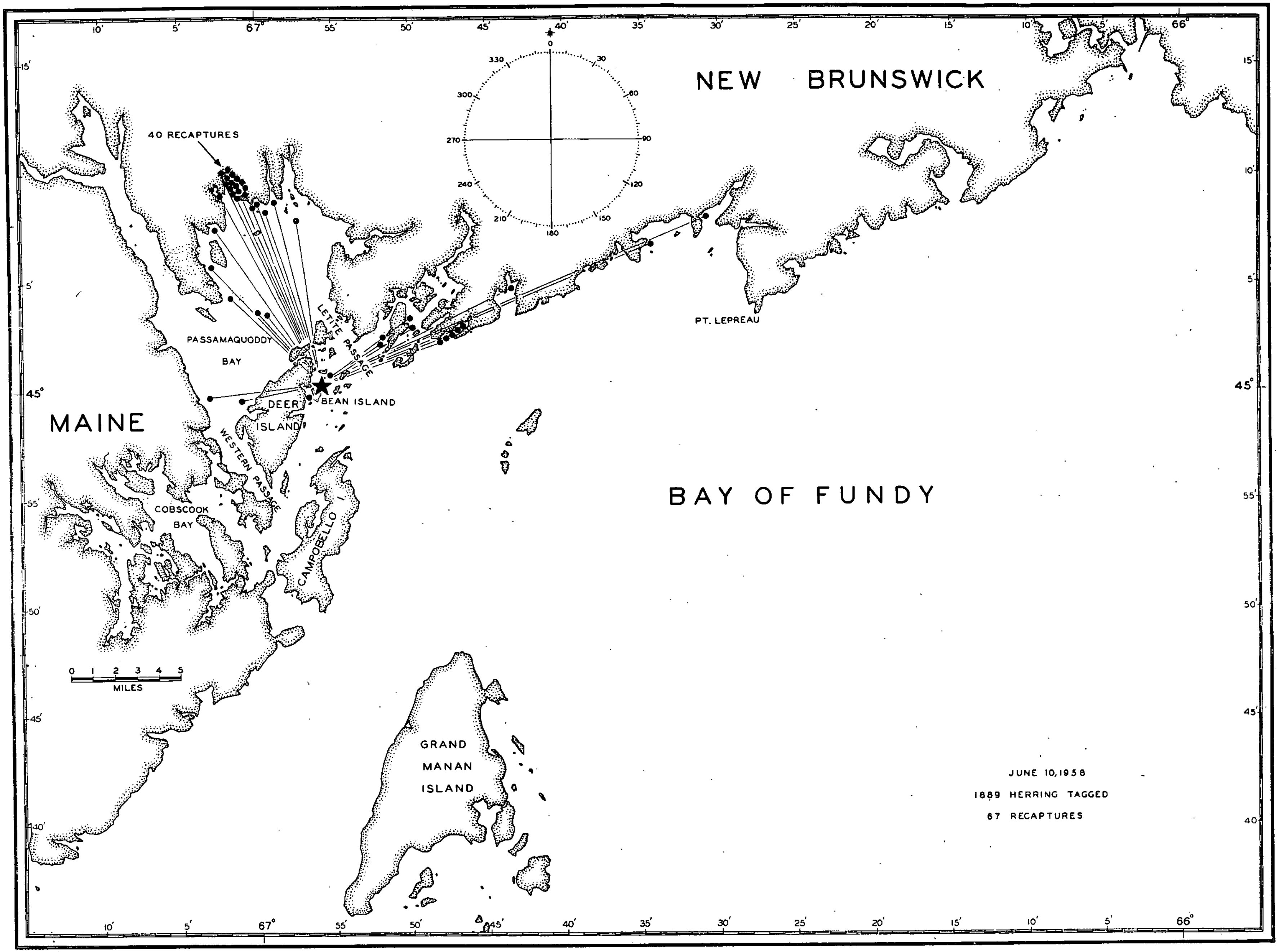


Figure 26. Recaptures from herring tagged at Bean Island, N. B., on June 10, 1958.

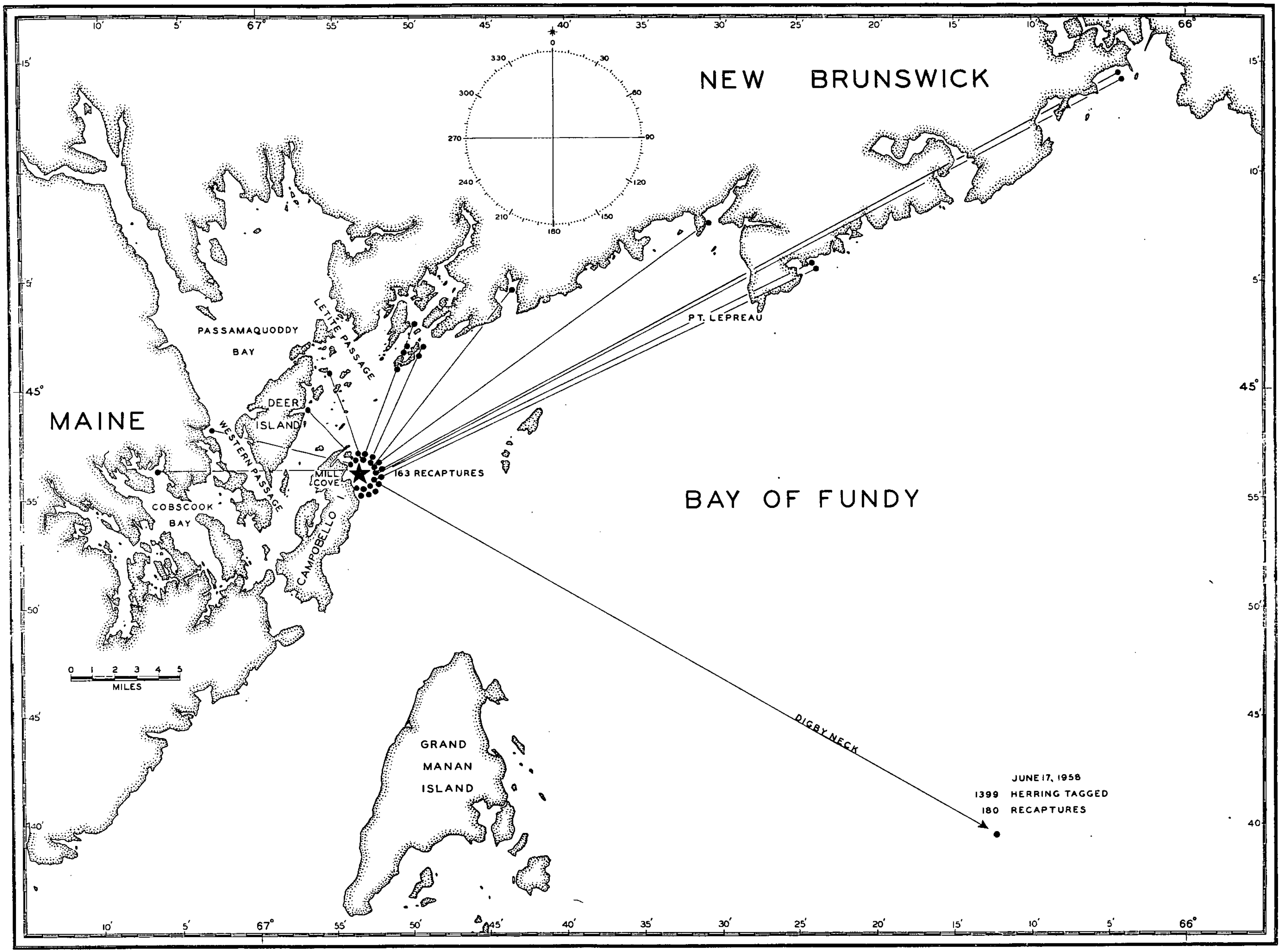


Figure 27. Recaptures from herring tagged at Mill Cove, N. B., on June 17, 1958.

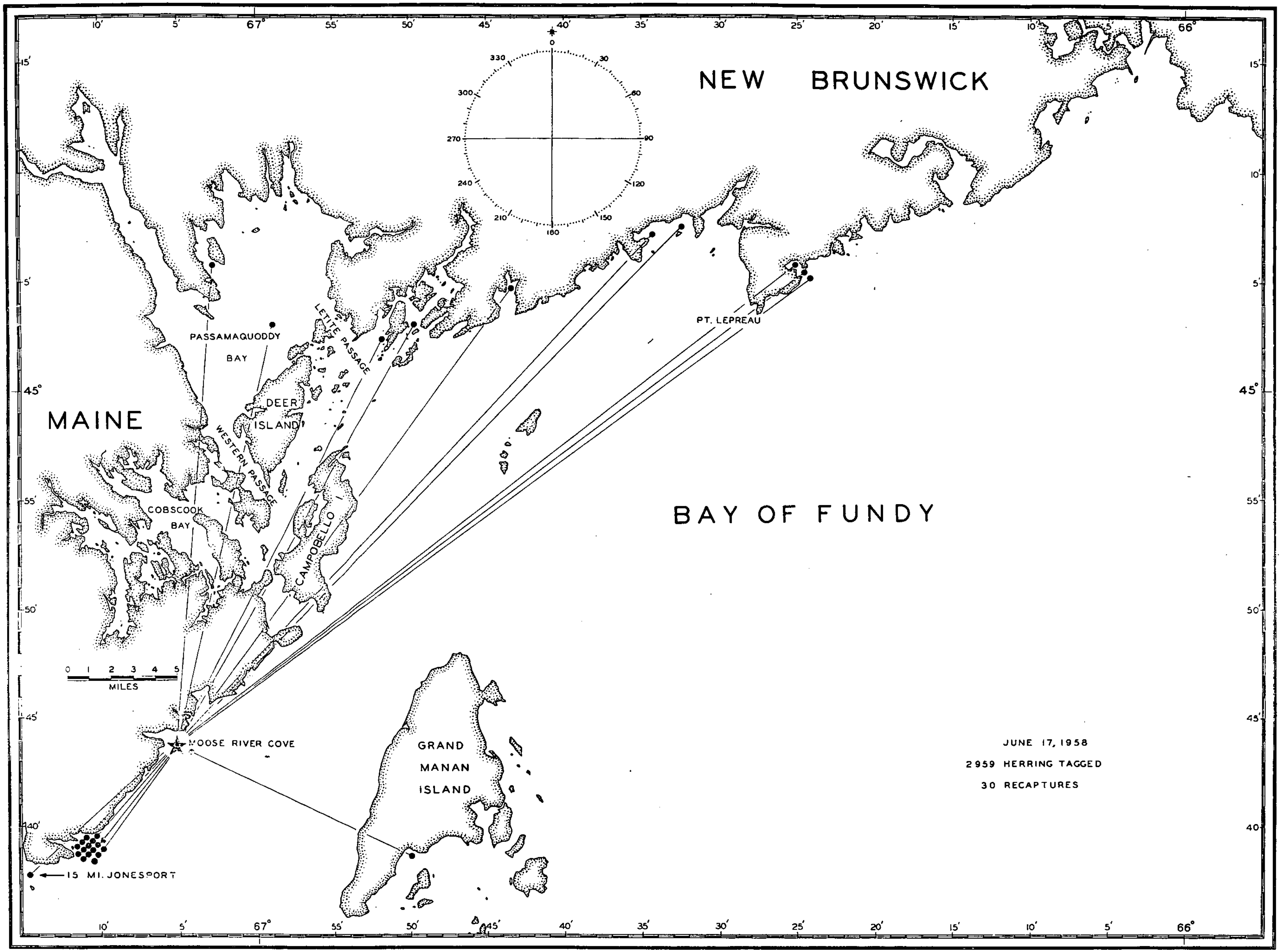


Figure 28. Recaptures from herring tagged at Moose River Cove, Me., on June 17, 1958.

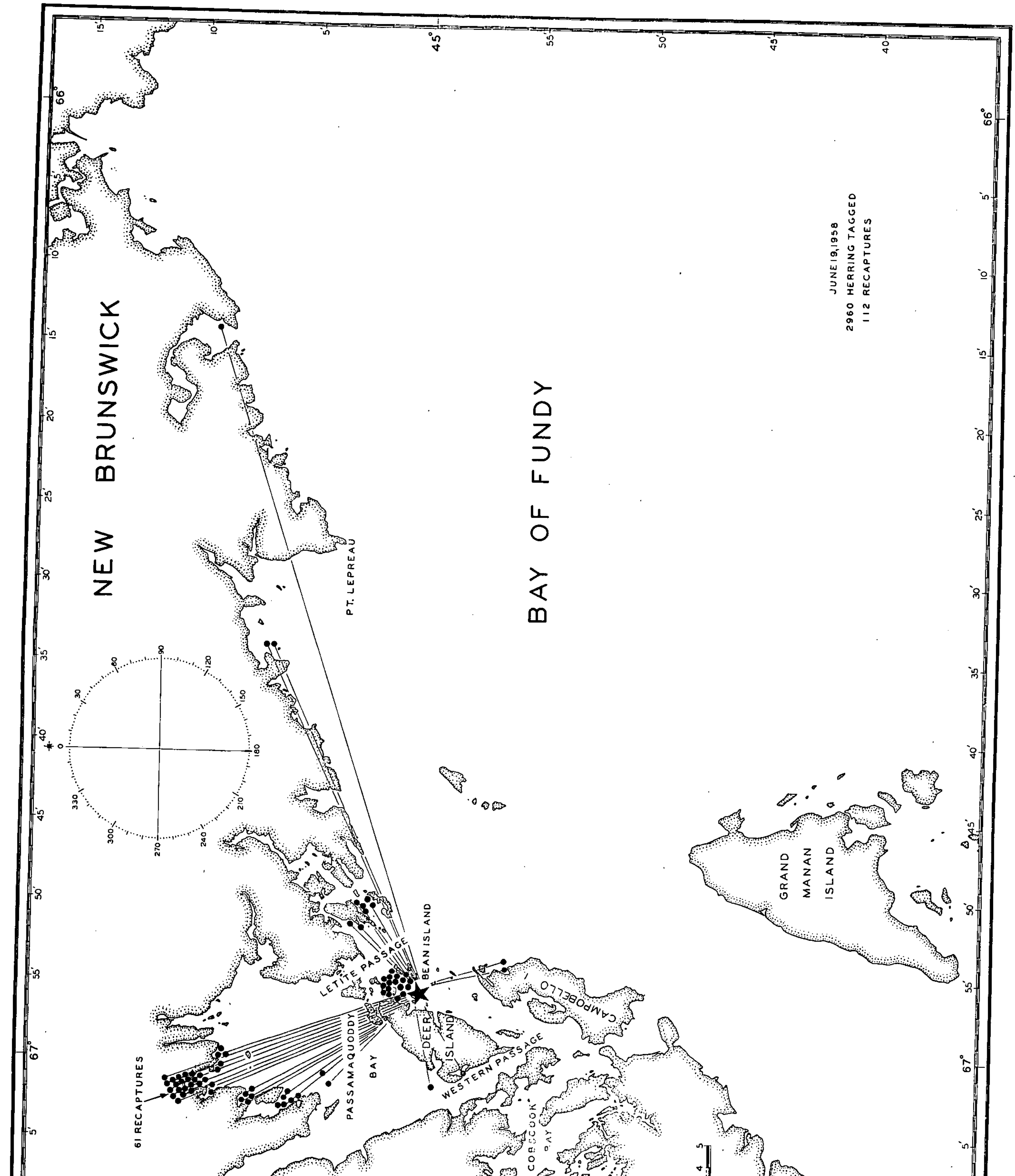


Figure 29. Recaptures from herring tagged at Bean Island, N. B., on June 19, 1958.

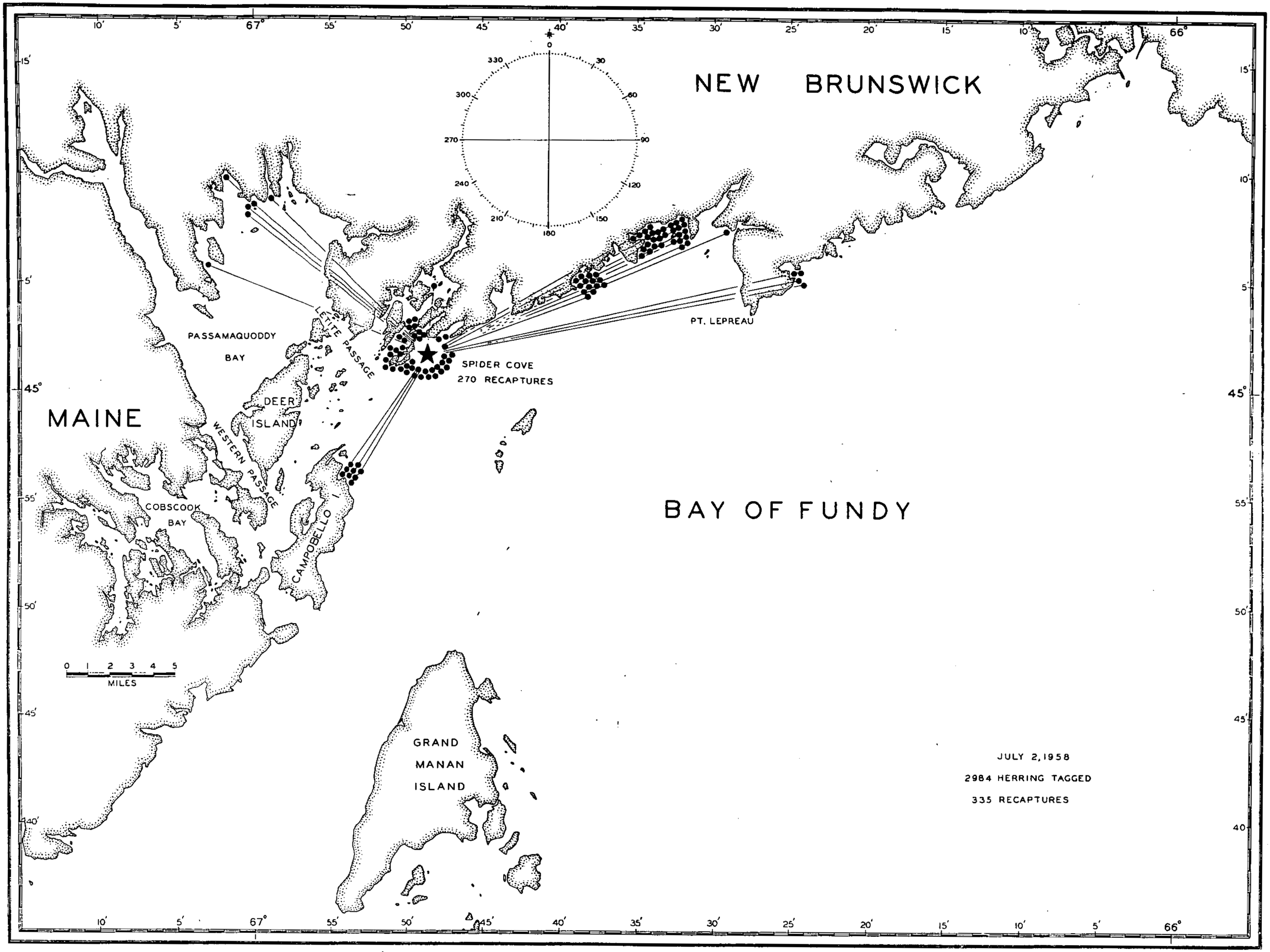


Figure 30, Recaptures from herring tagged at Spider Cove, N. B., on July 2, 1958.

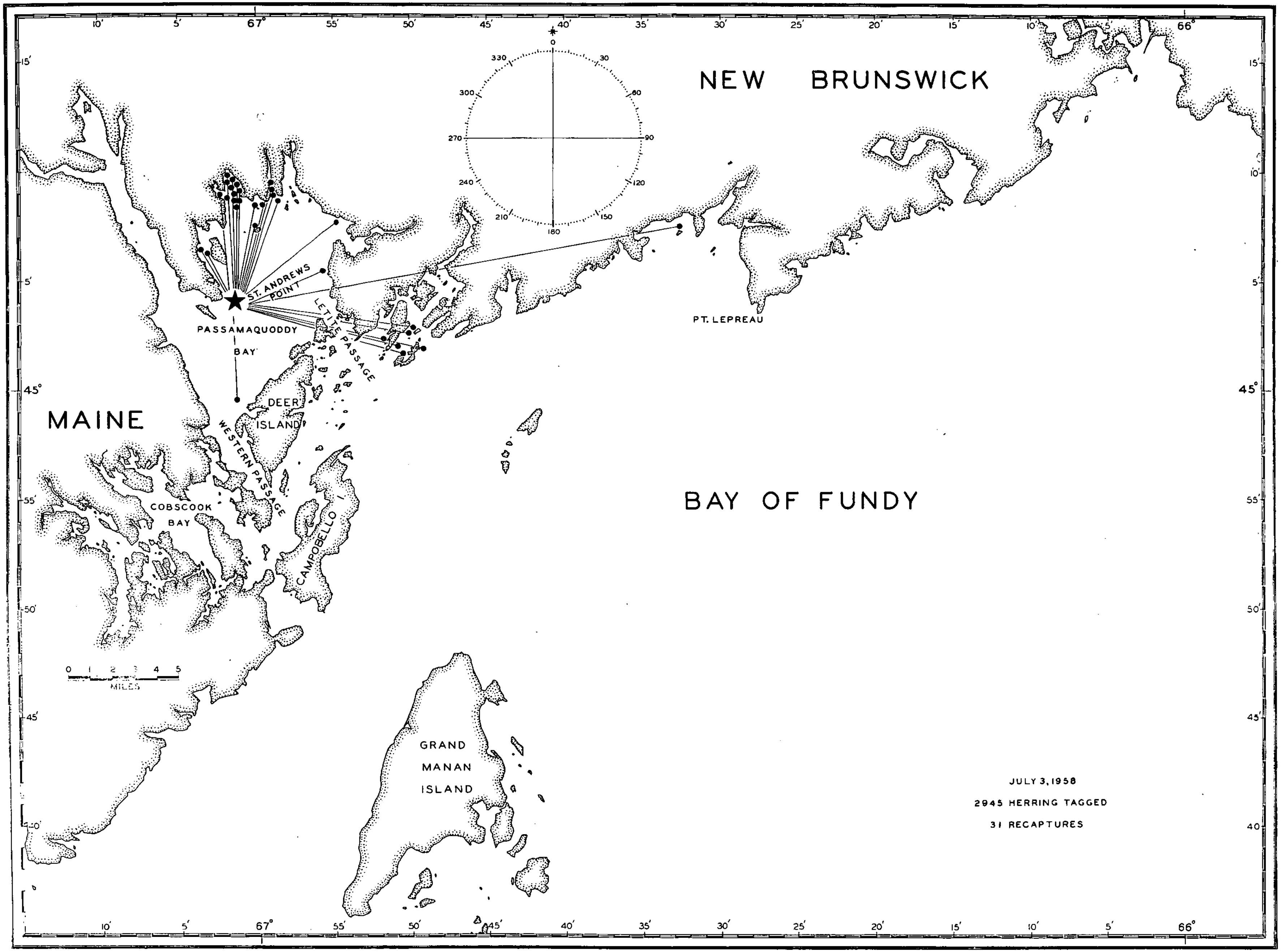


Figure 31. Recaptures from herring tagged at St. Andrews Point, N. B., on July 3, 1958.

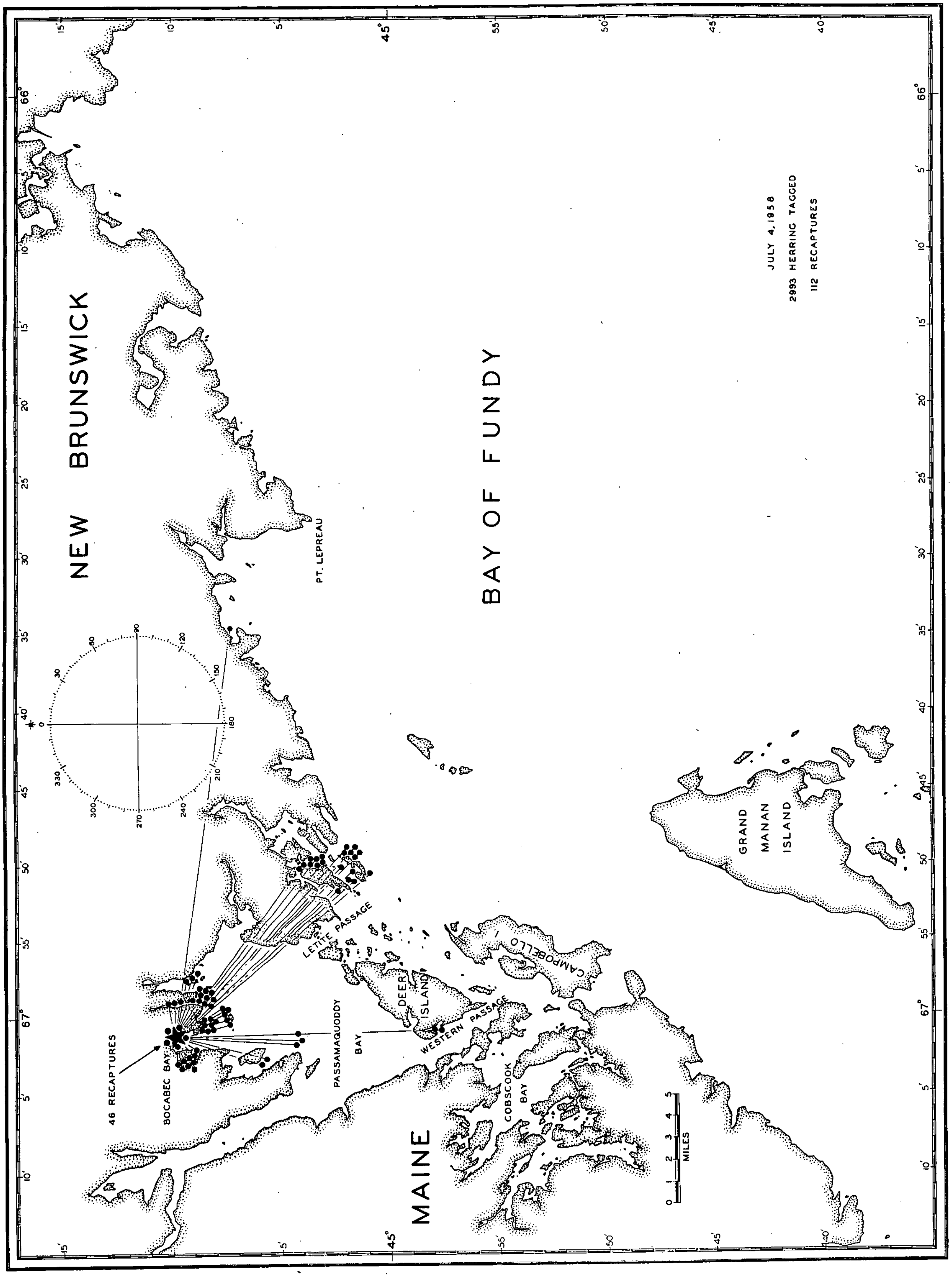


Figure 32. Recaptures from herring tagged at Bocabec Bay, N. B., on July 4, 1958.

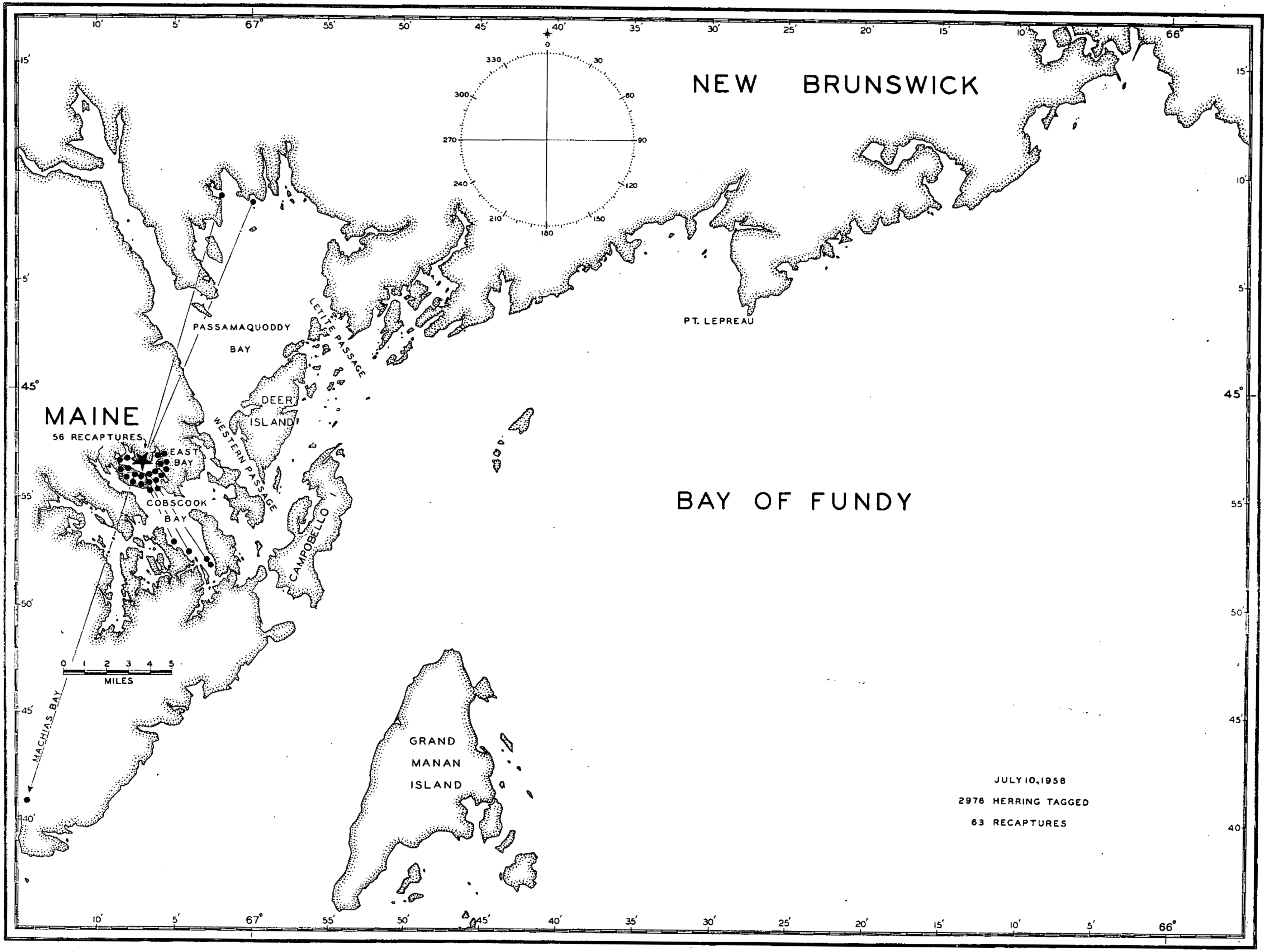


Figure 33. Recaptures from herring tagged at East Bay, Me., July 10, 1958.

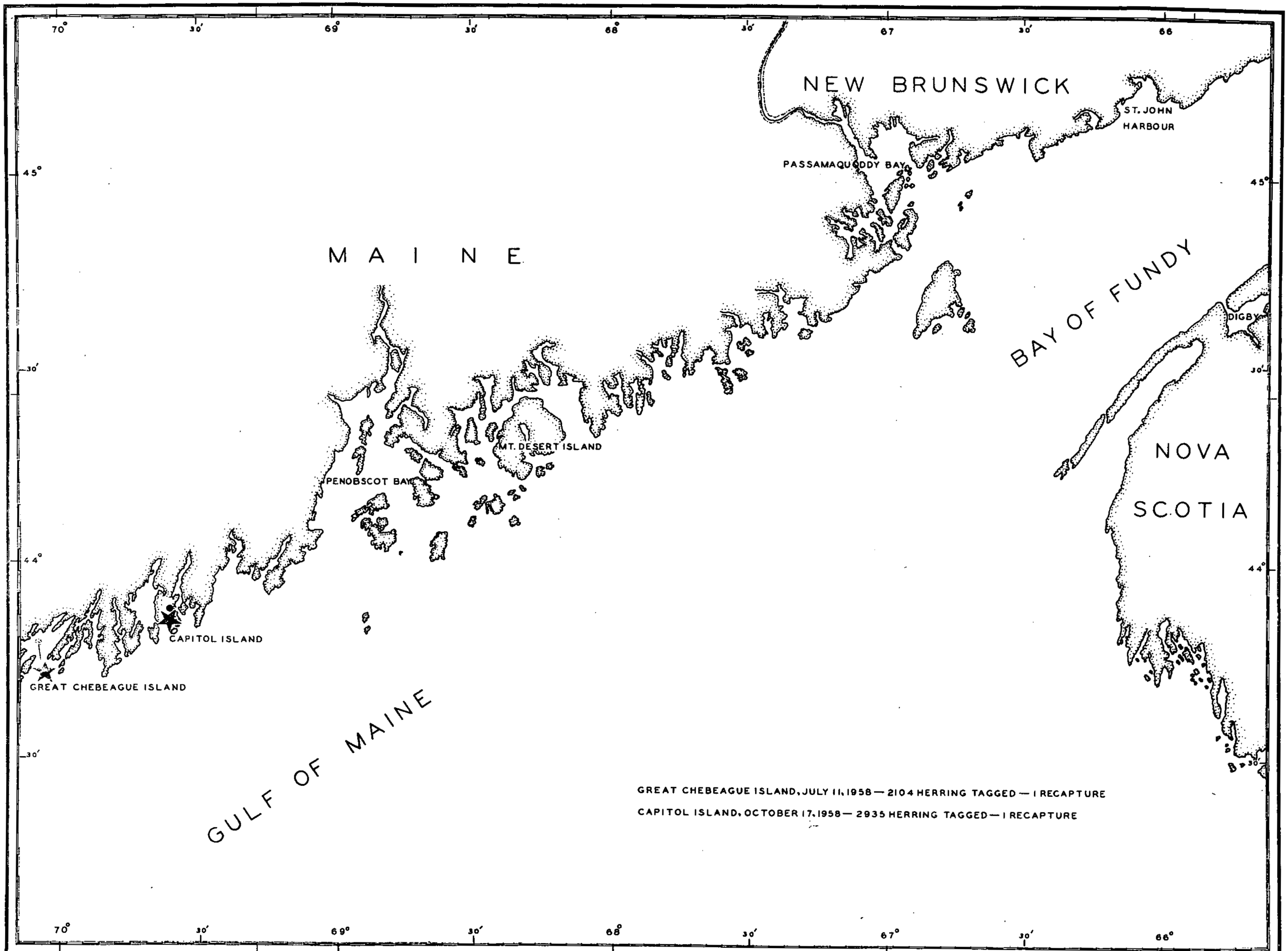


Figure 34. Recaptures from herring tagged at Great Chebeague Island, Me., on July 11, 1958; Capitol Island, Me., on October 17, 1958.

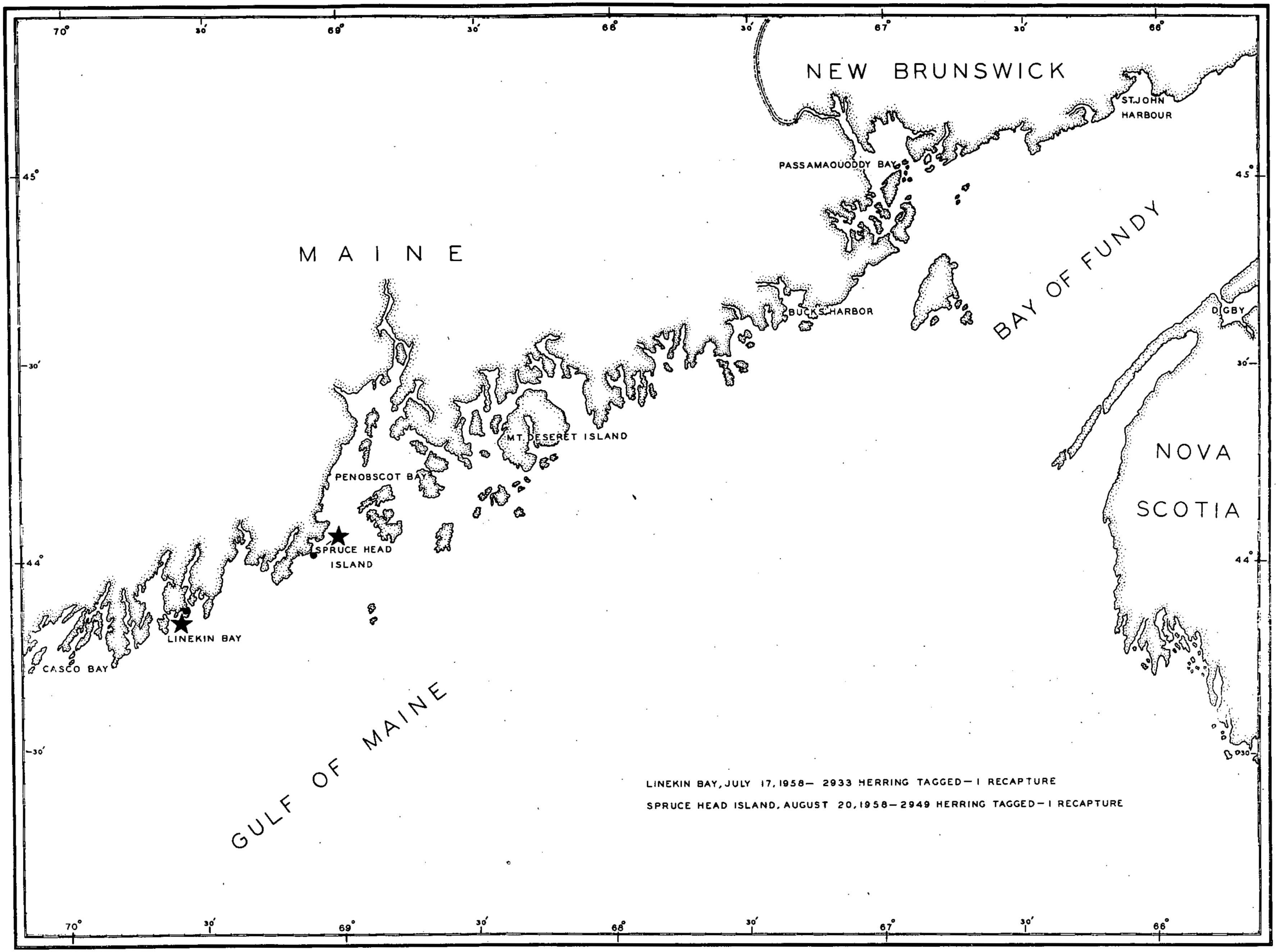


Figure 35. Recaptures from herring tagged at Linekin Bay, Me., on July 17, 1958; Sprucehead Island, Me., on August 20, 1958.

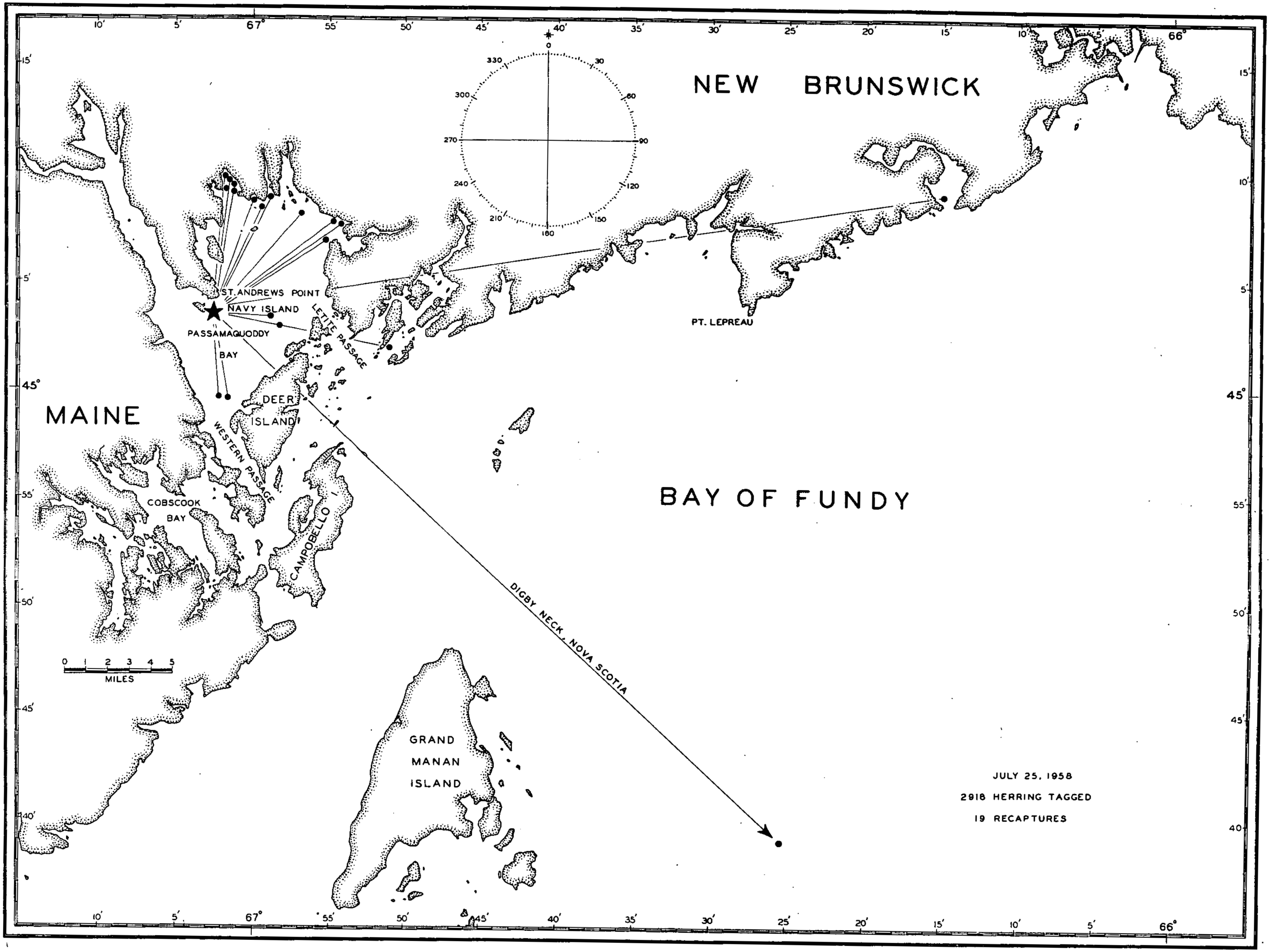


Figure 36. Recaptures from herring tagged at Navy Island, N. B., on July 25, 1958.

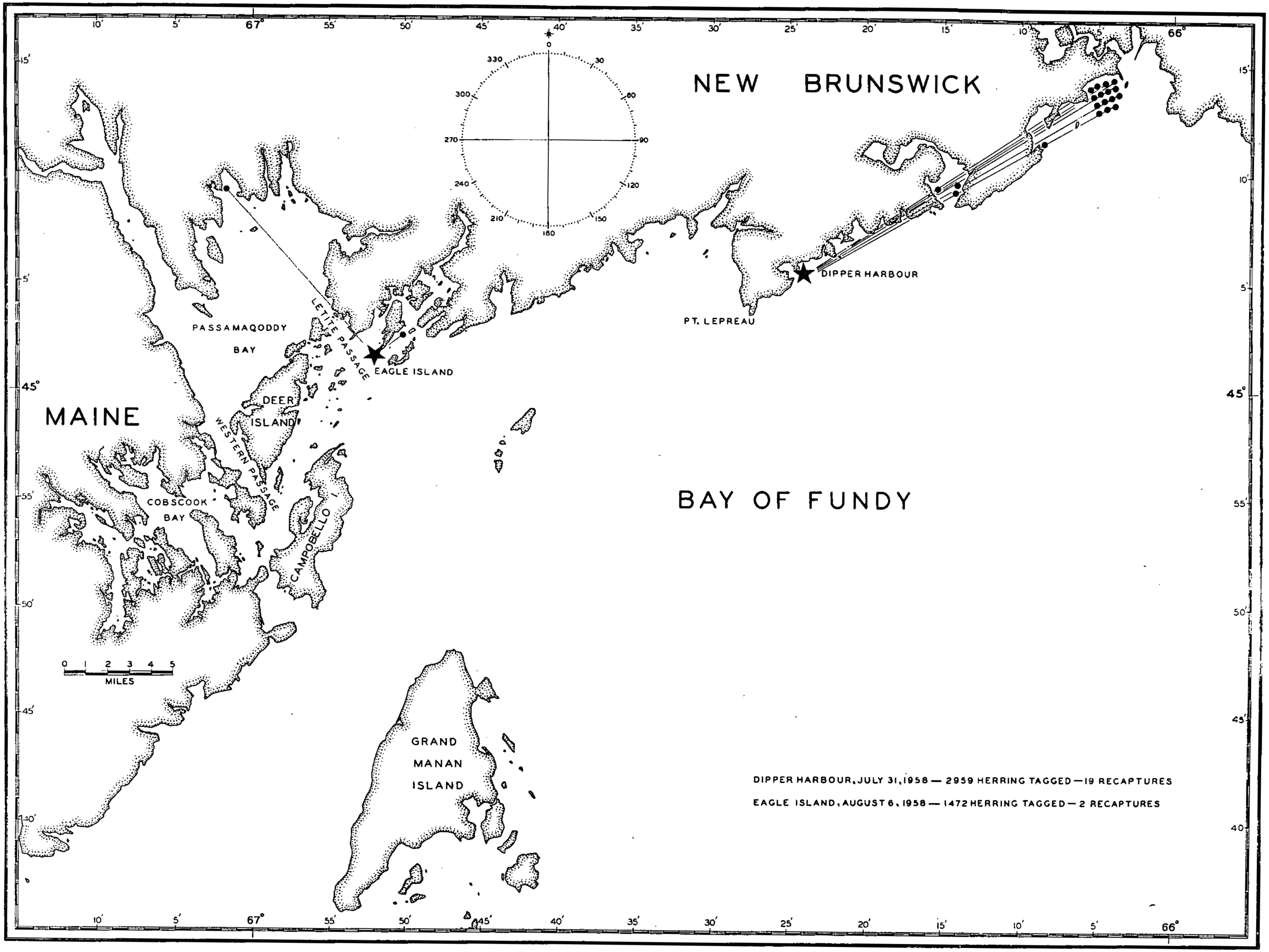


Figure 37. Recaptures from herring tagged at Dipper Harbour, N. B., on July 31, 1958; Eagle Island, N. B., on August 6, 1958.

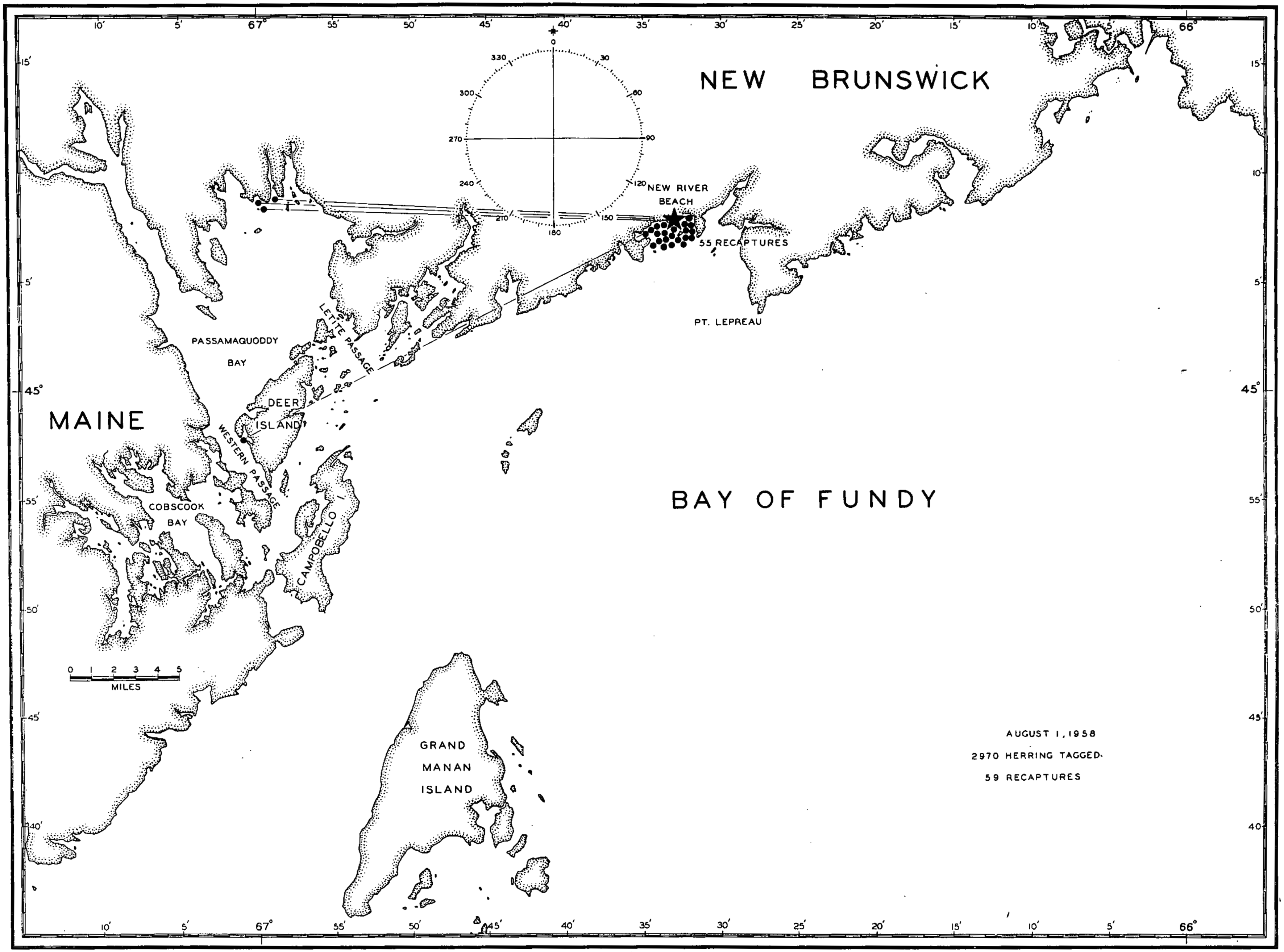


Figure 38. Recaptures from herring tagged at New River Beach, N. B., on August 1, 1958.

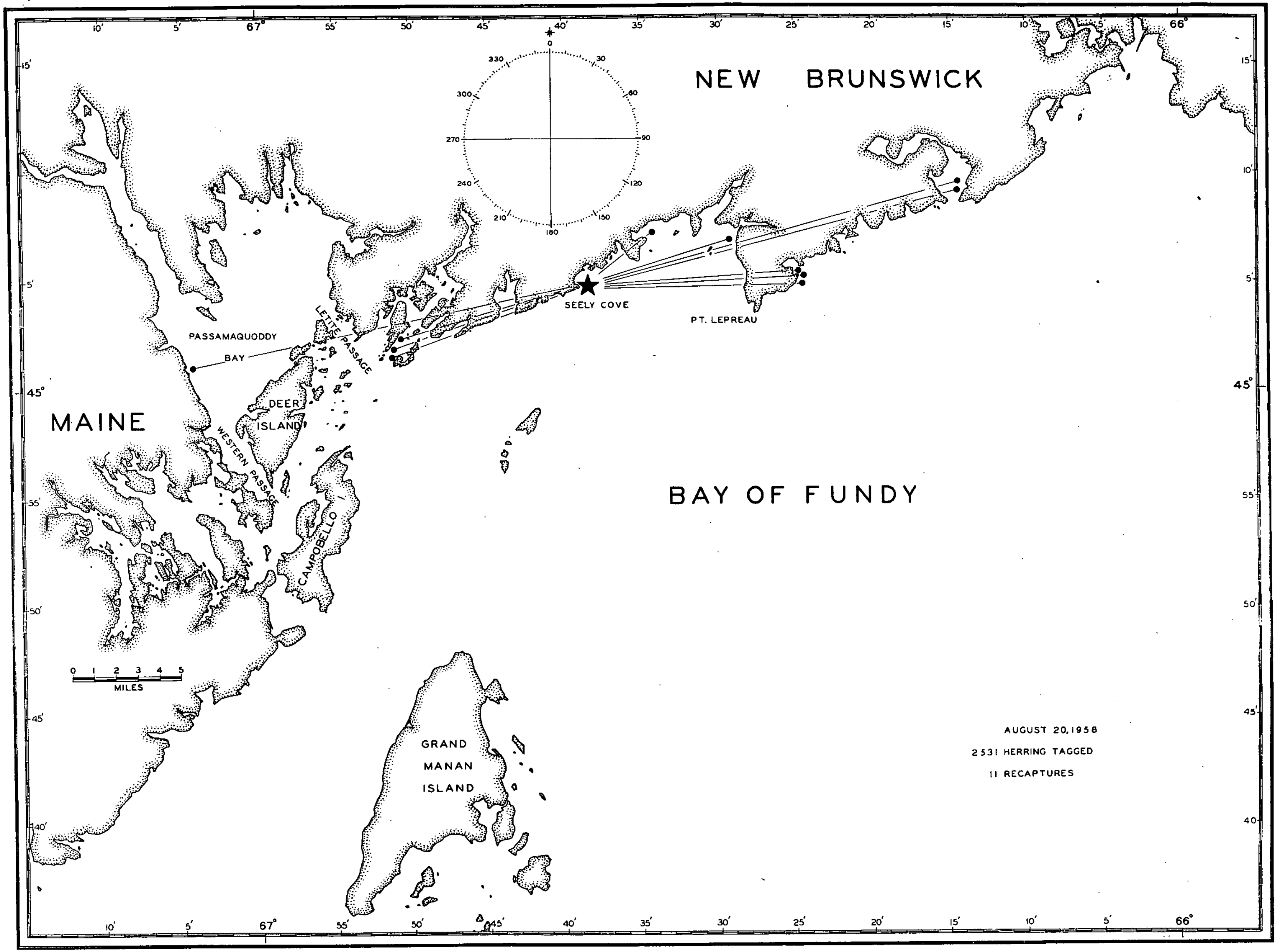


Figure 39. Recaptures from herring tagged at Seely Cove, N. B., on August 20, 1958.

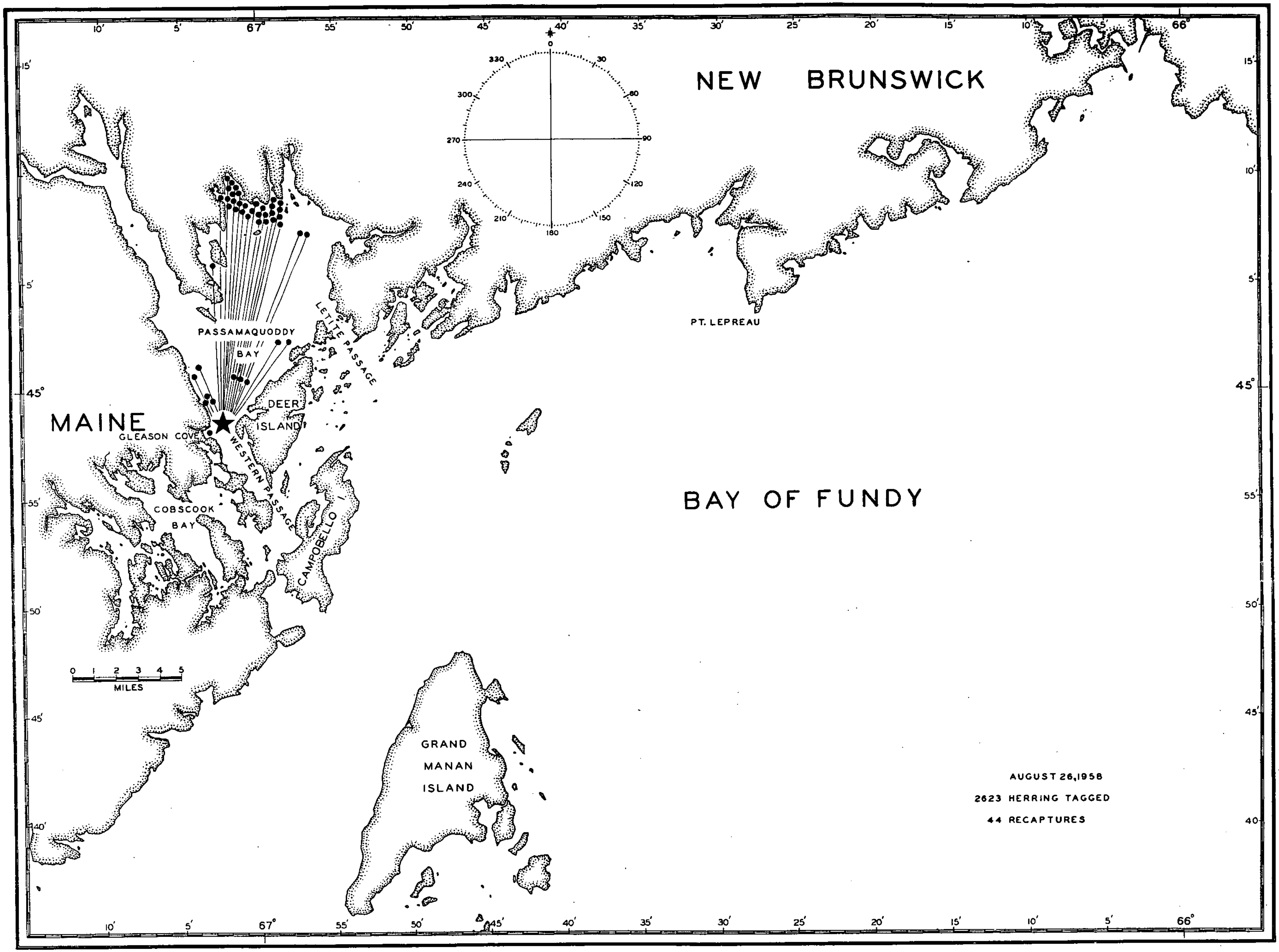


Figure 40, Recaptures from herring tagged at Gleason Cove, Me., on August 26, 1958.

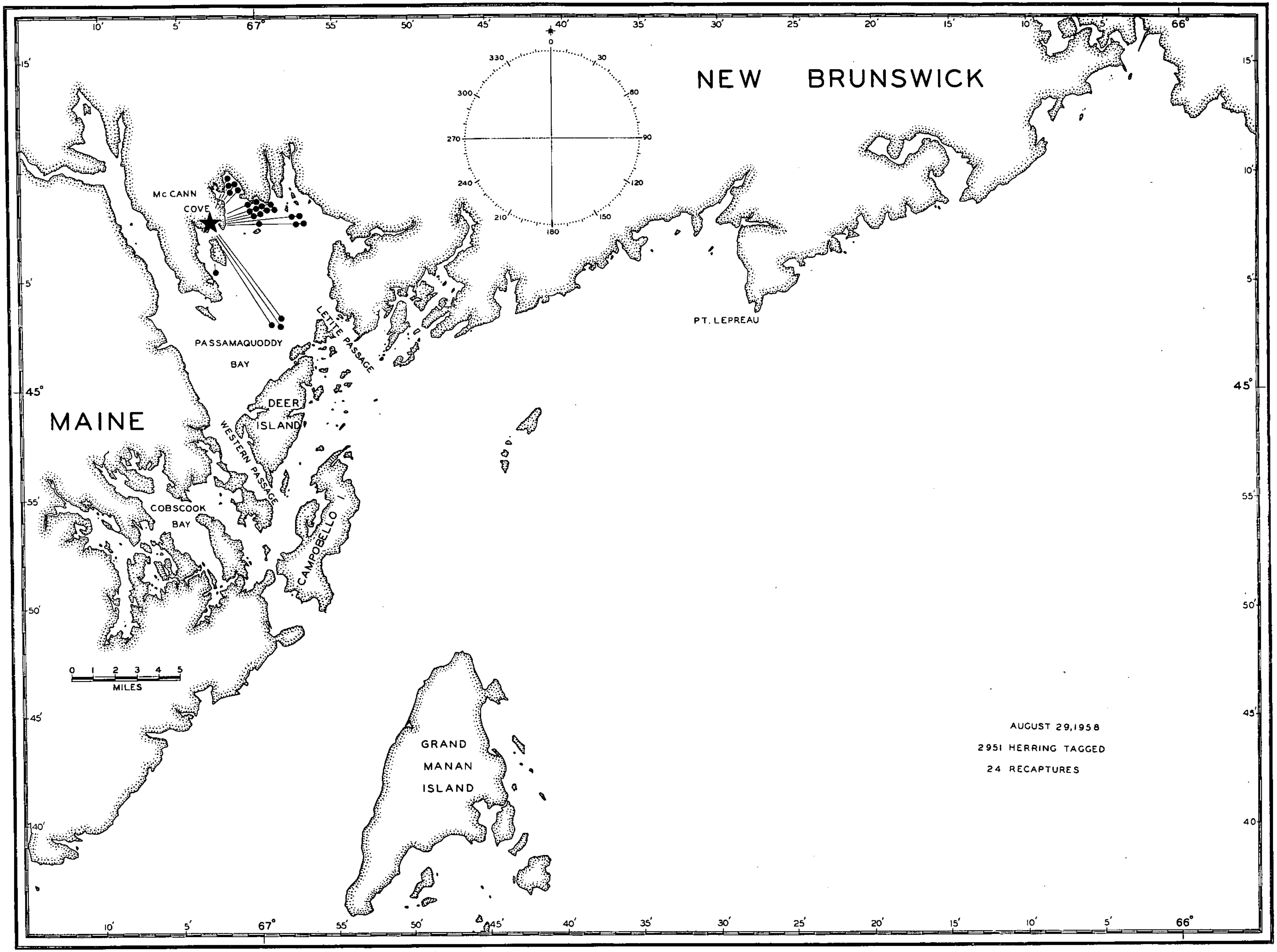


Figure 41. Recaptures from herring tagged at McCann Cove, N. B., on August 29, 1958.

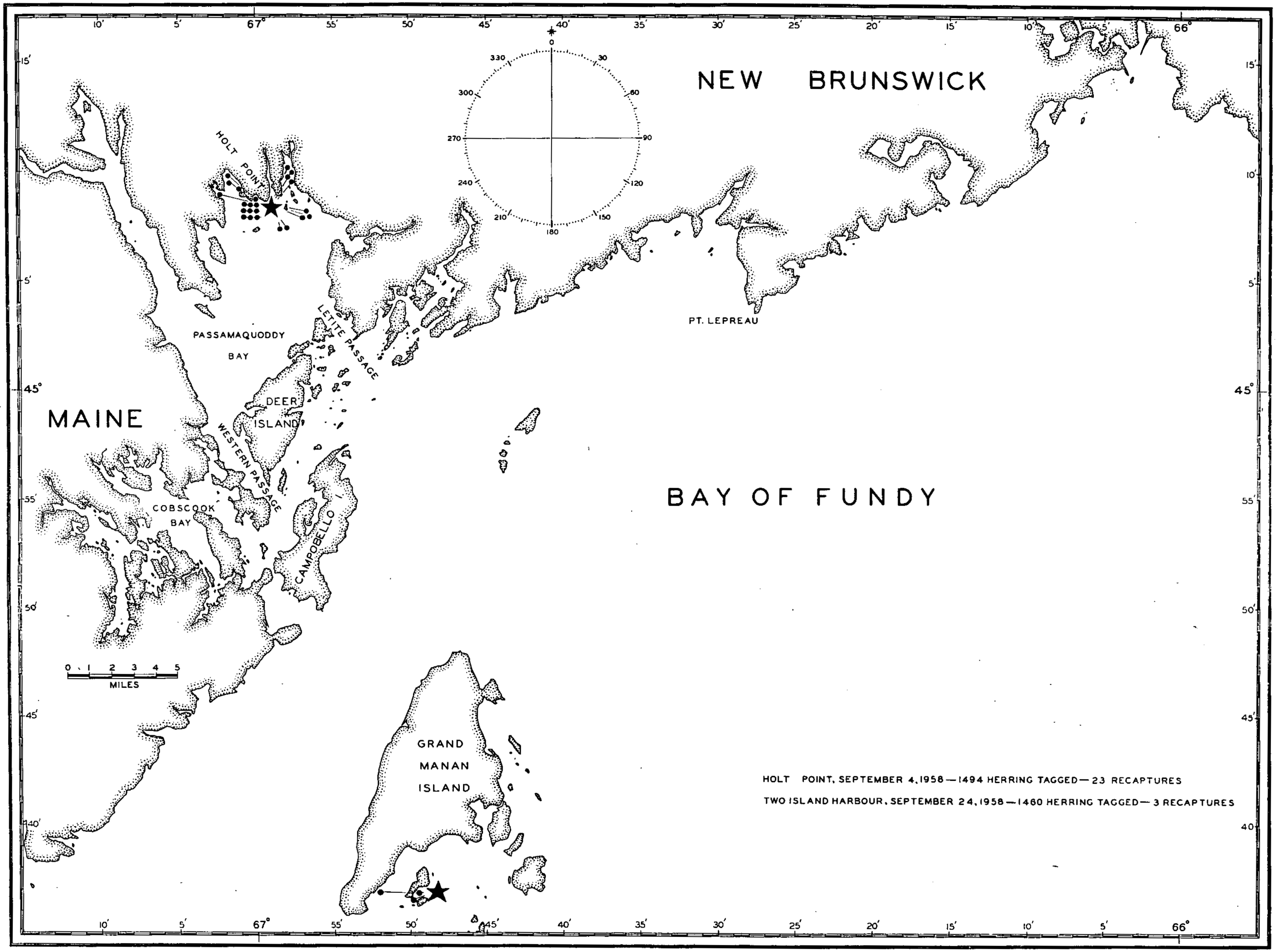


Figure 42. Recaptures from herring tagged at Holt Point, N. B., on September 4, 1958; Two Island Harbour, N. B., September 24, 1958.

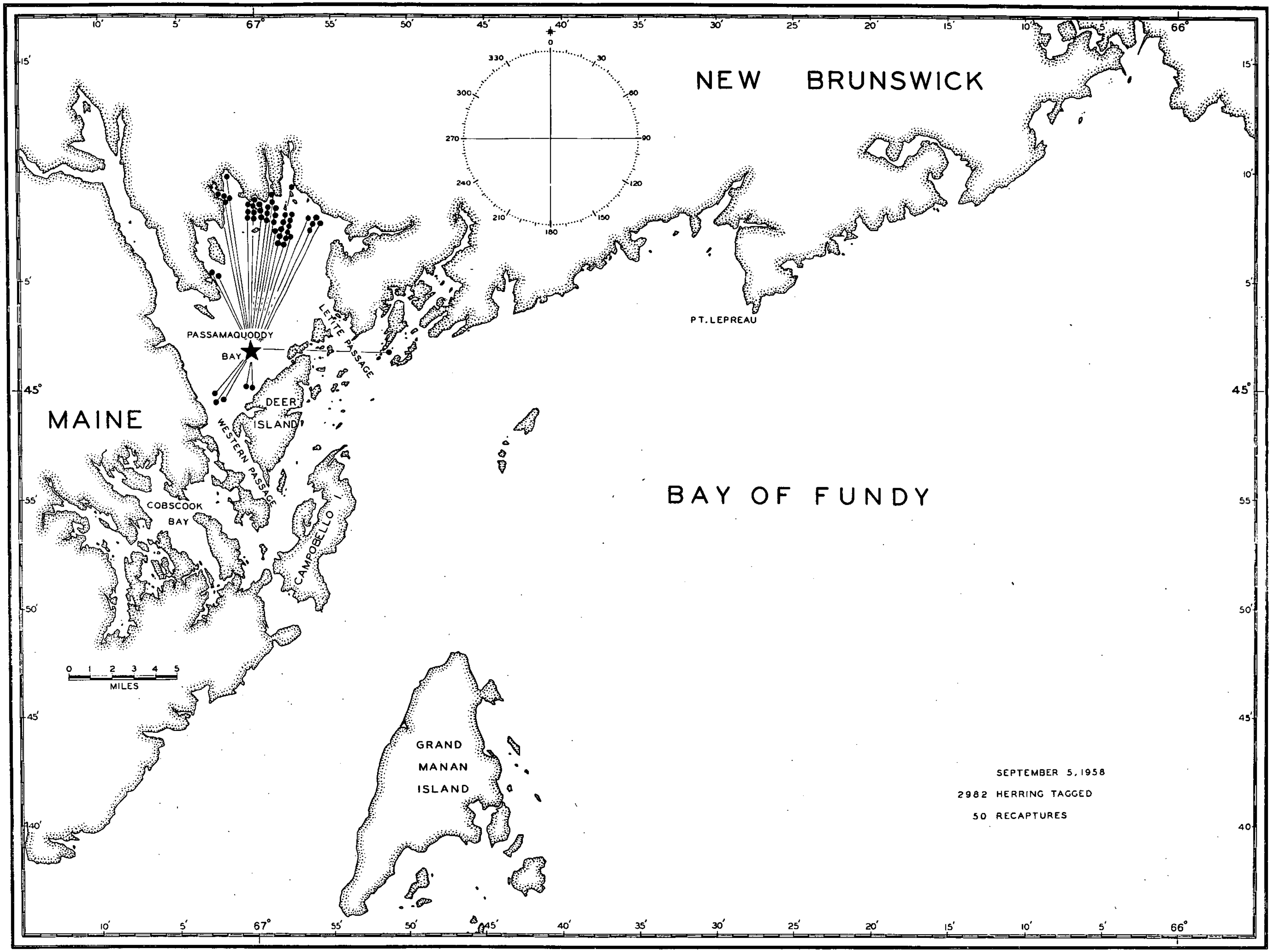
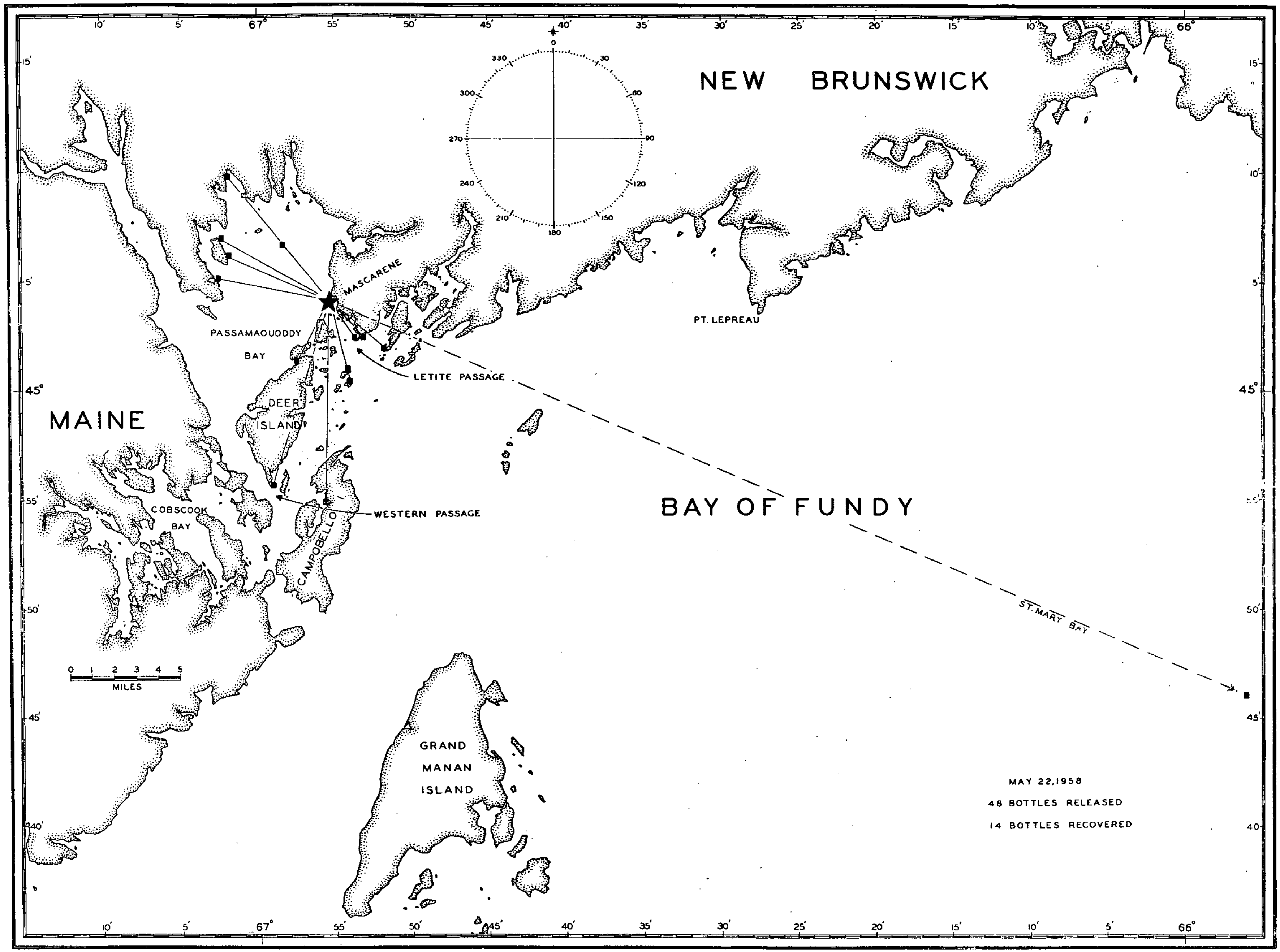


Figure 43. Recaptures from herring tagged in Passamaquoddy Bay, N. B., on September 5, 1958.

Figure 44. Recoveries from drift bottles released at Mascarene Shore, N. B., on May 22, 1958.



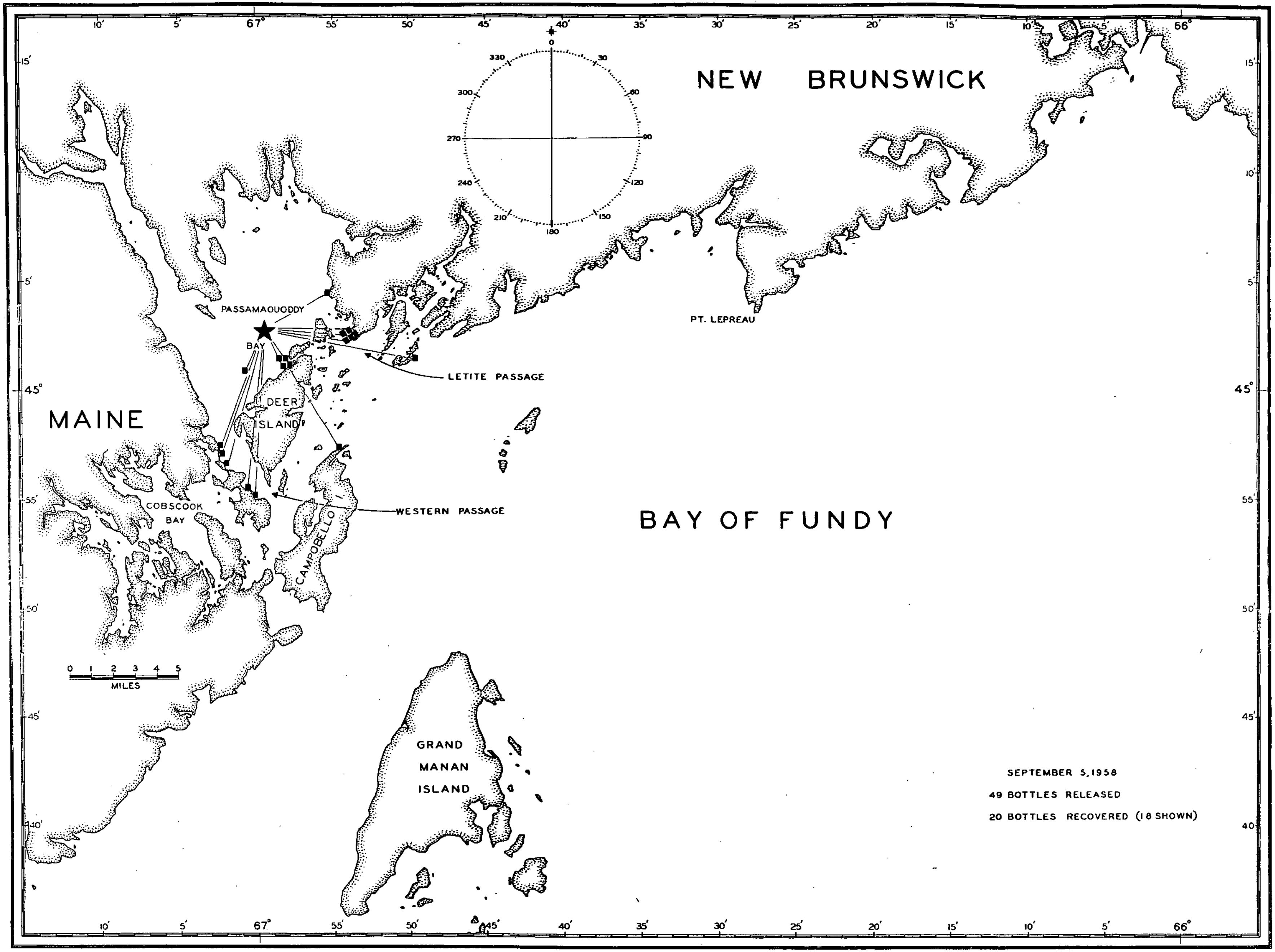


Figure 45. Recoveries from drift bottles released in Passamaquoddy Bay, N. B., on September 5, 1958.

CHAPTER 4

A QUALITATIVE AND QUANTITATIVE STUDY OF THE PLANKTON OF THE QUODDY REGION IN 1957 AND 1958 WITH SPECIAL REFERENCE TO THE FOOD OF THE HERRING

by

J. E. Henri Legaré and Delphine C. Maclellan
Fisheries Research Board of Canada
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ABSTRACT

Investigations of the composition, abundance, and distribution of plankton communities within the Passamaquoddy region of New Brunswick and Maine were carried out in 1957 and 1958. Studies of the food of herring and possible relationships between zooplankton abundance, feeding activity, fat content, and catches of herring were included in the program. Similar quantities of zooplankton were found outside Passamaquoddy Bay and in Cobscook Bay. Slightly smaller volumes were taken in the passages but only one fifth as much inside Passamaquoddy Bay. Differences in zooplankton abundance suggest incomplete mixing of outside waters with those of Passamaquoddy Bay. The smallest volumes of zooplankton were taken in the spring and the largest in the summer months. Overall zooplankton volumes were much higher in 1958 than in 1957. There was evidence that herring were feeding in the upper water layers. A period of low feeding activity from March to August was followed by a period of active feeding from September to November. There was a positive correlation between feeding activity and fat content of herring but no relationship between quantities of zooplankton and feeding activity could be established, nor was it possible to demonstrate any relationship between zooplankton volumes and catches of herring over a period of ten years. Should dams be installed at the entrances to Passamaquoddy Bay, zooplankton concentrations for the high pool (Passamaquoddy Bay), the low pool (Cobscook Bay), and outside the Bays should tend towards equilibrium.

INTRODUCTION

Although most studies of plankton in the Passamaquoddy area have been part of larger projects that involved the Bay of Fundy and the Gulf of Maine, a substantial body of information is available concerning the planktonic types and herring food in both Passamaquoddy Bay and adjacent areas.

Moore (1898) made notes on the food available to the herring in the vicinity of Passamaquoddy Bay. Willey (1913, 1915) studied various planktonic forms in Passamaquoddy Bay and McMurrich (1915) reported on winter plankton collections from St. Andrews Bay. Davidson (1934) reported on the abundance of planktonic diatoms in the Passamaquoddy area. Bigelow (1926) made an extensive study of the plankton of the Gulf of Maine. Huntsman (1917, 1919, 1928, 1931, 1933, 1934, 1952, 1953, 1955) contributed much to the knowledge of the hydrography, the plankton and the herring problems in the Passamaquoddy area in a number of scientific reports over the past forty years. Battle (1934) reported on the clearing time for "sardine" herring in Passamaquoddy Bay, and, Battle et al (1936) studied the fatness of herring in different parts of the Passamaquoddy area and the types and quantities of food organisms present in herring stomachs. Stevenson (1933) investigated the vertical distribution of four species of plankton in the St. Croix River estuary. Jermolajev (1958) studied the zooplankton of the inner Bay of Fundy.

Studies of the hydrography of Passamaquoddy Bay and vicinity were made by Vachon (1917) and of the Bay of Fundy by Bailey (1957), Hachey and Huntsman (1933), Hachey (1952, 1956) and Watson (1936).

A major investigation of plankton in the Passamaquoddy area was carried out by the International Passamaquoddy Fisheries Commission in 1931 and 1932. As part of this investigation, Fish and Johnson (1937) made an extensive study of the zooplankton in the Bay of Fundy with particular attention to Passamaquoddy Bay and its passages. Gran and Braarud (1935) investigated the phytoplankton of the Bay of Fundy.

Johnson (1942) studied the effect of light on copepods as food for Passamaquoddy herring. Leim (1958) studied the fatness of herring in the Bay of Fundy and found values for herring from Campobello similar to those reported by Battle et al (1936). Leim (1956) listed and reviewed various papers published on Bay of Fundy herring. Chiasson (unpublished data) began a study of the food of "sardines" in Passamaquoddy Bay in 1955. This study was continued by Somerville (1956).

In 1956, the Fisheries Research Board of Canada and the United States Bureau of Commercial Fisheries began a joint investigation of the plankton in offshore areas of the Bay of Fundy and the Gulf of Maine. This investigation provided information on the distribution and abundance of herring larvae (Tibbo et al, 1958).

The present paper is a report on the composition, abundance, and distribution of the plankton communities within the Quoddy Region. The Quoddy Region encompasses Passamaquoddy Bay, Cobscook Bay, the passages, and outside Passamaquoddy inside a line from West Quoddy Head, Maine, to the northern tip of Grand Manan, N. B., and thence to Point Lepreau, N. B. Results of studies of the food and feeding habits of herring and relationships between the abundance of zooplankton and fat content, feeding activity, and catches of "sardine" herring are included.

MATERIALS AND METHODS

Materials and methods used in the investigation are shown in Table I.

Quoddy project (QP) cruises (Table I)

From January 1957 to December 1958, 14 stations in the Quoddy Region were occupied regularly (Fig. 1). Forty-three Quoddy project (QP) cruises were made, one a month during the winter months and two a month through the remainder of the year except in August 1957 and May and October 1958 when three cruises were made.

Oblique plankton tows at 20-10-0 m were made with a 1-m (diameter) nylon net of #0 mesh (12 to 15 meshes per cm). The net was towed at a slow speed for five minutes at each level. All QP cruises were made in the daytime. The M. B. Betty Lou IV was chartered for most of the cruises and the M. B. Mercury and M. B. Mallotus used for the remainder.

Prince 5 and 6 cruises (Table I)

Tows from Prince stations 5 and 6 (see Fig. 1 for these stations, renamed QP 2 and 8) have been carried out regularly by the Fisheries Research Board of Canada's Biological Station, St. Andrews, N. B. for more than 30 years. Analysis of the plankton from these stations for the years 1937 to 1959 (April) was made.

Quoddy passages cruises (Table I)

Fifteen exploratory cruises were made in October and November 1958, during the day and at night, in and close to the passages to Passamaquoddy Bay, to study the vertical distribution of zooplankton. Oblique tows were made for 15 minutes at 0, 20, 50, 75, and 100 m.

Exploratory cruises (Table I)

Exploratory tows were made in and close to the passages to Passamaquoddy Bay to catch herring larvae. On six occasions, a 1-m net was towed for 5 minutes at each 10-m level between the bottom and surface. Also four or five 12-in (diameter) nets were towed simultaneously at different levels. After sampling several depths with the small nets, 1-m closing nets were towed at the same depths.

J. J. Cowie cruises (Table I)

During the latter part of March 1958, a total of 46 oblique plankton tows were made with a 1-m net at 20-10-0 m around Grand Manan, in the entrance to the Bay of Fundy, and in St. Mary Bay (Fig. 2).

Table I. Table of materials and methods.

Cruises	Number	Date	Stations occupied	Frequency of cruises	Vessels used	Tows Day	Tows Night	Depth of tows(m)	Time of tows(min)	Kinds of nets
Quoddy project	43	Jan. 1957-Dec. 1958	14	Monthly in winter and twice monthly rest of year*	M.B. Betty Lou M.B. Mercury M.B. Mallotus	602	-	20-10-0	5 each depth	1 m #0
Prince 5	226	Aug. 1937-Apr. 1959	1	Monthly	M.B. Zoarces M.B. Mallotus M.B. Betty Lou M.B. Mercury	650	-	18-23 5-7 90-0	15 15 few	1 m #0 closing 12" #5 1 m #0
Prince 6	458	Jan. 1937-Apr. 1959	1	Weekly from 1937 to 1944 Monthly from 1945 to 1959	M.B. Zoarces M.B. Mallotus M.B. Betty Lou M.B. Mercury	1352	-	18-23 5-7 30-0	15 15 few	1 m #0 closing 12" #5 12" #5
Quoddy passages	15	Oct. - Nov. 1958	6	6 in Oct. 9 in Nov.	M.B. Mallotus M.B. Betty Lou M.B. Mercury	25 27	11 11	0,20,50, 75,100 0,20,50, 75,100	15 each depth	1 m #0 closing 12" #5
Exploratory	6	Oct.-Nov. 1958	6	4 in Oct. 2 in Nov.	M.B. Mercury M.B. Betty Lou	16	29	each 10 m depth from bottom to surface	5 each depth	1 m #0 12" #5
J.J. Cowie	2	Mar. 1958	46	latter part of Mar.	M.B. J.J. Cowie	46	-	20-10-0	5 each depth	1 m #0
Lurcher	-	Apr. - Dec. 1958	1	1 night and 1 day tow weekly	Lurcher Lightship	23	23	surface	15	1 m #0

* Three cruises per month in August 1957 and May and October 1958.

Lurcher cruises (Table I)

From mid-April to the end of December 1958, the crew of the Lurcher Lightship (location Lat. 43°48'30"N., Long. 66°31'45"W.) assisted in collecting plankton samples. Two plankton collections were made on the same day each week, one in daylight, the other at night. Samples were from the surface while the ship was at anchor on the Lurcher Shoals, off Yarmouth, N. S., and were made with a 1-m net at half-tide, either ebb or flood.

Examination of tows

After each tow, the plankton was washed down with salt water into pint sealers, preserved in 5% formalin and examined in the laboratory.

Zooplankton: Both qualitative and quantitative analyses were made of the zooplankton. A square glass dish placed on a black paper marked out in 100 1-in squares was used to examine the entire sample. Fish larvae were removed first, identified, measured, and preserved for further study. Various forms of medusae, siphonophore fragments, ctenophores and salps, considered to be non food items, were removed and their displaced volumes recorded. The displaced volumes of the remainder which was considered to be herring food, were measured and recorded.

The zooplankton was identified to species and counted. The total number of copepods in each sample was estimated and the percentage abundance of each species recorded.

Phytoplankton: Occurrence of phytoplankton was noted and quantities estimated. Identification of the dominant species was made with a special plankton microscope. Glass chambers of a known volume were filled with an aliquot of the sample, and the field scanned under magnification. Percentage abundance, by numbers, of the dominant species was recorded.

Examination of herring stomachs

Seventeen samples of about 100 herring each were obtained from weirs in Passamaquoddy Bay and vicinity (Fig. 3) for stomach analysis. These samples were taken from March to November in 1958. A total of 1,696 herring stomachs were examined. The fish were slit ventrally immediately after capture and strong formalin poured into the abdominal cavity to arrest digestion. Stomachs were removed the same day and contents analysed under a binocular microscope. The frequency of occurrence and the percentage of various organisms were recorded, and displaced volumes measured for each sample. Mean total lengths of the herring were recorded for each sample.

ABUNDANCE AND DISTRIBUTION OF ZOOPLANKTON

Introduction and description of ecological groups

The fourteen stations selected for the Quoddy project (QP) cruises are distributed in waters that are slightly different in physical and chemical properties and as such have different plankton communities. Stations outside Passamaquoddy differ in their environmental conditions from those inside the Bay, in the passages and in Cobscook Bay (Appendix I, Chapters 1 to 4). Stations 1, 2, and 14 were chosen to represent conditions outside Passamaquoddy, stations 3, 4, 12, and 13 those in the passages, stations 10 and 11 those in Cobscook Bay and stations 5, 6, 7, 8, and 9 those inside Passamaquoddy Bay (Fig. 1).

The zooplankton was divided into 5 ecological groups: *boreal*, *neritic*, *benthic*, *northern* and *southern*. The seasonal importance of these groups in each of the four divisions of the Quoddy Region described above and the relative abundance of all the zooplankton taken in the QP cruises are given in Table II.

Of the *boreal* species three copepods were abundant in the Quoddy Region, *Calanus finmarchicus*, *Pseudocalanus minutus*, and *Centropages typicus*. Occurring in much smaller numbers but also important were the copepods *Metridia lucens* and *Temora longicornis*, the euphausiids *Meganyctiphanes* and *Thysanoessa*, the chaetognath *Sagitta elegans* and the mollusc *Limacina retroversa*.

A total of 12 plankters are listed as *neritic* in the Quoddy Region (Table II) but only three were abundant, the copepods *Tortanus discaudatus*, *Acartia clausi*, and *Eurytemora herdmani*. Also common were the coelenterate *Aurelia aurita* and the cladocerans *Evadne nordmanni* and *Podon leuckarti*.

Benthic species, especially their larvae, played an important part in the zooplankton community in the Quoddy Region (Table II). Large numbers of crab, mussel, and barnacle larvae made up a high percentage of the zooplankton catch during their breeding seasons. Harpacticoid copepods, represented by 16 species, occurred in small numbers especially during the spring and summer and the trochophore larvae of various annelids were found in fair numbers in all seasons.

Twelve species of *northern* and *southern* ocean migrants were represented by only a few specimens in the Quoddy Region (Table II). *Southern* migrants were always scarce in the QP cruises although *Salpa fusiformis* reached large concentrations in the winter zooplankton in St. Mary Bay, N. S. Among the *northern* migrants, 2 copepods, *Metridia longa* and *Calanus hyperboreus* were found quite commonly at 100 m during the exploratory cruises of October and November 1958 in and near the passages. Other *northern* species were always scarce.

Table II. Seasonal composition of zooplankton. Based on Quoddy project data from 1957 and 1958 combined. Figures are percentages, by numbers, relative to total zooplankton.

Species	Passamaquoddy Bay				Cobscook Bay				Passages				Outside			
	Spring %	Summer %	Autumn %	Winter %	Spring %	Summer %	Autumn %	Winter %	Spring %	Summer %	Autumn %	Winter %	Spring %	Summer %	Autumn %	Winter %
Boreal species																
Annelids - Tomopteris catherina	0.01	F*	0.01	0.04	0.05	F	F	0.09	0.03	F	F	0.04	0.01	F	F	0.09
Amphipods - Euthemisto, Hyperia	0.02	0.06	0.61	0.03	0.16	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.01	F	0.13	0.01
Appendicularians - Fritillaria, Oikopleura	0.09	0.10	0.07	-	-	-	-	-	F	0.01	-	-	-	F	F	-
Chaetognaths - Sagitta elegans	0.36	0.12	0.12	0.33	0.40	0.09	0.18	0.26	0.29	0.07	0.11	0.29	0.10	0.17	0.01	0.27
Coelenterates - Aglantha digitale	0.11	0.02	-	0.44	0.20	-	-	0.26	0.05	0.02	-	0.41	0.53	0.01	0.14	0.09
Stephanomia cara	1.07	0.06	0.07	0.75	1.01	0.04	0.06	0.40	2.04	0.22	0.03	0.52	6.64	0.57	0.14	19.77
Copepods - Anomalocera patersonii	-	-	-	-	-	-	F	-	-	F	-	-	-	0.54	F	-
Calanus finmarchicus	13.79	14.79	16.91	80.27	19.40	34.90	70.00	88.17	17.08	37.15	56.16	84.37	14.92	14.62	11.38	64.78
Centropages typicus	0.76	0.48	24.81	5.18	0.35	0.47	20.39	2.96	0.17	0.34	35.10	3.91	1.17	1.40	81.75	9.08
Euchaeta norvegica	-	F	0.04	1.79	0.74	1.00	0.93	2.07	1.07	0.50	0.12	1.39	0.35	F	-	0.39
Metridia lucens	2.11	0.60	0.12	2.67	6.43	1.28	1.38	4.89	9.25	1.92	2.07	7.42	2.91	0.04	0.13	2.19
Microsetella norvegica	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-
Oithona similis	-	-	-	-	-	-	0.23	-	-	0.01	-	-	0.01	0.16	0.08	0.17
Pseudocalanus minutus	19.69	18.75	0.21	0.74	51.25	51.44	0.15	0.16	45.82	50.77	0.42	0.53	6.82	8.47	0.30	0.25
Temora longicornis	0.08	3.62	1.03	0.08	0.02	0.24	1.19	-	0.14	0.50	2.22	-	-	0.56	3.48	-
Ctenophores - Pleurobrachia pileus	0.01	0.67	0.07	0.01	0.08	0.33	0.04	0.06	0.01	0.19	F	F	F	0.04	0.10	F
Euphausiids - Eggs	-	-	-	-	-	-	-	-	-	-	-	-	46.46	65.55	-	-
Meganyctiphanes, Thysanoessa	3.31	2.62	2.60	1.08	2.07	0.38	0.17	0.11	1.61	0.40	0.27	0.16	0.89	0.25	0.10	0.01
Fishes - Eggs	1.79	1.75	2.19	0.03	0.51	0.02	F	-	2.31	0.15	0.06	F	3.55	0.56	0.03	0.15
Larvae	0.91	0.36	0.02	0.08	0.48	0.09	F	0.02	0.22	0.10	F	0.01	0.05	0.03	F	0.01
Molluscs - Clione limacina	0.21	-	-	-	0.38	0.18	-	-	0.05	0.07	-	-	0.46	0.01	0.03	2.50
Limacina egg cases	0.02	0.03	-	-	0.11	0.01	F	-	0.14	F	-	-	-	-	-	-
Limacina retroversa	1.03	0.19	0.04	-	0.58	0.01	0.12	-	1.01	-	0.01	0.06	4.51	0.05	-	-
Neritic species																
Amphipods - Caprella linearis	-	0.02	0.04	0.02	-	F	0.01	F	-	0.02	F	F	-	-	F	F
Cladocerans - Evadne, Podon	0.17	0.30	0.07	-	-	-	-	-	-	0.03	F	-	-	0.26	0.01	-
Coelenterates - Aurelia aurita	0.89	0.08	0.13	0.01	0.04	0.01	0.25	-	F	0.03	0.21	F	0.02	0.05	0.57	F
Hydroids (floating)	-	0.02	0.03	0.02	0.05	0.01	0.01	0.01	0.04	0.01	0.03	0.01	-	-	F	0.03
Copepods - Acartia clausi	12.91	8.62	1.50	1.67	0.75	0.10	0.25	-	2.68	1.58	1.45	0.10	1.11	0.36	0.68	0.23
Acartia longiremis	-	-	-	-	-	-	-	-	-	-	-	-	-	F	F	-
Caligus rapax	-	0.02	0.18	-	0.01	F	0.01	-	-	F	0.01	-	F	F	0.01	-
Centropages hamatus	-	-	-	-	-	F	-	-	-	-	-	-	-	F	-	-
Eurytemora herdmani	2.08	7.20	0.83	-	0.13	2.03	0.37	-	0.73	1.88	0.01	-	-	1.37	0.09	-
Eurytemora hirundoides	F	F	F	F	F	-	-	F	F	-	-	F	-	-	-	-
Tortanus discaudatus	9.85	29.53	45.04	4.06	2.44	2.60	2.37	0.03	1.97	2.34	0.59	0.38	0.23	4.02	0.53	0.04
Benthic species																
Amphipods - Calliopius laeviusculus	-	F	F	-	-	F	F	-	-	-	-	-	-	-	-	-
Annelids - Autolytus, Nereis	1.13	0.38	0.30	0.04	0.84	0.13	0.15	0.02	0.95	0.06	0.05	0.02	0.05	0.01	0.01	0.01
Trochophore larvae	-	0.22	1.02	-	-	-	0.39	-	-	0.22	0.13	-	0.13	0.02	0.16	-
Barnacles - Balanus balanoides larvae	20.62	0.57	-	-	4.02	0.36	-	-	7.25	0.27	-	-	5.58	F	-	-
Brittle-stars - Amphipholis squamata	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-
Copepods - Harpacticoids	2.40	0.04	0.01	0.68	3.24	0.05	F	0.13	0.76	0.03	0.45	-	0.55	F	0.04	-
Crabs - Zoea larvae	3.54	8.75	1.11	0.01	3.44	3.15	0.30	F	2.22	1.03	0.10	F	2.77	0.89	0.09	0.01
Cumaceans - Diastylis spp.	1.03	0.02	0.72	-	0.96	0.12	0.93	0.35	2.02	0.05	0.23	-	-	-	-	-
Isopods	-	-	-	-	-	F	-	-	-	F	-	-	-	-	-	-
Mussels - Mytilus edulis larvae	-	0.02	0.07	-	F	0.01	0.03	-	0.04	F	0.08	-	0.06	F	-	-
Mysids - Erythrops erythropthalma	-	-	0.02	-	-	-	-	-	-	-	F	-	-	-	-	-
Mysis stenolepis	0.01	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-
Nematodes	-	-	F	-	-	-	-	-	-	-	-	F	-	-	-	-
Nudibranchs	-	F	-	-	-	-	-	-	-	F	-	-	-	-	-	-
Ostracods	-	-	-	-	0.01	-	-	-	F	-	-	-	-	-	-	-
Scallops - Pecten spp. larvae	-	-	0.01	-	-	-	-	-	-	-	0.02	-	-	-	-	-
Sea-cucumber - larvae	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-	-
Sea-spider - larvae	-	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-
Sea-stars - Asterias vulgaris larvae	0.02	-	-	-	0.01	-	0.03	F	0.02	-	0.01	-	-	F	-	-
Sea-urchins - Strongylocentrotus droehbachiensis	-	-	-	-	-	-	F	-	-	-	-	-	-	-	-	-
Shrimps - Crago, Pandalus, Spirontocaris	-	-	-	-	F	-	-	F	-	-	F	-	-	-	0.01	-
Sponges - Fragments	-	-	-	-	-	-	-	-	-	F	-	F	-	-	-	-
Northern species																
Copepods - Aetidius armatus	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-
Calanus hyperboreus	-	-	-	-	-	-	-	-	-	-	F	F	-	-	F	F
Metridia longa	-	-	-	-	-	-	-	-	-	-	F	F	-	-	F	F
Scolecithricella minor	-	-	-	-	-	-	-	-	-	-	F	F	-	-	-	-
Southern species																
Copepods - Candacia armata	-	-	-	-	-	-	-	-	-	-	-	F	-	-	F	-
Euchirella rostrata	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-
Monstrilla dubia	F	F	-	F	F	-	F	-	-	-	-	-	F	F	-	-
Oithona plumifera	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-	-
Paracalanus parvus	-	-	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-
Pleuromamma robusta	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	-
Rhincalanus nasutus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F
Salps - Salpa fusiformis	-	-	-	-	-	-	-	-	-	-	F	-	-	-	-	-

*F = a few

Seasonal and regional abundance

The relative abundance of the numbers of zooplankters in the Quoddy Region fluctuated widely from season to season. Zooplankters were most abundant in summer (63%), decreasing through autumn (20%) and winter (11%) to a minimum in the spring (6%) (Table V).

Table III shows the seasonal variation of zooplankters in the Region. Barnacle nauplii, Limacina retroversa and harpacticoid copepods were most abundant in the spring. Twenty of the zooplankters were most abundant in the summer and included Eurytemora herdmani, cladocerans, euphausiid eggs, and Pseudocalanus minutus. Centropages typicus, Aurelia aurita, Caligus rapax, Euthemisto compressa, mussel larvae, Temora longicornis, trochophore larvae and cumaceans were most abundant in the autumn. Aglantha digitale, Stephanomia cara and Tomopteris catherina were most abundant in the winter. Table III also shows that most zooplankters were found at all seasons throughout the Quoddy Region. Some were abundant for one season only and were rare or disappeared in other seasons. Table II shows that euphausiid eggs made up 66% of the number of organisms taken outside the Bay in summer. In autumn, 82% of the zooplankton was Centropages typicus and in winter 65% was Calanus finmarchicus. In the passages, Pseudocalanus minutus accounted for 51% of the zooplankton in summer, while in autumn and winter Calanus finmarchicus made up 56% and 84% respectively of the zooplankton. In Cobscook Bay, zooplankton was 51% Pseudocalanus minutus in spring and summer, 70% and 88% Calanus finmarchicus respectively in autumn and winter. In Passamaquoddy Bay, 80% of the winter plankton was Calanus finmarchicus. Tortanus discaudatus was the most important form in the autumn (45%) and summer (30%). Pseudocalanus minutus was abundant both in the summer (19%) and in the spring (20%).

Variation in the numbers of zooplankters in the four parts of the Quoddy Region is shown in Table IV. Zooplankton was most abundant in Cobscook Bay (33%), outside Passamaquoddy (32%), and in the passages (28%), and much less abundant inside Passamaquoddy Bay (7%). All species varied in abundance in the four areas (Table IV). In Passamaquoddy Bay, boreal and ocean migrant species seldom reached large concentrations. A few neritic and benthic species were abundant but never reached concentrations comparable to the abundant species found in the Gulf of Maine by Bigelow (1926). Bigelow (1926) also found that zooplankton volumes in the Bay of Fundy were poorer than those in the Gulf of Maine. Fish and Johnson (1937) reported smaller zooplankton volumes in the Bay of Fundy than in the Gulf of Maine and still smaller volumes inside Passamaquoddy Bay.

Table V shows the seasonal variation in the numbers of zooplankters in Passamaquoddy Bay, Cobscook Bay, the passages and outside Passamaquoddy. In Passamaquoddy Bay, 56% of the catch was taken in summer, 19% in autumn, 15% in winter, and 10% in spring. In the passages,

Table III. Seasonal variation in numbers of zooplankters in the Quoddy Region. (Data for 1957 and 1958 combined).

Species	Spring %	Summer %	Autumn %	Winter %
Acartia clausi	13.59	69.62	14.99	1.79
Aglantha digitale	23.61	7.36	17.21	51.83
Aurelia aurita	7.30	19.79	72.71	0.18
Balanus balanoides nauplii	75.96	24.03	--	--
Calanus finmarchicus	2.86	48.34	23.03	25.76
Caligus rapax	2.46	27.06	70.50	--
Crab zoea	11.22	85.84	2.90	0.03
Cladocerans (Podon, Evadne)	1.53	95.57	2.91	--
Centropages typicus	0.33	4.40	91.03	4.25
Clione limacina	15.10	43.45	2.02	39.42
Diastylis spp.	32.63	18.62	38.20	10.56
Euchaeta norvegica	6.86	51.98	9.16	32.00
Euphausiids	20.97	59.42	15.31	4.28
Euphausiid eggs	5.48	94.52	--	--
Eurytemora herdmani	2.16	95.02	2.81	--
Euthemisto compressa	9.33	28.16	57.98	4.51
Fritillaria and Oikopleura	8.70	73.91	--	17.40
Harpacticoids	60.38	10.12	20.97	8.54
Hydroids (Floating)	12.74	47.55	29.90	9.80
Limacina retroversa	79.77	14.24	4.76	1.22
Metridia lucens	20.02	35.60	12.48	31.91
Mytilus edulis (larvae)	13.89	23.14	62.96	--
Nereid larvae (trochophores)	2.21	46.03	51.77	--
Nereis virens	36.95	46.77	14.55	1.76
Oithona similis	2.82	59.32	34.18	3.67
Pisces (larvae)	25.56	70.61	0.87	3.01
Pisces (eggs)	32.31	56.03	11.01	0.66
Pleurobrachia pileus	1.19	89.66	6.94	2.21
Pseudocalanus minutus	8.42	91.17	0.25	0.15
Sagitta elegans	12.06	52.41	13.56	21.96
Stephanomia cara	25.91	24.78	2.38	46.94
Temora longicornis	0.38	44.35	55.18	0.09
Tomopteris catherina	14.90	9.83	4.00	71.27
Tortanus discaudatus	3.73	71.74	23.21	1.30

Table IV. Variation in numbers of zooplankters in the four parts of the Quoddy Region. (Data for 1957 and 1958 combined.)

Species	Passamaquoddy Bay	Cobscook Bay	Passages	Outside
	%	%	%	%
Acartia clausi	36.18	18.65	32.98	12.18
Aglantha digitale	9.20	28.67	25.81	36.33
Aurelia aurita	11.08	14.86	19.54	54.50
Balanus balanoides nauplii	28.03	25.38	29.50	17.08
Calanus finmarchicus	4.78	44.24	36.26	14.71
Caligus rapax	50.82	14.76	18.04	16.40
Crab zoea	23.52	46.74	13.83	15.90
Cladocerans (Podon, Evadne)	17.60	--	6.74	75.67
Centropages typicus	4.49	11.03	23.77	60.72
Clione limacina	1.21	37.89	20.47	40.42
Diastylis spp.	10.75	56.63	32.63	--
Euchaeta norvegica	3.21	67.51	27.16	2.12
Euphausiids	34.75	26.33	23.47	15.43
Euphausiid eggs	--	--	--	100.00
Eurytemora herdmani	21.66	32.25	23.82	22.26
Euthemisto compressa	32.52	28.92	9.63	28.91
Fritillaria and Oikopleura	78.27	--	21.74	--
Harpacticoids	14.88	46.80	30.15	8.18
Hydroids (floating)	11.27	40.68	39.71	8.33
Limacina retroversa	10.25	12.21	14.04	63.49
Metridia lucens	3.74	41.49	48.89	5.89
Mytilus edulis (larvae)	14.81	24.07	52.78	8.33
Nereid larvae (trochophores)	23.84	16.56	43.05	16.56
Nereis virens	24.75	45.22	27.32	2.74
Oithona similis	--	24.76	2.82	72.31
Pisces (larvae)	26.78	37.12	26.81	9.34
Pisces (eggs)	29.45	3.57	18.07	48.92
Pleurobrachia pileus	17.32	50.71	21.36	10.61
Pseudocalanus minutus	3.55	49.03	39.05	8.36
Sagitta elegans	8.70	35.78	24.68	30.83
Stephanomia cara	2.61	7.63	13.10	76.67
Temora longicornis	17.43	12.02	27.02	43.53
Tomopteris catherina	5.28	56.73	23.65	14.34
Tortanus discaudatus	48.37	17.19	11.74	22.68
All species	7	33	28	32

Table V. Seasonal variation in the numbers of zooplankters in the four parts of the Quoddy Region and in the Region as a whole. (Data for 1957 and 1958 combined.)

Season	Passamaquoddy Bay	Cobscook Bay	Passages	Outside	Quoddy Region
	%	%	%	%	%
Spring	10	6	6	6	6
Summer	56	63	59	67	63
Autumn	19	14	24	23	20
Winter	15	17	11	4	11

59% of the catch was taken in summer, 24% in autumn, 11% in winter, and 6% in spring, while in Cobscook Bay percentages were 63% in summer, 14% in autumn, 17% in winter, and 6% in spring. Outside Passamaquoddy 67% of the catch was taken in summer, 23% in autumn, 4% in winter, and 6% in spring.

Table VI shows the area variation in zooplankters in each season for the Quoddy Region. In spring, Cobscook Bay, the passages, and outside Passamaquoddy have nearly equal numbers of zooplankters (29-30%) while Passamaquoddy Bay has only 12%. In summer and autumn, largest numbers are caught outside Passamaquoddy (35-37%) while the catch in Passamaquoddy Bay is only 6% of the total number of zooplankters taken. In winter, Cobscook Bay has 51% and the passages 27% of the total numbers of zooplankters taken during that season. Passamaquoddy Bay has 9% and the outside 13%. Fish and Johnson (1937) report a similar condition.

Table VI. Area variation in the numbers of zooplankters in each season for the Quoddy Region. (Data for 1957 and 1958 combined.)

Area	Spring	Summer	Autumn	Winter
	%	%	%	%
Passamaquoddy Bay	12	6	6	9
Cobscook Bay	30	33	23	51
Passages	29	26	34	27
Outside	29	35	37	13

They state: "A combination of environmental conditions apparently accounts for the small volumes characterizing Passamaquoddy Bay. Added to the fact that this bay opens into a relatively barren coastal area during the autumn and winter months when the local environment would seem to be most favourable for offshore species, the available source of supply in outer waters is approaching a minimum. Later.... the water warms and the winter (offshore) stock declines in Passamaquoddy Bay before the influence of vernal augmentation becomes appreciable."

Monthly and annual abundance

Monthly volumes of zooplankton taken in the four areas of the Quoddy Region in 1957 and 1958 are shown in Figure 4. There were striking variations in zooplankton volumes from month to month, for the same month, from year to year and from one locality to another. The greatest difference was observed in Cobscook Bay where zooplankton volumes were six times higher in January 1958 than in January 1957. This was due to large pulses of juvenile Calanus finmarchicus and to adult Sagitta elegans, euphausiids, and Tomopteris catherina. Temperatures in January 1958 were 2-3°C above those of the previous year (Appendix I, Chapter 1). In the outside area, volumes in January 1957 were twice as great as in January 1958 because of a pulse of adult Sagitta elegans. In the passages, catches in January 1958 were twice those in January 1957 due to larger concentrations of Calanus finmarchicus and Euchaeta norvegica. Zooplankton volumes in all parts of the Quoddy Region decreased in February and were small in March and April of both years. In February and March 1957 and 1958, the smallest volumes were found outside. Somewhat higher volumes were taken in the three other areas. No great differences were found between catches in April and May of the two years in each area. Temperatures also coincided in the two years (Appendix I, Chapter1). In late April volumes increased and were quite pronounced in June 1957 in Cobscook Bay when annelids were breeding, and in June 1958 in the passages when Calanus finmarchicus and Pseudocalanus minutus were very abundant. Outside, in the passages, and in Cobscook Bay, zooplankton volumes in July 1958 were exceedingly high by comparison with those of July 1957. In July 1958, temperatures were slightly higher than those of the previous year (Appendix I, Chapter 1). A great abundance of coelenterates in 1957 apparently prevented the summer bloom. Volumes in July 1958 were five times greater than in June of that year and the most zooplankton was found in Cobscook Bay. Volumes were much greater inside the Bay in July 1958 than in July 1957. More than twenty species were responsible for the bloom. Outside, in August 1957, zooplankton volumes showed an increase over July. The increase was due to the appearance of large numbers of adult euphausiids. The occurrence of adult euphausiids in large numbers was not observed in August 1958. Zooplankton volumes showed a marked decline in August 1958 in the passages, outside and inside Passamaquoddy Bay when extensive schools of jellyfish appeared over the whole region. In Cobscook Bay, volumes of zooplankton were still very high in August 1958. In Cobscook Bay, Calanus finmarchicus was even more abundant in August than in July. In September 1957, zooplankton volumes were on the increase in the passages, Cobscook and inside Passamaquoddy Bay but not outside. The increase was again due to large numbers of Calanus finmarchicus. In September 1958, zooplankton was on the decline in all areas. The greatest zooplankton volumes in 1957 were found in October and were due to a bloom of Centropages typicus. Volumes were great outside and in Cobscook Bay and still greater in the passages. Zooplankton was on the decline inside. In October 1958, the number of Centropages typicus was much smaller than in 1957 and volumes instead of being on the increase were still on the decline. From September to December temperatures were lower in 1958 than in 1957 (Appendix I, Chapter 1). In November 1957, a sharp decline in zooplankton abundance occurred, while in November 1958 the autumn bloom started to show in the passages and in Cobscook Bay. Calanus finmarchicus and Centropages typicus were then mainly responsible for the bloom. In December 1957, zooplankton volumes were small over the whole Quoddy Region. In December 1958, volumes were very much greater than in 1957. Stocks of Calanus finmarchicus, Euchaeta norvegica, Metridia lucens and Sagitta elegans were abundant in that month.

Vertical distribution

Fifteen special cruises were made in and around the passages to study the depth distribution of zooplankton (Table I). Tows were made during day and night at 0, 20, 50, 75, 100 m with a 12-in #5 plankton net and at the same depths with a 1-m closing plankton net. The day tows made with the 12-in net showed much larger zooplankton concentrations at 75 and 100 m than at 0, 20, and 50 m. The night tows made with the same net showed much larger volumes in the upper 20 m than at 50, 75, and 100 m (Fig. 5A). The day tows made with the 1-m closing net showed small concentrations in the upper 75 m and much larger volumes at 100 m. The night tows showed more zooplankton near the surface than at other depths (Fig. 5B). In general, zooplankton organisms were more abundant in the deeper levels in the daytime and more abundant in the upper levels at night. Stevenson (1933) reporting on vertical distribution of 4 zooplankters found that 3 out of the 4 species tended to rise to higher levels in the water at night and to descendout of the range of strong sunlight during the day.

The depth distribution of 6 zooplankters (copepods, euphausiids, crab zoea, Sagitta, amphipods and herring larvae) was studied in and around the passages. Figure 6 shows the depth distribution, by numbers, of 14 copepod species. Mean numbers of copepods per tow were plotted for males, females, and juveniles. Greatest numbers of Calanus finmarchicus (males, females, juveniles) were taken at 100 m although quantities were found at all depths. Pseudocalanus, over 98% females, were mainly centered in the deep water layers but abundant at all depths. The males and juveniles were scarce in October and November 1958 and only found in the upper layers (0-20 m). Centropages typicus (males, females, juveniles) were uniformly distributed throughout the water mass. Some copepod species were abundant in the upper water layers only, while others were most abundant from 50-100 m. Species that were most abundant in the upper layers included Temora longicornis (females), Acartia clausi (females), Tortanus discaudatus (males, females, juveniles), Oithona similis (males, females), Metridia longa (females) and Candacia armata (males). The species that were most abundant in the deeper layers included Metridia lucens (males, females), Calanus hyperboreus (males, females), Metridia longa (males), Scolecithricella minor (females), and Euchaeta norvegica (males, females, juveniles).

The depth distribution of five other zooplankters is shown in Figure 7. Euphausiids, crab zoea and amphipods were found in greater numbers in the upper 20 m but were also found at all depths. Sagitta elegans was abundant at all depths but much more so at 100 m. A few herring larvae were found at 0, 20, 50, 75, and 100 m.

Annual, monthly and regional abundance of six dominant copepod species

A total of six species accounted for 94% of the numbers of copepods caught in the Quoddy plankton cruises (Fig. 8). They were: Calanus finmarchicus (42%), Pseudocalanus minutus (28%), Centropages typicus (14%), Tortanus discaudatus (6%), Acartia clausi (2%), and Eurytemora herdmani (2%). Two other dominant species, Metridia lucens and Temora longicornis, are not listed above because counts were made on the genus and each genus included more than one species. The first three species (Calanus, Pseudocalanus, and Centropages) were immigrants to the Region and made up 84% of the catch. The remaining species (Tortanus, Acartia, and Eurytemora) were endemic to the Bay and made up only 10% of the catch.

Of the total number of copepods of all species taken in both years, 22% were taken in 1957 and 78% in 1958. Table VII shows that there were wide differences in the annual abundance of each of the six dominant species of copepods. Six times as many Calanus and twenty times as many Pseudocalanus were caught per tow in 1958 as in 1957. The 1957 collections had more than three times as many Centropages as those of 1958. Catch per tow of Tortanus was five times greater in 1958 than in 1957. More than twice as many Acartia were found in 1958 as in 1957 and the catches of Eurytemora in 1957 were less than a third of those in 1958.

The monthly variations in abundance of the six dominant copepod species in 1957 and 1958 are shown in Table VII and Figure 9.

The population of Calanus in both years was at a minimum in March, April, and May. In 1957, the catch was larger in the autumn and winter months than in the spring and summer months. Peaks of abundance were reached in October and January. In 1958, Calanus reached its maximum abundance in July and catches were high in autumn and winter (Fig. 9 A, B).

Calanus accounted for over 42% of the total number of copepods taken. This compares favourably with Fish and Johnson's (1937) values of 39.9% for the Bay of Fundy. In 1957, Pseudocalanus was taken in abundance in May, June and July while in 1958, Pseudocalanus was abundant only in July, and catches were much smaller in April, May and June (Fig. 9 C, D).

Table VII. Monthly and annual abundance of the six dominant copepod species taken in the Quoddy Region in 1957 and 1958.

Month	Calanus		Pseudocalanus		Centropages		Tortanus		Acartia		Eurytemora	
	1957	1958	1957	1958	1957	1958	1957	1958	1957	1958	1957	1958
Jan.	3,139	14717	18	7	194	340	5	98	--	49	--	--
Feb.	595	2768	1	6	7	532	--	54	12	14	--	--
Mar.	132	532	1	500	6	27	--	76	5	3	--	46
Apr.	190	632	46	816	4	27	1	13	113	96	2	22
May	38	487	489	1406	6	9	86	141	55	111	24	5
June	158	3623	847	5704	2	18	201	1213	104	292	34	245
July	483	20541	705	31448	3	426	169	4607	253	1265	201	1624
Aug.	142	6109	15	47	249	40	164	67	53	2	318	32
Sept.	1723	2403	4	35	333	301	319	307	6	19	12	31
Oct.	3147	1707	49	4	13854	2197	170	803	214	24	1	18
Nov.	904	4823	34	1	1263	281	331	239	43	104	6	--
Dec.	965	9986	20	104	411	252	90	52	--	49	--	--
Annual Avs.	968	5694	186	3340	1361	371	128	639	72	169	50	169

(Average numbers per tow)

Centropages reached its peak of abundance in October of both years (Fig. 9 E, F). In 1957, catches of Tortanus were high from May to December and small from January to April while in 1958, Tortanus reached maximum abundance in July and catches in other months were much lower. June and October also had high catches (Fig. 9 G, H). The population of Acartia fluctuated throughout 1957 with large catches in April, July, and October. In 1958, most of the catch was made in July but small numbers were taken in all other months (Fig. 9 I, J). In 1957, Eurytemora was most abundant in July and August. Only small numbers were taken in the spring, autumn and winter months. In 1958, Eurytemora was abundant in June and July only (Fig. 9 K, L).

There were also wide differences in the regional abundance of the six copepod species in the Quoddy Region in 1957 and 1958 (Fig. 10 and 11).

In 1957, the largest catches of Calanus were made in the passages and in Cobscook Bay (Fig. 10 A). In 1958, nearly equal numbers of Calanus were caught in Cobscook Bay and in the passages and somewhat lower numbers were caught inside Passamaquoddy Bay (Fig. 10 B). The distribution of Pseudocalanus was similar in 1957 and 1958. Outer Western Passage had the highest concentrations, followed by Cobscook Bay. Catches inside and outside Passamaquoddy Bay were much smaller (Fig. 10 C, D). During 1957 and 1958, Centropages was abundant outside Passamaquoddy Bay. Catches in the passages were less than half those outside Passamaquoddy and much less inside this Bay (Fig. 10 E, F).

In 1957 and 1958, the largest catches of Tortanus came from the St. Croix River estuary and along the Perry Shore. Large catches were obtained throughout Passamaquoddy and Cobscook Bays. Smaller catches came from the passages and outside Passamaquoddy (Fig. 11 A, B). Acartia, in 1957, was abundant in inner Western Passage and inside Passamaquoddy Bay. In 1958, the largest concentrations were taken near the Perry Shore inside Passamaquoddy Bay (Fig. 11 C, D). In 1957 and 1958, catches of Eurytemora were quite uniformly distributed throughout the Quoddy Region (Fig. 11 E, F).

SOME CHARACTERISTICS OF IMPORTANT PLANKTERS

Diatoms

In Passamaquoddy Bay, the spring bloom of diatoms started in late March in 1957 and in early April in 1958. By mid-April in both years this Bay had a rich flora of diatoms which had its maximum in late May. Greatest concentrations were found near and in the passages. Outside Passamaquoddy, low volumes were observed in May in both years but in late June very rich patches were found. The spring maximum was observed in early June in Cobscook Bay. In Grand Manan Channel, high diatom concentrations were found in early July in 1957. However, over the whole Region the spring bloom extended chiefly from mid-April to mid-June. A few rich patches were found in July and early August. The autumn bloom reported by Davidson (1934) in the Quoddy Region was not observed. Catches in autumn were very small.

In 1957, the spring bloom of diatoms in the Region was heavier and lasted longer than in 1958. The composition of the catch varied from month to month and the dominant diatoms disappeared suddenly after their maximum concentration was reached. Thus in May 1958, the dominant diatoms were Biddulphia (95%), Thalassiosira (3%), Chaetoceros (1%) and in June 1958 the dominant diatoms were Thalassiosira (75%), Chaetoceros (20%) and Coscinodiscus (4%).

Copepods

Copepods normally formed the greater part (79%) of the zooplankton in the Quoddy Region (Fig. 12) and were distributed widely. The species are listed by 5 sub-orders.

Sub-order CALANOIDA: Acartia clausi, A. longiremis, Aetideus armatus, Anomalocera patersonii, Calanus finmarchicus, C. hyperboreus, C. minor, Candacia armata, Centropages hamatus, C. typicus, Euchaeta norvegica, Euchirella rostrata, Eurytemora americana, E. herdmani, Gaidius tenuispinus, Labidocera aestiva, Metridia longa, M. lucens, Microcalanus pusillus, Paracalanus parvus, Pleuromamma robusta, Pseudocalanus minutus, Rhincalanus nasutus, Scolecithricella minor, Scolecithrix danae, Temora longicornis, T. stylifera, Tortanus discaudatus.

Sub-order HARPACTICOIDA: Alteutha depressa, Dactylopusia tisboides, D. vulgaris, Diosaccus tenuicornis, Halithalestris croni, Harpacticus chelifer, H. gracilis, H. uniremis, Microsetella rosea, Parathalestris Jacksoni, P. pygmaea, Sapphirina gemma, Thalestris gibba, T. longimana, Tisbe furcata, Zaus goodsiri.

Sub-order CYCLOPOIDA: Oithona plumifera, O. similis, Oncaea conifera.

Sub-order MONSTRILLOIDA: Monstrilla dubia, M. serricornis.

Sub-order CALIGOIDA: Caligus rapax.

Crabs

Few zoea were found from September to May. Large pulses of Cancer zoea were observed in Passamaquoddy and Cobscook Bays in June and July. Crab megalopa began to appear in March and were found frequently from March to November. The megalopa were most abundant inside Passamaquoddy Bay.

Barnacles

Barnacle nauplii began to appear in March and were very abundant in April and May. No barnacle nauplii were caught after July.

Eggs

Eggs of invertebrates were found in considerable numbers in summer. Euphausiid eggs were extremely abundant outside and present in small numbers inside Passamaquoddy Bay. Fish eggs occurred throughout the year and were more abundant outside than inside this Bay.

Euphausiids

Larval stages of euphausiids had their peak abundance from May to September. Adults were abundant in spring and summer and they were distributed over the whole region.

Jellyfishes

Jellyfishes were found irregularly. The principal species found was Aurelia aurita. Extensive schools were observed at the surface in late summer. Numbers declined rapidly in late September. One species of comb jelly, Pleurobrachia pileus, was common in the Region. The largest numbers were found in outer Western Passage and in Cobscook Bay. Juveniles were most common inside Passamaquoddy Bay. The period of abundance was from mid-July to early September. A siphonophore species, Stephanomia cara, was also very common in winter and spring. The largest catches were made outside Passamaquoddy Bay and in the passages.

Chaetognaths

The juveniles of Sagitta elegans amounted to nearly 20% of the catch in July at Station 1. Adults were common throughout the year and most abundant in July at all stations.

Annelids

Annelids were found in small numbers at many stations. Trochophore larvae were abundant in early summer and in autumn in Cobscook Bay and along the Perry Shore.

Cladocerans

During the summer, occasional pulses of Podon leuckarti and Evadne nordmanni were found inside and outside Passamaquoddy Bay. Cladocerans were scarce from November to May.

Amphipods

Euthemisto compressa and Hyperia galba were the species found most commonly in the Quoddy Region. Other species were rare at all times.

Fish larvae

Fish larvae were found at all stations throughout the year but never in large concentrations. Twenty-two species were identified: Ammodytes americanus (sand launce), Anarhichas lupus (wolffish), Anguilla rostrata (eel), Apeltes quadracus (stickleback), Aspidophoroides monopterygius (alligator fish), Clupea harengus (herring), Cryptocanthodes maculatus (wrymouth), Cyclopterus lumpus (lumpfish), Enchelyopus cimbrius (four-bearded rockling), Gadus callarias (cod), Glyptocephalus cynoglossus (flounder), Hippoglossoides platessoides (sand dab), Melanogrammus aeglefinus (haddock), Merluccius bilinearis (whiting), Myoxocephalus scorpius (sculpin), Neoliparis atlanticus (sea snail), Osmerus mordax (smelt), Pholis gunellus (rock eel), Pollachius virens (pollock), Poronotus triacanthus (butterfish), Pseudopleuronectes americanus (winter flounder), Urophycis tenuis (hake).

Larvae of rock eels, sand dabs, lumpfishes, wrymouths, and sea snails were found frequently. Other species were represented by a few individuals. Larvae were most common in summer and particularly in June. Only six herring larvae were taken in Quoddy project (QP) cruises in 1957 and 1958. Three were taken outside Passamaquoddy Bay (Stations 1 and 2), two in the passages (Station 3), and one inside the Bay (Station 9). Two larvae were taken in October, two in November, one in December, and one in April. Larvae varied in length from 15 to 42 mm.

Exploratory plankton tows made in October and November 1958 at 10 m intervals from surface to bottom, near and in the passages, produced 9 herring larvae. They varied from 17 to 32 mm in length. Four were taken at the entrance to Western Passage, 3 in Western Passage at Station 12, one at Station 2 and one at Station 4 near Letite Passage. Several tows were made at ebb-tide in the passages and no larvae were taken. However, the 2 larvae found at Stations 2 and 4 outside Passamaquoddy were taken at ebb-tide. Of the 9 larvae taken in the exploratory tows, 6 were found at night in the passages, 2 near the bottom, 2 at 50 m, one at 20 m, and one at the surface. The 3 larvae caught in daytime were from 50, 75, and 100 m. Of the 3 larvae, 2 were caught in the passages and one outside Passamaquoddy.

The Prince tows from 1937 to 1959 (April) had an additional 40 herring larvae (Table VIII) from 2,002 tows (650 tows Prince 5; 1,352 tows Prince 6). Of these larvae, 23 came from Prince 5 (outside) and 17 from Prince 6 (inside). Two-thirds were taken from September to January and one-third in March-June. Thirty-six larvae were found in 18-23 m oblique hauls and 4 in vertical hauls. None came from the 5-7 m oblique tows.

PLANKTON IN RELATION TO HERRING

Since herring are zooplankton feeders, any changes in zooplankton abundance during periods of feeding might be expected to affect their concentration and distribution. It was therefore necessary to know more about their food, the importance of the various zooplankton species as items of food, the periods of feeding activity and the possible relationships between abundance of zooplankton, food, feeding activity, fat content, and catches of herring.

Of the 1, 696 herring stomachs examined, 1, 098 contained food. The frequency of occurrence of the main food items is shown in Table IX. Fifty different organisms were recorded. Copepods, eggs, barnacles and mussel larvae, cladocerans and crab zoea occurred most frequently. The parasitic trematode, Brachyphallus crenatus, also appeared in large numbers.

Average lengths of the fish examined ranged from 60 to 298 mm (Table X). In general, the smaller fish (60 to 103 mm) fed mostly on small zooplankton organisms such as Eurytemora, Acartia and eggs. The large fish (200 plus mm) fed mostly on larger organisms such as Pseudocalanus, Calanus, Tortanus and Euchaeta. Somerville (1956) also noted this.

Stomach contents consisted chiefly of copepods endemic to Passamaquoddy Bay such as Eurytemora herdmani, Acartia clausi, and Tortanus discaudatus, and it can be assumed that the herring were feeding more actively inside than outside the Bay. These species are also surface forms and it is reasonable to conclude that herring were feeding mostly in the surface layers. Depth recorder traces confirm the presence of herring in the upper water layers during the period of the weir fishery from May to October (Appendix II, Chapter2).

Outside Passamaquoddy Bay, Pseudocalanus minutus and Calanus finmarchicus were abundant in the stomachs of herring. Also found in large numbers were harpacticoid copepods and larvae of barnacles.

Mean monthly zooplankton volumes per tow for the Quoddy Region have been plotted against mean monthly food volumes in the stomachs per sample of 100 fish (Fig. 13). In July and August, when zooplankton volumes were high, the food in the stomachs was low. In June, September, October, and November, when zooplankton concentrations were lower than in July and August, the food in the stomachs was high. In March when zooplankton concentrations were small, the food in the stomachs was also small. The quantity of food in the stomachs indicated a period of active feeding from September to November and a period of less active feeding from March to August (Fig. 13). It is interesting to note that Leim (1958) found lowest fat content in "sardines" from April to June and highest fat content from August to November..

Mean zooplankton volumes for May to October 1947 to 1957, in the Prince tows, have been plotted against average yearly catches per weir for the same years (Fig. 14). In the area outside Passamaquoddy Bay in 1948, 1951, 1952, 1953, 1954, and 1955, high zooplankton concentrations were found and herring catches were below average. Smaller zooplankton concentrations were found in 1946, 1947, 1949, 1950, 1956, 1957 and herring catches were generally much better. In the area in Passamaquoddy Bay, the zooplankton concentrations were always low and herring catches varied from high in 1947, 1948, 1952, 1957 to small in 1949, 1955, 1956.

No positive correlation between feeding activity and zooplankton volumes and between zooplankton volumes and "sardine" catches is apparent.

COMPARISON WITH PREVIOUS STUDIES

A comparison of results with those of previous investigations is limited to generalities, because of the difference in methods used in the collection and examination of the plankton. The only other intensive survey of the zooplankton of the Quoddy Region was made from July 1931 to September 1932 by Fish and Johnson (1937). They made 20-minute oblique tows at the surface, 50 m and bottom in contrast to the 15-minute oblique tows at 20, 10, and 0 m made in the present investigation. In addition, the present work covers a slightly longer period.

Present findings often confirm those of other studies in the Region. The greater volume of the plankton was made up of copepods of which eight species, (Calanus, Pseudocalanus, Centropages, Tortanus, Metridia, Acartia, Eurytemora, Temora) formed 75%. Fish and Johnson (1937) found a similar percentage for the same species. Fluctuations in the numbers of Calanus finmarchicus contributed most markedly to volumetric changes in the zooplankton through the different seasons and in the different areas. This was also observed by Fish and Johnson (1937), who state that the stock of Calanus finmarchicus fluctuated in abundance at each season in different regions, the western part of the Gulf of Maine being the principal source of supply.

Volumes of zooplankton were five times greater outside than inside Passamaquoddy Bay for the two years 1957 and 1958. In the Bay of Fundy, in 1931 and 1932, volumes varied from 46.9 cc/tow in outer Passamaquoddy to 20.0 cc/tow in Passamaquoddy Bay (Fish and Johnson, 1937). Somerville (1956) reported that volumes outside were 8 times larger than inside Passamaquoddy Bay during the summers of 1955 and 1956.

Zooplankton was most abundant in Cobscook Bay and outside Passamaquoddy throughout the present investigation and it was found by Battle et al. (1936) and by Leim (1943) that herring from Cobscook Bay and Harbour de Loutre, Campobello (outside Passamaquoddy) were fatter than those from other localities in the Quoddy Region. No relationship could be shown between feeding activity and abundance of food organisms. Our results of herring stomach analyses may have been biased since the fish were taken in weirs and some fish may have had time to clear themselves.

Fish and Johnson (1937) reported a winter boreal group in the Bay of Fundy region derived from Gulf of Maine waters, with Pseudocalanus minutus assuming greater relative importance in Passamaquoddy

Table VIII. Herring larvae taken at stations Prince 5 (outside Passamaquoddy Bay)and Prince 6 (inside Passamaquoddy Bay) from 1937 to 1959 (April).

Date	Depth	Herring larvae	Length of larvae
	m	no	mm
Prince 5			
Oct. 13/42	18-23	2*	6
Dec. 15/47	"	2	22, 24
Dec. 10/49	"	1	16
Sept. 14/50	"	3	9, 10, 11
Sept. 10/51	"	1	8
Nov. 15/51	"	1	18
Dec. 15/52	"	4	16, 19, 20, 23
Nov. 10/53	"	2	14, 18
Sept. 15/54	90- 0	1	14
Nov. 10/54	18-23	2	13, 14
May 13/55	90- 0	1	17
June 10/55	18-23	1	28
Dec. 12/55	90- 0	1	27
May 11/56	"	1	49
Prince 6			
Oct. 1/40	18-23	1	10
Oct. 15/42	"	1	7
Sept. 23/43	"	2	7, 8
Oct. 6/43	"	1	11
Oct. 27/43	"	1	17
June 8/44	"	1	8
June 21/44	"	1	11
Dec. 10/49	"	1	20
June 11/52	"	1	9
Nov. 21/52	"	1	35
June 12/53	"	1	11
Mar. 10/54	"	1	14
June 11/54	"	1	6
Dec. 14/54	"	1	14
May 13/55	"	1	14
Jan. 12/59	"	1	25

* 1 damaged

Table IX. Frequency of occurrence and frequency percentages of main zooplankton organisms found in stomachs of herring taken from March to November in 1958. (Samples from weirs in Passamaquoddy Bay and vicinity.)

Zooplankton organisms	Frequency of occurrence	Frequency percentages %
Eurytemora herdmani	508	46.3
Acartia clausi	363	33.1
Copepod eggs	363	33.1
Pseudocalanus minutus	257	23.4
Tortanus discaudatus	225	20.1
Balanus (cypris)	190	17.3
Copepod (juveniles)	142	13.0
Calanus finmarchicus	128	11.7
Copepod (Harpacticoids)	109	9.9
Mytilus edulis (larvae)	106	9.7
Podon spp.	79	7.2
Crab (zoea)	77	7.0
Fish (eggs)	75	6.8
Temora longicornis	74	6.7
Euchaeta norvegica	59	5.4
Total number of stomachs examined	1,696	
Total number of stomachs with food	1,098	64.7
Total number of stomachs empty	598	35.3

Bay. In the present investigation, Pseudocalanus minutus accounted for 51% of the plankton in summer in the passages and for 51% of the plankton in spring and summer in Cobscook Bay. During the summer months in 1957 and 1958 the importance of the neritic forms, especially the copepods Tortanus discaudatus, Acartia clausi, and Eurytemora herdmani became greater. These three species which are endemic to the Bay were also the dominant neritic forms in Fish and Johnson's investigations (1937). The autumn invasion of Centropages typicus reported by these scientists was also very pronounced in our collections.

In addition to the copepod population, representatives of almost all other plankton groups have been observed in the present investigation and by Fish and Johnson (1937). The eggs and larvae of pelagic fishes were found in small numbers in the present investigation and in that of Fish and Johnson (1937).

Table X. Date of capture, average length of fish, and mean food volumes found in herring stomachs.

Time of capture 1958	Stomachs examined no	Average length mm	Settled volume per 100 fish cc
March 5	100	103	5
June 10	102	145	22
June 17	108	132	9
June 17	107	202	30
June 19	102	148	34
June 24	102	176	4
June 24	56	298	8
July 2	103	162	2
July 4	101	150	20
July 10	100	176	2
July 15	15	60	1
July 25	100	155	19
July 31	100	159	15
August 29	100	137	1
Sept. 4	100	167	40
Oct. 6	100	233	50
Oct. 7	100	168	10
Nov. 20	100	193	--

The spring maximum of phytoplankton reported by Davidson (1934) and Fish and Johnson (1937) was observed in late May with greatest concentrations around the passages. The autumn bloom reported by Davidson (1934) was not observed.

Fish and Johnson (1937) commented on the sporadic invasions of adult Meganyctiphanes in summer in the Quoddy Region. This was also observed in the summer of 1957.

Influence of temperature on zooplankton abundance has been suggested by the difference in volumes for different times of the year in 1957 and 1958. Evidence that low temperatures affect abundance has also been found in Passamaquoddy Bay by Battle (1929) and Huntsman and Sparks (1924). Diurnal migrations of many zooplankton species have been reported by Stevenson (1933) and Johnson (1942) in the Quoddy Region and by many other scientists elsewhere. Present findings on depth distribution of zooplankton were in agreement.

Analyses of herring stomachs taken in 1958 showed that small herring fed mostly on smaller zooplankton organisms while larger herring were eating larger organisms. This agrees with the findings of Battle (1934) and Somerville (1956). Herring were feeding mostly on surface plankters such as Eurytemora, Tortanus, and Acartia and were therefore, presumed to be distributed in the upper water layers when feeding.

Battle et al. (1936) noted the fatness of herring from the neighbourhood of Campobello and the leanness of fish in the Perry Shore region. Zooplankton concentrations were much higher in the former area and agree with Battle's findings (1936). The periods of high and low feeding activity reported in the present work corresponded to the periods of fatness and leanness in herring reported by Leim (1958).

PLANKTON IN RELATION TO THE PASSAMAQUODDY POWER PROJECT

How will the plankton of the Quoddy Region be affected if dams are installed across the entrances to Passamaquoddy Bay? To answer this question, a look at the predicted environmental changes is necessary (Appendix I, Chapter 7). Outside Passamaquoddy only slight changes in oceanographic conditions are anticipated except in areas contiguous to the emptying gates, therefore, it is unlikely that plankton abundance will be affected. Distribution of some species will be changed according to the extent of changes in the range, direction and velocity of tidal streams.

In Passamaquoddy Bay (high pool), the mean water level will be raised about 6 ft, with a tidal range averaging 4 ft. Mean tidal current speeds are expected to be about one-fifth the present values. During periods that gates will be opened, current speeds in the passages should be similar but slightly lower than the present and somewhat higher speeds are expected at mid-depths. Surface temperatures in the high pool are likely to reach 20°C in summer and less than 0°C in winter. Below the surface layer, the expected range should be 0°-13°C. Partial ice cover is expected in winter. Mean surface salinities will be lowered and bottom salinities will be altered slightly.

Zooplankton volumes inside Passamaquoddy Bay are only one-fifth those outside and made up of a mixture of offshore forms, neritic forms endemic to the Bay and benthic invertebrates. The migration of offshore forms into the Bay will be possible but delayed to a certain extent due to the fact that filling gates will be opened only 2-1/2 hours in every 12-1/2. Since water movement will be in one direction only, plankton will probably accumulate inside the Bay and tend towards equilibrium with outside concentrations. Grazing by herring and other plankton feeders will continue to affect to some extent zooplankton concentrations in the high pool.

Species endemic to the high pool will be subjected to the new environmental conditions throughout the year. Higher summer temperatures should not be fatal to the plankton. Diatoms have a great resistance to changes of temperature and salinity by forming resting spores. Most zooplankton species have a heat death above 20°C. Huntsman and Sparks (1924) give the following heat death temperatures: Copepods (22-31°C), Decapods (23-33°C), Sagitta elegans (25.5-27.5°C), Tomopteris catherina (31.6°C). Exposure to a few degrees below zero Centigrade in winter for a prolonged period of time would be fatal to many plankters but this is not likely to happen. Only the upper few metres will reach those temperatures and the zooplankton might be expected to migrate down below the thermocline where temperatures will be much the same as at present. Heilbrunn (1956) states that several species, including cladocerans, sink to the bottom when the water becomes too cold.

Above and below optimum temperatures, life and vital activity will be increased or reduced. The more sensitive organisms and the early stages of many species will be most affected. Migrants from offshore, breeding outside, will not suffer. The major endemic copepods being both eurythermic and euryhaline will not likely be affected either.

Clam, mussel and barnacle larvae should be reduced in proportion to the reduction of the parent stocks and of the inter-tidal beach area with a potential increase after new beds are established. Higher temperatures will likely hasten the development of larvae. Scallop larvae will likely be more numerous.

Other bottom invertebrate larvae will be increased or reduced in proportion to the increase or reduction in the parent population.

Partial ice cover will not affect the abundance of plankton but may effect the distribution of species. In the Kennebecasis River, where ice cover occurs, excellent catches of zooplankton, actively reproducing, were made in February.

The lowering of surface salinities will likely affect the few floating species incapable of adaptation and downward movement. They are not likely to die, since salinities will remain above their threshold of survival but they might fail to reproduce.

All saline water reaching the low pool will carry with it the total fresh water discharged into the high pool and also plankton volumes from the high pool. After a time, plankton will tend towards equilibrium between the two pools and plankton communities in the low pool should be similar to those in the high pool.

SUMMARY

Investigations of the composition, abundance, and distribution of the plankton communities within the Quoddy Region of New

Brunswick and Maine were carried out. Studies were also made on the food of the herring and possible relationships between food volumes, feeding activity, fat content and herring catches.

Plankton cruises were made in the Quoddy Region, around Grand Manan, in St. Mary Bay, and on the Lurcher Shoals.

During 1957 and 1958, 14 stations were occupied in the Quoddy Region during 43 Quoddy project (QP) cruises. Oblique tows were made at 20-10-0 m. Tows from Prince stations 5 and 6 were analysed for the period 1937 to 1959 (April). A total of 15 exploratory cruises were made during the day and at night in and close to the passages during October and November 1958 to study vertical distribution of zooplankton. In addition, special tows were made during the same cruises to catch herring larvae. All depths were sampled and many types of gear and fishing methods were used.

The 14 Quoddy project (QP) stations were grouped according to four areas: Passamaquoddy Bay, outside, passages, and Cobscook Bay. The composition of boreal, neritic, benthic, northern and southern species was studied in each area. Offshore species seldom reached large concentrations inside Passamaquoddy Bay. Abundant in the Bay were neritic endemic species such as Tortanus discaudatus, Acartia clausi, Eurytemora herdmani. Outside, in the passages and in Cobscook Bay, plankton was a mixture of boreal, neritic and benthic species.

Zooplankters were most abundant in summer (63%), decreasing through autumn (20%) and winter (11%) to a minimum in the spring (6%).

Zooplankton was most abundant in Cobscook Bay (33%), outside (32%), and in the passages (28%), and much less abundant inside Passamaquoddy Bay (7%). The difference in zooplankton volumes between outside and inside Passamaquoddy Bay suggests that migration from outside into the Bay is not very successful.

Concentrations of zooplankton were higher in 1958 than in 1957. Higher water temperatures in 1958 were shown to be partly responsible.

Zooplankton volumes were greater at 75-100 m than at 0, 20, and 50 m in daytime and also greater at 0-20 m than at 50, 75, and 100 m at night.

Six species accounted for 94% of all copepods. They were: Calanus finmarchicus, Pseudocalanus minutus, Centropages typicus, Tortanus discaudatus, Acartia clausi and Eurytemora herdmani. Their abundance fluctuated monthly and annually.

The spring bloom of diatoms in the Quoddy Region extended from mid-April to mid-June and a few rich patches of diatoms were found in July and early August. In 1957 the spring bloom of diatoms was heavier and lasted longer than in 1958.

Copepods accounted for 79% of the total zooplankton. Fifty species were identified. Calanus finmarchicus accounted for 42% of the total copepods.

Twenty-two species of fish larvae were identified. None were found in large concentrations. Fifty-five herring larvae were caught, 37 outside and in the passages and 18 inside Passamaquoddy Bay.

A total of 1,696 herring stomachs were analysed. Of these, 1,098 contained food. Fifty different zooplankton organisms were recorded in the diet. Copepods had the highest frequency of occurrence. Small herring (60 to 103 mm) fed mostly on smaller organisms and feeding was more active inside Passamaquoddy Bay. The species occurring with highest frequency in the herring diet were surface forms suggesting that herring feed in the surface layers.

Herring fed little from March to August and fed actively from September to November.

Positive correlation was found between feeding activity and fat content. No relationship was found between feeding activity and volumes or kinds of zooplankton available nor between zooplankton concentrations and commercial catches of "sardines" for the period 1947 to 1957.

Should dams be installed at the entrances to Passamaquoddy Bay, zooplankton concentrations for the high pool, the low pool, and outside should tend towards equilibrium.

ACKNOWLEDGMENTS

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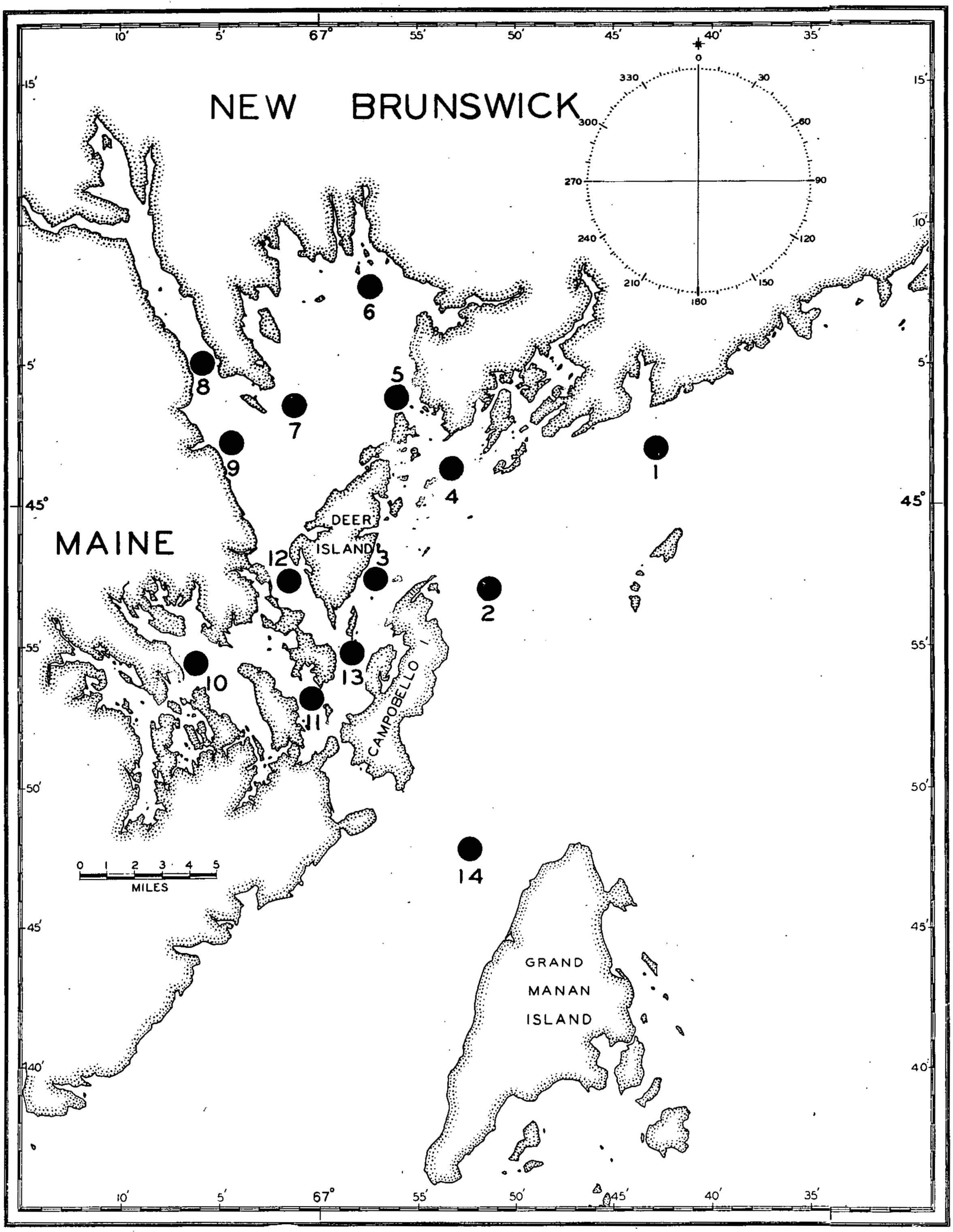

Figure 1. Stations occupied during the Quoddy project (QP) cruises in 1957 and 1958.

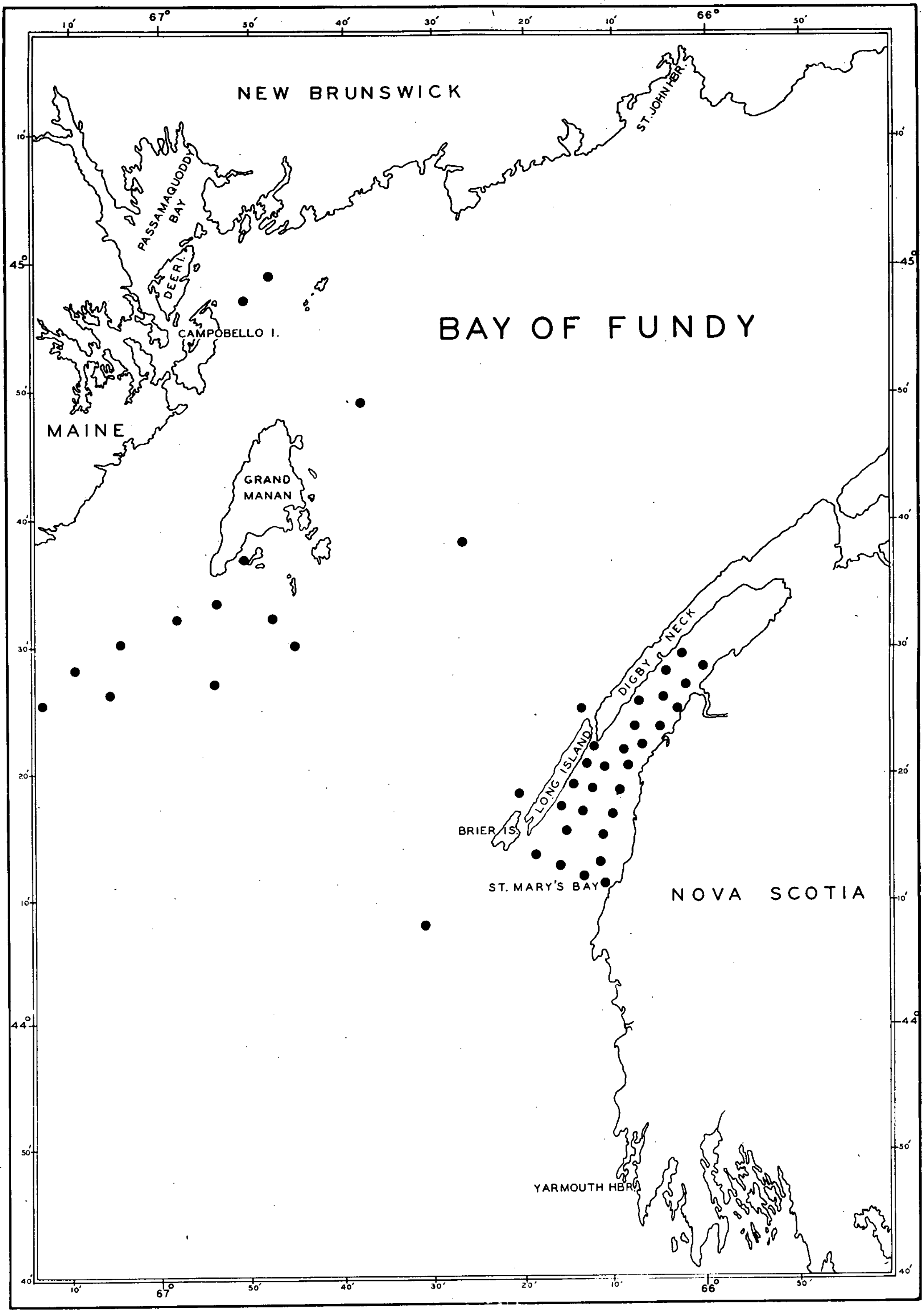

Figure 2. Stations occupied during the M. V. J. J. Cowie cruises, March 1958.

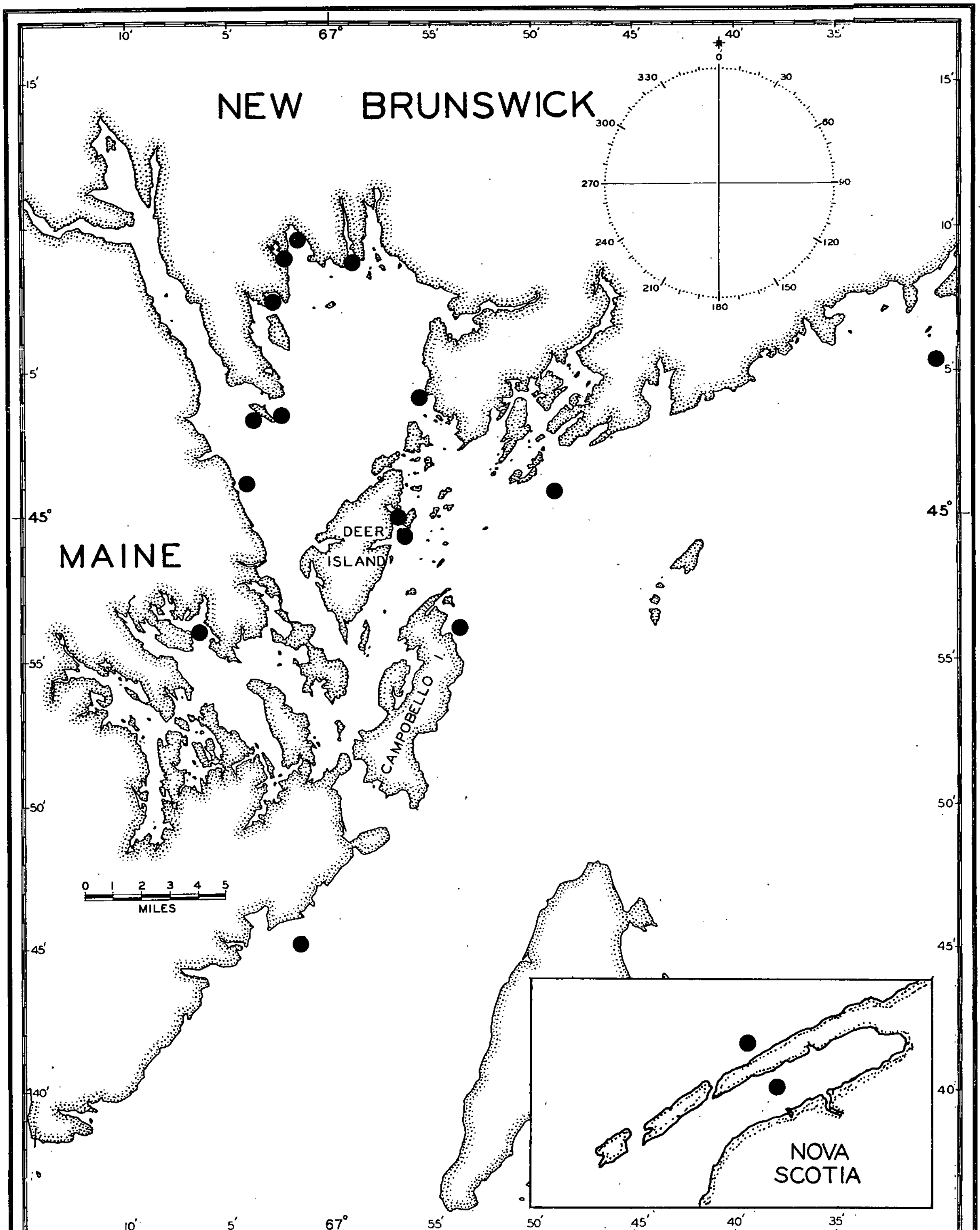

Figure 3. Locations at which herring samples were obtained for stomach analysis in 1958.

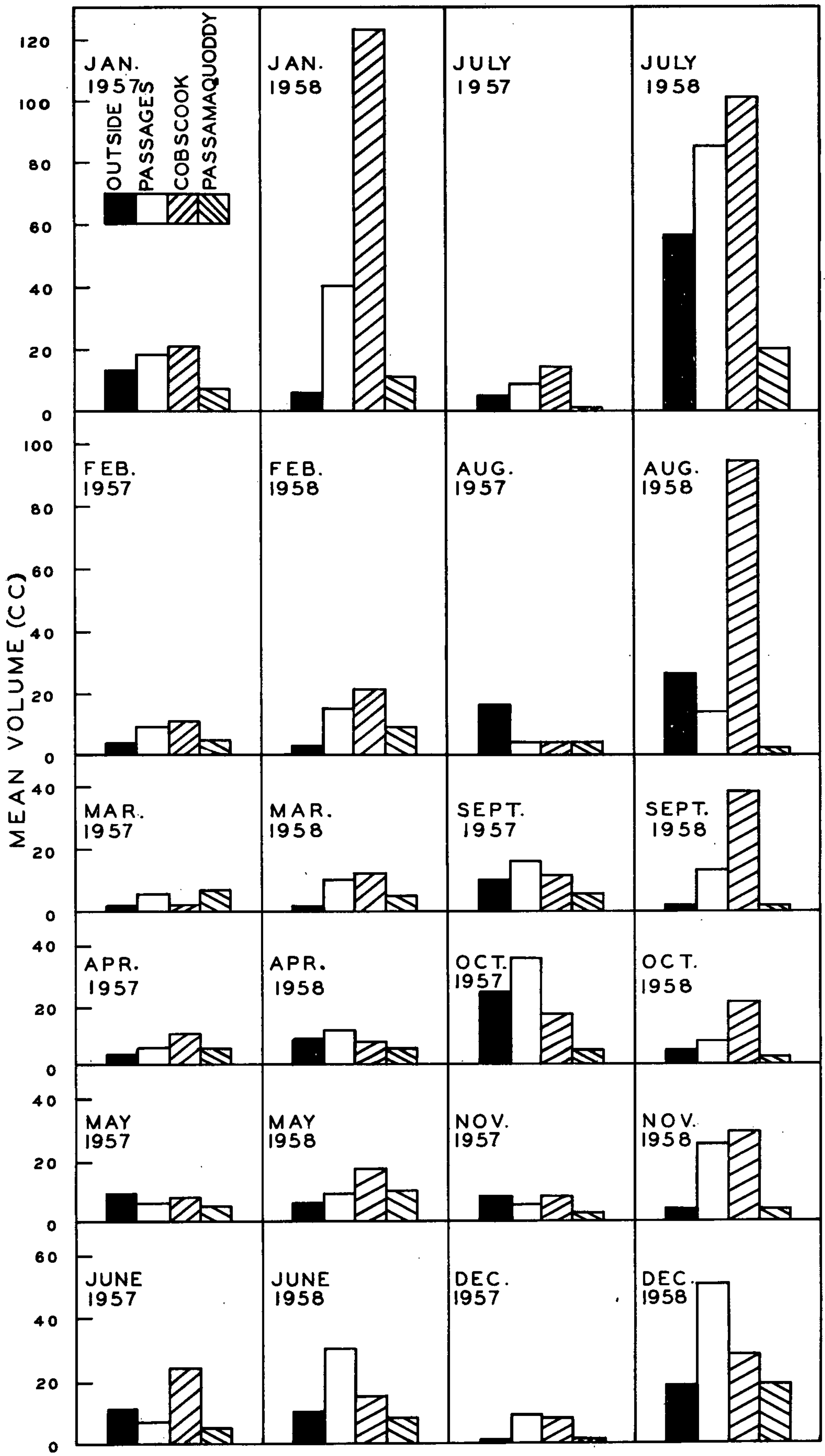

Figure 4. Distribution of zooplankton volumes, January to December 1957 and 1958, outside Passamaquoddy, in the passages, in Cobscook Bay and in Passamaquoddy Bay.

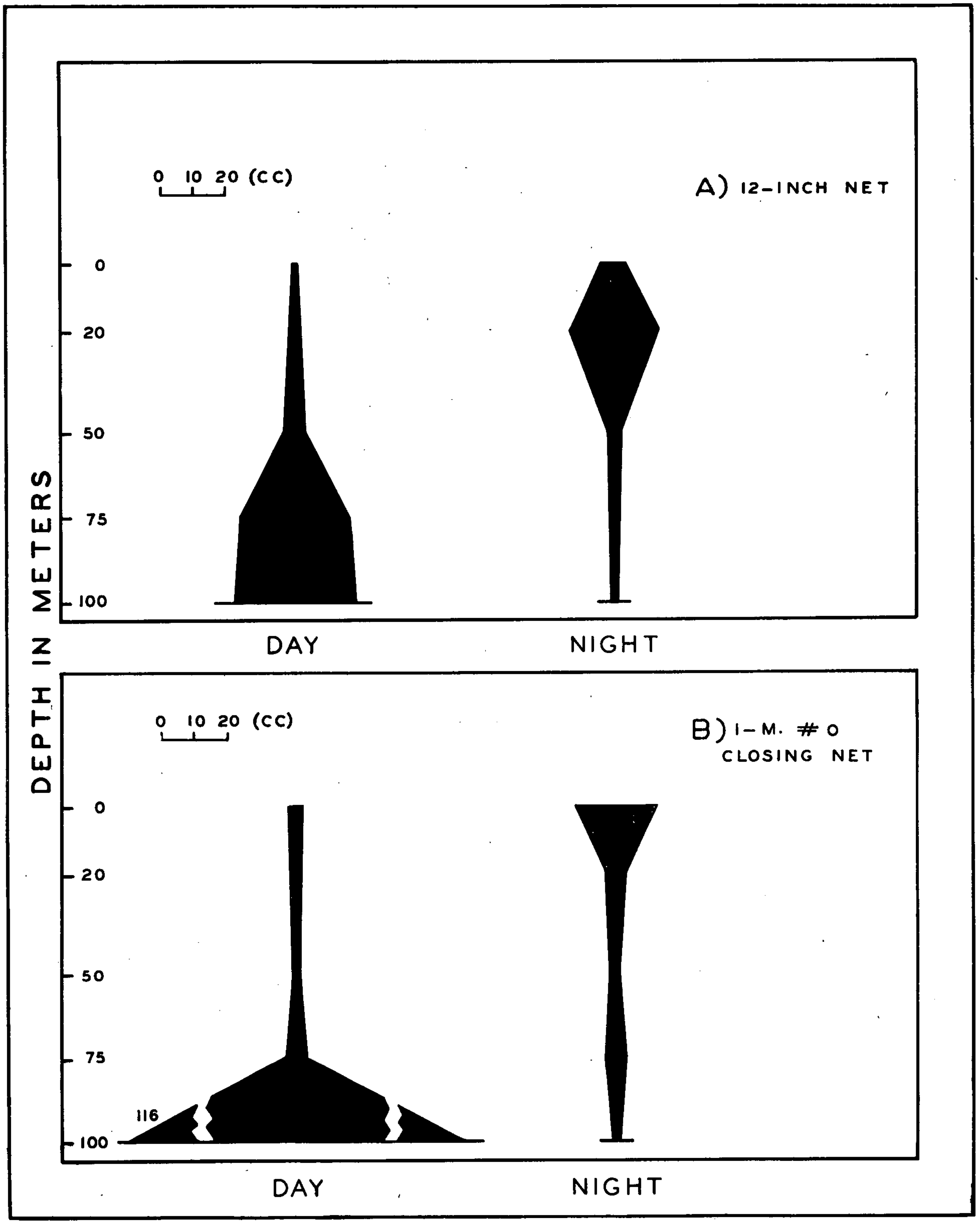

Figure 5. Vertical distribution of zooplankton, day and night. A. volumes taken with 12-in nets; B. volumes taken with 1-m closing nets.

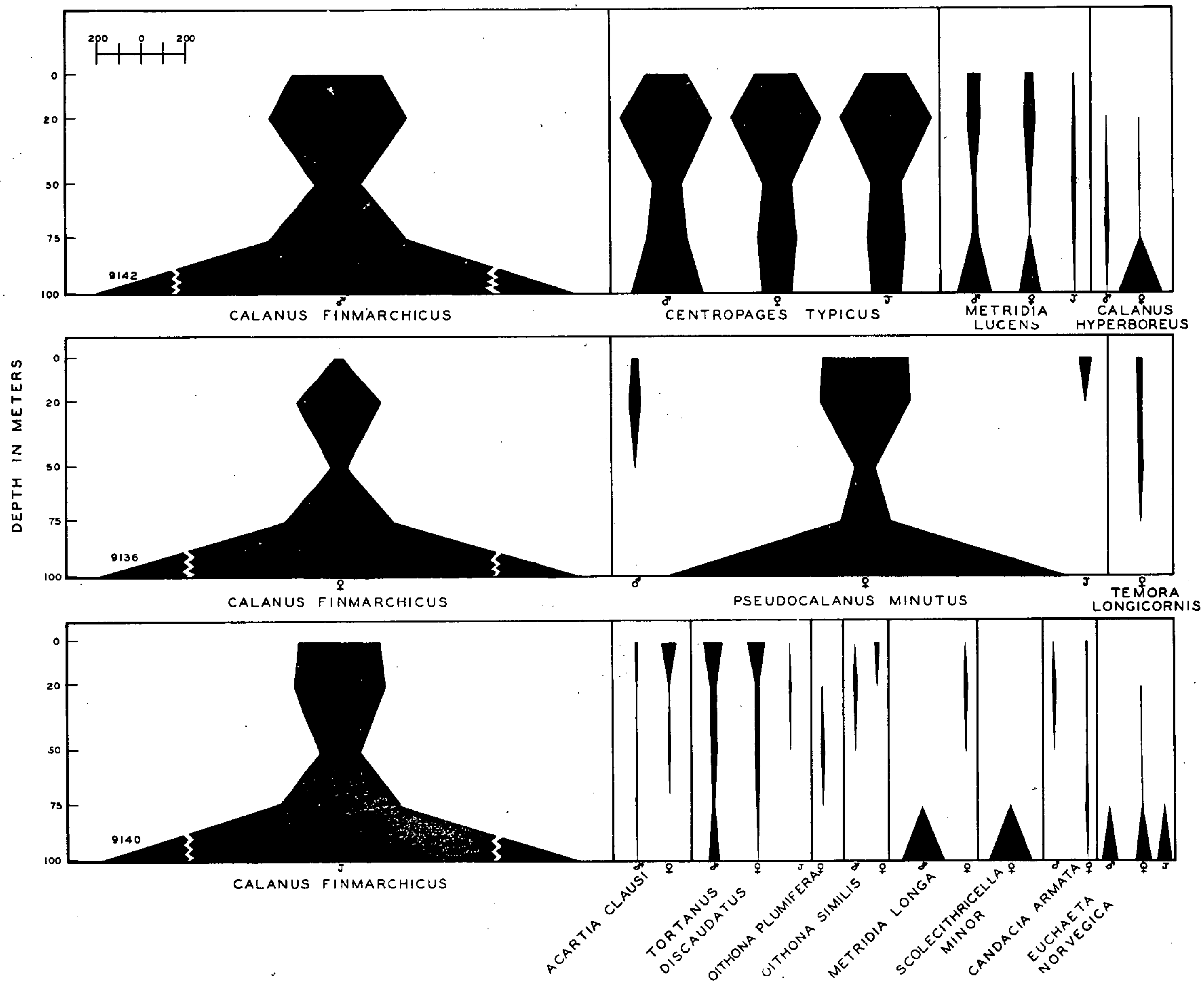

Figure 6. Vertical distribution of 14 copepod species; males, females and juveniles.

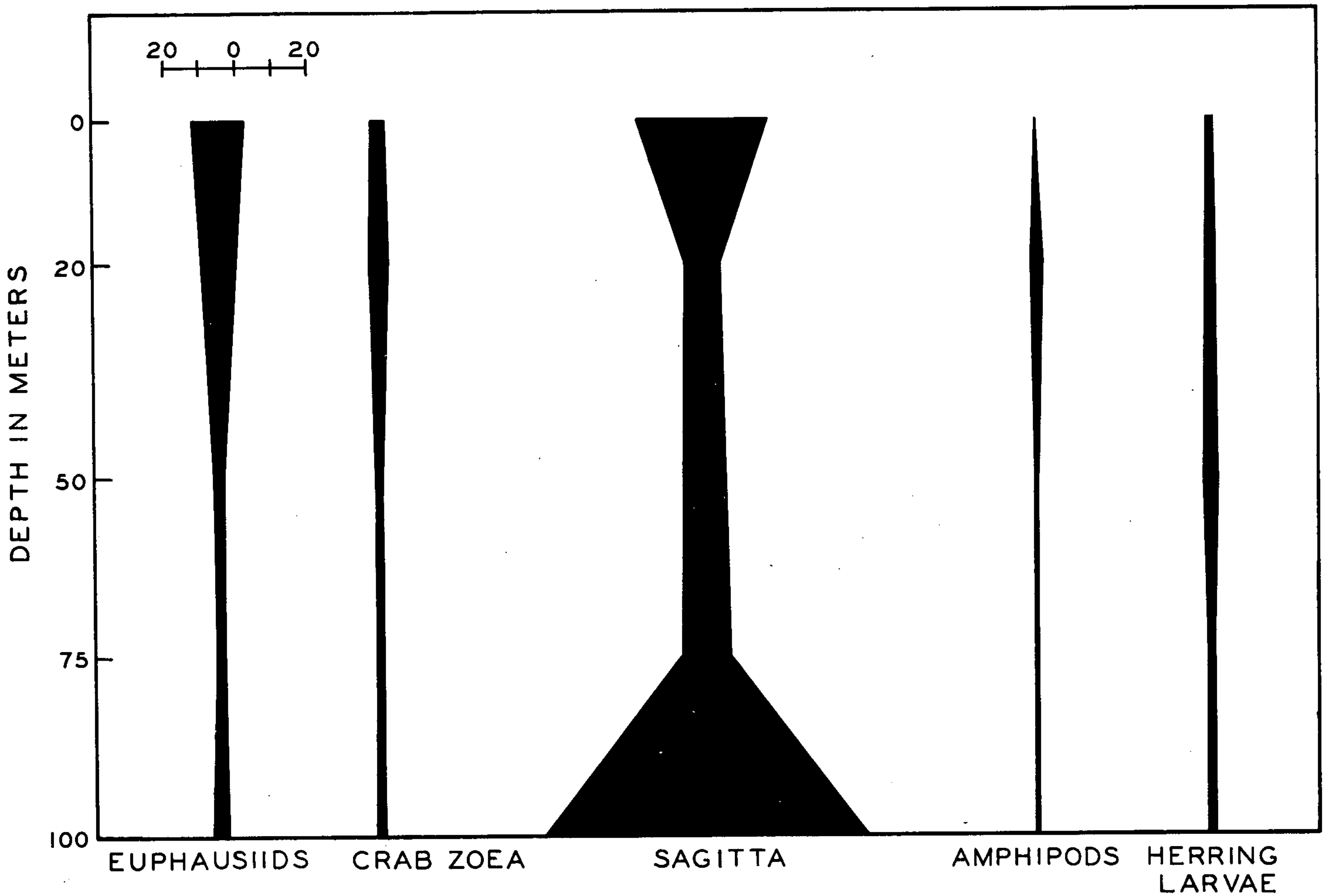

Figure 7. Vertical distribution of euphausiids, crab zoea, Sagitta, amphipods and herring larvae.

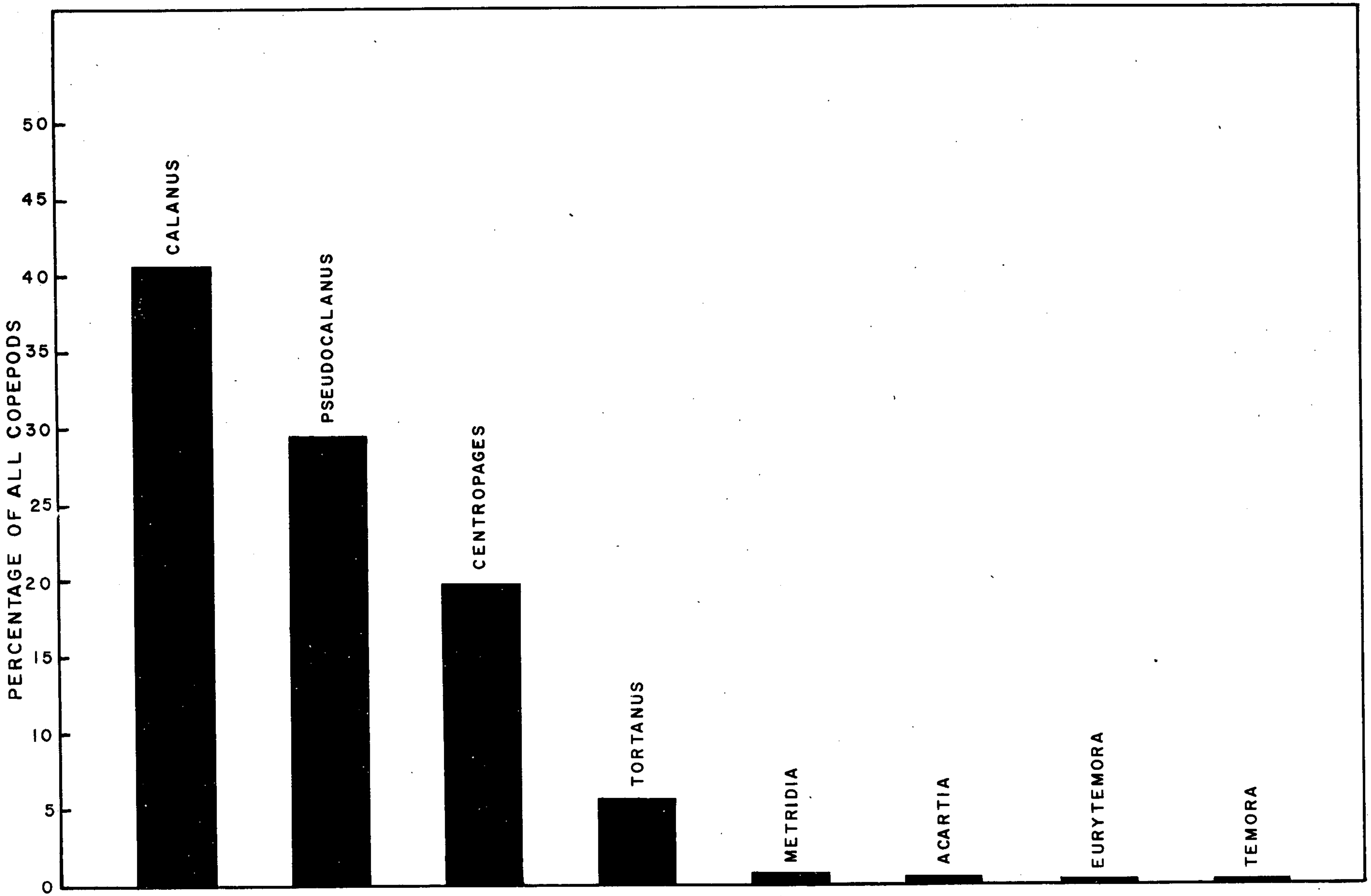

Figure 8. Percentages, by numbers, of the 8 dominant copepod species found in the Quoddy Region in 1957 and 1958 combined.

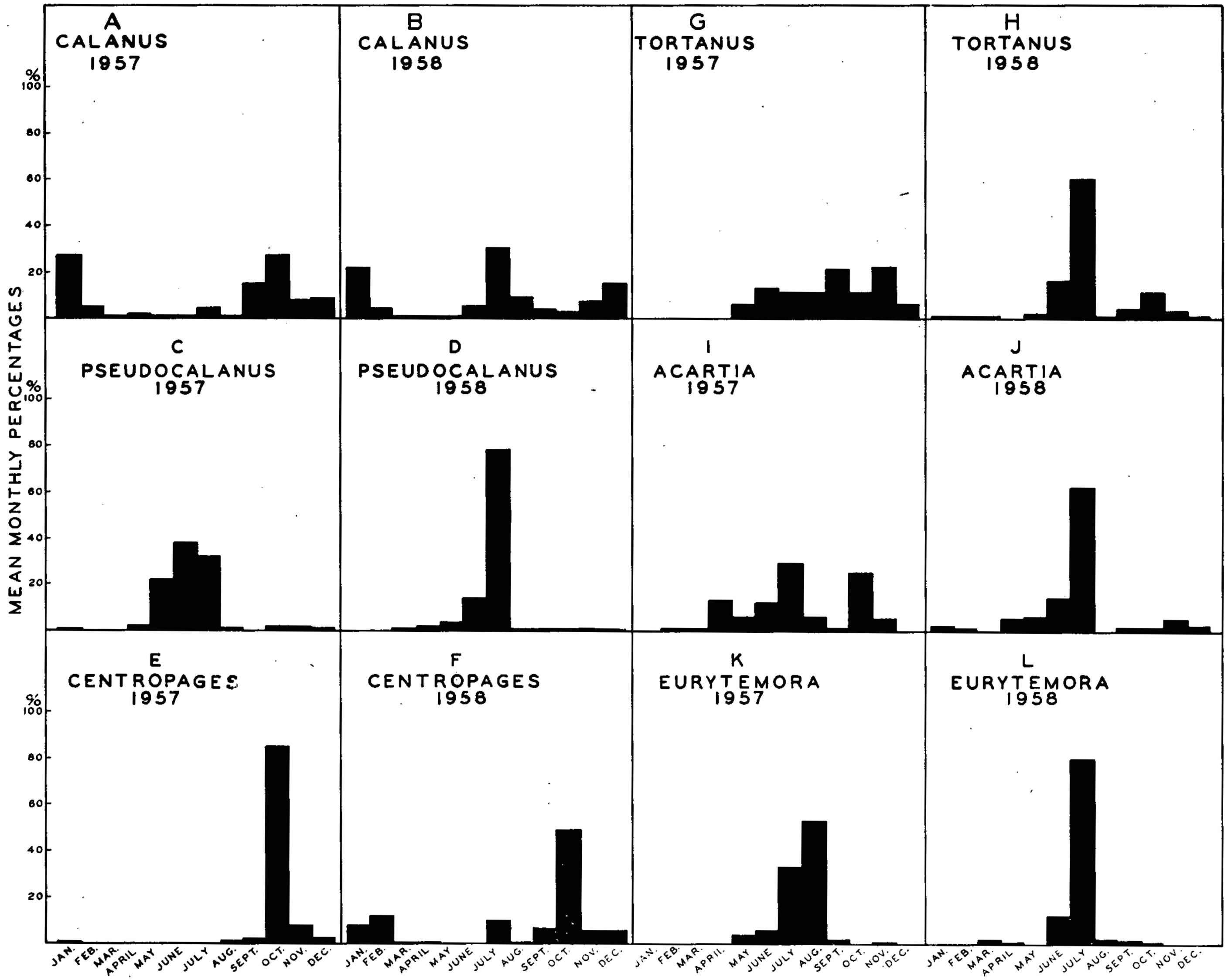

Figure 9. Mean monthly percentages by numbers of Calanus, Pseudocalanus, Centropages, Tortanus, Acartia and Eurytemora, in 1957 and 1958 in the Quoddy Region.

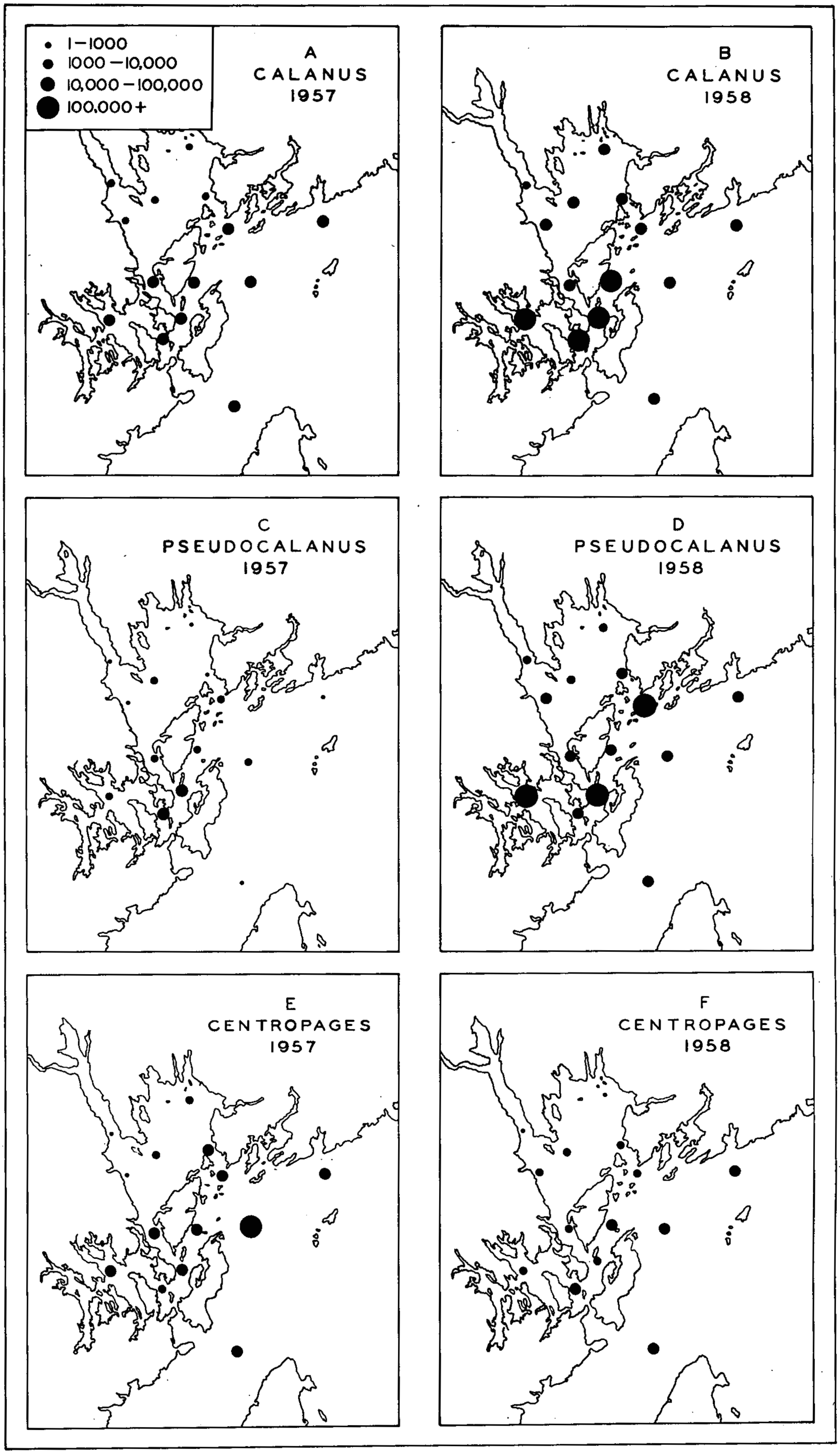

Figure 10. Horizontal distribution of numbers of Calanus finmarchicus, Pseudocalanus minutus and Centropages typicus, in 1957 and 1958 in the Quoddy Region.

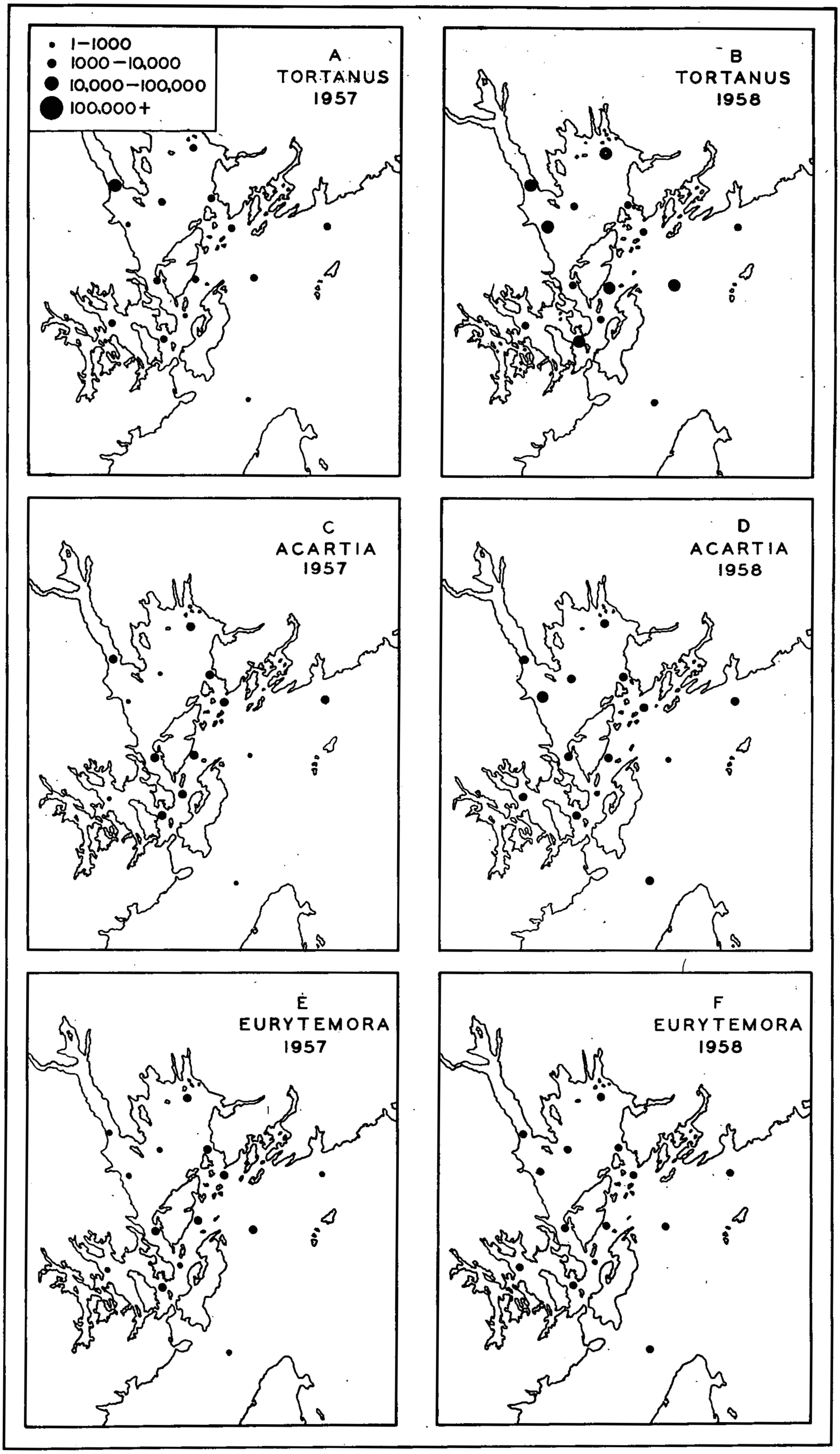

Figure 11. Horizontal distribution of numbers of Tortanus discaudatus, Acartia clausi and Eurytemora herdmani in 1957 and 1958 in the Quoddy Region.

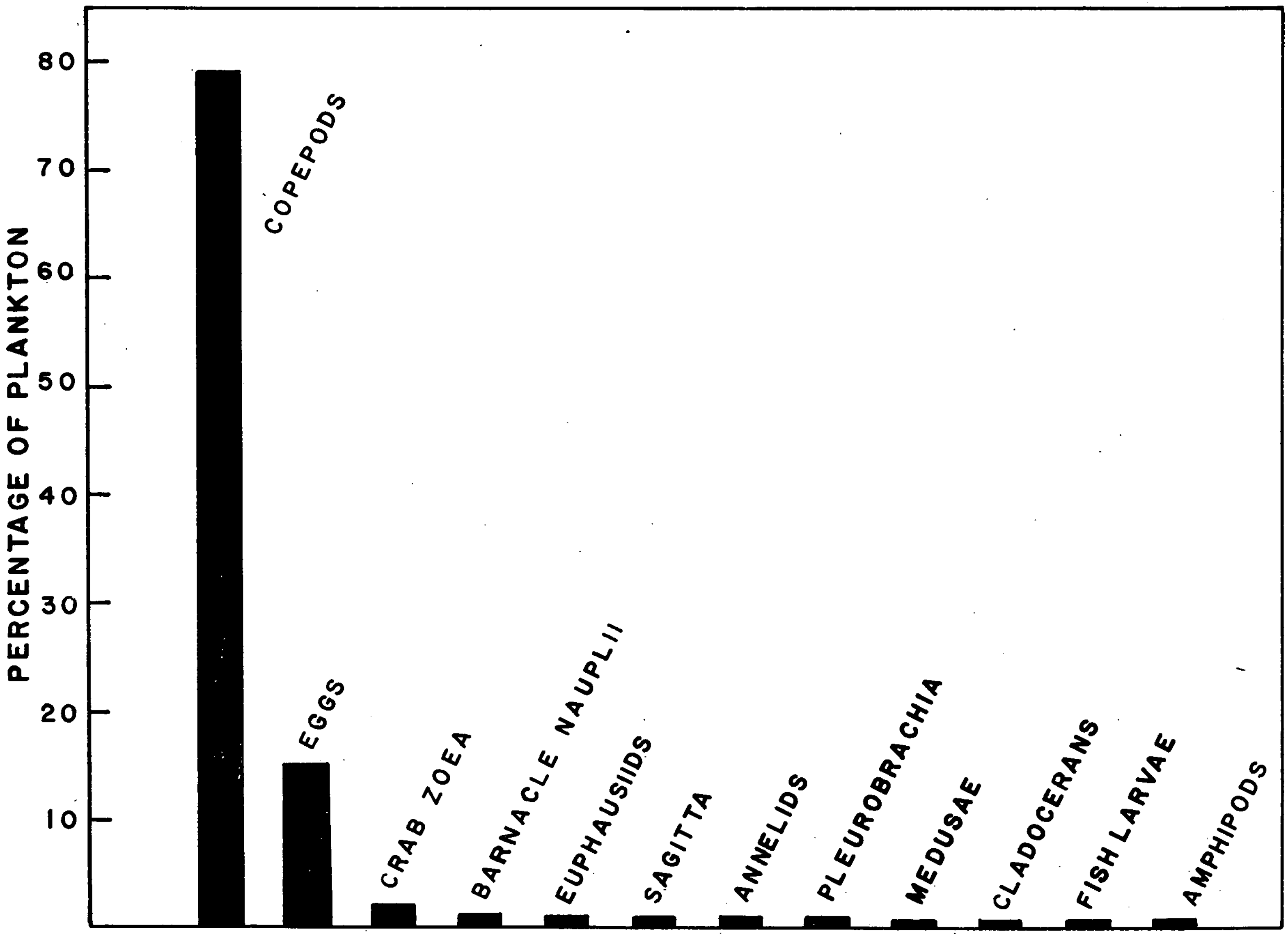

Figure 12. Percentages, by numbers, of the most important constituents of the zooplankton in the Quoddy Region in 1957 and 1958 combined.

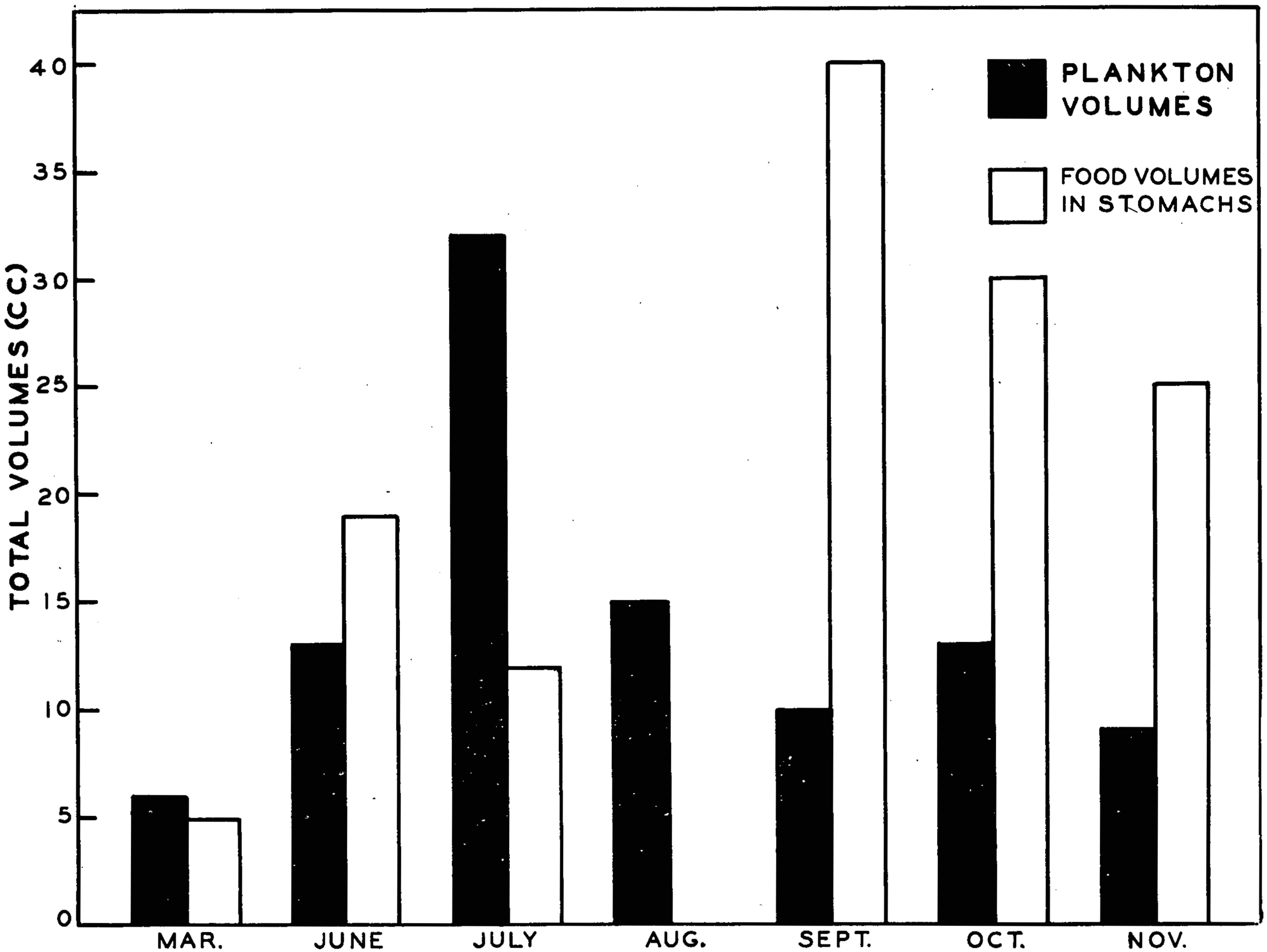

Figure 13. Mean zooplankton volumes over the Quoddy Region plotted against mean food volumes found in herring stomachs.

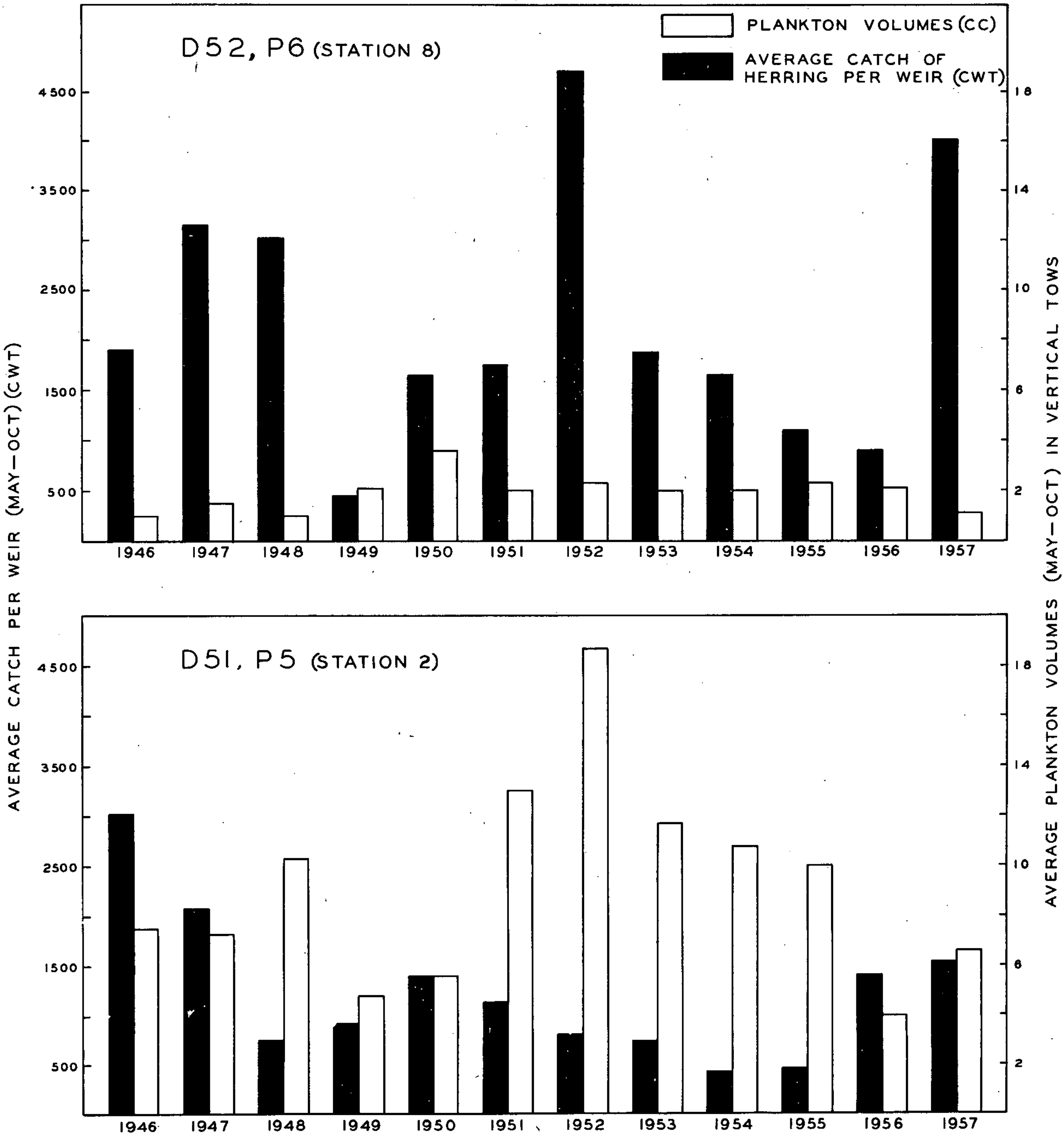

Figure 14. Comparison of the average annual zooplankton volumes at Prince stations 5 and 6 and the average annual catch of herring per weir from the Department of Fisheries statistical districts 51 and 52 for the years 1946 to 1957. (N.B. Statistical district 51 encompasses Deer and Campobello Islands at the entrance to Passamaquoddy Bay and district 52 extends from Back Bay to the International Boundary).

CHAPTER 5

LARVAL HERRING (CLUPEA HARENGUS L.) IN THE BAY OF FUNDY AND THE GULF OF MAINE

by

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Boothbay Harbor, Maine.

ABSTRACT

A major portion of the Bay of Fundy and Gulf of Maine has been surveyed for occurrence and distribution of herring larvae. Plankton samples obtained with Hardy continuous plankton recorders and plankton nets confirm major spawning areas off the southwest coast of Nova Scotia and on the northern edge of Georges Bank. Newly-hatched larvae were found in abundance in these areas, but nowhere else. The drift of larvae as indicated by non-tidal surface currents suggests that Nova Scotia spawnings are the major contributors to the commercial stocks of herring in the inshore areas of Maine and New Brunswick. Georges Bank spawnings may also supply some herring to this region, but to a lesser extent.

INTRODUCTION

Canada and the United States have a common interest in a fishery for young herring that are found in vast numbers in inshore waters of Charlotte County, New Brunswick, and along the Maine coast. Average annual landings approximate 200 million pounds and provide raw materials for 'sardine'canneries, pet food canneries, and reduction plants.

There has been no recent evidence of major spawnings within the principal coastal 'sardine' areas; in fact during the past 10 years only small quantities of adult herring have been caught there. About 1875, when the 'sardine' industry started to become important, the fishery for adult herring in the area began to decline, and this trend has continued (Huntsman, 1953). Spawnings at Grand Manan, New Brunswick, and along the Maine coast were very extensive at one time (Earle, 1887) and still occur fairly regularly but appear to be of only minor importance now. Where then are the breeding grounds and the nursery areas for the fish that populate the Quoddy Region? What is the survival, growth, and dispersal of the larvae and how are they transported?

To answer these questions, the Fisheries Research Board of Canada and the United States Bureau of Commercial Fisheries began, in 1956, a co-operative investigation of the offshore areas of the Bay of Fundy and the Gulf of Maine.

The main part of the program was carried on from September through February in 1956-57, 1957-58, and 1958-59. Additional data were available from Prince station tows taken monthly in the Passamaquoddy region and from cruises made by the M. V. T. N. Gill from May 1955 to January 1956. In March 1958, cruises with the M. B. Mallotus were carried out in the Grand Manan area at the entrance to the Bay of Fundy, and in St. Mary Bay, Nova Scotia.

Autumn and winter months were selected for the co-operative cruises because of known spawnings in southwestern Nova Scotia and on Georges Bank in August and September. Surveys were designed to study the abundance, size, and distribution of the larvae that resulted from these spawnings.

Although the problem of the origin of the 'sardine' herring in southern New Brunswick and Maine remains unsolved, some progress has been made and the discoveries to date are recorded in the following report. A preliminary report on these investigations was published by Tibbo et al, 1958.

MATERIALS AND METHODS

Canadian vessels used were M. V. Harengus (Fig. 1) C. N. A. V. Fort Frances, C. G. S. A. T. Cameron, M. B. Mallotus, and M. V. J. J. Cowie. United States Bureau of Commercial Fisheries supplied the M. V. Silver Bay (Fig. 1), M. V. Albatross III, M. V. Delaware, and M. V. T. N. Gill. In the initial planning, a series of cruise lines and stations was established (Fig. 2) and followed as closely as possible throughout the investigation. The total length of the cruise lines was approximately 2,550 miles. Hardy continuous plankton recorders were towed throughout the cruises. Recorders had an aperture 3/4 inch (19 mm) square and propeller angle setting of 70°. This propeller setting usually provided a 2-inch (51 mm) section of gauze for each 5 miles (8 km) of cruising. Canadian vessels towed one recorder at a depth of 10 metres. United States vessels used two recorders--one at the surface and one at 10 metres.

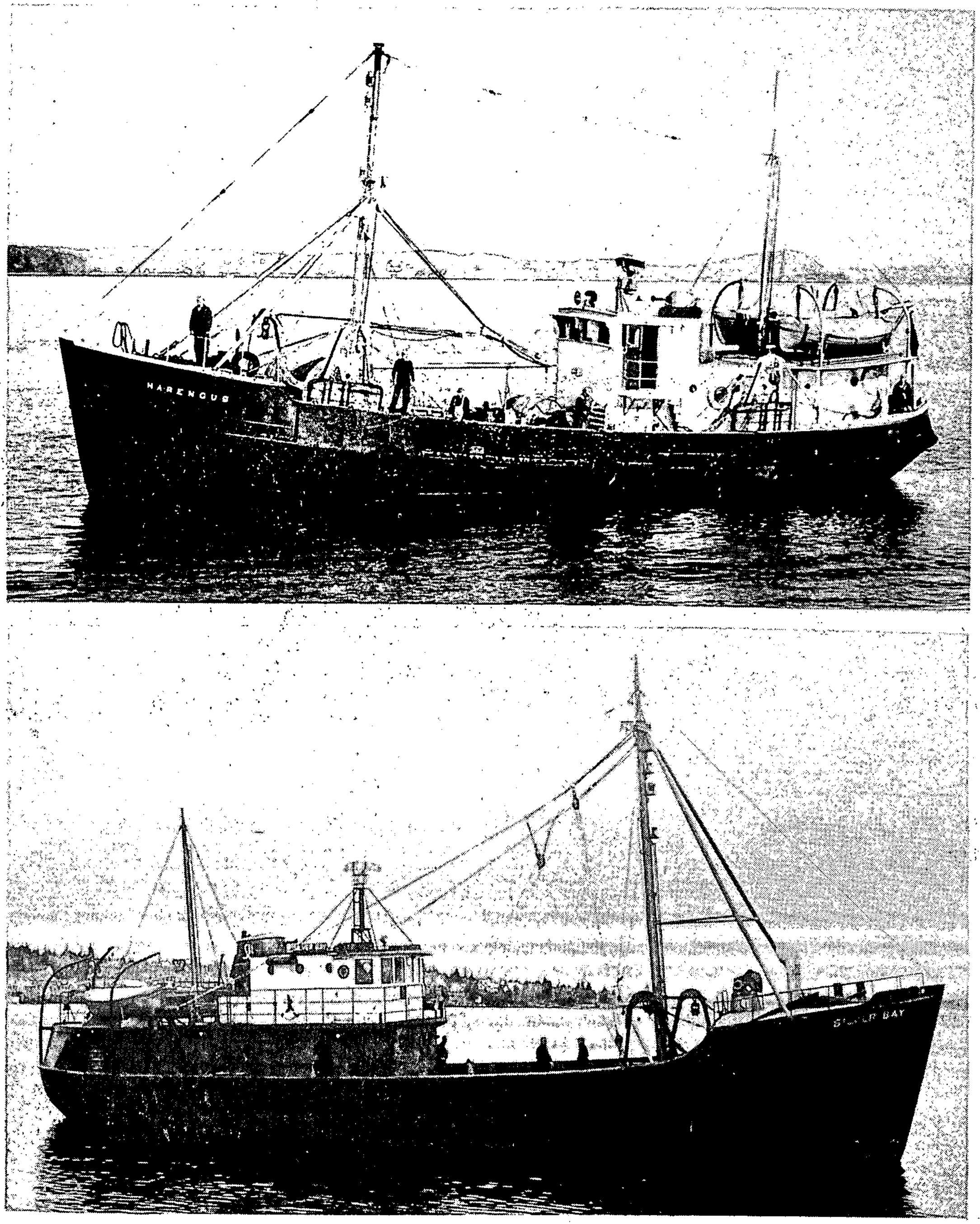

Figure 1. Two of the vessels used for the plankton cruises (upper) Canadian Research vessel M. V. Harengus, (lower) United States chartered vessel M. V. Silver Bay.

Additional plankton collections were made with silk or nylon 1-metre plankton nets of # 0 mesh (12-15 threads per cm). Nets were towed for 15 minutes at each station at approximately 3 knots. Two kinds of 3-level tows were made. One was at 10, 5, and 0 metres and the other was at 20, 10, and 0 metres. United States vessels made plankton tows every 4 hours and Canadian vessels towed at 95 established stations that were about 4 hours steaming-time apart.

Herring larvae were removed from the recorder gauzes and plankton collections. In tows that contained more than 100 larvae, a sample of 100 was taken for length measurements, otherwise all larvae were measured. Two length measurements were used, viz., total length from tip of lower jaw to longer lobe of caudal fin, and standard length from tip of lower jaw to caudal peduncle. For this report, standard lengths of larvae 12 mm and larger were converted to total lengths by use of the formula:

$$Y \text{ (total length)} = 1.181\, X \text{ (standard length)} - 2.0$$

(Below 12 mm, the two lengths are identical.)

Occurrence of herring larvae at two plankton stations in the Passamaquoddy region, Prince 5 (Lat. 44°57'10"N., Long. 66°51'00"W.) and Prince 6 (Lat. 45°04'54"N., Long. 67°06'07"W.) was recorded. These stations have been occupied monthly for more than 20 years by the Fisheries Research Board of Canada's St. Andrews Biological Station, giving 1,816 Prince station collections covering the years 1937 to 1959 (April). Routine at Prince stations included vertical tows from 90 to 0 metres and 15-minute oblique tows, one from 23 to 18 metres and the other from 7 to 5 metres. All tows were made with a 1-metre # 0 plankton net.

From May 1955 to January 1956, 10 plankton cruises using the United States research vessel T. N. Gill were made chiefly in coastal waters of the Gulf of Maine. A total of 191 plankton tows were taken with a 1-metre net towed for 15 minutes at 10, 5, and 0 metres (5 minutes at each depth). Data on larvae taken are included in this report.

During most cruises, bathythermograph casts, drift-bottle releases, and air and surface water temperature observations were taken.

ABUNDANCE OF HERRING LARVAE

The total number of herring larvae examined was 65,475. The numbers of larvae taken, the gear used, the numbers of 1-metre net tows made, and the distances Hardy recorders were towed are listed in

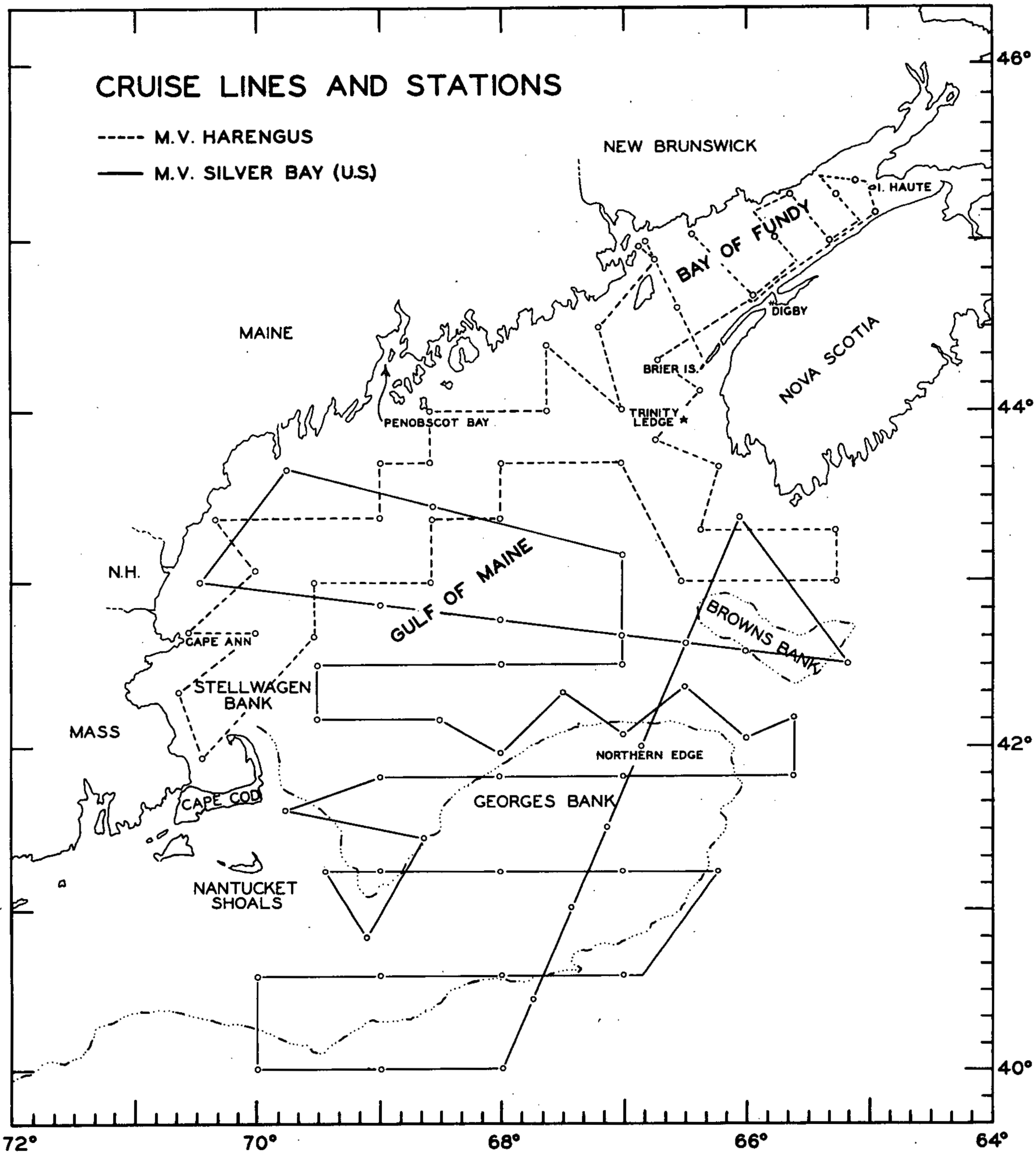

Figure 2. Cruise lines and stations occupied during the September to February cruises 1956-57 and 1957-58.

Table I. There were 40 larvae taken at Prince stations and 353 during T. N. Gill cruises. The majority of larvae, however, were taken in the joint cruises from September to February 1956-57, 1957-58, and 1958-59. Except for December 1956 when additional tows were made in areas where larvae were known to be abundant, largest numbers were taken in September and October of each year (Table I). The catch decreased sharply in November and was very light in January and February. Additional tows in December 1956 were made to investigate depth distribution of larvae and these account, in part, for the large number (18,319) taken during that month.

No attempt is made here to compare abundance of larvae for the three seasons (1956-57, 1957-58, 1958-59) because of variations in numbers of tows and in localities where tows were made. In all three seasons, large numbers of larvae were taken in a few tows and a comparison of average numbers per tow would have little meaning. Only 251 larvae were taken with plankton recorders, in contrast to 65,225 in 1-metre nets.

DISTRIBUTION OF HERRING LARVAE

Catches indicate that during September, larvae are not widely dispersed in the Gulf of Maine. In September 1956 (Fig. 3A) large concentrations were found on Georges Bank. Small numbers were found around Nantucket Shoals off Massachusetts and near Ile Haute and Brier Island in the Bay of Fundy. A few individuals were taken off the coast of Maine. In September 1957 (Fig. 3B) cruises covered only the Bay of Fundy, the coast of Maine, and the northern edge of Georges Bank. The only herring larvae captured were in the Bay of Fundy and along the southwest coast of Nova Scotia. A major concentration occurred near Brier Island. Absence of larvae on Georges Bank suggests that herring in the area had not spawned, or eggs had not yet hatched. In September 1958, there were no cruises in either the Gulf of Maine or the Bay of Fundy.

In October, larvae were more widely distributed. In October 1956 (Fig. 3C) larvae occurred throughout most of the Georges Bank area with major concentrations on the northern edge. Both Hardy recorder and plankton-net samples caught larvae on the southern portion of Georges Bank. Scattered larvae were taken in the Bay of Fundy. A few were found around Stellwagen Bank and offshore from Penobscot Bay. In October 1957 (Fig. 3D) large numbers were taken on the northern edge of Georges Bank and near Trinity Ledges at the southern tip of Nova Scotia. Larvae were taken in 29 out of 33 tows in the Bay of Fundy. They were well dispersed throughout the Bay with largest concentrations near Digby. Some larvae were taken offshore in the vicinity of Penobscot Bay and off Cape Cod. In October 1958 (Fig. 5A) larvae were widespread over Georges Bank with the largest concentration again occurring on the northern edge. In the Bay of Fundy,

Table I. Herring larvae caught in different years.

Date	Vessel or station	1-metre net Larvae	1-metre net Tows	Hardy Recorders Larvae	Hardy Recorders Miles towed
1937-1959	Prince Station 5	23	622	...	...
1937-1959	Prince Station 6	17	1,194	...	...
1955-1956	T. N. Gill	325	191	28	3,051
Sept. 1956	Silver Bay, Harengus	5,619	101	23	2,619
Oct. 1956	Silver Bay, Harengus	6,453	96	52	2,788
Nov. 1956	Silver Bay, Harengus	1,635	100	37	2,768
Dec. 1956	Silver Bay	18,319	109	...	...
Jan. 1957	Delaware	196	51	9	1,842
Feb. 1957	Albatross III	259	97	18	1,550
Sept. 1957	Harengus	4,187	53	0	1,345
Oct. 1957	Harengus	12,017	70	1	615
Nov. 1957	Harengus	347	48	11	510
Dec. 1957	Albatross III, Delaware	271	76	34	2,347
Jan. 1958	Albatross III, Delaware	93	62	23	1,804
Feb. 1958	Fort Francis	46	67	4	1,795
Oct. 1958	Harengus, Delaware	15,020	109	1	2,796
Nov. 1958	Harengus	111	67	2	755
Dec. 1958	Delaware	136	8	5	187
Jan. 1959	A. T. Cameron	129	79	3	1,910
Feb. 1959	A. T. Cameron	21	18	...	...
Total		65,224	3,218	251	28,682

23 tows contained herring larvae and showed a wide dispersion throughout the Bay. A few larvae were taken off the tip of Nova Scotia as well as in the vicinity of Penobscot Bay and farther south along the coast of Maine and Massachusetts.

Larvae in November 1956 (Fig. 3E) were more widely dispersed than for most months during the survey. They were heavily concentrated on Georges Bank, but in general, were farther south than in September and October. Dense concentrations on the northern edge of Georges Bank in September and October appear to have been broken up with some larvae moved northeastward over Browns Bank, but the majority moved southward on Georges Bank. Only a few larvae were caught in the Bay of Fundy, along the Maine coast, on Stellwagen Bank and in the central portion of the Gulf of Maine. In November 1957 (Fig. 3F), larvae were again concentrated heavily on the northern edge of Georges Bank. As in November 1956, some dispersal of larvae northward toward the Nova Scotia coast was evident, while in the Bay of Fundy major concentrations were found in the northern part of the Bay and along the west coast of Nova Scotia. Along the Maine coast, a few larvae were taken offshore in the vicinity of Penobscot Bay. In November 1958 (Fig. 5B), the distribution of larvae was similar to that of November 1957. Although there were no large concentrations of larvae, some were found on the northern edge of Georges Bank, off the southwest tip of Nova Scotia, and throughout the Bay of Fundy. A few larvae were taken along the Maine coast.

In December 1956 (Fig. 4A), sampling was restricted to Georges Bank and inshore areas of Maine and New Hampshire. Heavy concentrations of larvae were found on the southern half of Georges Bank and smaller concentrations on Stellwagen Bank. In December 1957 (Fig. 4B), larvae from 1-metre net catches were scarce over Georges Bank and in the Bay of Fundy. The heavy concentrations of September, October, and November now showed a more widely dispersed pattern of distribution. A short cruise in December 1958 revealed a small concentration of larvae in the Great South Channel between Georges Bank and Cape Cod (Fig. 5C).

In January 1957, 1958, and 1959, (Fig. 4C, D, and 5D), distributions were similar for the Gulf of Maine and Georges Bank. There was no cruise in the Bay of Fundy in January 1957. In January 1958, and 1959, small concentrations of larvae were found at more than half of the stations occupied in the Bay of Fundy, showing a wide distribution of larvae.

In February 1957, sampling was restricted to inshore areas of the Gulf of Maine and the Bay of Fundy and a wide distribution of larvae was observed as shown in Fig. 4E. In February 1958 (Fig. 4F), only small numbers of larvae were taken anywhere, most of them on or immediately north of Georges Bank. In February 1958 (Fig. 5E), a short cruise in St. Mary Bay showed a general distribution of larvae throughout the Bay.

Differences between catches of larvae in January and February were chiefly in numbers taken rather than in distribution. It is likely that by January the larvae were large enough to avoid the plankton nets.

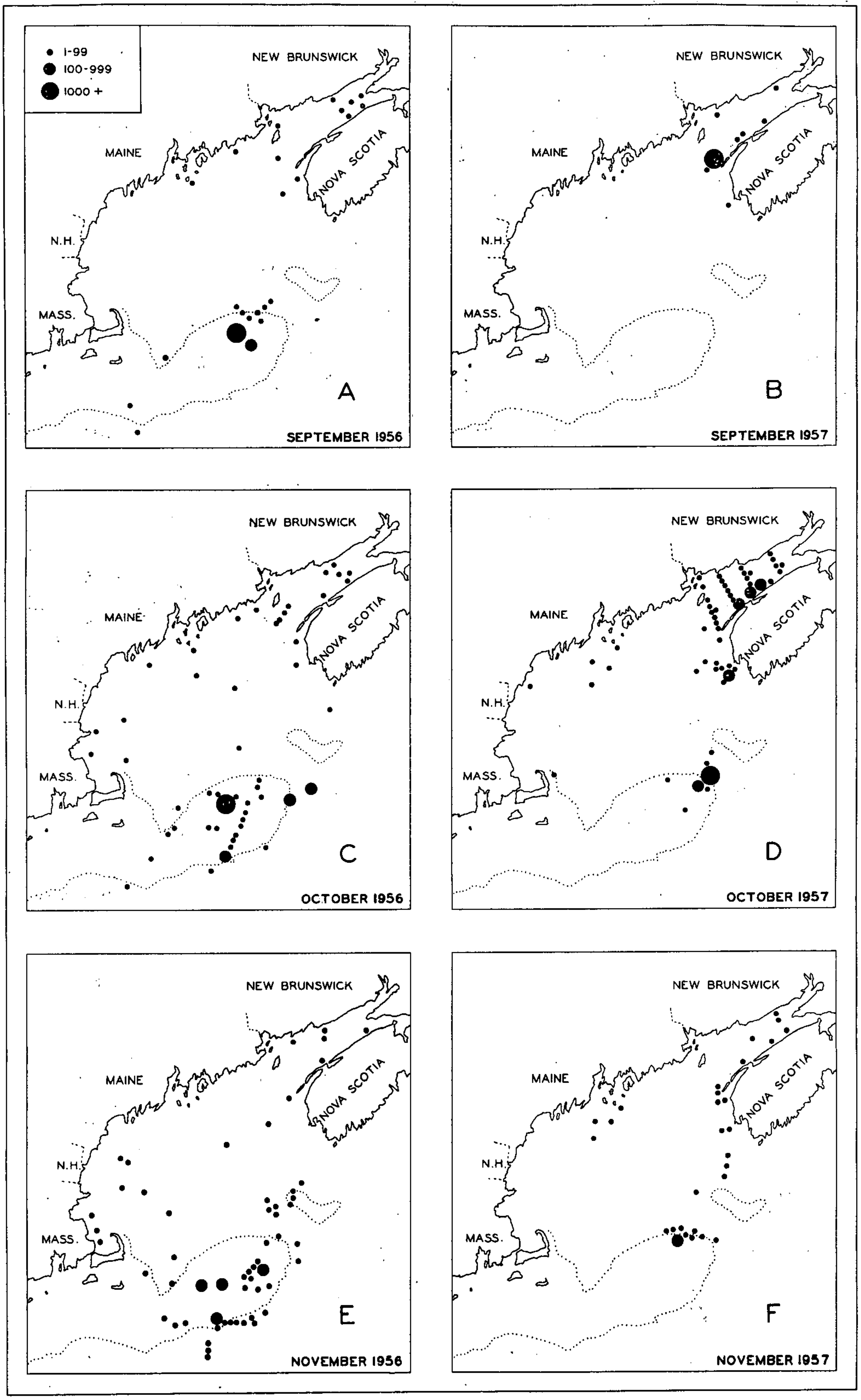

Figure 3. Distribution of herring larvae September to November 1956 and 1957.

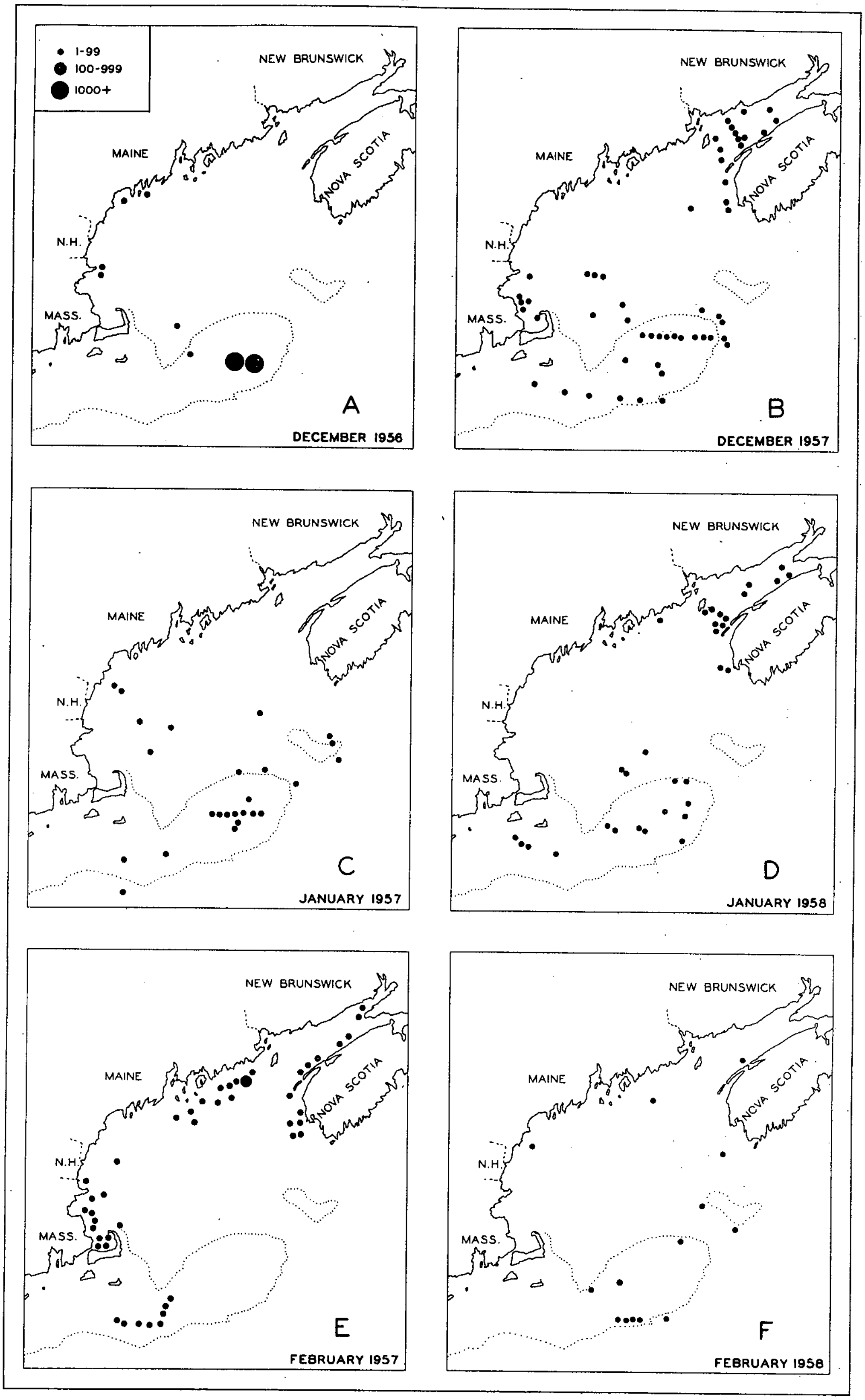

Figure 4. Distribution of herring larvae December to February 1956-57 and 1957-58.

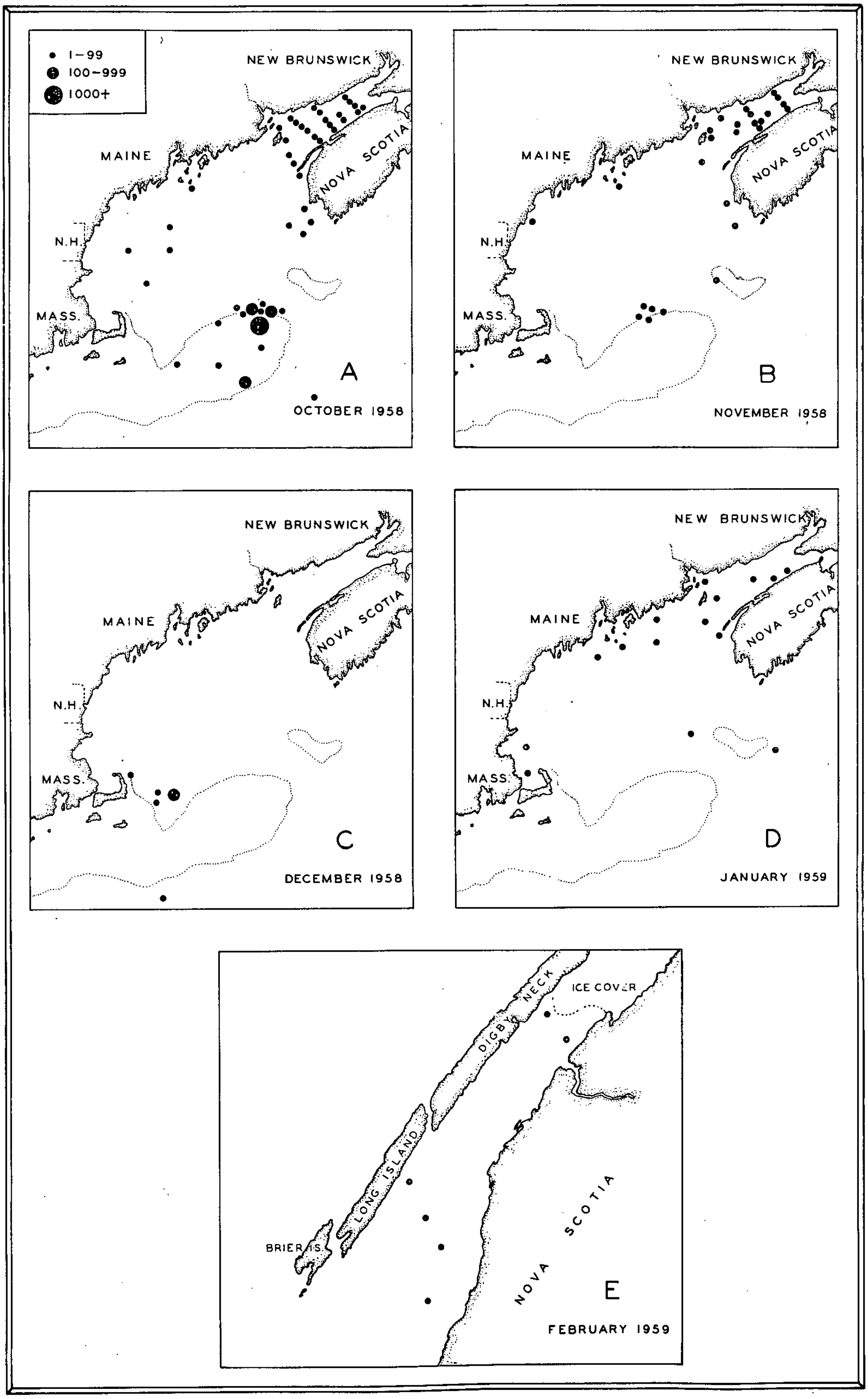

Figure 5. Distribution of herring larvae October 1958 to February 1959.

Distribution and numbers of larvae taken during the T. N. Gill cruises are shown in Fig. 6. In April, 17 larvae were caught west of Penobscot Bay, Maine. In June and July, no larvae were taken. In August, 18 newly-hatched larvae were taken in one tow on Trinity Ledges. In October, no larvae were taken in a cruise from Penobscot Bay to Cape Ann. A November cruise in the Gulf of Maine, on Georges Bank, and in the Bay of Fundy took 51 larvae on Georges and Browns Banks, on Trinity Ledges, in the Bay of Fundy, and around Penobscot Bay. In December, a short cruise was made along the New England coast during which 187 larvae were taken. Fifty-two herring larvae were taken during a January cruise along the western coast of Nova Scotia, the coast of Maine, and around Cape Cod. Distribution of 28 larvae taken with plankton recorders during T. N. Gill cruises was similar to that for the 1-metre net hauls.

LENGTH COMPOSITION

Size composition of larvae by months are given in Table II, and Fig. 7 and 8. For Fig. 7, a arbitrary division of larvae into small (4-9 mm), medium (10-19 mm), and large (20-50 mm) size groups has been made. Herring larger than 50 mm and larvae that were damaged were not included in Fig. 7 and 8.

In September 1956, 94% of the larvae were in the small, 5% were in the medium, and less than 1% were in the large size-categories. In September 1957, 99% of the larvae were small, 1% were of the medium size, and less than 1% were large. In October 1956, there were still large numbers of small larvae (95%) as was the case for October 1957 (92%) and 1958 (94%). No small herring larvae were taken after October in 1956 and 1958, but in 1957, 36% of the November catches and 1% of the December catches were small. This tends to confirm a later spawning on Georges Bank in 1957. For all three seasons, January and February samples contained no newly-hatched larvae but for these months in 1958, there were more of the medium-size group than during the same period in 1957 and 1959.

Length frequency distributions for the three seasons (Table II, Fig. 8) show bi-modality particularly for November and December 1956, for November and December 1957, and February 1959. The general pattern of larval growth is seen in the shift of histograms to the right as the seasons progress (Fig. 8). In September samples, the range of larval lengths is quite small, and the population appears to be homogeneous (Table II). As the season advances, larvae from other spawnings are added to existing populations, and the size range increases. This may be due to a mixture of larvae from separate populations, but is more likely the result of separate spawnings that occur progressively later within the same parent population.

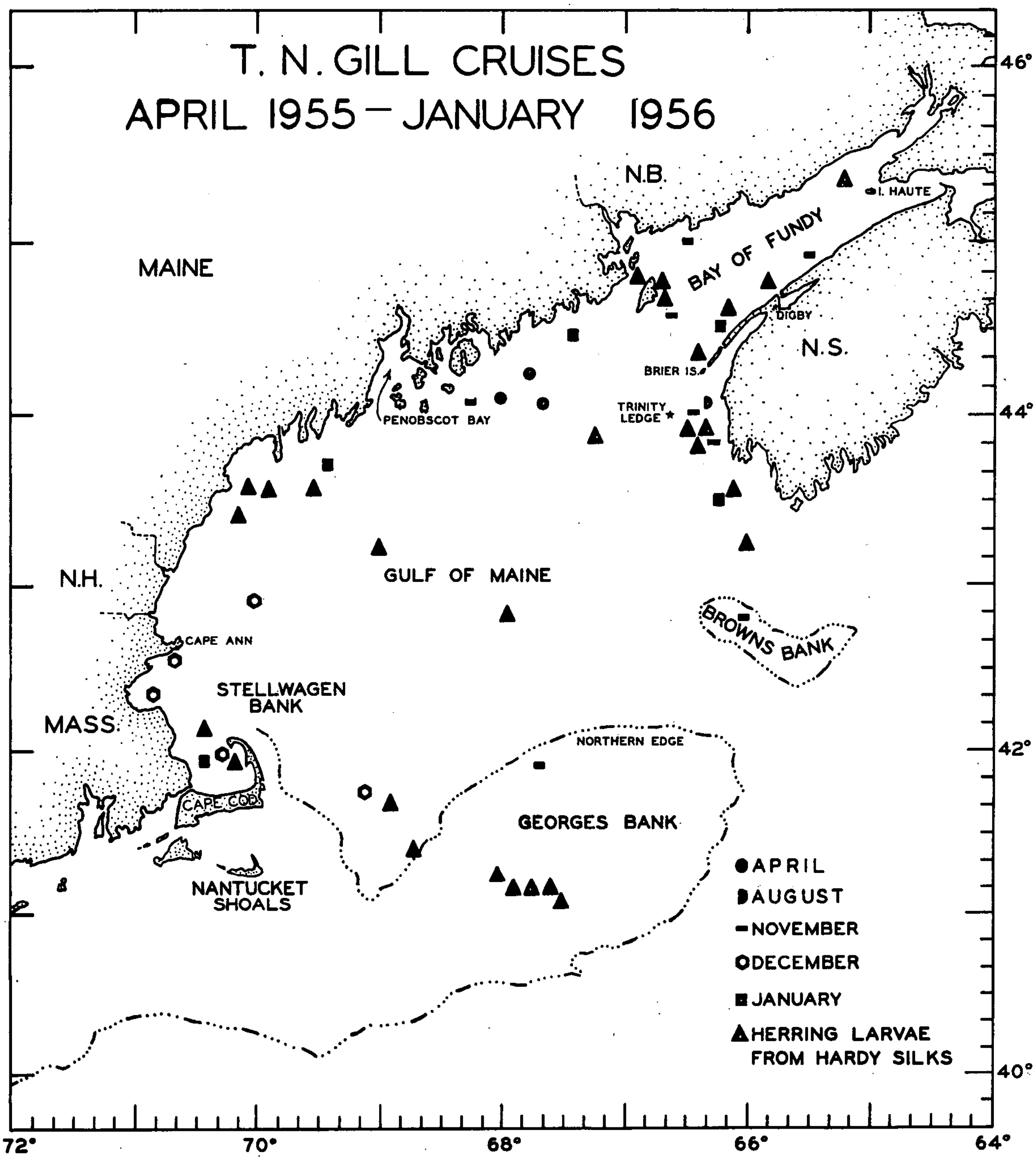

Figure 6. Distribution of herring larvae caught during the <u>T. N. Gill</u> cruises April 1955 to January 1956.

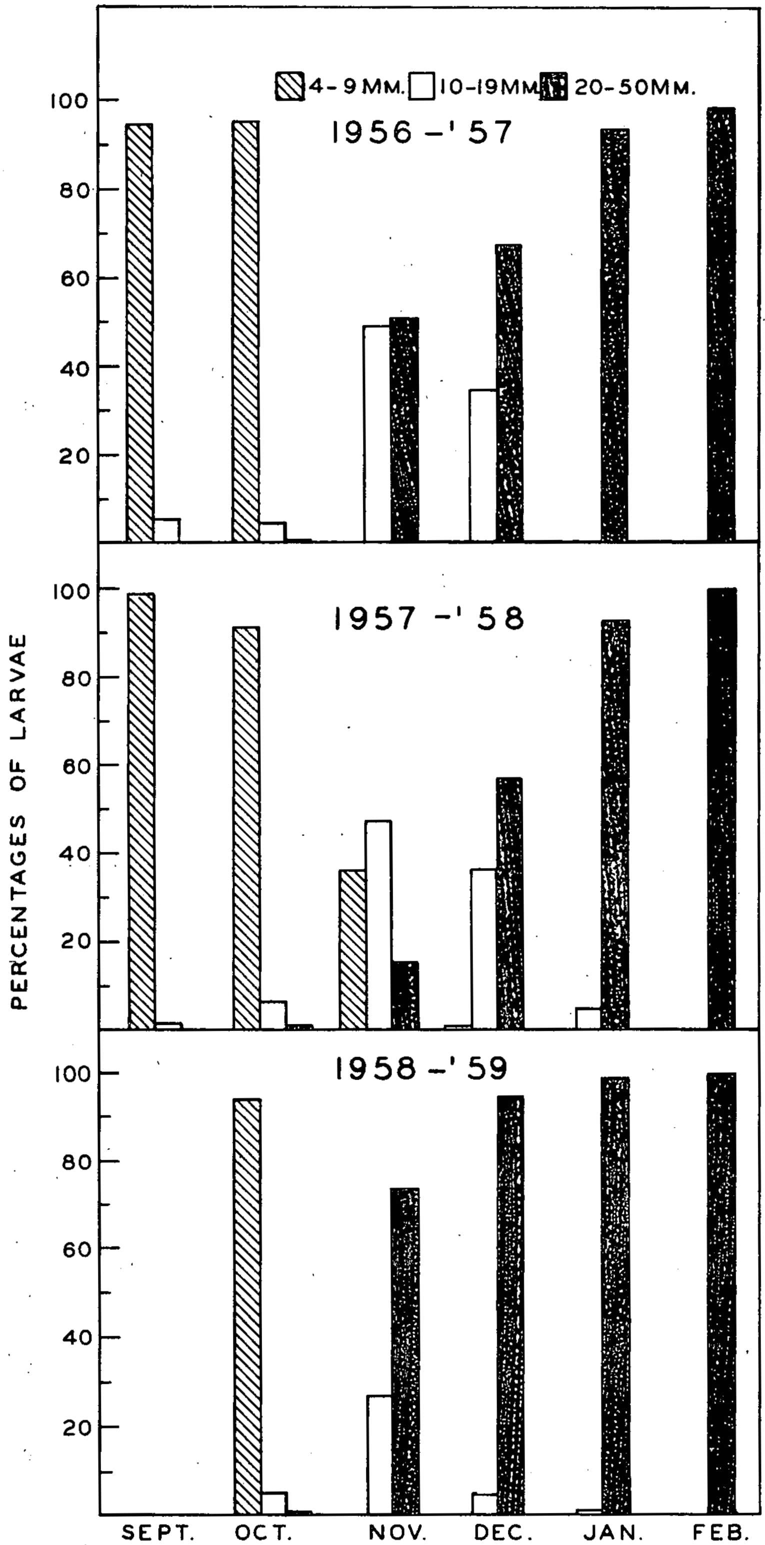

Figure 7. Variations in the relative abundance of small, medium, and large herring larvae during the autumn and winter months.

Table II. Number of larvae of various sizes taken in the Bay of Fundy and Gulf of Maine.

	1956						1957						1958			1959	
Length	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Oct.	Nov.	Dec.	Jan.	Feb.
mm.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.	no.
4	0						204	105									
5	633	230					1,107	3,567					455				
6	2,894	2,587					1,530	5,183		2			3,454				
7	1,049	2,708					942	1,926	4	1			6,469				
8	308	455					267	161	89	1			3,478				
9	421	142					89	79	32				276				
10	228	89	11				1	46	3	2			26				
11	42	39	23				1	42	2	6			56				
12	11	39	52				1	103	14	5			100	1			
13	6	19	52	32				130	18	12			121	2			
14	3	28	62	36			1	159	8	12			179	1		1	
15	11	27	99	245			1	179	13	12	2		154	2			
16	2	20	121	572			1	75	23	12	2		90	4	1		
17	1	7	130	1,100				40	29	12	1		26	6	3		
18	2	9	133	1,837			5	31	30	9			22	5	2		
19	2	2	119	2,211			35	21	25	16			17	8	1		
20	0	7	61	2,287			2	25	12	16			19	19	1	1	
21	2	5	91	2,264				25	13	18	4	1	14	10	2	1	
22		4	75	1,517	1			23	16	13	4		20	13	4	3	
23		7	60	826	1			14	4	13	3	3	13	4	15	4	
24		4	71	564	2	1		8	4	18	4	2	6	7	18	2	
25		7	101	513	2			12	3	14	4	2	11	5	9	10	1
26			74	453	3			8	1	12	3	4	7	1	16	5	
27			94	926	4	5		7		8	6	2	3	4	20	3	
28		1	67	883	7	5		4	1	7	4	3	1	2	24	7	
29			45	741	9	5		7		8	6	5	1		9	6	
30			28	587	9	4		8	1	8	10	5	1	7	5	7	
31			20	409	8	2		3		6	10	2	1	5	3	2	
32			14	164	10	3		5		3	7	3		2	2	11	1
33			9	100	9	6				3	5	2		1	1	6	1
34			6	28	9	7		1		3	4	1				8	4
35			3	7	9	9		1		1	4	1				7	4
36				2	11	8		1			4	3				12	1
37					14	8				1	1					4	1
38				1	14	14				1	1	1		1		9	
39			1		14	20					2	2				6	1
40			1		20	24		1				1				2	2
41			2		15	26						1		1		3	
42					7	31										1	2
43					1	30										2	1
44					1	23										1	
45						18											
46					1	3										3	1
47						1										1	1
48					1	1						1					
49					1												
50												1				1	
*	4	17	10	14	13	5		17	2	16	2						
Total	5,619	6,453	1,635	18,319	196	259	4,187	12,017	347	271	93	46	15,020	111	136	129	21

* Damaged larvae or larvae over 50 mm.

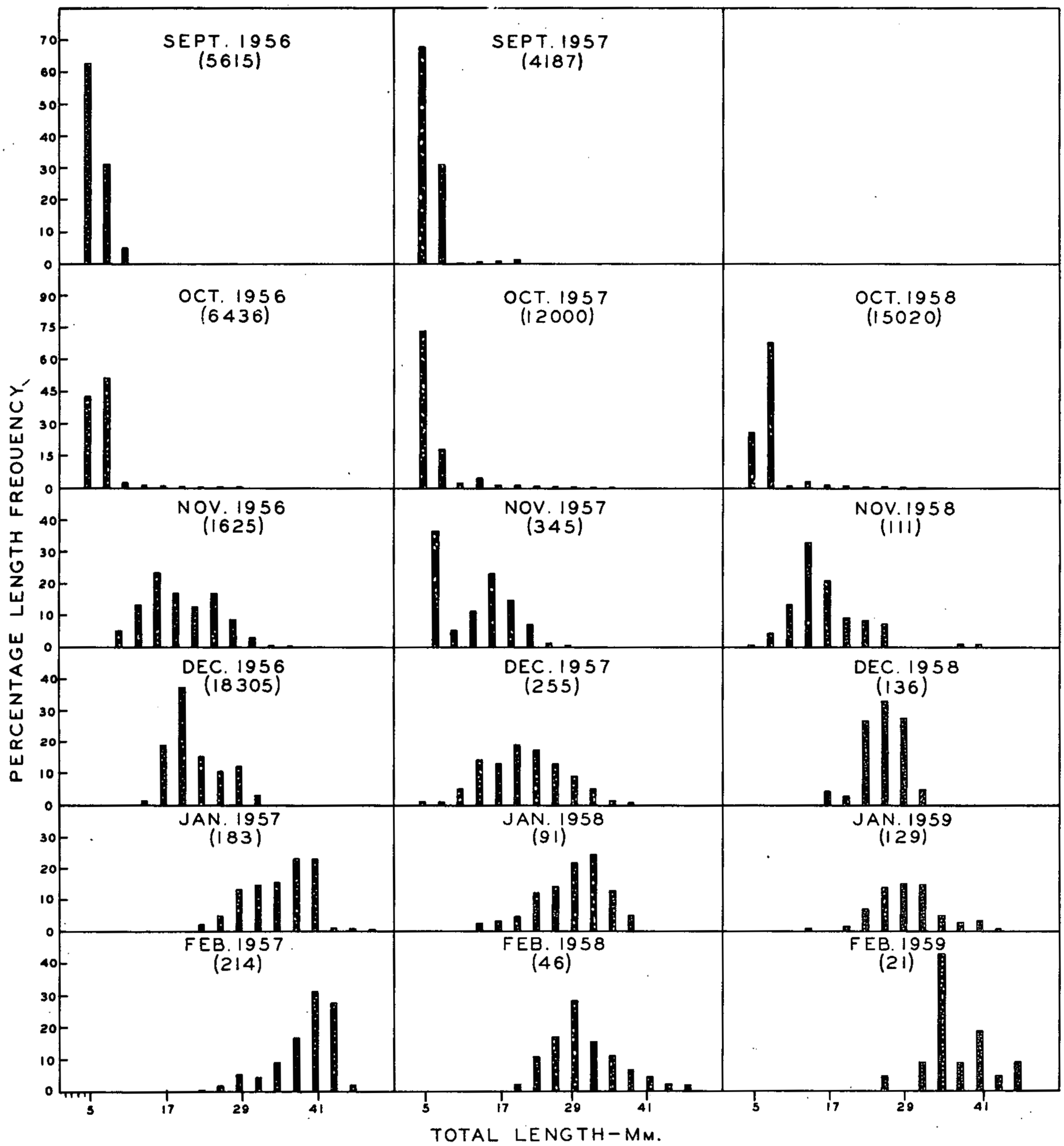

Figure 8. Length frequency distributions of herring larvae September to February 1956-57, 1957-58, and October to February 1958-59. Data are combined in 3 mm size groups.

RATE OF GROWTH

An approximate measure of growth can be obtained by plotting mean lengths of herring larvae taken during each month. Data for three seasons have been combined and growth curves are shown for the two major spawning localities; southwest Nova Scotia and the northern edge of Georges Bank (Fig. 9).

Spawning usually begins during the latter part of July in southwest Nova Scotia and about mid-August on Georges Bank. Hatching occurs two to three weeks or more later in each area and is dependent on temperature conditions on the spawning grounds. In plotting mean lengths for various ages (Fig. 9), we have assumed that larvae hatched in southwest Nova Scotia are approximately 1 month old in September while those hatched on Georges Bank are 1 month old in October. The values shown for three months of age, for example, are mean lengths for catches in November for Nova Scotia larvae and mean lengths for catches in December for Georges Bank larvae.

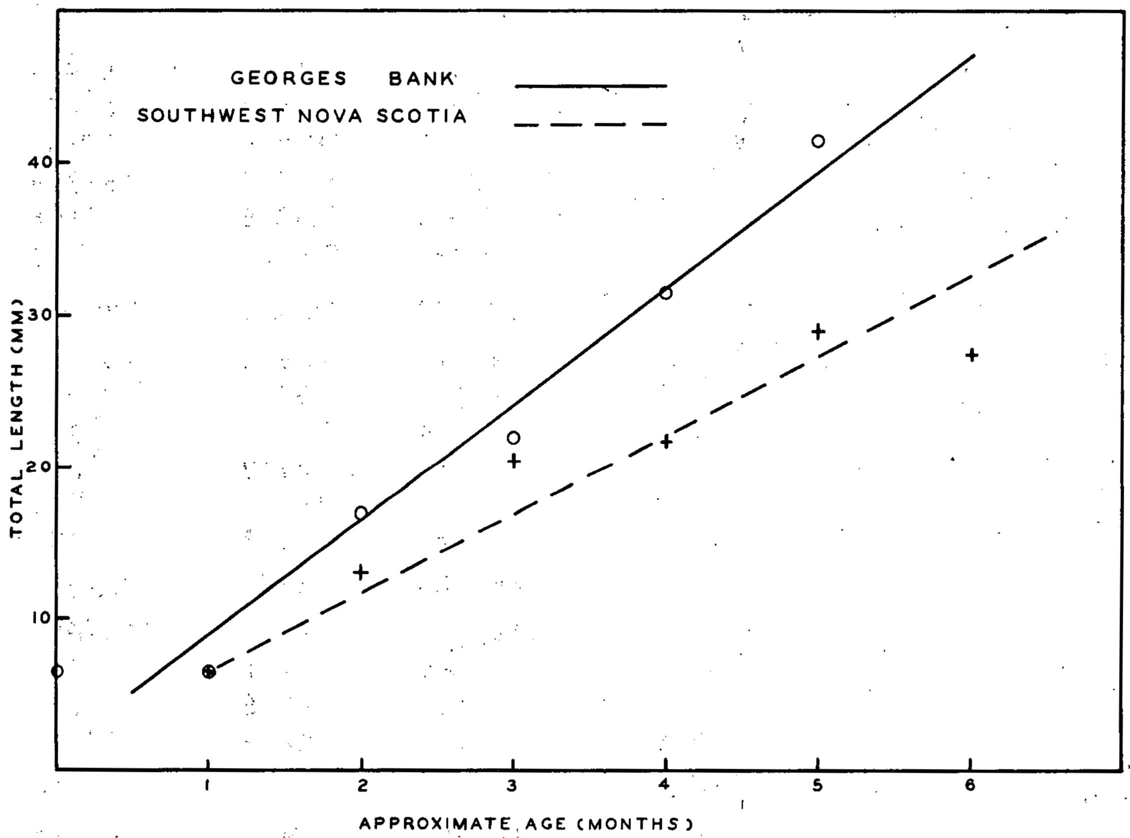

Figure 9. Growth rates of herring larvae (data for southwest Nova Scotia and Georges Bank 1956-59).

Regardless of the method of comparison, it is evident that Georges Bank herring larvae are larger for a given age than Nova Scotia herring larvae. It is also apparent that these two stocks of herring are relatively discrete. The difference in growth rate for the larvae may be accounted for by the higher (2-4°C) surface water temperatures and the greater abundance of food organisms on Georges Bank.

DAY AND NIGHT CATCHES OF HERRING LARVAE

Day and night catches for the September to February cruises are given in Table III. Division between day and night was made on a 12-hour basis with the dividing points at 6 AM and 6 PM. There were 1,186 tows taken, 651 during the day and 535 at night.

Table III. Day and night catches of herring larvae, by months.

Period	Day		Night		Total
	no.	%	no.	%	no.
Sept. 1956	4,555	81.0	1,064	19.0	5,619
Oct. 1956	5,909	91.6	544	8.4	6,453
Nov. 1956	25	1.5	1,610	98.5	1,635
Dec. 1956	2,245	12.3	16,074	87.7	18,319
Jan. 1957	1	0.5	195	99.5	196
Feb. 1957	18	6.3	241	93.7	259
Total	12,753	39.3	19,728	60.7	32,481
Sept. 1957	72	1.7	4,115	98.3	4,187
Oct. 1957	570	4.7	11,447	95.3	12,017
Nov. 1957	23	6.6	324	93.4	347
Dec. 1957	60	22.1	211	77.9	271
Jan. 1958	4	4.3	89	95.7	93
Feb. 1958	7	15.2	39	84.8	46
Total	736	4.3	16,225	95.7	16,961
Oct. 1958	815	5.4	14,205	94.6	15,020
Nov. 1958	62	55.9	49	44.1	111
Dec. 1958	6	4.4	130	95.6	136
Jan. 1959	10	7.8	119	92.2	129
* Feb. 1959	21	100.0			21
Total	914	5.9	14,503	94.1	15,417
Grand total	14,403	22.2	50,456	77.8	64,859

* Tows done in daytime only.

Total catches for the three seasons show that 22% of the larvae were taken during the day and 78% during the night. Calculated on the basis of average catch per tow, 33% were caught during the day and 67% during the night.

Larvae were taken chiefly at night except in 1956, when 81% of the September catches and 92% of the October catches were made in daytime. In both months, the high percentages resulted from single tows. In November 1958, slightly more larvae (56%) were caught during the daytime.

Differences between day and night catches were particularly evident in January and February collections when from 85% to 99% of the larvae were caught at night. During these months 738 of the 744 larvae caught were more than 19 mm long. At these sizes, larvae may be expected to avoid a plankton net particularly during daylight hours.

These results are in agreement with those of Bridger (1956) who found a similar relationship between day and night catches of herring larvae.

SPAWNING AREAS AND SEASONS

From sizes and abundance of larvae taken, spawning areas have been determined (Fig. 10). Jean (1956) reported larvae as small as 4 mm in the Gulf of St. Lawrence. In northern Scotland, herring larvae hatch at 6 to 8 mm (Fage, 1920). Bowers(1952) reported that newly-hatched larvae in Manx waters vary from 6 to 9 mm in length.

In determining the spawning grounds in the Gulf of Maine and the Bay of Fundy, larvae from 4 to 9 mm in total length were considered newly hatched and not far removed from the spawning areas. In a few instances, chiefly in southwest Nova Scotia, direct evidence of spawning is available from collections of eggs but, in general, newly-hatched larvae have been used as indicators of spawning grounds.

Areas

The largest spawning area in the Gulf of Maine is on the northern edge of Georges Bank (Fig. 10). This is a shoal area, varying in depth from 3 1/2 to 50 fathoms. It is characterized by the strong tidal currents and heavy mixing. The bottom varies from a granular boulder type to a fine sandy type (Wigley, 1957). Newly-hatched herring larvae were found in large numbers in this area and as many as 5,726 were taken in a single, 15-minute plankton tow.

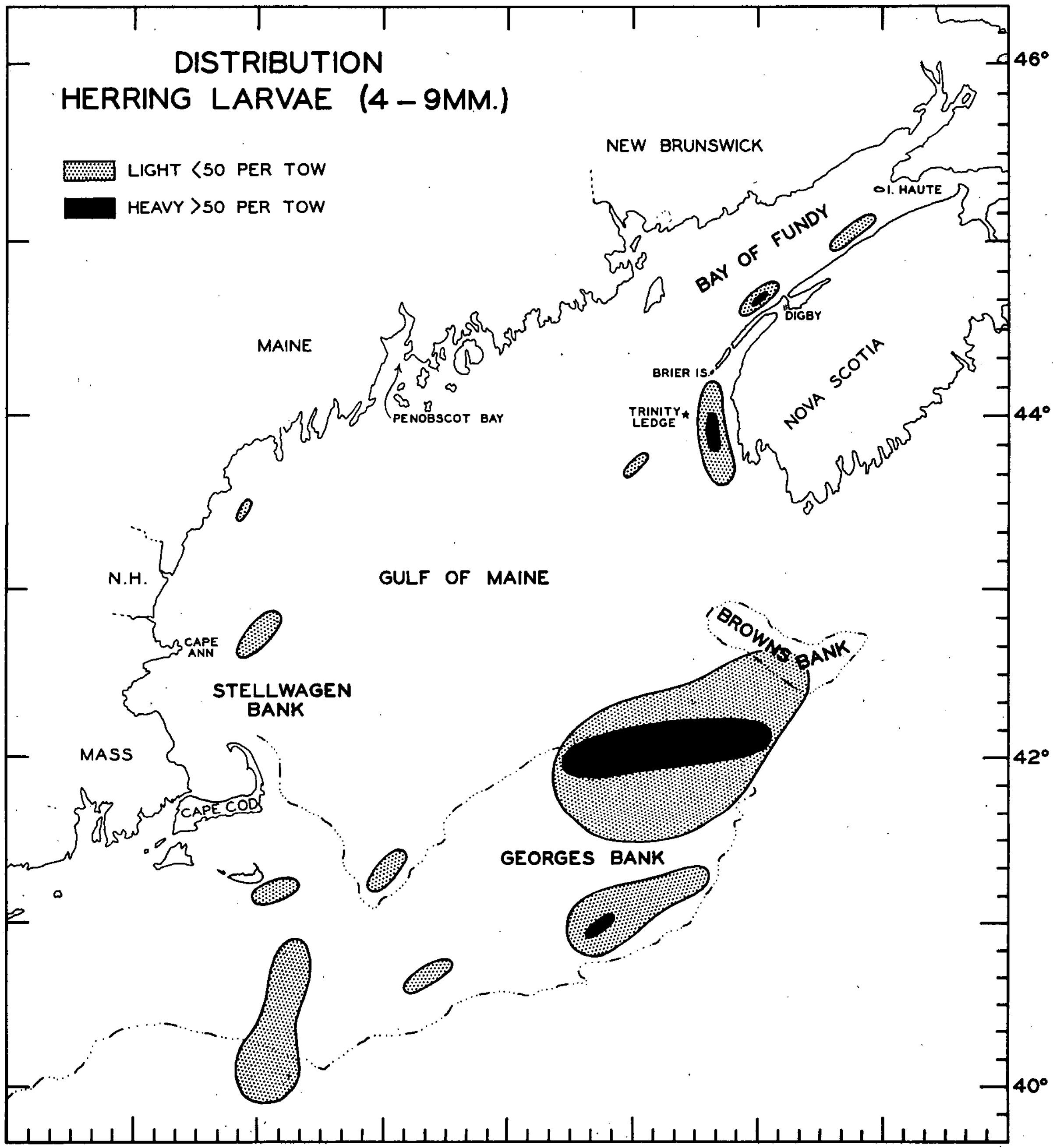

Figure 10. Herring spawning areas in the Bay of Fundy and the Gulf of Maine estimated from the distribution of newly-hatched (4-9 mm) larvae.

Fig. 10 also indicates that herring spawn along the southwest coast of Nova Scotia from the Seal Island group northward along the Nova Scotia coast to Brier Island in the Bay of Fundy. Another spawning area lies just north of Digby and could, presumably, be an extension of the latter area. Depths vary from 3 to 50 fathoms. Temperatures are fairly uniform from top to bottom due to strong tidal mixing. Character of the bottom has not been described.

Other spawning areas are not extensive, but may contribute to the stocks of herring in the region. Although few larvae were taken, there is evidence of small spawnings around Penobscot Bay, Stellwagen Bank, and Nantucket Shoals. Moore (1898), Huntsman (1919), and Bigelow and Schroeder (1953) reported an important spawning in the waters south of Grand Manan. Leim (1958) reported the presence of recently-hatched larvae in the southern Grand Manan area seasonally from 1917 to 1955. It is evident that spawnings occur regularly in this area but not to the same extent as in southwestern Nova Scotia and on Georges Bank.

Spring spawning

McNairn (1933) reported small spring spawnings at the heads of the Bay of Fundy and St. Mary Bay. Fish and Johnson (1937) also reported spring spawnings in the Bay of Fundy region. Bigelow and Schroeder (1953) reported a few instances of spring spawning in the inshore waters of Nova Scotia and New Brunswick. Mr. E. G. Sollows (personal communication) found some larvae in May near Tucket Island and in St. Mary Bay that were almost certainly spawned in the spring. Mr. John B. Colton, Jr. (unpublished data) caught a few small larvae (9-10 mm) on Georges Bank and along the coast of Maine during the spring of 1955 and 1956. Eight spring-spawned larvae were taken in the Passamaquoddy area in Prince tows (unpublished data).

There were few instances of spring-spawned larvae being taken during the course of this investigation. In March 1958, a cruise covering the Grand Manan area, the entrance to the Bay of Fundy and St. Mary Bay showed no newly-hatched larvae. A few of the large larvae caught in September and October 1956, 1957, and October 1958 may have been spawned in late spring or early summer.

It is evident that, for the Gulf of Maine and the Bay of Fundy region, spring spawning is light and much less important than the heavy autumn spawning. Graham (1936) also found that "spring spawning produced no considerable contributions to the herring stock (in the Bay of Fundy area)".

Autumn spawning

Most Fundy herring spawn in summer or autumn (McNairn, 1933). Fish and Johnson (1937) found that herring spawn in the Gulf of Maine in summer and autumn but in the Fundy region both spring and autumn spawning takes place. Bigelow and Schroeder (1953) reported heavy spawnings southwest of Grand Manan, around the Trinity Ledges off southwestern Nova Scotia, and light irregular spawnings along the Maine coast.

Heavy spawnings occurred on Georges Bank and along southwestern Nova Scotia from August to October in 1956, 1957, and 1958. There was no evidence of spawning in November and December of 1956 or 1958, but there were signs of a light spawning in November and December 1957. Whiting fishermen report that "mature herring arrive on Georges Bank in August and hang just off the northern edge until conditions are right, then, moving into the shoal areas, they spawn".

DISCUSSION AND CONCLUSIONS

The data from these investigations have been considered as part of the background information required to satisfy the International Passamaquoddy Fisheries Board reference from International Joint Commission of determining the "effects which the construction, maintenance, and operation of the tidal power structure proposed might have upon the fisheries in the area". (c.f. I.J.C. Docket 72 October 3, 1956.)

In order to predict the effects of theproject on the distribution and abundance of herring larvae, it is necessary to know something of the anticipated environmental conditions after the dams are built. Hydrographic conditions of temperatures, salinity, and currents in the Bay of Fundy are expected to remain relatively unchanged except in the immediate vicinity of the dams and in the high- and low-level pools and hence the production and distribution of larvae outside the Quoddy Region should not be affected.

There is no evidence that herring spawn inside Passamaquoddy or Cobscook Bays or to any great extent immediately outside these areas. While summer temperatures in these bays will increase and the water masses become more stable there seems to be no reason to expect that these areas will become major spawning grounds for herring.

Large herring larvae (40-60 mm) are frequently found in large numbers inside Passamaquoddy and Cobscook Bays. Fishermen consider this to be normal for the late spring and early summer months each year and it is confirmed by occasional sonic-sounder surveys and special fishing experiments. In July 1958, for example, large numbers of larvae were taken along the Mascarene shore. In June 1959, echo-sounder recordings indicated a widespread distribution throughout Passamaquoddy Bay and samples were obtained from the Bocabec and Navy Island areas.

Presumably, these larvae were brought into the bay as plankton. Assuming that this occurs regularly the proposed structures at the entrances to Passamaquoddy Bay might tend to delay such an immigration but would not, necessarily, prevent it since the filling gates will be opened regularly during each tide.

It is possible to establish a general pattern of movements of herring larvae from spawning grounds on the basis of known non-tidal surface currents. Day (1958) found that current patterns on Georges Bank shift with seasons and prevailing winds. Assuming that currents are important means of distributing larvae, we can speculate on their movements. On the basis of Day's current patterns some larvae from Georges Bank spawnings may be carried northward towards the Nova Scotia coast and into the Bay of Fundy but the great majority are carried southward and away from the Bay of Fundy. Hence, Georges Bank spawnings probably contribute little to the sardine fisheries in the Passamaquoddy area. In the Bay of Fundy, surface water movement is somewhat more complex, but usually, it is counter-clockwise moving into the bay along the southwest coast of Nova Scotia, and outward along the coast of New Brunswick and Maine. The most likely source of sardines in southern New Brunswick and eastern Maine appears to be the spawnings of southwest Nova Scotia.

SUMMARY

1. Investigations to discover the breeding grounds, nursery areas, survival, growth and methods of transport of the larvae of herring that populate the Passamaquoddy area of New Brunswick and Maine were initiated jointly in 1956 by the Fisheries Research Board of Canada and the United States Bureau of Commercial Fisheries.

2. Offshore cruises with plankton nets and Hardy continuous plankton recorders were carried out in the Bay of Fundy and the Gulf of Maine from September through February 1956-57, 1957-58, and 1958-59,

3. Of the 65,475 larvae examined, 64,859 larvae were taken in 1-metre net hauls and 223 in plankton recorders. In addition, 40 larvae from Prince station tows and 353 from T. N. Gill cruises were available for study.

4. Largest numbers of larvae were taken in September and October of each year. Catches decreased sharply in November and were small in January and February.

5. Larvae were abundant only in the Bay of Fundy and on Georges Bank. Small numbers were taken occasionally throughout most of the survey area.

6. Newly-hatched larvae (4 to 9 mm) were found chiefly in September and October. In some seasons, hatching may extend well into November and possibly into December. Growth is slow and larvae presumably from September and October hatchings, are found in February.

7. During the period September to February, the growth rate of herring larvae on Georges Bank is faster than for southwest Nova Scotia larvae.

8. About 78% of all larvae in plankton nets were taken at night. The difference between day and night catches was more pronounced for large larvae (20 to 50 mm).

9. The largest spawning area in the Gulf of Maine is on the northern edge of Georges Bank. Large spawnings occur off the Nova Scotia coast from Trinity Ledges to Digby. Small spawnings occur in Penobscot Bay, Stellwagen Bank, Nantucket Shoals, and south of Grand Manan. No spawning was detected in Passamaquoddy Bay.

10. Late summer and autumn spawnings are undoubtedly the major contributors to the herring stocks in the Bay of Fundy and Gulf of Maine. Spring spawnings are of only minor importance.

11. The more likely source of herring in the Quoddy Region are the spawnings of southwest Nova Scotia. Georges Bank spawnings presumably contribute little to these fisheries.

12. No changes in the location or extent of the spawning grounds are anticipated if the proposed Passamaquoddy tidal power dams are built.

ACKNOWLEDGMENTS

The authors wish to extend their thanks and appreciation to the masters and crew members of the various vessels and to technical staffs from both St. Andrews and Boothbay Harbor laboratories for assistance in the collection of data. We are especially grateful to Mr. K. A. Smith, Chief, Maine Herring Exploration and Gear Research, for providing data from the T. N. Gill cruises 1955-56 and to Mr. John B. Colton, Jr., United States Bureau of Commercial Fisheries, Woods Hole, Massachusetts, for providing data from the Albatross III cruises 1953-56. Mrs. Ruth V. Cating and Mr. George B. Vaughan of the Boothbay Harbor laboratory and Mrs. Delphine C. Maclellan of the St. Andrews laboratory, assisted materially in the examination of plankton tows and measurements of herring larvae.

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PASSAMAQUODDY HERRING CATCHES IN RELATION TO THE ENVIRONMENT

by

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ABSTRACT

Exploratory-fishing operations were successful in confirming the presence of a large spawning population of herring on the northern edge of Georges Bank. Sonic-sounder cruises showed that in general the largest concentrations of herring in the Quoddy Region were in the open waters where there are no weirs. It was impossible to establish any consistent correlation between herring landings in the Quoddy Region and various meteorological, biological, and oceanographical factors.

INTRODUCTION

A study of herring landings in the Passamaquoddy area shows that year-by-year there is great variation in the availability, and possibly in the abundance of herring.

Exploratory fishing was carried on during 1957 and 1958 in the Quoddy Region, on Georges Bank, in Kennebecasis and Long Reach, and in inshore waters of Maine, to provide additional information on the movements of herring, to supplement the shore sampling program, and to locate schools or populations of herring that were not subjected to commercial exploitation. The investigations in the Kennebecasis and Long Reach areas of the Saint John River were conducted because some of the physical characteristics of that region might be similar to those in Passamaquoddy Bay if power dams were installed. The species of fish taken in the Kennebecasis and Long Reach areas were the same as those common to the Quoddy Region (Appendix I, Chapter 5). The United States Bureau of Commercial Fisheries conducted experiments off Maine (Appendix III, Chapter 5). The exploratory-fishing project was carried out with various kinds of fishing gear and with electronic-detection equipment.

Correlation studies were undertaken because an understanding of the changes associated with the fluctuations in catch might assist materially in predicting changes resulting from the installation of the proposed dams. Comparisons were made between seasonal and yearly yields of sardines in the Quoddy Region and various environmental factors such as rainfall, river discharge, air and water temperatures, salinities at various depths, wind speed and direction, sunshine and cloud-cover. Catches were also compared with the abundance and distribution of the planktonic forms which make up the food of herring in the area.

MATERIALS AND METHODS

The commercial herring fishery in and around Passamaquoddy Bay is carried on chiefly with weirs that are built out from the shore. Stop or drag seining and some purse seining is done but these too are usually within short distances of the shore.

In an attempt to learn something of the distribution, abundance, and movements of herring in the open waters of Passamaquoddy Bay and adjacent areas special fishing experiments were carried out. These involved the use of Dutch herring trawls inside the Western entrance to Passamaquoddy Bay; curtain gill nets, graduated-mesh gill nets and mid-water trawls at various points in the Bay; and gill nets, Isaacs-Kidd trawls, Dutch herring trawls and Larsson trawls in the Passages.

Four autumn (1955 to 1958 inclusive) and one winter (1958) cruise were carried out on the northern edge of Georges Bank to locate spawning areas and populations of herring now not exploited commercially. Fishing was done with Dutch herring trawls and gill nets.

The Kennebecasis and Long Reach investigations involved four seasonal cruises in 1957 and 1958 during which gill nets of various kinds, line trawls, and Dutch herring trawls were used.

In developing the Passamaquoddy program one of the questions raised was "are there any correlations between seasonal or yearly yields of herring and various environmental factors such as rainfall, sunshine and water temperatures?". It seemed worthwhile to search for such relationships although it was realized that there was probably no simple answer to the question and that the distribution and abundance of herring were almost certainly the result of the interaction of a great many physical and biological factors.

Comparisons were made between seasonal and annual discharge from the St. Croix and Magaguadavic Rivers and herring landings in Passamaquoddy Bay in the same year and in one, and two years later. Similar studies were made of discharge from the Saint John River and catches in various parts of Charlotte County. A search was made for possible relationships between water temperatures at Prince Stations 5 and 6 (Fig. 1) and catches in all 4 statistical districts of Charlotte County.

Abnormally high- and low-catch years were compared with precipitation, river discharge, salinities and water temperatures, sunshine, cloud-cover, wind speed and direction. Quantities of plankton collected monthly at Prince 5 and 6 from 1947 to 1956 were also compared with the herring catches in the various parts of the area.

RESULTS OF INVESTIGATIONS

Gear experiments

In attempting to locate stocks of herring that were not being fished commercially, sonic sounders and various kinds of fishing gear were used in Passamaquoddy Bay and its approaches, and several cruises were made to areas as far distant as Kennebecasis Bay and the northern edge of Georges Bank.

Gill nets: In August 1957 curtain gill nets and graduated-mesh gill nets were fished in Passamaquoddy Bay and small numbers of herring (maximum 23) were taken. In the Passages at the mouth of the Bay it was impossible to anchor gill nets. Gill netting in the Kennebecasis area, with some of the nets 50 feet deep, showed herring to be evenly distributed from top to bottom.

Bottom trawls: Bottom-trawl fishing with Dutch herring trawls on the northern edge of Georges Bank in 1955 gave evidence of a large spawning population of herring in that area during late August and early September. Mature fish, some of them in the ripe and running stage, were taken in quantities of 2,000 to 5,000 pounds per tow at depths of 60 to 90 fathoms. Smaller but substantial quantities were taken in the same area in mid August, 1956. A cruise to Georges Bank in 1957 confirmed the presence and abundance of spawning herring in the area. The largest catch for a single tow was estimated at 17,000 pounds. In October 1958 moderate catches of herring were taken in the same region. In January 1958 thirteen tows with a standard # 41 groundfish trawl (with a small-mesh cod end) on the northern edge of Georges Bank yielded average catches of about 150 pounds. Some herring were taken in every tow during this cruise but the maximum quantity was only 350 pounds. These herring were large, mature fish that had recovered from spawning, presumably during the previous autumn.

Dutch herring trawls were used in May 1957 inside the western entrance to Passamaquoddy Bay and catches of 50 to 70 pounds of herring and smaller quantities of other species were made. In 1958, unsuccessful attempts were made to recapture herring that had been branded and released a short time before in Letite Passage. Dutch herring trawls were also used in the Kennebecasis area in both 1957 and 1958. Small catches of herring and other species were taken there in both years.

Larsson trawls: Throughout October 1957 a Larsson trawl was used in and around Passamaquoddy Bay but no fish were caught despite indications of their presence on echo sounders. These trawls were also used unsuccessfully in the Passages at the mouth of the Bay in 1958.

Isaacs-Kidd trawls: A modified trawl of this type with a 5 foot opening was operated in 1958 in the Passages at the mouth of Passamaquoddy Bay but no fish were caught. A similar type of mid-water trawl with an opening 16 feet square was tested in Passamaquoddy Bay at various times in 1958 without success.

Sonic-sounder surveys:

Sonic-sounder surveys were carried out frequently in Passamaquoddy Bay and occasionally in other areas of the Bay of Fundy and the Gulf of Maine.

In 1956, weekly cruises were made in Passamaquoddy Bay from May to August and on Georges Bank in September and October. In 1957, because of equipment failures and shortage of vessels, sonic-sounder cruises were made only in October, and only in Passamaquoddy Bay. In 1958, cruises were made weekly throughout most of the year with special attention given to the summer and early autumn months when the herring fishery in Passamaquoddy Bay was most active. The results of these cruises showed that, in general, the largest concentrations of herring were in the open areas away from the small coves and inlets where the majority of weirs are located. Large quantities (at least 2,250,000 pounds) of herring were taken by commercial purse seiners in the centre of Passamaquoddy Bay in September, the only period in 1958 that they operated there.

Figure 2 illustrates the distribution of herring schools in Passamaquoddy Bay during the period May to August. In May, the fish were not as abundant as in the other months and tended to be closer to shore. Only in May were there any substantial quantities of herring located in the St. Croix estuary. Herring were most abundant in June and July and were found throughout most of the open waters in the central and northeast part of Passamaquoddy Bay. In August the distribution was similar to June and July but the quantities located were smaller.

Environmental factors

Comparisons of herring landings in the various statistical districts with temperatures (air and water), rainfall, river discharge, wind speed and direction, sunshine and cloud-cover showed that little if any relationship exists between such factors and the abundance, distribution or movements of herring in the Quoddy Region. For example, there was no apparent relationship between river discharge and catch per weir in the same year, and one and two years later. Unusual catch years (both high and low) compared with river discharge, salinities and cloud-cover, showed no significant correlation. Significant correlation was demonstrated between the catch in some districts and the overall abundance of plankton in the area, but in only 2 of the 10-year period from 1947 to 1956.

More than two hundred comparisons were made altogether but it was impossible to establish any consistent correlation between catch and physical conditions.

SUMMARY AND CONCLUSIONS

Exploratory fishing was successful in establishing the presence of a large spawning population of herring on the northern edge of Georges Bank in autumn. This spawning is a probable source of the young herring which populate the Passamaquoddy area.

Exploratory fishing was not successful in locating large bodies of herring in the Kennebecasis, nor in taking sardines in quantity at mid-depths in the Quoddy Region.

The correlation studies were unsuccessful in establishing significant relationships between catch and physical conditions over long periods of time. An overall appraisal suggests that while the abundance of herring may be related to the physical conditions of the environment, there is no apparent relationship between physical conditions and seasonal and annual catches in the Quoddy Region. It is probable too that there is little or no relationship between abundance and catch in the Quoddy Region. Perhaps this is not surprising in view of an extremely variable market demand and the fact that the weirs and stop or drag seines operate only on the fringes of the area of herring distribution.

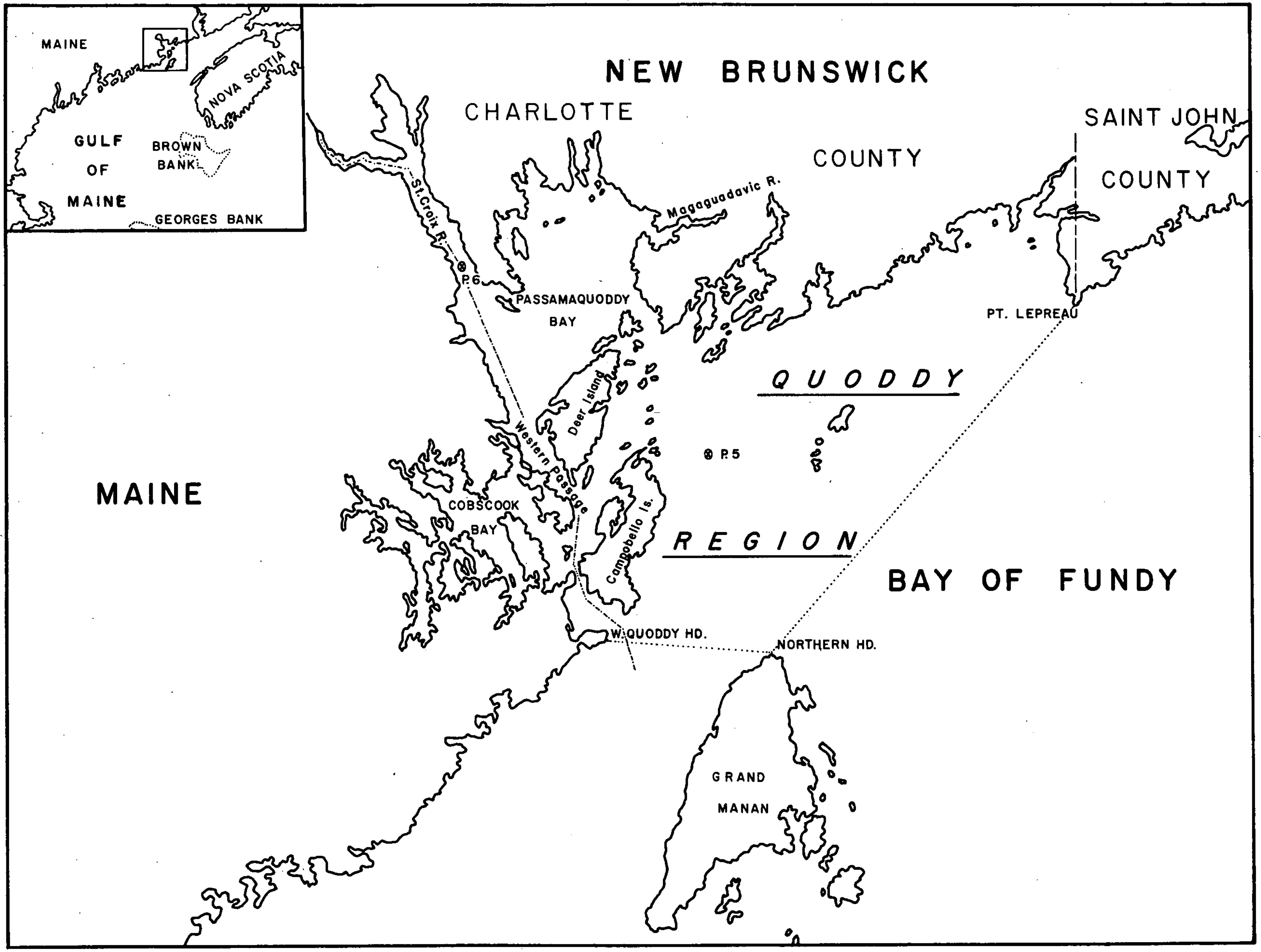

Figure 1.

Map of the Passamaquoddy region showing principal places mentioned. (Charlotte County, N. B. includes Grand Manan.)

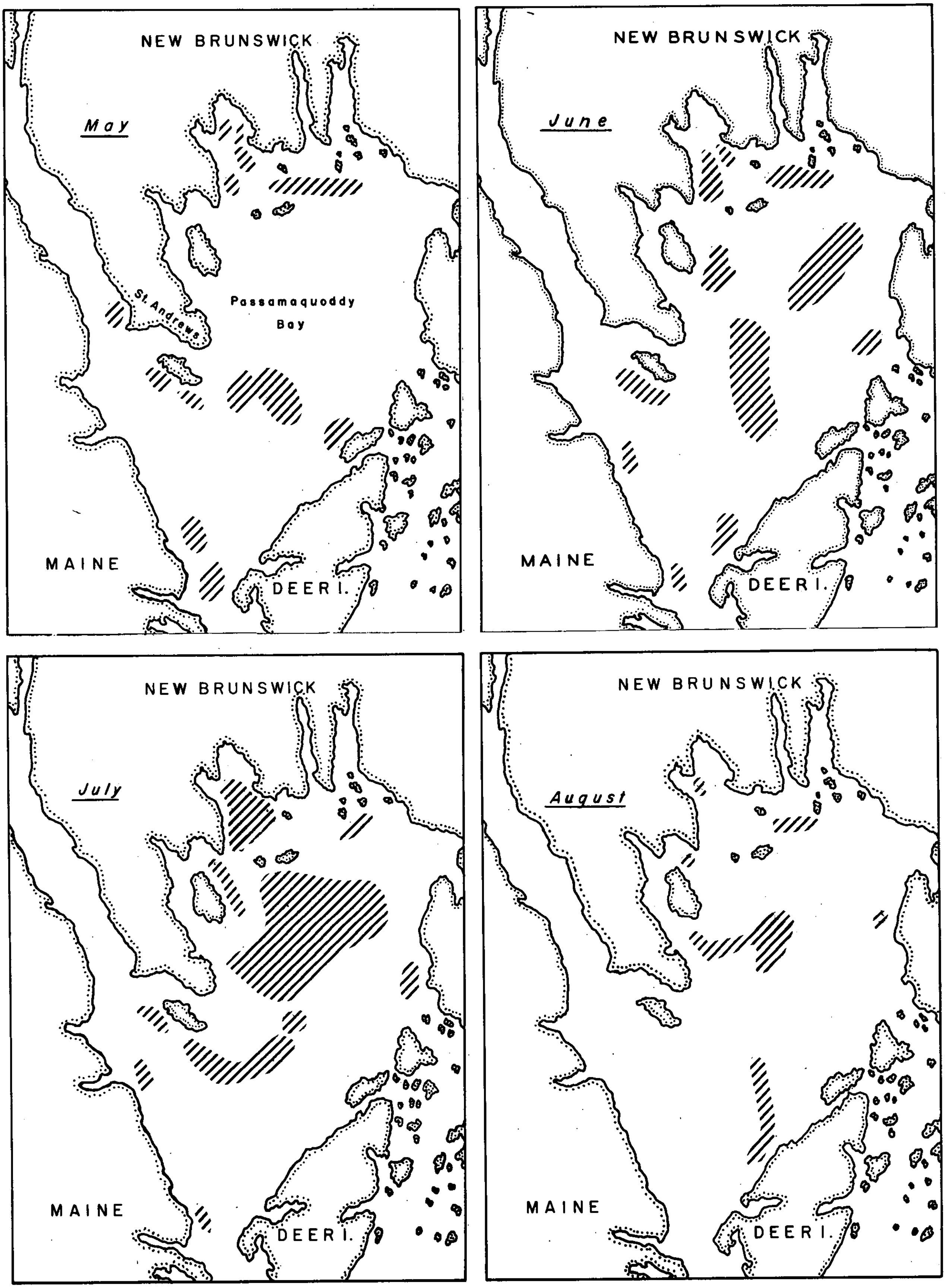

Figure 2. Maps showing the location of herring schools in Passamaquoddy Bay during May to August inclusive, as determined from sonic-sounder recordings.

PREDICTED EFFECTS OF PROPOSED TIDAL POWER STRUCTURES ON GROUNDFISH CATCHES IN CHARLOTTE COUNTY, N. B., CANADA

by

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INTRODUCTION

The groundfish fishery of Charlotte County, New Brunswick, Canada, has been examined as a basis for prediction of the effect of the proposed Passamaquoddy power project on landings of groundfish species.

LANDINGS

The commercially important groundfish species have been pollock, Pollachius virens (L.), haddock, Melanogrammus aeglefinus (L.), cod, Gadus callarias L., hake, Urophycis tenuis (Mitch.), flounders, mainly the winter flounder, Pseudopleuronectes americanus (Walb.), and redfish, Sebastes marinus (L.).

Annual Charlotte County landings and landed values of these species are summarized in the table. The statistics have been averaged by 5-year periods for the years 1937-1956. Landings of pollock, haddock, cod, and hake have been converted from gutted weights, as normally recorded in Canadian statistics, to round weights by using a conversion factor of 1.2. In 1958 groundfish landings exceeded 14 million pounds with a landed value of 380 thousand dollars. Pollock has always been the dominant species by weight, but haddock brings a better price and in some years total landed value exceeds that of pollock.

Although changes in the abundance of groundfish species have had some effect on landings, the major fluctuations are related to changes in methods of capture and in marketing conditions. For example, the decreasing importance of cod and the increased landings of haddock have been caused by increasing water temperatures, but also by the conversion from line fishing to otter trawling, and the conversion from salt-fish to fresh- and frozen-fish marketing since World War II.

Landings for the year 1958 are described in Figure 1. Groundfish landings in statistical district 52, inside the dam sites, are of very little importance. The major species is haddock, and present landings are largely taken by one small dragger. Landings in District 51, Campobello and West Isles, make up a substantial proportion of the Charlotte County groundfish catch. Otter trawlers land some haddock and flounders, but most of the catch is still taken by line-fishing methods. Landings in District 53, Eastern Charlotte County, have become increasingly important with the opening, in 1958, of a fish plant at Beaver Harbour for fresh and frozen groundfish. Most of the fish are landed by 60-foot draggers. Although most of these draggers are based at Grand Manan, District 50, marketing facilities there are limited, and groundfish landings are mainly hook-and-line catches of pollock for salting.

Charlotte County groundfish landings and landed values

Landings--thousands pounds round weight

Species	1937-41 Average	1942-46 Average	1947-51 Average	1952-56 Average	1957	1958
Pollock	4,798	3,098	3,920	6,581	6,539	7,980
Haddock	1,108	964	1,328	2,656	1,945	3,000
Cod	2,224	1,570	1,871	1,719	1,210	1,677
Hake	1,778	536	1,006	3,002	1,571	1,284
Flounders					205	266
Redfish			3	37		3
Total	9,907	6,168	8,128	13,994	11,472	14,241

Landed value--hundreds dollars

Species	1937-41 Average	1942-46 Average	1947-51 Average	1952-56 Average	1957	1958
Pollock	203	837	549	1,026	1,505	1,404
Haddock	186	458	658	1,096	955	1,588
Cod	194	481	437	451	315	467
Hake	72	117	154	487	287	242
Flounders					74	91
Redfish			1	6		8
Total	655	1,894	1,799	3,066	3,136	3,801

Since World War II purse seines, otter trawls, Norwegian jigs, and new methods of trolling have been introduced to the pollock fishery. Purse seines are used to catch small (harbour) pollock, mainly in the months of January to April. Otter trawls and lures take their best catches of large pollock during summer months.

CATCHES

The distribution of groundfish landings is related to the areas in which the catches are made, and to the location of suitable wharves and fish buyers. Long-term statistics of groundfish catches by area fished are not available, but a survey was made for the year 1958 to assess current catches from high pool, low pool, outside the dams, and from the Grand Manan area. The results are summarized in Figure 2.

The 1958 groundfish catch in the high-pool area was about 200 thousand pounds, and about 150 thousand pounds of this was haddock. The haddock catch represented part of the total annual landings of one dragger fishing on Perry Shore, Hardwood Island, Macmaster Island, and Clam Cove Head fishing grounds. Catches of cod, pollock, and winter flounder amounted to only about 20 thousand pounds each.

The groundfish catch from the low-pool area has been very small, except for an annual pollock catch of about 1.5 million pounds. These pollock are caught by small-boat, line fishermen in the Green Island Shoal area of Head Harbour Passage, just inside a proposed dam site.

The 1958 catch of groundfish from grounds just outside the dam sites was about 4 million pounds. Significant catches of pollock, haddock, cod, hake, and flounders were taken from Beaver Harbour, Wolves, Head Harbour, White Horse Island, Grand Manan Channel, and below Quoddy Head fishing grounds. Most of the catch was taken by line fishing, but important catches were also taken by seine net and by otter trawl.

The catch of groundfish from the Grand Manan area was about 8 million pounds in 1958. Pollock was the main species, but good catches of haddock and cod were also taken. Otter trawlers take most of the groundfish from inshore Gravelly and Soundings grounds and from offshore Grand Manan Bank. Line fishermen take their smaller share of the groundfish catch from inshore grounds.

PREDICTED EFFECTS OF POWER STRUCTURES

About 90% of the Charlotte County groundfish landings are caught outside the proposed Passamaquoddy dam sites. There is no reason to believe that this part of the catch would be measurably affected by construction of power dams. Fishing grounds immediately outside the dam sites might be altered, but the total catch should not be affected.

About 200 thousand pounds of groundfish, or about 1 1/2 % of the County groundfish catch, are now taken annually from the high-pool area. Three quarters of this catch is haddock. These haddock move in and out of Passamaquoddy Bay each year, as part of a New England stock (Appendix II, Chapter 8). The proposed dams are likely to reduce or even eliminate this annual migration in and out of the high-pool area. Since the haddock fishery inside the Bay is marginal now, with one dragger taking most of the annual catch, it is expected that the small, high-pool haddock fishery would be virtually eliminated with the construction of dams. The cod, pollock, and flounder fisheries of this area are very small, and it is anticipated that the total catch of these species will not change appreciably if dams are built. It has been pointed out (Appendix II, Chapter 9) that conditions will be more favourable for the winter flounder fishery.

The low-pool fishery for pollock would be greatly reduced by construction of power dams. The annual catch of about 1 1/2 million pounds of pollock from the Green Island Shoal area of Head Harbour Passage depends on a concentration of fish which are feeding on the shoals and in the eddies of this area. Although this local pollock fishery is expected to decrease, part of it will simply shift to other feeding grounds within the same general area.

SUMMARY

It is predicted that the construction of power structures will have no measurable effect on Charlotte County groundfish landings as a whole. It is expected that the 1.7 million pounds, or 12% of the Charlotte County groundfish catch, taken in 1958 inside the dam sites, will be greatly reduced. Specifically, it is forecast that the pollock line fishery in Head Harbour Passage, which yielded 1.5 million pounds in 1958, will be greatly reduced, the haddock dragger fishery will be reduced or eliminated in the high pool, and the flounder fishery in Passamaquoddy and Cobscook Bays will probably increase.

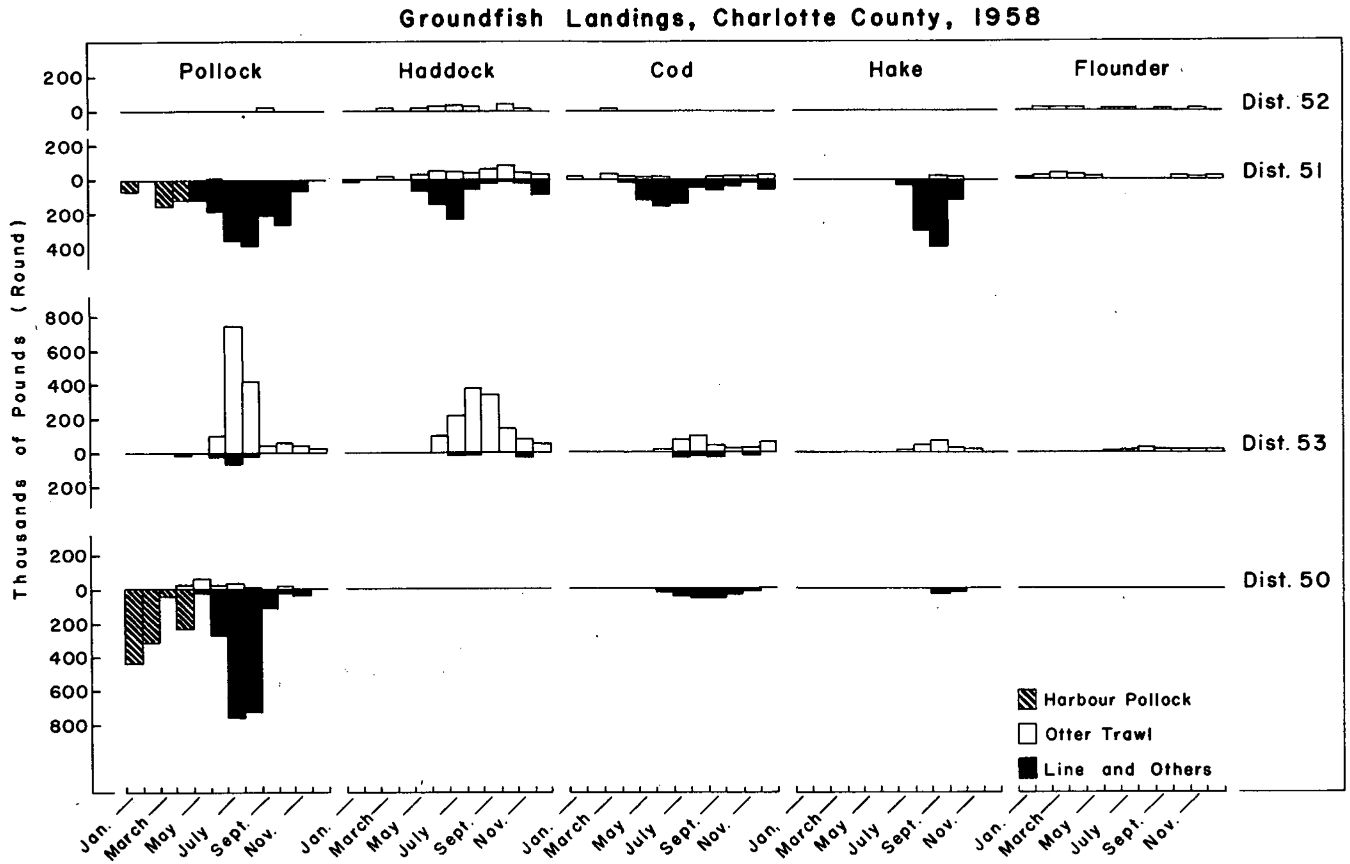

Figure 1. Monthly landings for the year 1958 of groundfish (pollock, haddock, cod, hake, and flounders) in Charlotte County, New Brunswick (Statistical Districts 50 to 53) by gear fished.

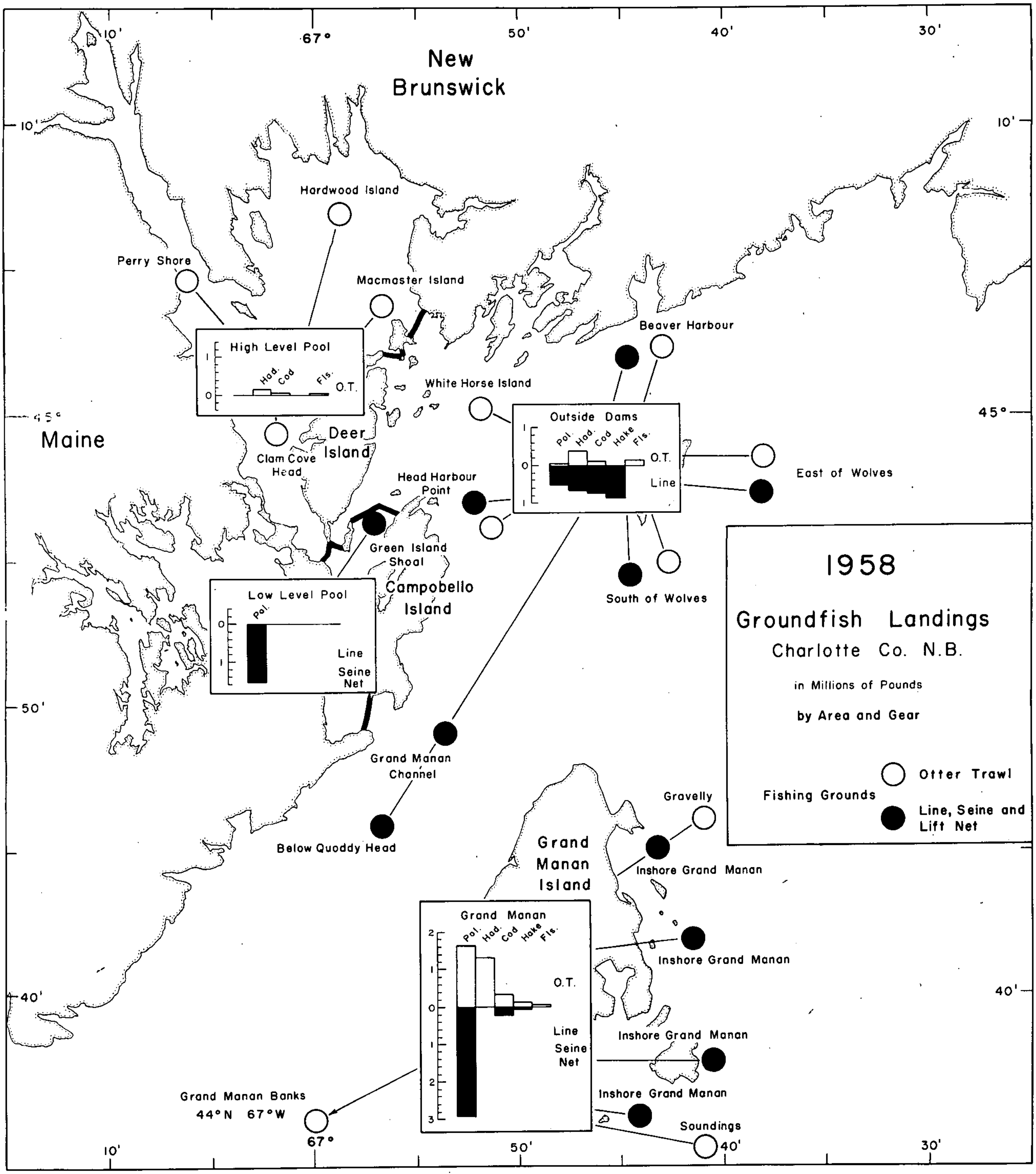

Figure 2. Landings for the year 1958 of groundfish (pollock, haddock, cod, hake, and flounders) in Charlotte County, New Brunswick, by area (high pool, low pool, outside dams, and Grand Manan) and by gear fished (otter trawl, line, seine, and lift net).

CANADIAN STUDIES OF HADDOCK IN THE PASSAMAQUODDY BAY REGION

by

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INTRODUCTION

Accounts of brief studies of the life-history of haddock, Melanogrammus aeglefinus (L.), of Passamaquoddy Bay have been presented by Huntsman and Needler (1927) and Needler (1929, 1930). More recent haddock studies there have included sampling of Canadian landings for sizes, fishing for haddock with small-mesh nets, and haddock tagging. The results of these studies form a basis for prediction of the effects of proposed power structures on stocks of haddock in the vicinity of Passamaquoddy Bay.

RELATIONSHIP OF STOCKS

Sizes

Within and immediately outside Passamaquoddy Bay the fishery for haddock is seasonal in nature. Landings are greatest from May to December and much reduced from January to April (Appendix II, Chapter 7). Sampling of the haddock stocks which have produced these landings has been carried out since 1954. Length distribution of haddock catches and landings from Passamaquoddy Bay during the autumn, October to December, for the period 1948-57 is shown in Figure 1, Panel A. Catches from 1954-57 were made by a research vessel using an otter trawl with 40-foot headrope and codend covered with a 1 1/2-inch stretched mesh cover. They include haddock smaller than those normally landed. The length distribution of haddock in commercial landings for 1957 is shown in Figure 1, Panel B.

Scrod haddock, 40-50 cm and about 1 1/2-2 1/2 pounds, predominated in the research vessel catches. Virtually no fish below 30 cm in length were taken, but in 1955 and 1956 haddock around 30 cm in length were more numerous than in other years (Fig. 1). Only a few large haddock over 50 cm were taken in any year between 1954 and 1957.

A comparison of modal sizes suggests the progress of particular year-classes through the fishery. In 1954 haddock catches had a mode between 38 and 42 cm; in 1955 the mode was between 44 and 48 cm. Similarly, the group of fish around 30 cm in 1955 probably corresponded with the group around 38 to 42 cm in 1956.

Commercial vessels landed haddock down to about 35 cm but most fish were between 40 and 50 cm. Only a few larger fish (over 50 cm) were landed. The scarcity of larger fish was also recorded by Needler (1930) who concluded that haddock 5 years of age and over were seldom found in Passamaquoddy Bay.

Tagging

In November and December 1957, 1,085 haddock caught by otter trawl were tagged near the mouth of the Bay of Fundy. Of these, 508 were tagged and released in Passamaquoddy Bay, 507 in Grand Manan Channel, and 70 off Digby Neck on the eastern side of the Bay of Fundy. All were tagged with yellow Petersen disk tags, attached to the back of the fish by stainless steel wire.

The distribution of recaptures from these tagged fish is shown in Figure 2. In November and December, immediately following tagging, haddock were recaptured close to the tagging region. Later in the "winter", December to May 1957-58 (Fig. 1) haddock tagged in Passamaquoddy Bay and Grand Manan Channel were widely distributed. Most "winter" recaptures came from the Gulf of Maine off Portland and Gloucester, in the vicinity of Jeffreys Ledge. An additional group of recaptures came from off the northwest edge of Georges Bank. In both these regions the majority of recaptures were made during February to April. About 15% of the distant recaptures of haddock tagged on the New Brunswick side of the Bay of Fundy were retaken during the winter of 1957-58 off southwestern Nova Scotia around Digby Neck and Browns Bank.

While only a few fish were tagged off Digby Neck, the returns complement the results from Passamaquoddy Bay tagging. Most of the Digby Neck tagged haddock recaptured during the following winter were taken around BrownsBank, but two fish were recaptured at Jeffreys Ledge off Gloucester, Mass.

In the "summer" following tagging, June to November 1958, most recaptures from haddock tagged on the western side of the Bay of Fundy were retaken in Passamaquoddy Bay. Only a few were retaken outside the Islands around the entrances to the Bay. Distant recaptures in "summer" included three from Georges Bank, one off Cape Cod, two off Portland, four within the Bay of Fundy, and one off St. Margaret Bay.

While tagged fish recaptures were considerably reduced in numbers during the second "winter" season (December to May 1958-59), the pattern of distribution of recaptures was only slightly changed. In December 1958, recaptures were greatest just outside the entrances to

Passamaquoddy Bay, while later in the winter most recaptures were from New England and off Nova Scotia. The proportion of distant recaptures retaken off Nova Scotia in the second winter was much higher than in the first winter, 40% and 15%, respectively.

Conclusion

The evidence shows that Passamaquoddy Bay haddock are not produced by local spawning since (1) the spawning season, March-April, corresponds with their southern migration and reduced abundance in the Bay, and (2) few small fish, under 30 cm, were taken within the Bay.

The combined evidence of tagging results, timing of commercial landings, and size compositions of haddock is interpreted to mean that haddock stocks within Passamaquoddy Bay are recruited each spring during a northward migration of fish along the coast of the Gulf of Maine and Bay of Fundy. Throughout the period studied, these recruits have been most important to the fishery as fish of scrod size, 40-50 cm in length. These fish summer within the Bay but leave in early winter to intermingle with haddock stocks in the Gulf of Maine. In addition, some fish cross the Bay of Fundy, and mix with haddock stocks off southwestern Nova Scotia.

FORECAST OF EFFECTS OF POWER STRUCTURES

From the statistics of landings in 1958 (Appendix II, Chapter 7) it appears that the principal haddock stocks in the Charlotte County region are outside the proposed high and low pools. There is no evidence to suggest that these stocks would be materially affected by the construction of power dams.

Hydrographic conditions predicted within the high pool after construction of the power structures are not expected to be lethal for haddock. Thus, the crucial questions appear to be whether or not haddock would continue to move into the high pool, or, if not, whether an adequate resident population might develop. There does not seem to be a clearcut answer to these questions. Presumably haddock will still be physically able to move into the high pool. However, in other areas of lowered salinity with narrow passages, such as Bras d'Or Lakes in Cape Breton, haddock are not present even though cod and flatfish are found. It also seems unlikely that the expected changes would influence haddock to begin extensive spawning within the high pool. It seems probable that haddock stocks within the high pool would be seriously reduced if not virtually eliminated.

SUMMARY

From 1954 to 1957 haddock within Passamaquoddy Bay have been of intermediate sizes. Few small fish or large fish have been captured either by commercial fishermen or in small-mesh research nets. Tagged fish of the Passamaquoddy Bay region moved out of the Bay during winter and mingled mainly with haddock stocks off the New England States. In the following summer recaptures of tagged fish were again most numerous within Passamaquoddy Bay. Stocks of haddock within the Bay appear to result from annual migrations into the Bay in early summer.

It is predicted that the proposed power structures would have no effect on haddock stocks outside the high and low pools but that they would probably seriously reduce the haddock population within the high pool.

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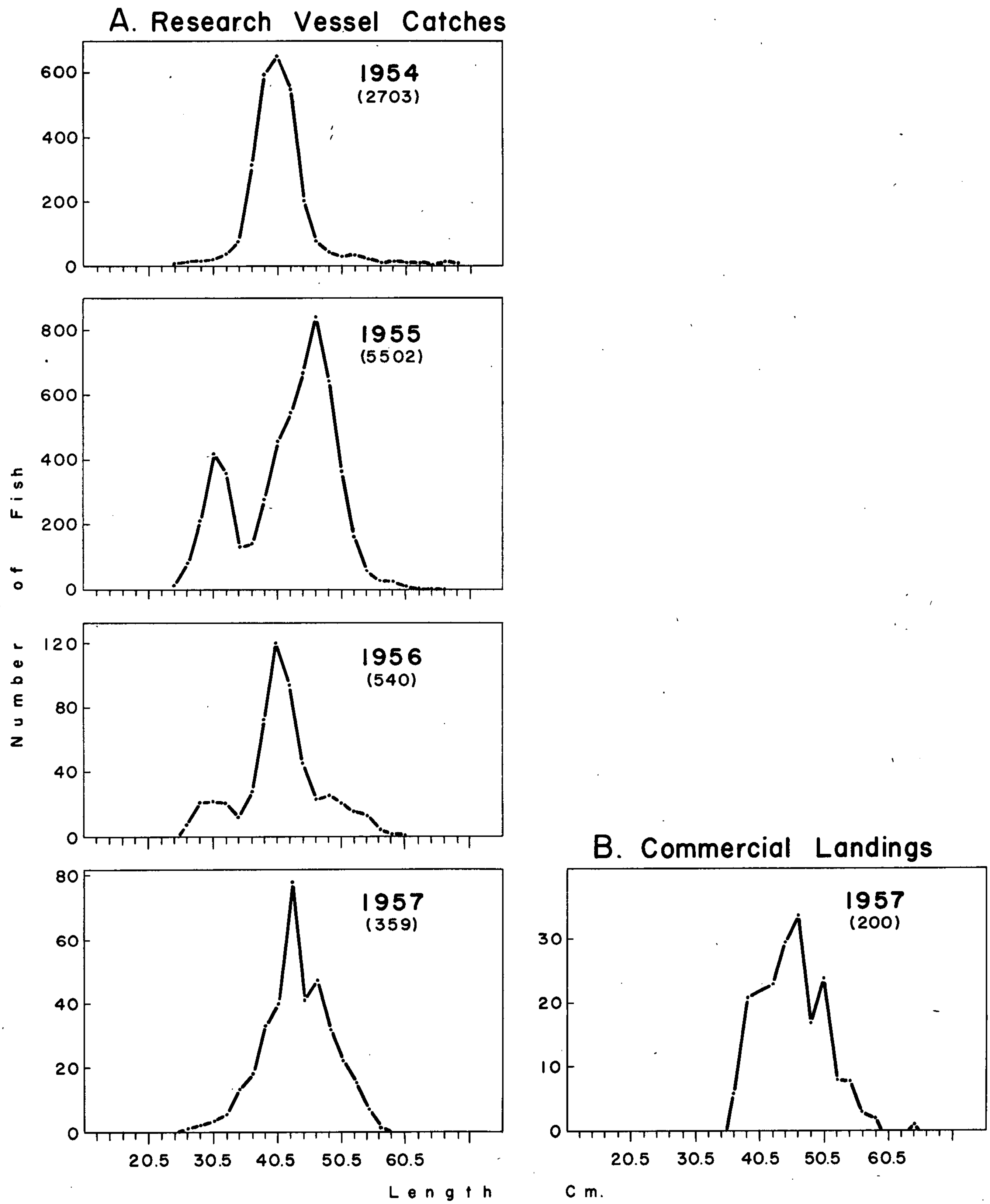
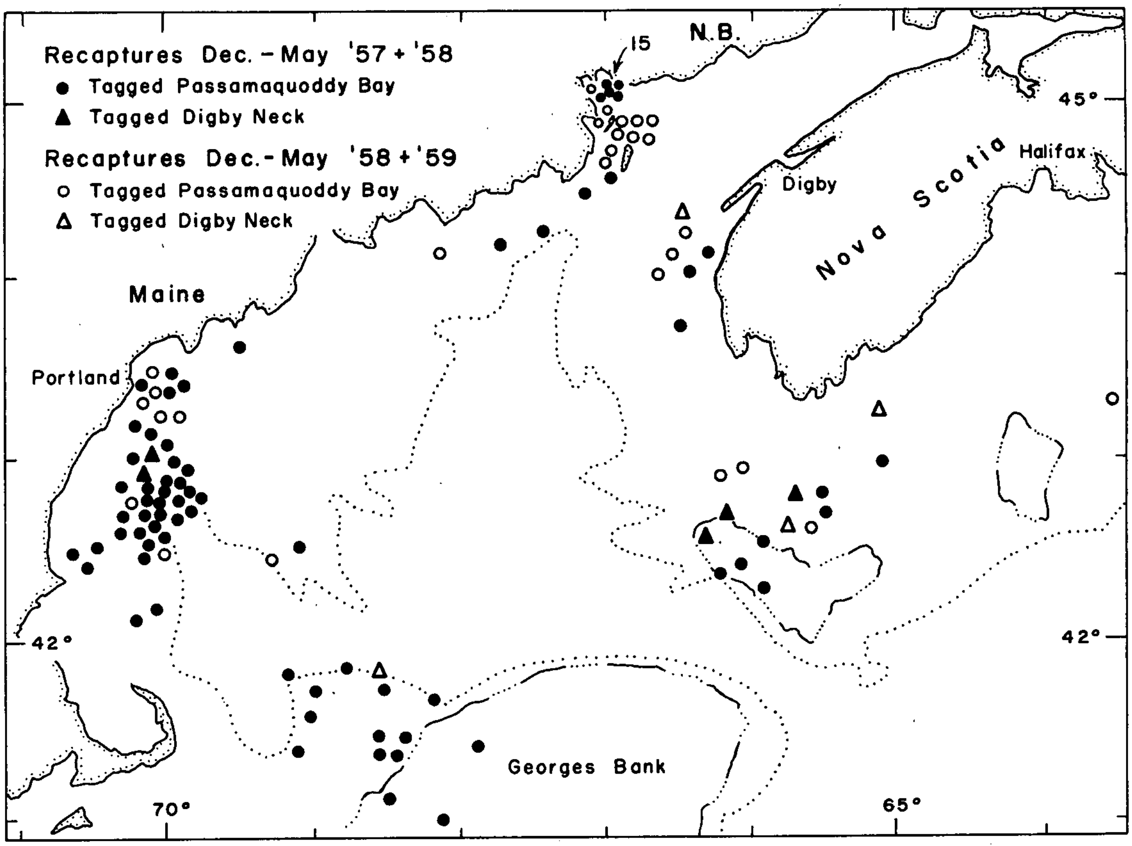


Figure 1. Size composition of haddock from Passamaquoddy Bay during autumn, October to December

A. Catches by research vessel with a 1-1/2-inch stretched mesh codend cover, 1954 through 1957.

B. Landings by commercial trawler, 1957.

Recaptures During "Winter" Season



Recaptures During "Summer" Season

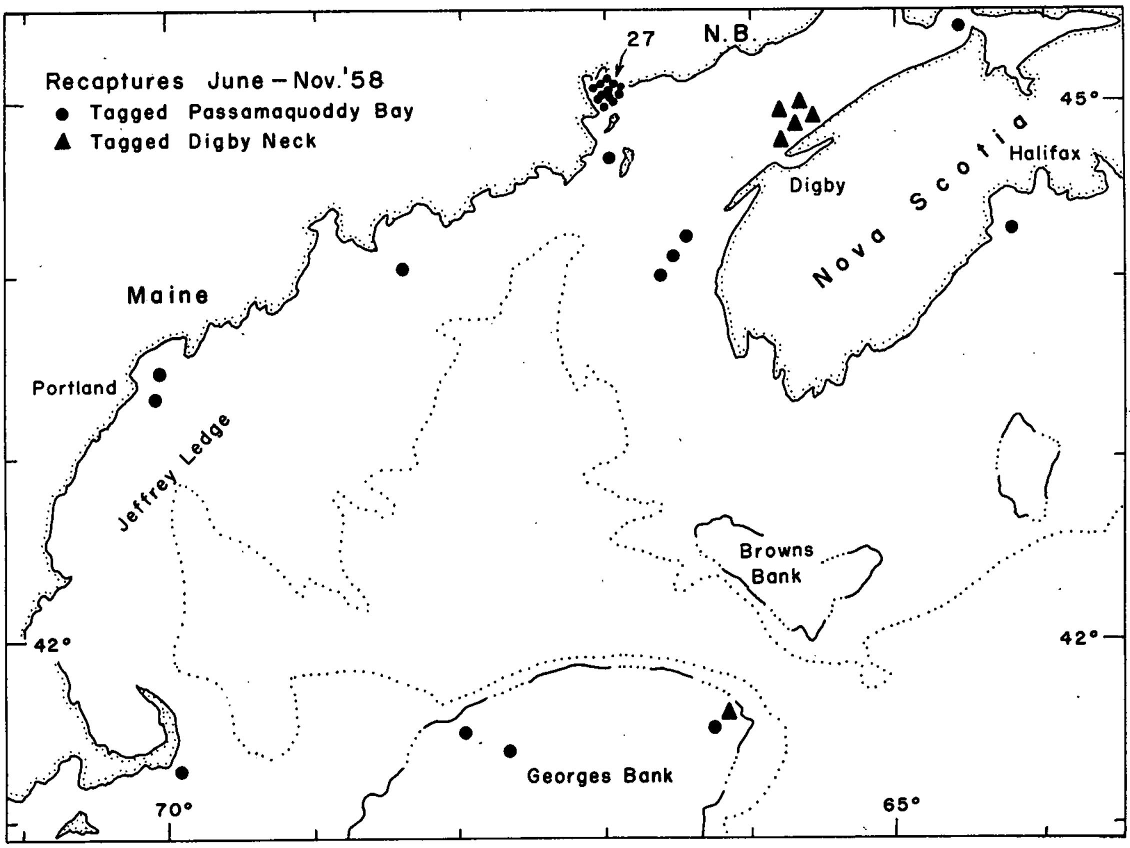


Figure 2. Recaptures of haddock tagged in the Passamaquoddy Bay, N. B., region and off Digby Neck, N. S. (Figures record the number recaptured in Passamaquoddy Bay.)

STUDIES OF WINTER FLOUNDERS FROM THE CANADIAN REGION OF PASSAMAQUODDY BAY

by

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INTRODUCTION

Beginning in 1947 a detailed study of the life-history of the winter flounder, Pseudopleuronectes americanus (Walb.), was carried out in the Canadian region of Passamaquoddy Bay. This detailed study, part of a broader exploratory program, included dragging in different seasons, depths, and areas. Flounders thus obtained were measured and various biological observations were recorded.

A broad picture of their depth distribution in relation to temperature was developed from comparisons among several regions with different temperature conditions. The effect of high temperature and low salinity on the survival of winter flounders was studied experimentally to determine whether or not these factors restricted their distribution in Canadian waters.

The results of these investigations are summarized in this paper to provide a basis for forecasting the probable effect on winter flounder stocks of proposed power structures across the mouth of Passamaquoddy Bay.

LIFE-HISTORY

Spawning

Examination of the gonads of mature flounders caught in Passamaquoddy Bay shows that spawning begins in April and is completed by the end of May (Table I). The peak of spawning activity occurs between mid April and mid May. Exploratory fishing at various depths has shown that mature fish are concentrated in shallow water at spawning time.

Sizes and ages

Age determinations were carried out for about 2,000 fish from Canadian waters, with a majority of these from Passamaquoddy Bay.

Table I. Estimation of stage of gonad development for winter flounders in Passamaquoddy Bay.

Date	No. of fish examined: Male	No. of fish examined: Female	Males: Ripe %	Males: Spawning %	Males: Spent %	Males: Recovered %	Females: Ripe %	Females: Spawning %	Females: Spent %	Females: Recovered %
May 19-27/47	241	133	6	35	50	9	5	5	83	7
Feb. 16/49	11	6	91			9	83			17
Mar. 14/49	17	13	83			17	92			8
Apr. 16/49	47	30	69	13	13	5	53	13	27	7
May 13/49	31	29	19	23	45	13	34	11	48	7

The age-length relationship for winter flounders from Passamaquoddy Bay, with comparative data for flounders from St. Mary Bay, N. S., and Long Island, N.Y., is presented in Table II. The location of these and other regions mentioned in this paper is shown in Figure 1.

Flounders from Passamaquoddy Bay are much slower growing than those from St. Mary Bay and Long Island Sound. The slower growth is characteristic of such Canadian regions as Pubnico Harbour, N. S., and Northumberland Strait. Fast-growing fish occur only around Digby Neck in such areas as St. Mary Bay and Annapolis Basin.

Seasonal movements

Seasonal change in depth distribution of winter flounders was studied in Passamaquoddy Bay by sampling at intervals from May 1947 until March 1950. Most of the sampling was carried out with a 12-foot beam trawl.

Intensive sampling from May 1947 through April 1948 revealed that from May to September the distribution of winter flounders in Passamaquoddy Bay remained relatively stable (Fig. 2 and 3). Immature fish were concentrated at depths less than 10 fathoms with the smallest fish being nearest shore. Mature flounders were concentrated in very shallow water, less than 5 fathoms, at the time of spawning in early spring. After spawning, some large, mature fish dispersed into deeper water although the majority still remained in the shallow-water zone.

By November both immature and mature fish had begun to move into deeper water within the Bay. By January the abundance of both immature and mature fish was much reduced at all depths in Passamaquoddy Bay. Similar

Table II. Age and average length in cm of winter flounders from Canadian and New York waters.

Place	Passamaquoddy Bay, N.B.	St. Mary Bay, N. S.		Long Island N.Y.
Month	May	April-June		February - April
Age	Length cm	Length cm		Length cm
		(1)	(2)	
I	7.9			
II	11.8	17.5		27.9
III	18.7	26.5		29.2
IV	23.5	31.4	35.0	34.6
V	25.7	34.9	37.2	37.2
VI	28.2		39.5	39.1
VII	31.0		41.5	40.6
VIII and over	32.4		42.7	48.2

(1) Sample from a small weir; (2) Samples from the commercial landings.

reductions in abundance occurred in succeeding winters, 1949 and 1950, although in 1949 it was not so marked for immature fish.

The reduced abundance in winter has been interpreted to mean that flounders were more spread out in the deep water of Passamaquoddy Bay; that low temperature reduced their catchability; and that possibly some flounders moved outside the Bay. Direct determination by tagging of movement out of the Bay has not been possible since there is no fishery for flounders outside the Bay.

Lethal temperatures

Flounders acclimated to known temperature levels were exposed to constant high temperature using methods similar to those described by Fry et al. (1942, 1946, 1947). Observations on mortalities were continued for at least 24 hours in all tests where fish were still living. Survival curves were determined and the temperature at which 50% of the fish survived for 24 hours was found by interpolation. Since systematic observations were terminated at 24 hours, the demarcation of the temperature tolerance zone is probably a little too high. It appears adequate, however, to relate the zone of tolerance to temperatures likely to be encountered by this species.

Under the experimental conditions noted above, the upper lethal temperature ranged from about 20 to 26°C for winter flounders acclimated from 4 to 24°C, respectively. The ultimate upper lethal temperature was about 26 to 27°C.

Tolerance to reduced salinities

Winter flounders are known to have a tolerance for reduced salinity. Sumner (1906) reports that they were normally kept in aquaria in New York where the salinity was approximately 50% that of normal sea water. Exposure to water of approximately 15 ‰ during the summer of 1948 at St. Andrews (water temperature 13-14°C) produced no deaths in 2 weeks. Flounders exposed to water of about 8‰ died in from 72 to 96 hours. Winter flounder eggs will hatch in waters of reduced salinity (down to 3/8 normal sea water) without apparent abnormalities (Scott, 1929).

Relationship to other areas

The seasonal distribution of winter flounders was studied by exploratory fishing in a number of regions in addition to Passamaquoddy Bay. These included Annapolis Basin, St. Mary Bay and Pubnico Harbour in Nova Scotia, and in the eastern end of Northumberland Strait. Most fishing was carried out with a 12-foot beam trawl, although some hauls were made using a flounder drag with 40-foot headrope. Seasonal changes in distribution of winter flounders off the coast of the United States have been compiled from accounts by Lobell (1939), Merriman and Warfel (1948), Perlmutter (1939, 1947), and from published statistics of United States commercial landings.

The winter flounder is found in inshore waters from Labrador to Georgia. South of Cape Cod winter flounders spawn in winter and early spring in the shallow water of such regions as Long Island Bays and Block Island Sound. They regularly withdraw from these shallow waters to deeper, cooler water in summer months.

North of Cape Cod they spawn in similar shallow regions in early spring. In summer they may withdraw to deeper, cooler water in some regions, such as Northumberland Strait, but not in others such as Passamaquoddy Bay. Withdrawing to deeper, cooler water in spring and summer is correlated with an increase in temperature of the shallow waters above 15°C. Throughout much of the winter flounder's geographic range its "summer" distribution is related to temperature rather than depth. Thus, they appear to be most abundant between temperatures of 12 and 15°C, where temperatures above and below this level are available. It is concluded that this is the "preferred" temperature range for the winter flounder.

Conclusion

Winter flounder stocks within Passamaquoddy Bay are maintained by local, shallow-water spawning in early spring. Throughout the summer they are mainly confined to the shore zone. Fish appear to be resident year round, although reduced experimental catches in winter may mean that some migrate out of the Bay during this season.

Present water temperatures in Passamaquoddy Bay are cooler for most of the year than those "preferred" by winter flounders. Slow growth of winter flounders in Passamaquoddy Bay, compared to warmer water regions off the United States and in St. Mary Bay and Annapolis Basin, N. S., may be a result of relatively cold water throughout most of the year.

FORECAST OF EFFECTS OF PROPOSED POWER STRUCTURES

None of the predicted hydrographic changes within the high pool appear to be lethal to winter flounders for they have a wide zone of temperature tolerance and a marked resistance to reduced salinities. The critical situation may occur during spawning in shallow water in early spring when increased run-off would tend to reduce the salinity of the surface layer. However, salinities of the order predicted do not appear to be lethal to either adults or larvae.

Higher temperatures in the high and low pools would probably result in increased growth rate of winter flounders. Warmer water extending deeper should increase the area of grounds where the winter flounders are available to commercial dragging. Reduced tidal influence may also increase small-boat fishing and could result in a sports fishery for winter flounders of the type developed in Long Island waters. The general result of the proposed power structures seems likely to be beneficial to the small fishery for winter flounders within the dam sites.

SUMMARY

Resident populations of slow-growing winter flounders in Passamaquoddy Bay maintain themselves by local spawning alongshore. Both mature and immature fish are concentrated in shallow water in early spring and throughout most of the summer. They move deeper in fall and are less abundant in winter, probably because they are spread out more, and because lower temperatures reduced their catchability, and possibly because some fish moved out of the Bay.

Flounders are tolerant to both high and low temperatures and reduced salinities. They appear to have a "preferred" temperature range

of about 12 to 15°C. It is predicted that the construction of power structures may increase their growth rate in the high and low pools by increasing water temperatures for longer periods in summer. Water conditions and resulting depth distribution may make flounders more available to otter trawling and provide possibilities for a sport fishery.

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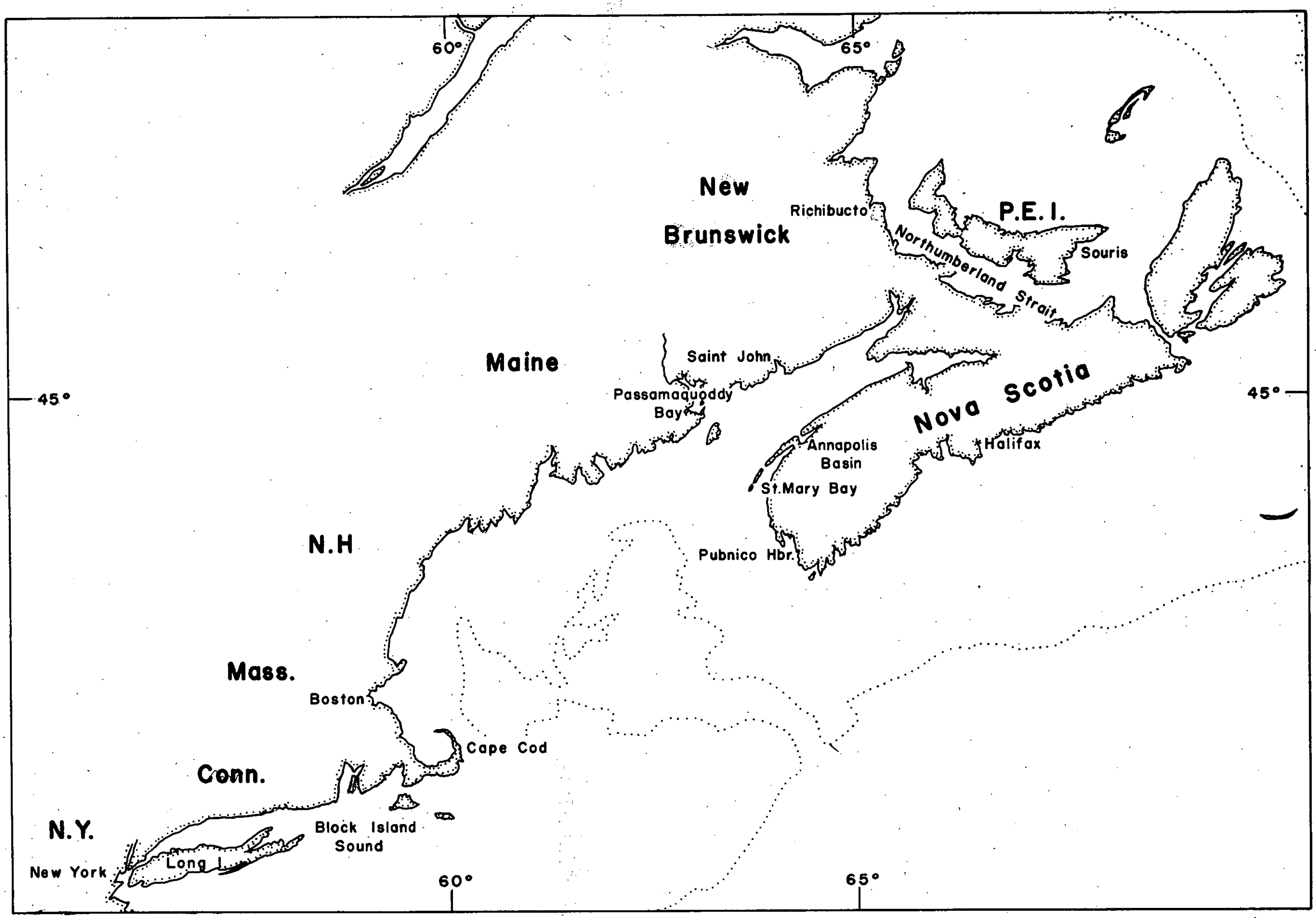

Figure 1. Map of the east coast of Canada and the United States showing localities mentioned in the text.

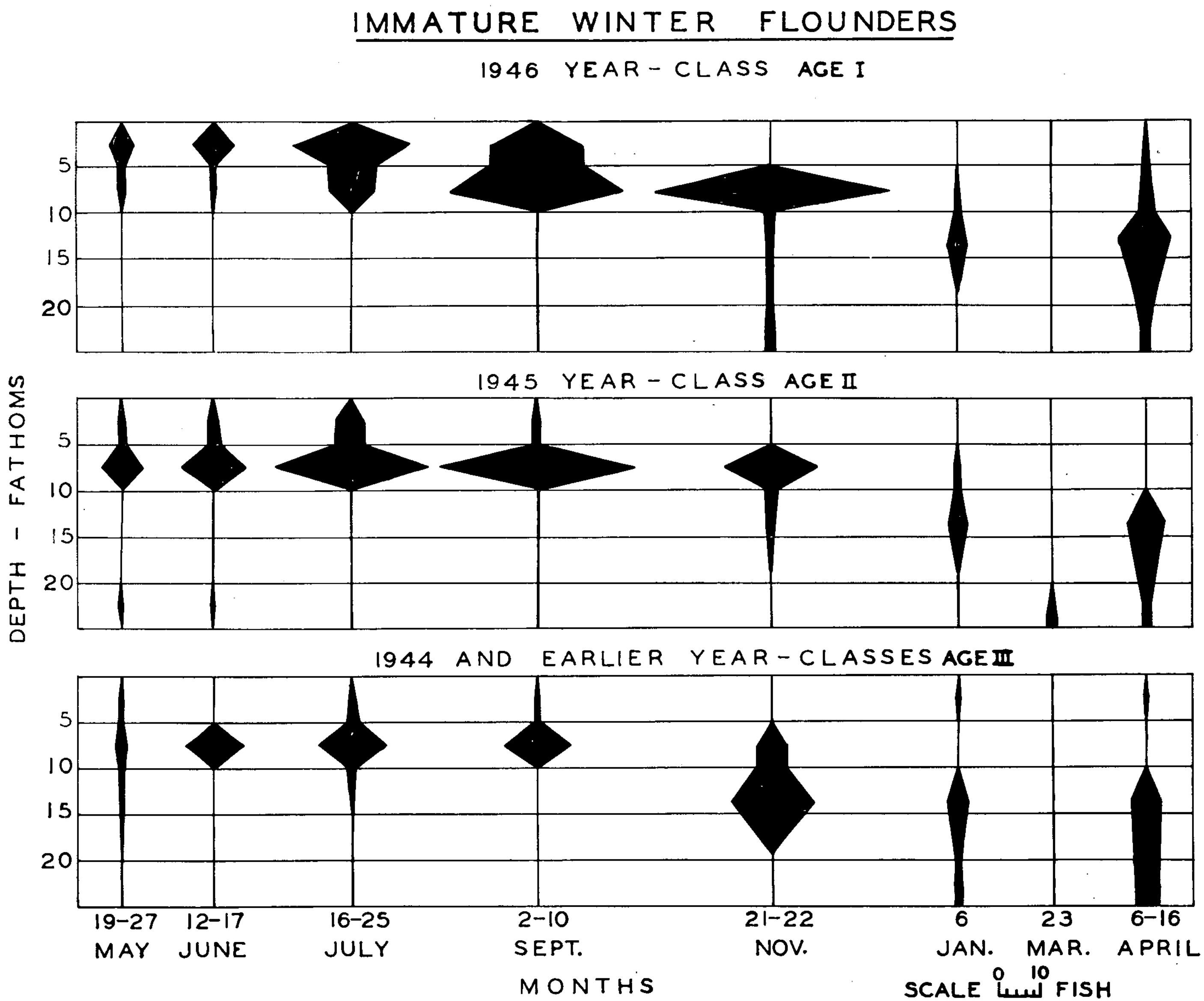

Figure 2. Catch per 15-minute drag of immature winter flounders in Passamaquoddy Bay, by depth, age, and month from May 1947 to April 1948.

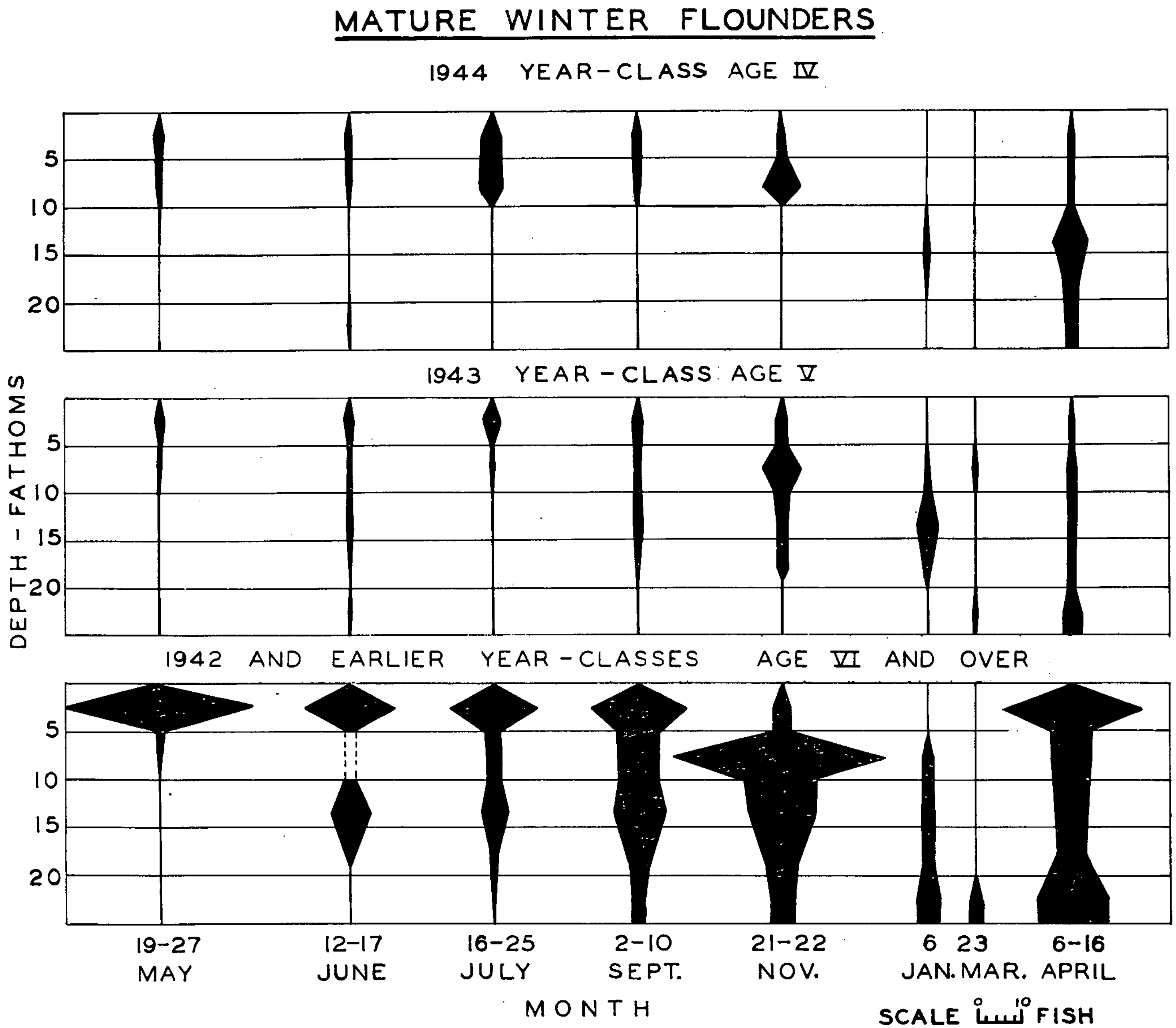

Figure 3. Catch per 15-minute drag of mature winter flounders in Passamaquoddy Bay, by depth, age, and month from May 1947 to April 1948.

POSSIBLE EFFECTS OF PASSAMAQUODDY TIDAL POWER STRUCTURES ON THE CANADIAN LOBSTER FISHERY

by

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INTRODUCTION

The purpose of this report is to consider how, in the light of present knowledge, the proposed Passamaquoddy tidal power structures might affect the lobster fishery. The lobster has been studied intensively for many years and considerable knowledge has accumulated as to how it is affected by the various physical, chemical, and biological factors of its environment. This report is concerned in general with the waters of Charlotte County, N. B., but for reasons to be discussed later, special attention is given to Passamaquoddy Bay.

THE PRESENT SITUATION

The fishing season

In Canada, the lobster fishing seasons are specified by regulation. For many years prior to 1956 a split or double lobster season was in effect in Charlotte County, the open season extending from November 15 to January 15 and from May 1 to June 24. In 1956 the regulation was revised to permit continuous fishing from November 15 to June 24. Average monthly landings from 1956 to 1958 for the four statistical districts of Charlotte County are shown in Table I.

Annual landings 1937-1958

The average weight and value of the Charlotte County lobster catch from 1937 to 1958 by 5-year periods and statistical districts are listed in Table II.

During the 20-year period from 1937 to 1956 the landings increased several-fold. The increase in value was even more striking. Catches for 1957 and 1958 suggest that the trend has levelled off.

Table I. Charlotte County average monthly lobster landings and values for 1956-58.

	District 50 Grand Manan			District 51 West Isles & Campobello		
	Landings '000 lb	Value '000 $	per lb ¢	Landings '000 lb	Value '000 $	per lb ¢
January	69.4	35.9	.52	2.7	1.4	.51
February	35.2	21.8	.62	.7	.4	.60
March	20.5	12.5	.61	.4	.3	.63
April	36.1	20.5	.57	2.2	1.1	.52
May	107.3	46.6	.43	20.0	7.7	.38
June	60.8	26.7	.44	26.1	10.1	.39
November	278.7	119.0	.43	54.6	26.7	.49
December	196.7	88.3	.45	34.4	17.4	.51
	804.8	371.3	.46	141.2	65.0	.46

	District 52 International Boundary to Back Bay			District 53 Back Bay to Pt. Lepreau		
	Landings '000 lb	Value '000 $	per lb ¢	Landings '000 lb	Value '000 $	per lb ¢
January	8.9	4.0	.45	6.5	3.2	.49
February	.2	.1	.58	3.2	1.7	.52
March	.2	.1	.56	.5	.3	.59
April	.6	.2	.34	2.3	1.2	.51
May	4.8	1.7	.36	16.4	6.2	.38
June	3.9	1.5	.38	17.5	6.7	.38
November	21.0	8.4	.40	110.2	44.9	.41
December	6.9	3.1	.44	51.3	22.8	.44
	46.5	19.2	.41	207.9	86.9	.42

The density of stocks of legal-sized lobsters in Passamaquoddy Bay and off southern Grand Manan

Population estimates based on landings for the 1947-51 period and on tag returns, show lobsters to be much more abundant off southern Grand Manan than in Passamaquoddy Bay. Average landings from Passamaquoddy Bay for the 1947-51 period are estimated at 55,000 pounds

Table II. Average weight and value of Charlotte County lobster landings, 1937 to 1958.

Period	District 50 Grand Manan Landings '000 lb	District 50 Grand Manan Value '000 $	District 51 West Isles & Campobello Landings '000 lb	District 51 West Isles & Campobello Value '000 $
1937-41	307.3	55.1	20.1	3.4
1942-46	466.5	154.4	63.9	22.0
1947-51	742.5	271.1	89.6	31.3
1952-56	874.3	367.4	108.9	44.2
1957	740.5	291.3	141.9	55.3
1958	856.0	420.8	144.3	75.2

Period	District 52 International Boundary to Back Bay Landings '000 lb	District 52 International Boundary to Back Bay Value '000 $	District 53 Back Bay to Pt. Lepreau Landings '000 lb	District 53 Back Bay to Pt. Lepreau Value '000 $
1937-41	5.9	1.0	82.0	15.1
1942-46	46.3	15.3	145.4	48.5
1947-51	32.5	11.2	196.6	70.3
1952-56	34.8	14.0	241.9	95.5
1957	71.5	26.8	209.6	72.6
1958	41.8	18.1	168.4	77.4

(32,500 from District 52 plus 22,500 lb or one quarter of the catch from District 51. Maine catches in the Bay are extremely small and have been ignored.) The area of the Bay from low tide and outside Dochet's Island is estimated at roughly 60 square nautical miles. Of 265 tagged lobsters liberated off Brandy Cove from September 1957 to April 1958, 48 (18.1%) were recaptured by commercial fishermen from November 1957 to November 1958. Fishing may be more intense in other parts of the Bay but it seems unlikely that more than 25% of the stock is removed annually. This indicates a total stock of 220,000 pounds of legal-sized lobsters, or an average density of 3,700 pounds per square nautical mile.

Landings off southern Grand Manan from 1947-51 averaged 663,000 pounds from fishing grounds estimated to cover 55 square nautical miles. From 4,930 tagged lobsters liberated on this area during this 5-year period, 2,789 tags (56.7%) were returned. This suggests a total stock of 1,170,000 pounds at a density of 21,300 pounds per square nautical mile; nearly six times the estimate for Passamaquoddy Bay.

Size distribution of catchable lobsters

The carapace length distributions of lobsters caught off southern Grand Manan, off the northern side of Deer Island, and in the St. Croix estuary off the Biological Station are shown in Figure 1. The high proportion of large lobsters in the Deer Island and St. Croix estuary catches confirms the conclusion that the lobster stocks in Passamaquoddy Bay are lightly fished.

Size and abundance of mature lobsters

In the southern Gulf of St. Lawrence some lobsters mature at a length of 7 inches and a weight of 1/2 pound. Since lobsters below 7 inches are protected, many reach maturity. In the Bay of Fundy, few mature before they are 12 inches long weighing 2 pounds. These differences are believed to result from differences in the summer water temperature. Where the fishery is intense, as off southern Grand Manan, few lobsters escape to reach maturity. In Passamaquoddy Bay, though lobsters in general are not abundant, the stocks are so lightly fished that a relatively high proportion reaches maturity.

Lethal levels of temperature, salinity, and dissolved oxygen for adult lobsters

At normal levels of salinity and dissolved oxygen, fully acclimated, hard-shelled lobsters can withstand temperatures as high as 30°C. Similarly at low temperatures and high oxygen levels they can withstand a salinity of 10‰. At low temperatures and normal salinity, they can withstand reductions in dissolved oxygen to 10% of the normal levels. Any two or all three of these factors may interact to cause mortality at intermediate levels; for example, a combination of 25°C, 15‰, and 25% dissolved oxygen is lethal for lobsters.

Lobster larvae

Lobster larvae hatch from mid-June to mid-September. On hatching they normally rise to the surface where they spend one or two months swimming freely. After four moults they reach the fifth stage and settle to the bottom wherever they have been carried by surface currents. Mortality during this free-swimming period is quite variable but averages 95%. The larvae grow most rapidly at temperatures of 20 to 25°C. Such temperatures would presumably improve survival by shortening the vulnerable free-swimming period. At temperatures of 15 to 20°C, salinities below 20‰ are definitely unfavourable. Larvae are abundant in the southern Gulf of St. Lawrence and relatively scarce in the Bay of Fundy. The relative scarcity in the Bay of Fundy is believed to result from the scarcity of mature lobsters and from poor survival of the larvae in the cooler water.

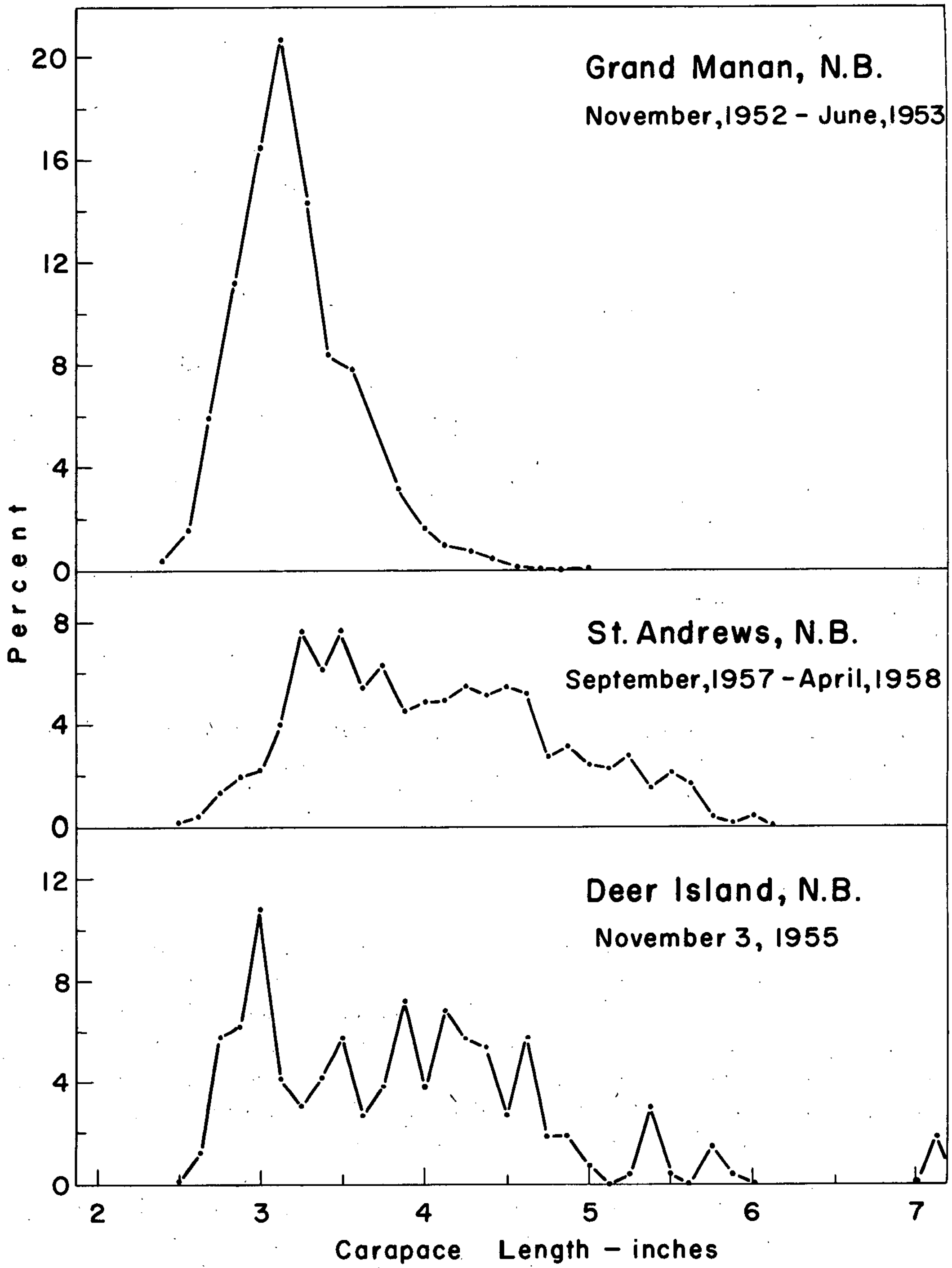

Figure 1. Carapace length distribution of lobsters caught off southern Grand Manan, in the St. Croix estuary near St. Andrews, N. B., and along the northern shore of Deer Island.

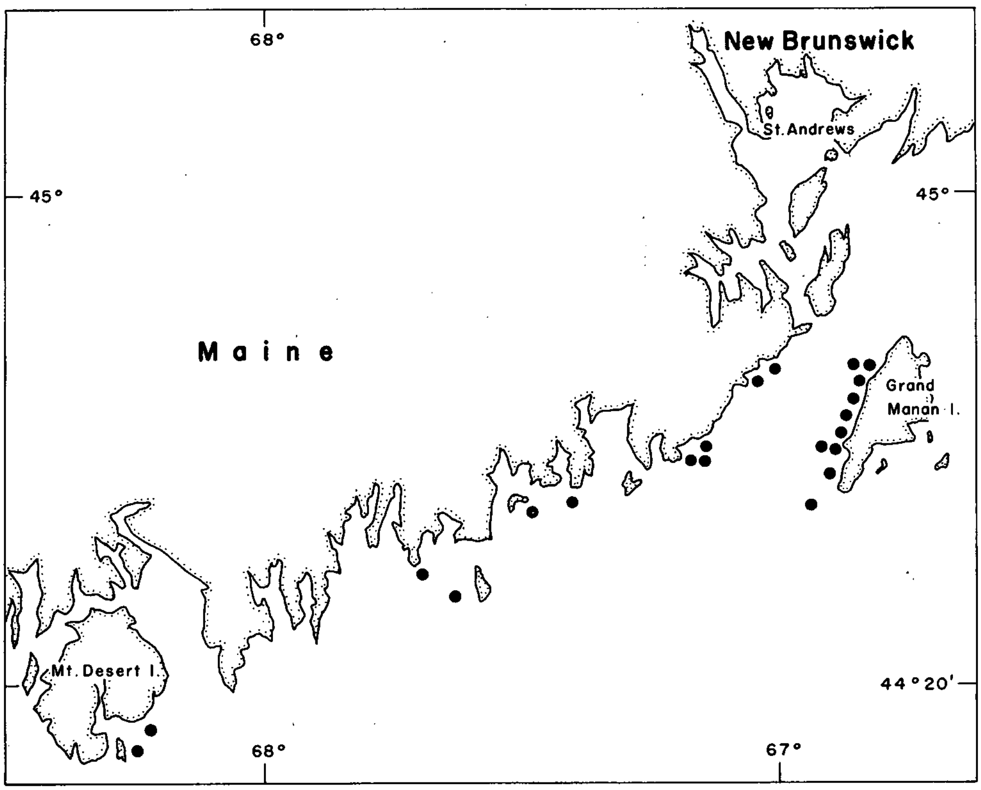

Figure 2. Recapture points of the 21 tagged lobsters that moved off the southern Grand Manan fishing grounds. Of 7,959 liberated from 1945 to 1952, a total of 4,742 were recaptured.

Movements of adult lobsters

From 7,959 tagged lobsters liberated off southern Grand Manan from 1945 to 1952, 4,742 tags were returned by commercial fishermen. Of these, 99.8% were recovered by Grand Manan fishermen. None of these tagged lobsters were reported from nearby Campobello or Deer Islands or from the New Brunswick mainland. A few tagged lobsters were recaptured along the western shore of Grand Manan and along the coast of Maine, as shown in Figure 2.

Of 265 tagged lobsters liberated in the St. Croix estuary off this Biological Station, from September 1957 to April 1958, 48 were recovered by commercial fishermen from November 1957 to November 1958. The movements of these lobsters are indicated in Figure 3.

These taggings indicate that there is very little exchange of adult lobsters between the four statistical districts of Charlotte County. It appears that for practical purposes the stocks in these four districts can be considered discrete.

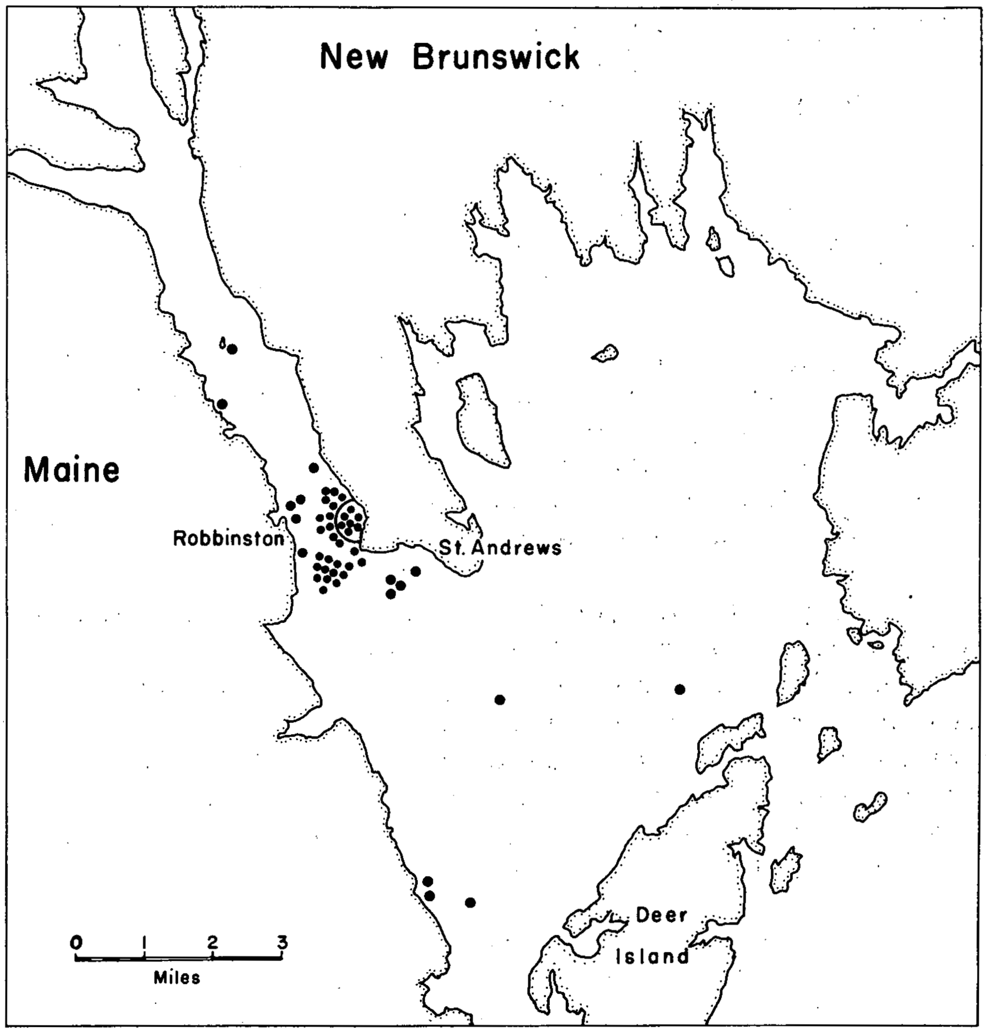

Figure 3. Recapture points of 48 tagged lobsters recovered November 1957 to November 1958 from 265 liberated near St. Andrews, N. B., September 1957 to April 1958.

POSSIBLE EFFECTS OF TIDAL POWER STRUCTURES

Since the stocks in the four statistical districts appear to be essentially discrete with very little intermingling, it is expected that the proposed tidal power structures would affect appreciably only those stocks inside the proposed dams. This would include all of statistical district # 52 and possibly one-quarter of district # 51. Lobster landings in this area for the 7-year period 1952 to 1958 averaged 71,000 pounds, valued at $29,000.

If Passamaquoddy Bay becomes ice-covered from say mid-December to mid-March, winter lobster fishing would be impossible.

Although this is a period of high prices, the present winter catch in Passamaquoddy Bay is such a small proportion of the total, as shown in Table I, that its disappearance would have only a minor effect on the total landed value. No doubt the lobsters could be harvested effectively in 4 1/2 rather than 7 1/2 months as was done prior to 1956.

The predicted increase in surface temperatures to a summer maximum of about 20°C would favour the growth and presumably the survival of the free-swimming larvae. The present scarcity of larvae in Passamaquoddy Bay is not necessarily the prime factor in limiting commercial production but it could well play an important part. Low surface salinities are unfavourable for larvae but the predicted low of 20 ‰ is not expected to extend beyond mid-May in most years and occasionally to mid-June. The larvae, however, do not start to hatch before mid-June, after which the salinities are expected to reach suitable levels. The decreased exchange of water between Passamaquoddy Bay and the Bay of Fundy should favour the retention and settlement of larvae within Passamaquoddy Bay.

Since the predicted changes in temperature and salinity are expected to be restricted to a relatively thin surface layer, no major effects on the bottom stages are expected. Any increase in temperature to which the stocks on the bottom were subjected would be expected to result in more rapid juvenile growth and earlier maturity. This, in turn, could result in an increased hatch of larvae. If recruitment increases appreciably this could lead to more intensive fishing which would be followed by a decline in the size composition of the catch.

In general, it appears that hydrographic changes of the order predicted, are unlikely to have marked effects on the lobster stocks in Passamaquoddy Bay. Increased temperature and reduced water exchange could favour the growth, survival, and retention of larvae within Passamaquoddy Bay. This in turn might result in a modest increase in the commercial production of lobsters. No measurable effect on the stocks outside the dammed area is expected.

CANADIAN MOLLUSCAN SHELLFISHERIES AND PASSAMAQUODDY POWER DEVELOPMENT

by

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ABSTRACT

Three molluscan shellfish warrant consideration in predicting the effects of power development on Canadian fisheries in the Quoddy Region. Due to the reduction in the area of clam flats in the high pool, the Region's soft-shell clam production now at 4 million pounds will be expected to drop to about 2 million pounds annually and reduce fishermen's earnings by about $100 thousand. Because water exchange will decrease in the high pool, scallop production in the Region now at 60 thousand pounds may be expected to increase about 50% annually and increase fishermen's earnings by about $12 thousand. Shipworms are not a problem now but they will become a vexing problem in the low and high pools because water temperatures will increase. The cost of preventative treatment and damages caused by shipworms are expected to be high and are difficult to estimate.

INTRODUCTION

Molluscs are mostly sedentary animals. They are obliged to accommodate themselves to their surroundings, or perish. They cannot move to better places. In almost all their activities they show great dependence on environmental factors. There are, for instance, critical temperatures for shell movement, feeding, and spawning. When temperatures are above these critical levels there are clear relationships between temperature and the rates of these activities. It would be expected therefore, that the molluscs in the Quoddy Region (all the area inside a line drawn from Point Lepreau, N. B., to Northern Head, Grand Manan, N. B., thence to West Quoddy Head, Maine) would be markedly affected by such changes as would attend damming and power development. Predicted changes in water levels, water exchange, currents, temperatures and salinities are described in Appendix I, Chapter 7. Herein we forecast how these changes will affect the molluscs of commercial inportance.

There are many species of molluscs in the Region but only a few are of economic importance. The soft-shell clam is the most valuable. Fishermen of the Quoddy Region land 4 million pounds annually. The scallop is second in importance with landings of 60 thousand pounds. These species are the only two that are of direct and positive value, but they are important in another way too. They and a number of other molluscs (e.g. Yoldia) enter the food chains of fishes like haddock and flounder and this gives them an indirect commercial importance. Their present relative and total importance in this respect is only vaguely understood but they decidedly are assets. We know too little to predict how this indirect importance would be affected by damming and regardless of how they are affected, this importance will be greater or less depending on how the abundance of their finny predators is affected by dams.

A few species are liabilities or potentially so. Shipworms for instance, are not "worms" but burrowing shellfish. Clams burrow in sand and mud but shipworms burrow in wood. Because they are shellfish, it is proper to consider them here.

In the sections following, we predict how clam, scallops, and shipworms will be influenced by the power project.

SOFT-SHELL CLAMS

Commercially the soft-shell clam (Mya arenaria) is the most important mollusc in the Quoddy Region. Production has declined drastically in the past 10 years from over-digging and the green crab. Digging is less intense now and the abundance of the green crabs is decreasing somewhat in the productive areas. It is therefore reasonable to consider the mean of the last 19 years annual landings (1937 to 1955, inclusive) as approximating the area's sustainable level of production under present conditions.

To establish the yields from the three parts of the Quoddy Region the clam landings reported from the Canadian Department of Fisheries statistical districts were assigned to them in accordance with the following statements from Mr. Eldridge. Approximately two thirds of the landings in District 51 come from North Harbour, Deer Island. This part of the Island will be included in the high pool. The other third of this district's landings come from Campobello Island, and of this, approximately one third comes from the outside area of the Quoddy Region. The other two thirds come from the low-pool area. All clams landed in District 52 come from the high pool. Those landed in District 53 come from the outside area of the Quoddy Region.

Table I compares present and predicted landings and landed values of clams in the Quoddy Region.

Clam production will be drastically altered by the Passamaquoddy scheme. Predicted changes in the water levels (Appendix I, Chapter 7) will be by far the most important factor in determining the new clam production levels.

Table I. Average (1937 to 1955 incl.) annual landings of soft-shell clams (pounds of whole clams and value in dollars) for the Quoddy Region and predicted annual landings after damming.

Statistical District No.	Present landings: High pool	Present landings: Low pool	Present landings: Outside	Predicted landings: High pool, 1st 10 years	Predicted landings: High pool, Thereafter	Predicted landings: Low pool, 1st 10 years	Predicted landings: Low pool, Thereafter	Predicted landings: Outside
51								
Deer Island								
Pounds	52,300	---	---	0	2,600	---	---	---
Dollars	845	---	---	0	130	---	---	---
Campobello Island								
Pounds	---	17,300	8,700	---	---	9,000	19,000	8,700
Dollars	---	285	140	---	---	450	950	140
52								
Pounds	2,063,000	---	---	0	103,000	---	---	---
Dollars	44,520	---	---	0	5,115	---	---	---
53								
Pounds	---	---	1,945,000	---	---	---	---	1,945,000
Dollars	---	---	45,100	---	---	---	---	97,685
Totals by areas								
Pounds	2,115,300	17,300	1,953,700	0	106,000	9,000	19,000	1,953,700
Dollars	45,365	285	45,240	0	5,300	450	950	98,000

Grand totals for Quoddy Region	Present	Predicted: 1st 10 years	Predicted: Thereafter
Pounds	4,086,300	1,962,700	2,078,700
Dollars (19 year average)	90,890		
(current value 5¢ lb)	204,315	98,500	103,950

This follows from the fact that clams are intertidal animals. All other changes such as higher summer water temperatures which would hasten clam growth and encourage green crabs will be relatively trivial in their consequences.

To describe present conditions as a basis for prediction, observations were made both inside and outside Passamaquoddy Bay in the summer of 1958. St. Andrews Harbour is a polluted area where there is no commercial clam harvesting and was chosen as representing a near approach to natural inside conditions. The Pottery Bridge Flat in Tufts Cove is regularly harvested and exhibits conditions which seem typical of exploited inside flats. Two outside areas which are important clam producers were examined as controls--Lepreau Basin and Pocologan Harbour.

In each inlet a rectangular study area (long axis parallel to the shore line) was marked off with stakes in a grid pattern usually in 100-foot squares. A surveyor's transit was used to determine beach levels at the stakes with reference to mean sea level which is approximately equal to 14 feet above Saint John, N. B., tidal datum (Canadian Hydrographic Service, Publication No. 30). This permitted elevation-contouring of the study areas. Therefore, approximately square-foot samples of beach soil were dug at intersection points on the grid and clams found in the soil were counted. On the basis of these counts and general inspection of adjacent grounds for clam burrows, the positions of beds (areas where counts exceeded 3 clams per sq. ft.), were delineated. At the same time notes on soil character were compiled. The dimensions in feet of the beach areas studied were as follows--St. Andrews Harbour, 1,800 x 700; Pottery Bridge Flat, 1,800 x 1,000 Lepreau Basin, 1,200 x 600; and Pocologan Harbour, 1,200 x 800.

In spite of differences, records show that there were remarkable similarities in the four areas studied. Beach profiles were essentially similar. From shore grid stations close to high-water mark where the beach profile becomes horizontal, there is typically a steep seaward slope of solid rock, shingle, coarse gravel or rocky mud which changes suddenly within 100 feet to gravel-mud or mud flat. This flat slopes away with a uniform gradient to and beyond low-water mark and the soil becomes more and more muddy. Typically, clam beds were found in a zone about 300 feet wide between levels corresponding to one foot above mean sea level and 6 to 7 feet below mean sea level (Fig. 1 and Table 2). This is roughly equivalent to 31% of the vertical range of water levels at spring tides and to about 50% of the flat exposed. This clam zone is bordered by a ribbon of barren flat both above and below. The positions and extents of the clam zones when the tide is in its neap, mean, and spring phases may be judged from Figure 2 which describes present conditions as outlined in Appendix I, Chapter 7.

If we are to make predictions of the conditions that may be established after damming for power development, we must assume that the positions and extents of new clam beds will bear proportionately the same relations to the new high- and low-water levels as present beds bear to present water levels. This is a sweeping assumption and our predictions based on it are accordingly tenuous. They do not, for instance, take into account the possibility that clam enemies like flounders may find the new tidal conditions favourable to heavier predation on clams.

The predictions are summarized in Table II. Its data on observed and predicted water levels are taken from Figures 2 and 3 which are derived from Appendix I, Chapter 7. Its data on positions and dimensions of present clam beds come from Figure 1. The predicted positions and dimensions of the new intertidal flats were determined by projections of predicted water levels onto the bottom profile in Figure 1, and the positions and extents of the new clam beds on these new flats were worked out from simple calculations which are obvious from Table II itself.

Table II. Present conditions on St. Andrews Harbour clam flat (typical of Quoddy Region) and predicted conditions in high and low pool after damming. (see Figures 1, 2, and 3). All measurements in feet.

	Observed present conditions	Predicted conditions	
		High pool	Low pool
Highest high water	12.0	10.6	-0.1
Lowest low water	-11.8	3.2	-11.4
Tidal range	23.8	7.4	11.3
Mean water level	0.0	6.4	-4.5
Height of clam zone	7.5	2.3	3.5
Height of clam zone as % of tidal range	31%	31%	31%
Amount of clam zone above mean water level	1.0	0.3	0.4
Proportion of clam zone above mean water level	13%	13%	13%
Upper limit of clam zone	1.0	6.7	-4.1
Lower limit of clam zone	-6.5	4.4	-7.6
Horizontal extent of clam zone	280	14	300
Extent as a % of present clam zone	100%	5%	110%

Figure 3 shows that the nature of the tides will be quite differend, not only in amplitude but also in other characteristics, from those we have now. For example, there will be no overlapping of levels between spring and neap tides. This means that completely different parts of the beach will be exposed while the tide is in these two phases of its cycles. It is hard to judge how this will affect the reliability of predictions. But it is worth stating that the predicted high-pool conditions both of tide and of clam distribution would approximately describe those which may be observed now near the Biological Sub-station, Ellerslie, P.E.I., in Malpeque Bay.

High pool

Figures 1 and 3 show that present clam beds will be permanently submerged when the high pool is formed and will be inaccessible to fishermen. The clam beds will no longer be productive and will soon die out because they will be at levels where clams do not grow.

The new narrow clam zone will be found on a steeply-sloping intertidal flat (Fig. 1). We assume that its productive capacity per unit of area will be the same as that of the present flats and that the total production will be reduced in proportion to the reduction in the area of the flat, i.e., to 5% of present production (Table I). There are no clams on that part of the flat and most of our marketable clams are 6 to 8 years old. Thus, when the high pool is created, clam production from Passamaquoddy Bay will cease entirely for 6 to 8 years and probably for 10 years because natural stocking of new areas is a gradual process. It is likely to be especially slow here because soils are too coarse for clams now. There will have to be some resorting of sediments by wave action before clams can thrive.

After 10 years, production may be expected to climb to 106 thousand pounds (5% of present volume) which at todays prices will fetch fishermen $5 thousand annually (Table I).

Low pool

Figure 1 and Table II show that the new clam zone in the low pool will be of about the same extent (110%) as it is now, but its upper and lower boundaries will be 150 to 200 feet seaward of present boundaries. There will be an overlap of about 50% of new and old beds. Production from the area of overlap will therefore continue at its present level. Clams will die out in the upper half of the present bed because it will be too high for clams to survive. But clams will establish themselves in a 150- to 200-foot stretch of barren beach below the present clam zone. It will be 6 to 8 years and probably 10 years before this new clam zone comes into production. Thus, when the low pool is created, production from the affected area will drop for 10 years to half the present volume. Thereafter, it may be expected to recover to its present or a slightly higher (110%) volume of about 19 thousand pounds which at present prices will fetch the fishermen about $950 thousand annually (Table I).

Outside area

Clam landings in the outside area of the Quoddy Region are unlikely to be affected. Annual production should continue at about 2 million pounds and, at present prices, will fetch the fishermen about $100 thousand (Table I).

Quoddy Region as a whole

In general the effect of damming for power will bring about a substantial reduction in clam production. For the first 10 years it will be about 48% of present landings with an annual loss of about $100 thousand (Table I), but thereafter, there will be a slight recovery to about 51% of present landings.

Most of the loss will be felt in mainland communities bordering Passamaquoddy Bay but the North Harbour district of Deer Island should also be similarly affected. The clam fishermen in the low pool area of Campobello Island will suffer a temporary loss but in the long run they should benefit slightly.

These changes are not great nor is the annual dollar value of the region's clam fishery impressive when considered by itself, but in poor sardine years, weirmen regularly turn to clam digging to tide them over the lean times. Thus, clam fishing has been a stabilizing factor in the economy of fishing communities.

SCALLOPS

The scallop (Placopecten magellanicus) or sea scallop, as it is known on the United States east coast, is the only mollusc besides the soft-shell clam that is harvested from Canadian parts of the Quoddy Region in amounts to warrant consideration. The mean annual production for the period 1937 to 1955 inclusive, from the various parts of the Region is shown in Table III.

High pool

Scallops are deep-water forms and will not be affected appreciably by changes in water level. However, other predicted oceanographic changes are likely to alter scallop production and landings.

The reduced current speeds in Passamaquoddy Bay will favour silting, and, since scallops thrive best on a clean bottom, this change will make the Bay as a whole, less suitable for scallops. It is doubtful, however, that the principal scallop beds will be much affected because they are situated in the paths of what will be the main currents from inlet gates to turbines where silting is likely to be least.

Table III. Average (1937 to 1955 inclusive) annual landings of scallops (pounds of meats and value in dollars) for the Quoddy Region and predicted annual landings after damming.

Statistical district no.	Present landings			Predicted landings		
	High pool	Low pool	Outside	High pool	Low pool	Outside
51						
Deer Island						
Pounds	7,300	---	7,300	14,600	---	7,300
Dollars	2,770	---	2,770	5,840	---	2,920
Campobello Island						
Pounds	---	---	7,300	---	---	7,300
Dollars	---	---	2,770	---	---	2,920
52						
Pounds	21,900	---	---	43,800	---	---
Dollars	8,910	---	---	17,520	---	---
53						
Pounds	---	---	16,000	---	---	16,000
Dollars	---	---	7,240	---	---	6,400
Totals by areas						
Pounds	29,200	---	30,600	58,400	---	30,600
Dollars	11,680	---	12,780	23,360	---	12,240

Grand totals for Quoddy Region	Present	Predicted
Pounds (19-year average)	59,800	89,000
Dollars (current value 40¢ lb)	23,920	35,600

It is expected that water temperatures in the high pool will rise to about 68°F in summer. This will hasten development of larvae and improve larval settlement. On the other hand, it will retard growth rates of adults and will reduce their meat yields to levels approaching those in Northumberland Strait, where summer temperatures are also high. The advantages which these higher temperatures will afford will not be eliminated by the adverse effects but they will be greatly reduced. No allowance is made for them in predictions in Table III.

We have little basis for judging how scallop enemies will be affected by the changes. Some bottom feeding fishes like haddock that eat scallops may be less abundant (Appendix II, Chapter 7), but higher temperatures may favour increased abundance of starfish. The different effects on enemies seem likely to cancel one another and we have not considered them in making predictions.

Studies of the Bay of Fundy scallop by Dickie (1955) and studies of larval behaviour of other molluscs indicate that water exchange often regulates recruitment and population size. Larvae are carried about by water currents and the numbers that settle on their native beds vary inversely with the rate of water exchange. To make this generalization applicable to the Quoddy Region's scallop problem, we must assume that the main beds are self-sustaining. That is, the larvae that settle on any bed are progeny of the scallops that live there. The reliability of this assumption determines the reliability of our predictions.

It is expected that water exchange between the Passamaquoddy Bay (the high pool) and the Bay of Fundy will be reduced to about half. We may therefore expect scallop production to approximately double itself (Table III). This should increase fishermen's annual earnings by about $12 thousand.

Low pool

Scallop production in this area is insignificant. It will remain insignificant because water exchange rates will increase. There is a chance that small beds will develop between Campobello and Deer Island in the approaches to the inflow and outflow gates where the bottom will be kept clean by tidal action; and when the gates are closed, the reduced current speeds will permit fishing. The area south of Lubec Narrows will be too shallow and muddy to support scallops and summer temperatures will be too high.

It is expected that summer temperatures throughout the low pool will be high. While this might favour heavier settlements of larvae it is unlikely to offset the adverse effects of greater water exchange.

The combined net effect of all these interacting factors is likely to be slight and no allowance is made for them in our prediction (Table III).

Outside area

The outside area will not be greatly affected but small fishable beds may develop in the paths of inflow into the high pool and outflow from the low pool. These benefits will be so slight that no allowance is made for them in predictions.

Quoddy Region as a whole

Scallop production will improve in the high pool area and produce an overall increase of about 50% in landings. This will improve fishermen's earnings by about $12 thousand annually (Table III).

SHIPWORMS

Shipworms do not constitute a problem in Canadian parts of the Quoddy Region as a whole but they do cause damage at times in limited areas which have high summer water temperatures. For example, wooden parts of floats maintained for swimmers by the Algonquin Hotel in Katy's Cove, St. Andrews, N. B., are attacked periodically. Badly damaged and discarded float frames were found beached in the southwestern end of the Cove in 1958. The tunneling of this wood was like that caused by Teredo navalis with which we are quite familiar from our Gulf of St. Lawrence work. We feel sure this species is present in the Cove. However, no living animals were found that year for certain identification. In both 1957 and 1958 Teredinid larvae were found in plankton tows made in Sam Orr Pond, a warm-water branch of Birch Cove, tributary to Passamaquoddy Bay. In spite of searching, no adult animals were found for species deterimination. We suspect the larvae were Teredo navalis. Early workers reported Teredo from the Saint John N. B., district and it is not surprising to find evidence of it in the Quoddy Region.

Another shipworm, Xylophaga dorsalis is reported from Maine waters but we have not observed it here.

High and low pools

Most of the predicted oceanographic changes (Appendix I, Chapter 7) will affect Teredo. Reduced turbidity will favour growth of adults and reduced water exchange between Passamaquoddy Bay and the Bay of Fundy will favour retention of larvae within the Bay and their dense settlement on suitable substrates in the high pool. But the most important single factor will be the rise in water temperature.

Summer water temperatures in the high and low pools will approach 68°F. Because the threshold temperature for spawning of Teredo is 61°F breeding populations may be expected to spread throughout both pools from their present small foci. They will be a serious menace to all wooden structures exposed to sea water, wharves, boats, weir stakes, and lobster traps. Economically, Teredo will probably become the most important of all our molluscs, important because it will be a liability.

Outside area

The increased numbers of larvae produced in the high and low pools will increase the numbers that will escape through the turbines and locks to nearby parts of the outside area. This will produce some highly local damage to wooden structures, but the outside waters of the Quoddy Region as a whole will not be affected by the prevailing low temperatures. However, wooden boats from the outside area and elsewhere will require extra protection if they frequent the high and low pools in the summer months.

Quoddy Region as a whole.

We have no basis for predicting the annual losses that will attend the spread of Teredo. There will be heavy costs for protective treatment of wooden structures. Boat bottoms, mooring buoys, and wooden spar buoys, and wooden spar buoys used in navigation will have to be painted and renewed more frequently; lobster traps will have to be tarred and all wharves will have to be constructed of creosoted timber. If sardine weirs continue to be used after damming, annual repair costs will soar. In years following heavy settlements of shipworm larvae, weirs may have to be completely rebuilt.

The cost of combatting shipworms could easily equal or exceed the value of all the fisheries from the Quoddy Region.

SUMMARY

There are only three species of molluscan shellfish that are important enough to be considered in predicting the effects of power development on the fisheries in Canadian areas of the Quoddy Region.

The soft-shell clam is the Region's most important shellfish. Roughly 4 million pounds are landed annually. Only a few are taken from the low pool but the high pool and the outside area each contribute half. In the high pool the area of flats suitable for clams will be 5% of its present extent. Long-term clam production will be reduced accordingly but after impoundment there will be a 10 year period of adjustment during which no clams at all will be produced from the high pool. Conditions in the low pool and the outside area will not be affected appreciably. The effect on clam production for the Quoddy Region as a whole will be to reduce the annual landings by 2 million pounds. At present prices this will reduce income to fishermen by $100 thousand.

Sea scallops are harvested principally from the high pool and the outside area in about equal quantities totalling 60 thousand pounds annually. Very few come from Canadian parts of the low pool. Reduced water exchange in the high pool will be the most important change affecting scallops. Production should be doubled in this pool but there will be little or no change in the low pool and the outside area. This means that production for Canadian parts of the region will be increased by 50%, to 90 thousand pounds annually. The fishermen's earnings should increase by $12 thousand.

Shipworms (Teredo) are molluscan shellfish and important because they can damage wooden structures exposed to sea water. To date they have not been a serious problem because of their limited distribution. They are affected by many environmental factors but low summer water temperature now prevents their spread from a few small, warm-water areas. After damming, the increase in the summer water temperatures of impounded waters can be expected to permit breeding populations of shipworms to thrive throughout the high and low pools, but not in the outside areas. Preventative treatment of boats, lobster traps, buoys, navigation aids, and wharves in these pools will be costly and only partly effective. Damage to them and to wooden sardine weirs, will also be costly. The total cost cannot be estimated with any precision. They could equal or exceed the value of all the fisheries in the whole region.

All these predictions are based on reasonable but sweeping assumptions about the way in which the species mentioned will be affected by the new hydrographic conditions which have been forecast.

Surveying the whole shellfish picture, damming will probably result in a reduction in the net annual income to fishermen of about $90 thousand. Treatment of boats and gear to prevent shipworm attack and repair of shipworm damage will add considerably to fishermen's operating expenses and to the costs of maintaining certain public services.

ACKNOWLEDGMENTS

I wish to thank the various members of the Fisheries Research Board staff for their assistance in this work; Miss Barbara Shaw for her careful and patient efforts in assembling much of the data used in the section on soft-shell clams; Mr. W. A. Johnson for his instrument work in the grid and contour surveys of clam study areas; Mrs. R. M. Lord for working through the statistical records of shellfish landings; Mr. Peter Downer for his drafting of figures for this report; Drs. N. F. Bourne and L. M. Dickie for their advice on scallops; and Dr. R. Trites for his general interest, information and assistance. I would also thank agents of the Department of Fisheries: Mr. W. F. Doucet, Chief, Markets and Economics Service, Halifax, N. S., for supplying tabulated records of annual landings of molluscan shellfish for the statistical districts in the Quoddy Region, and Mr. G. E. Eldridge, Fisheries Officer, St. Andrews, N. B., for his advice in interpreting the landing records.

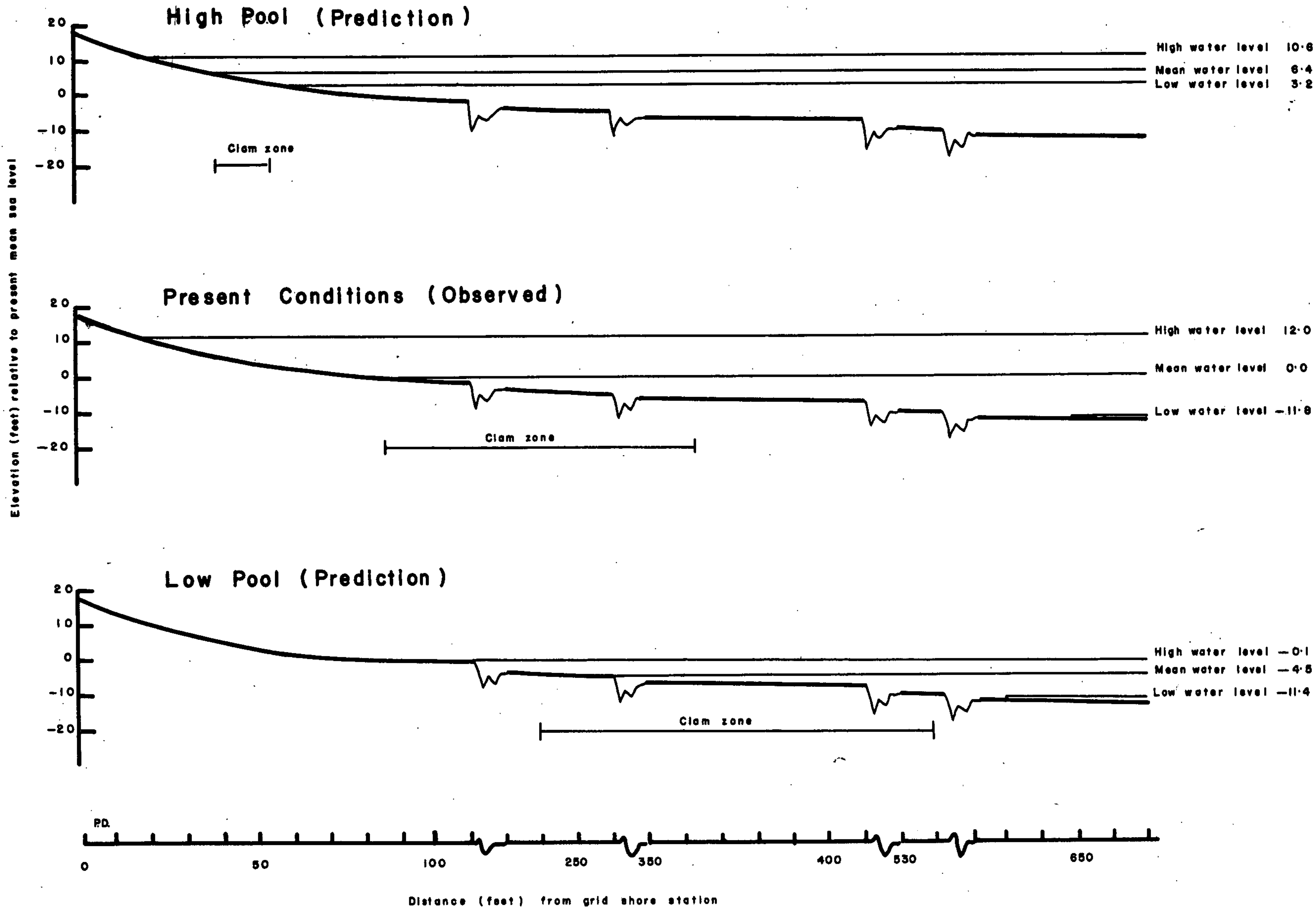

Figure 1. Profile of St. Andrews Harbour flat showing present and predicted water levels and clam beds.

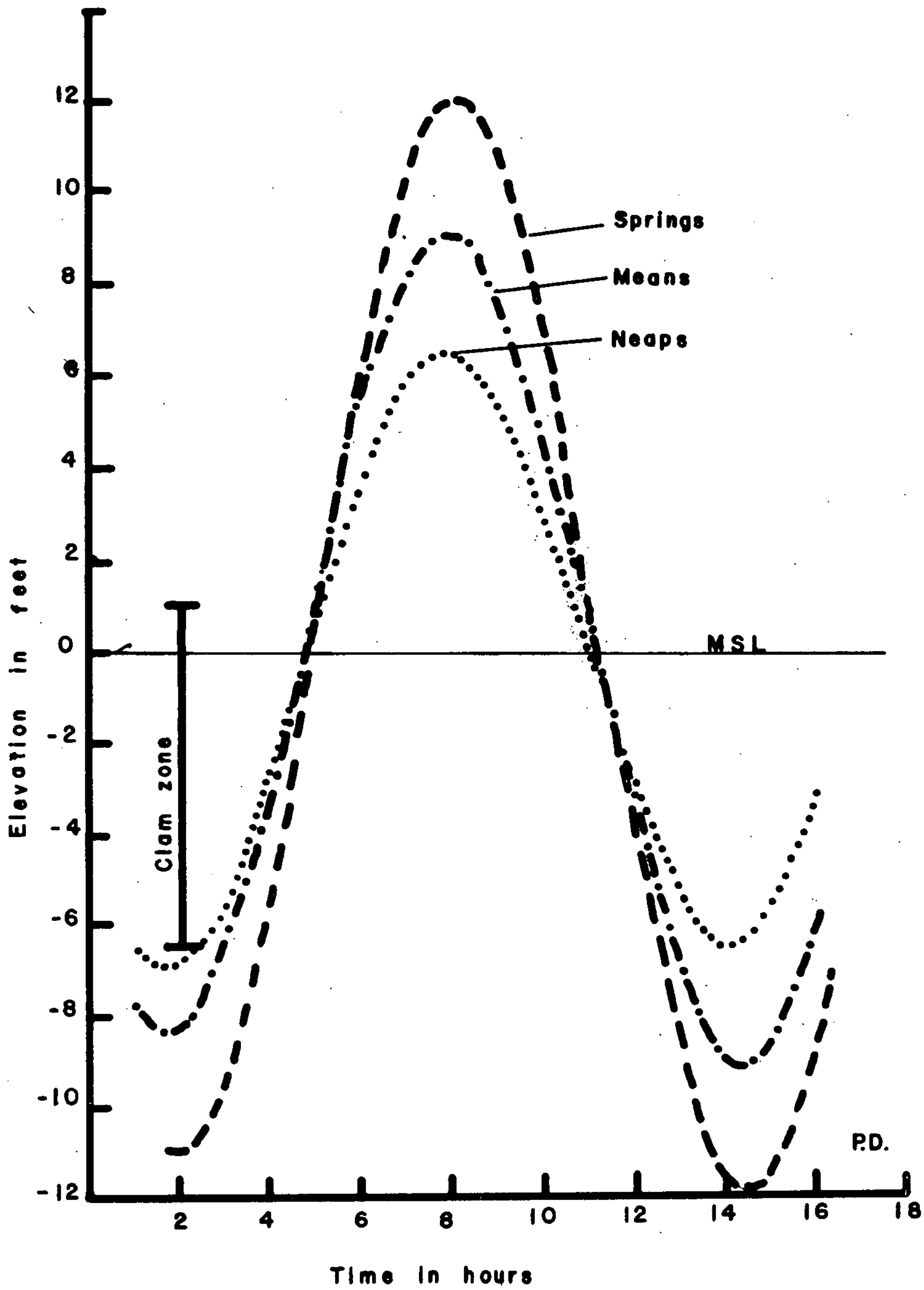

Figure 2. Present tidal fluctuations and distribution of clam beds as described in Appendix I and in Miss Shaw's records.

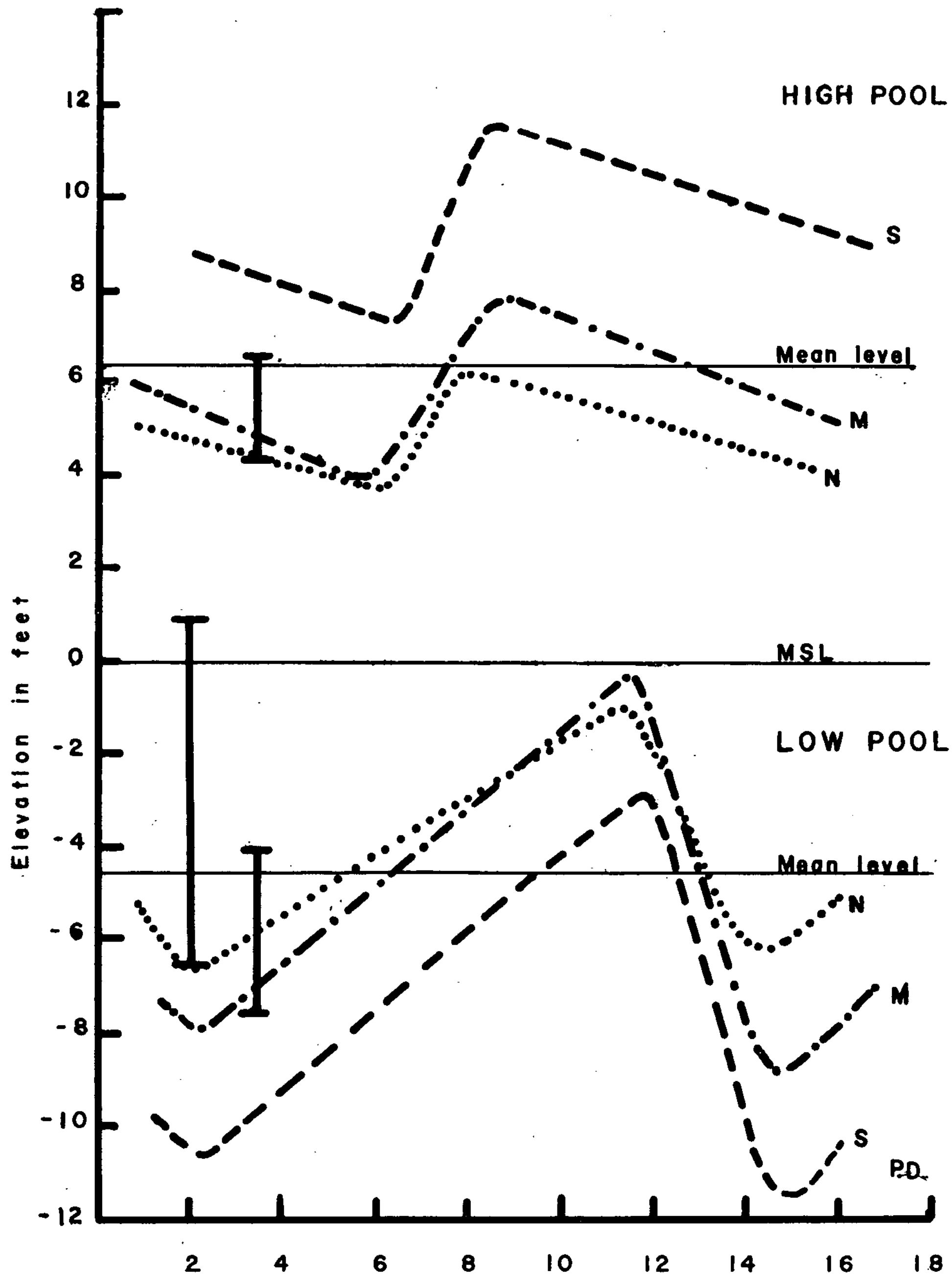

Figure 3. Predicted tidal fluctuations and distribution of clam beds in high and low pools after damming as described in Appendix I, Chapter 7 and in this report. The position of present clam beds is shown as in Figure 1 for comparison with the new conditions.

EFFECTS OF PROPOSED PASSAMAQUODDY POWER PROJECT ON ANADROMOUS FISHES IN CANADIAN WATERS

by

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INTRODUCTION

The anadromous fishes that have present or potential economic value in the vicinity of Passamaquoddy Bay include the Atlantic salmon, smelt, alewife, shad, eastern brook trout, and other introduced trout species. Elsewhere in eastern Canada the first four provide valuable commercial fisheries but in the Passamaquoddy region they are caught only occasionally, usually in herring weirs. Only salmon, smelts, and alewives are shown in the fisheries statistics for the 20-year period 1937-1956 and then only occasionally, with annual values of a few thousand dollars. None of the anadromous species were included in plans for special investigation in connection with the proposed power project.

In 1958, about one year before the end of the 3-year period of general investigation on the project, concern was expressed over the effects of the proposed dams on anadromous sport species which have considerable recreational value, particularly Atlantic salmon.

The first meeting of an Anadromous Fish Committee was held in Augusta, Maine, on July 24, 1958. Here salmon investigators for the State of Maine justifiably expressed fear that the power project would nullify their recent efforts to increase salmon for angling in Cobscook Bay tributaries, chiefly the River Dennys. For nearby Canadian rivers, the writer reported that the present value of the salmon sport fishery was quite low, but that there was a good potential value if improvements could be made in local salmon management. There was general agreement that little is known anywhere about the effects of dams on the behaviour of either adult Atlantic salmon coming in from the sea or young salmon migrating to sea as smolts. There has been no scientific investigation along these lines until very recently, and then on a very small scale. Effective fishways of two main types have been developed to allow ascending adult Atlantic salmon to negotiate dams of moderate height--the common fish ladder with baffles of various kinds, and the Borland hydraulic lock. The former has proved to be effective both in Europe and in Canada, while the latter has been limited to the British Isles. It was agreed that nothing could be done before the 1959 deadline to overcome our lack of scientific knowledge about Atlantic salmon in this area, and provide well-founded answers to many pertinent questions. Examples of the "unknowns" are: the migration patterns and general behaviour of fish in the Passamaquoddy area, the ability of fish to enter via the filling gates and/or negotiate the currents expected at the emptying gates, and the likelihood of fish using the navigation locks.

At a second meeting of the Anadromous Fish Committee held at Orono, Maine, on December 4, 1958, Mr. C. H. Clay, Chief Engineer of the Department of Fisheries in the Pacific area, gave valuable advice on the possibilities of incorporating effective fishways in the dam. This was based on experience with salmonid fishes obtained on the Pacific coast. As a result it was concluded that it should be possible to install fishways in the dams to prevent the supply of anadromous species from being seriously reduced by the power project. The committee agreed to recommend that suitable fish passage facilities be provided.

Since no special scientific investigations in connection with the Passamaquoddy project are involved for the anadromous fishes, this report has very limited scope. It merely (1) outlines the main features of the habits of each species to provide background for assessing the need for fishway facilities, (2) reviews commercial catch statistics of anadromous species in statistical districts 50, 51, 52, and 53 for the period 1937-1956, (3) discusses the present value of the sport fisheries for Atlantic salmon and trout, and their potential value if general management precedures were improved in the area and if fishway facilities were provided in the proposed power scheme. It is hoped that it will lead to adequate understanding of the situation when considered along with a similar report by those concerned about anadromous fishes in United States' waters.

HABITS OF VARIOUS SPECIES

Atlantic salmon (Salmo salar)

Adult Atlantic salmon may enter fresh water from the sea at any time from early spring until the fall. In some eastern Canadian rivers an early run predominates, in some the run is mainly in the fall, other have abundant runs both early and late in the season. Rivers in the Passamaquoddy area seem to have peak runs during July and August as indicated by records taken at a trap in a fishway on the Magaguadavic River at St. George, N. B., and by observations of salmon jumping a falls at head of tide on the Digdeguash River. Commonly adults remain in fresh water over winter and return to the sea the following spring. A small proportion, about 10%, of adults may be expected to return for spawning again. Marking and tagging experiments have shown that homing of adult Atlantic salmon to their rivers of origin is highly developed.

Spawning occurs in October and November, the fertilized eggs develop slowly in the stream bottom through the winter, and hatching of fry occurs in early spring. Growth of parr occurs in the streams for 2 to 4 years or longer, to produce smolts which migrate to the sea in May and June when about 5 to 7 inches long. The habits and utilization of salmon produced in streams in the Passamaquoddy area are unknown, since there have been no smolt marking or tagging experiments here. We have no information on the length of time they stay in Passamaquoddy Bay, nor on their destinations in salt water before returning after one year as 3 to 5 pound grilse, or after 2 or more years as 8 to 12 pound or larger salmon. Around the coasts of the Maritime Provinces and Newfoundland there is a commercial sea and estuarial fishery by gill nets and trap nets for adults, designed to catch them primarily while they are returning towards their natal rivers for spawning. In Charlotte County waters no commercial gear is set specially for salmon but some are taken in the herring weirs. It is to be expected that considerable numbers of salmon produced in local streams are caught in salmon gear set in other sea areas, some far-distant. Angling occurs in fresh water from the spring through the summer, with a preference for early season angling. Using standard fly-fishing techniques, salmon cannot be caught readily in the dark coloured waters of Charlotte County rivers. Successful angling might be encouraged by amending fishery regulations to permit other angling methods, such as spin-fishing.

Smelt (Osmerus mordax)

Adults run from the sea into lower freshwater areas of rivers in the spring, spawn and return to salt water without delay. The young smelts run out to sea as larvae within a few weeks. In many parts of the Canadian Atlantic coast a trap net or gill net fishery occurs for adults in salt water of estuaries from late summer to mid-winter. In some places there is a worthwhile sport fishery using hook and line. In the Passamaquoddy area except for occasional gill nets no special gear is operated for smelts, but considerable quantities are sometimes taken in herring weirs and marketed. The fishery statistics for Charlotte County show landings from July to December with peak catches in October and November.

Alewife (Pomolobus pseudoharengus)

Adults enter fresh water from the sea in spring and early summer, to spawn and return without delay to salt water. The young move out to salt water during their first summer. In many parts of the Atlantic coast a valuable commercial fishery is carried on for alewives as they pass through estuaries on their way to the rivers for spawning. In some places adults are trapped in fresh water for local consumption. In the Passamaquoddy area several trap nets for alewives are operated at St. George, N.B.; and some are caught in herring weirs.

Shad (Alosa sapidissima)

The habits of shad resemble those of alewives. They are fished along with other anadromous species elsewhere on the Atlantic coast, and provide a valuable fishery in some parts of the Bay of Fundy. They have never appeared in fishery statistics for Charlotte County in the past 20 years, but are taken occasionally in herring weirs. It is possible that altered environmental conditions resulting from the proposed power project might cause increased quantities in the Passamaquoddy area.

Trout

The Eastern Brook Trout (Salvelinus fontinalis) is native to Charlotte County, N. B. The Brown Trout (Salmo trutta), reared in hatcheries, has been introduced. An experiment is now in progress in Crecy Lake to learn the possibilities of introducing Rainbow Trout (Salmo gairdnerii) to improve local trout angling.

Brook trout now provide a sport fishery of considerable value in freshwater streams and lakes of Charlotte County. Owing to shallow, infertile soil in this hard rock area the drainage waters are relatively poor in trout foods. The fertility of local lakes can be increased, however, by adding commercial fertilizers. Trout production can be increased effectively by combining predator control with fertilization. Some brook trout spend their whole lives in fresh water, others migrate to salt water and are called "sea-run trout" or "sea trout" as they return to the streams. Spawning of adults occurs in the fall and the young develop in streams similarly to salmon, but prefer somewhat cooler waters. Practically nothing is known about the habits of sea-run trout in the Passamaquoddy area but it is believed that there are few sea-run individuals here. This is likely related to the lack of suitable estuarine conditions for sea-run trout, associated with the extreme tidal amplitude and the generally low sea water temperatures. Damming Passamaquoddy Bay would likely improve conditions for sea-run trout, which are so highly prized by anglers elsewhere.

Introduced brown trout seem to be thriving in local rivers and are contributing effectively to angling catches. Again, nothing is known about their sea-running habits but the proposed dams might lead to more of the sea-run type. The same would probably apply to rainbow trout if they were introduced to streams inside the dams.

PRESENT VALUE OF FISHERIES FOR ANADROMOUS SPECIES

Commercial fishery

The annual total landings of Atlantic salmon, smelt, and alewives during the 20-year period of 1937-1956 are listed in the accompanying tables for Statistical Districts 50, 51, 52, and 53, Charlotte County, N. B.

(i) Salmon Listed only once, as follows:

	District 52 International Boundary to Back Bay		
	Landed weight lb.	Landed value $	
1938	200	40	Taken in month of July

(ii) Smelts District 50 (Grand Manan) Nil.

	District 51 West Isles & Campobello		District 52 International Boundary to Back Bay		District 53 Back Bay to Pt. Lepreau	
Year	Landed weight lb.	Landed value $	Landed weight lb.	Landed value $	Landed weight lb.	Landed value $
1937	600	120	600	42	4,500	270
1938	400	40	7,200	360	1,000	50
1939	3,900	552	3,600	180	--	--
1940	--	--	10,900	545	--	--
1941	1,200	168	2,400	120	--	--
1942	7,900	1,453	--	--	--	--
1943	2,500	693	--	--	--	--
1944	--	--	--	--	--	--
1945	7,000	1,563	--	--	400	80
1946	--	--	--	--	--	--
1947	--	--	--	--	8,500	170
1948	--	--	--	--	--	--
1949	--	--	7,500	1,348	1,700	263
1950	--	--	7,400	1,199	--	--
1951	--	--	500	85	--	--
1952	--	--	200	40	100	20
1953	--	--	--	--	--	--
1954	--	--	--	--	--	--
1955	--	--	--	--	--	--
1956	--	--	--	--	--	--

Smelt landings occurred from July to December, with peak in October and November.

(iii) Alewives District 50 (Grand Manan) Nil
District 51 (West Isles & Campobello) Nil

	District 52 International Boundary to Back Bay		District 53 Back Bay to Pt. Lepreau	
Year	Landed weight lb.	Landed value $	Landed weight lb.	Landed value $
1937	--	--	--	--
1938	--	--	--	--
1939	--	--	--	--
1940	--	--	--	--
1941	--	--	--	--
1942	--	--	--	--
1943	2,900	29	--	--
1944	--	--	--	--
1945	--	--	--	--
1946	--	--	--	--
1947	--	--	8,500	170
1948	--	--	--	--
1949	484,900	4,122	--	--
1950	108,300	541	--	--
1951	--	--	--	--
1952	--	--	--	--
1953	67,000	1,005	--	--
1954	327,200	1,636	--	--
1955	10,000	100	--	--
1956	16,200	162	--	--

All alewife landings occurred in May and June

The quantities and their landed values are low, as might be expected since most of the catches are made incidentally by the herring weir fishery. Landings in District 52, the Canadian area inside the proposed dams, are of particular interest. Here Atlantic salmon are shown only once with a landed weight of 200 pounds valued at $40. Smelt are shown for 9 of the 20 years with a maximum total annual value of $1,348 for 7,500 pounds landed in 1949. Alewives are listed in only 7 years, with a maximum annual value of $4,122 in 1949 when 484,900 pounds were landed. In the other three statistical districts outside Passamaquoddy Bay the catches of all species were either nil or more infrequent and of less value than in District 52.

Sport fishery

Although some Atlantic salmon and many trout are caught by angling in Charlotte County waters reliable figures for the annual catch are lacking. No effort has been made to obtain an accurate creel census of sea-running fish caught in the streams here.

An attempt has been made to guess the number of salmon and trout that might run in from the sea and use fishway facilities to enter Passamaquoddy Bay if such were provided.

Under present conditions, with impassable obstructions and pollution on the St. Croix River and imperfect fishway facilities at the falls on the Magaguadavic River, perhaps 1,500 salmon now enter tributaries to Passamaquoddy Bay in an average year. Of these, 20% might be caught by anglers, giving an estimated annual catch of 300 salmon. Recently economists have attempted to place a value on salmon caught commercially and by angling in the provinces of New Brunswick and Quebec. In New Brunswick the value per fish was established at about $25, in Quebec at about $160. Using the more conservative New Brunswick average figure, the estimated value of the present salmon angling catch in the Passamaquoddy area would be $7,500.

It is guessed that 2,000 sea-run trout, including brook trout and brown trout, may now return to Passamaquoddy rivers each year. If 20% of these or 400 are caught annually and a value of $3 per fish is assigned as a fair fraction of the above estimated value for New Brunswick salmon on a weight basis, the present value of the sea-run trout fishery would be $1,200.

POTENTIAL VALUE OF FISHERIES FOR ANADROMOUS SPECIES

If the St. Croix River were improved by installing fishways at the present dams and other stream improvements were made here and on other tributaries to the area affected by the new power project, the production of anadromous fish would likely increase greatly.

On the basis of the International St. Croix River Engineering Board Report to International Joint Commission, September, 1957, the total annual run of Atlantic salmon into Passamaquoddy tributaries might be increased to about 15,000 fish. These might give about 3,000 salmon to anglers valued at $75,000 per year. The annual run of alewives into Passamaquoddy tributaries might be 3,000,000 fish and the run of shad 50,000 annually, if the St. Croix River were developed. These fish would have to use fishway facilities. Nothing useful can be predicted about smelts, since the present population is unknown. It is doubted that they would be able to use fishways that would be suitable for other species.

Under changed environmental conditions resulting from the construction of the new dams, the sea-run trout population could increase tremendously. A guess at the annual run into the basins can be based on estimated runs elsewhere under favourable conditions, as in Prince Edward Island--say 500,000 fish per year. This would bring the value of sea-run trout angling to 100,000 x $3 = $300,000 per year, provided that effective fishways were operating, to assure their ascent.

SUMMARY

Waters in the vicinity of the proposed Passamaquoddy power project, both inside and outside the dam sites, do not have sufficient quantities of adult fish of any anadromous species to justify significant commercial fishing effort. Some Atlantic salmon, smelt, alewives, and shad have been taken occasionally in herring weirs and there has been limited use of fishing gear set for smelt and alewives. No special scientific investigations of anadromous fishes in this area were included in the program of studies established in 1956-57 for the International Passamaquoddy Fisheries Board.

In the past year recognition of the potential value of the local sport fishery for Atlantic salmon and trout resulted in serious attention being given to the need for fishway facilities at the proposed dams. The Anadromous Fish Committee has recommended that suitable fishways be provided. Their design will have to be based on a knowledge of facilities being operated successfully elsewhere, for example on the Canadian Pacific coast and in Europe.

If the dams are built and if suitable fishways are provided it it likely that great increases will occur in local supplies of at least some anadromous species. At present the production of anadromous fishes in the Passamaquoddy area is handicapped by a lack of the typical estuarine environment that fosters an abundance of these species in other areas of the Atlantic coast. Reduced tidal amplitude, higher water temperatures and retention of brackish water over an extensive coastal area could support large populations of sea-run trout, for example. These would be very valuable for recreational sport fishing. Local production of other anadromous species like the alewife and shad might increase also and provide a more valuable commercial fishery than exists now.

FOREWORD

In considering the effects of building dams at the entrance to Passamaquoddy Bay between New Brunswick, Canada, and Maine, U. S. A., it was evident that consideration must be given to the interference with the normal migration pattern of anadromous fish. The question about what provisions should be made to facilitate normal movements was referred to Messrs. M. C. Bell and C. H. Clay jointly. They carefully assessed the situations at filling and emptying gates and at the power house in the light of their experience with fishway operations on the Pacific Coast and have provided the following report. - J. L. H.

FACILITIES FOR ANADROMOUS FISH PASSAGE, PASSAMAQUODDY PROJECT

by

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and

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INTRODUCTION

The basic assumptions made in discussing the facilities listed in the summary and shown in Fig. 1 are as follows:

1. That anadromous fish will require passage at all possible combinations of water levels because migration will extend over many tidal cycles and extreme tides might occur during the migration period.

2. That anadromous fish will be mainly attracted by outflow from the basin, and therefore will not necessarily be attracted to the area of the filling gates, but because of the possibility of the presence of fish opposite them at some time during the ocean phase of their life, and because of the high velocities occurring during the filling cycle, some fish may be swept through the filling gates into the upper pool.

3. That the size of fishway required is a minimum which is not governed by the numbers of fish to be passed, even if the St. Croix River populations were to be developed to maximum capacity. The minimum design suggested incorporates pools 8 feet wide, 10 feet long, and 6 feet deep which is the minimum which will provide satisfactory hydraulic conditions for fish passage. This size is the same as that recommended by the St. Croix River Board for the facilities on that river.

4. That swimming ability of Atlantic Salmon is similar to Pacific coast steelhead, and other anadromous species concerned are somewhat weaker.

FISH PASSAGE INTO LOWER POOL

Under full operating conditions it is expected that most of the fish seeking passage to all streams tributary to the Lower and Upper Pool would be attracted to the 70 emptying gates. At this point, all the fresh water runoff from both basins would be discharged over a short period at each low tide. The discharge rate would vary up to a maximum of 1,500,000 cfs (approximately) under spring tide conditions. From the data available and on the assumptions outlined, it is estimated that most fish will certainly not be able to ascend through the emptying gates to the Lower Pool at discharges over 1,000,000 cfs, and further it is unlikely that many will be able to ascend at discharges over 750,000 cfs. These correspond to maximum velocities of 16 fps and 12 fps respectively in the throat of the gates. This means that fish will be able to ascend through the emptying gates only over a period which is considerably less than 50% of the time the emptying gates are open.

The data supplied gives the maximum discharge of 1,500,000 cfs with only 3.3 feet of head on the gate structures. It is concluded from this that there is a high velocity of approach and high velocity downstream from the gates, which extends the area of high velocity through which the fish must ascend for some unknown distance above and below the gate structure itself. It is this distance which determines the upper limit of the velocity which the fish can ascend, and the best estimate possible has been made on this basis.

Because passage is restricted to flows less than 750,000-1,000,000 cfs, it follows that the total time of migration which is already short, is divided into two periods on each emptying cycle, one immediately after the gates open and a second before they close. (See Fig. 2).

If it appears that these short periods are insufficient to ensure passage of all of the fish, then the period of passage could be lengthened to cover the whole emptying cycle by provision of a fishway at the north end of the row of emptying gates. It must be pointed out, however, that no fishway system in existence is operating under similar conditions of rapid change of flow and maximum flow. The flow out the gates is similar to the spillway discharge at a dam, and the largest comparable facilities are on the Columbia River where the flood flows are only half the maximum at Passamaquoddy.

A general indication of the type of facilities required is given in Fig. 3, and consists of a 30 foot channel with suitable training walls extending downstream to a point where access is possible for the fish (less than 12 fps maximum) and upstream to a point where the fish can enter the pool without being swept back through the gates. Because of the rapidly changing conditions of head and velocity which will occur on the emptying cycle, it is felt a conventional type of fishway would not be practical. It is, therefore, tentatively proposed that this channel instead carry sufficient regulating gates to form a pool type fishway with the head between pools regulated automatically to less than 12 inches. When the pool and the sea level balance, the fishway would be closed off in the same way as the emptying gates.

Without local cost data and more detailed planning, it is difficult to set a cost on such a structure, but it would certainly be more than the cost of one emptying gate bay. It is felt that an additional $500,000 might cover the necessary additional walls and gates.

FISH PASSAGE AT POWERHOUSE

Fish facilities will be required at the powerhouse in order to ensure maintenance of any runs to tributaries of the Upper Pool, including the potential runs to the St. Croix River. A set of facilities to completely ensure fish passage should include a collection system which would be the most expensive part. The powerhouse length approximates that at The Dalles Dam on the Columbia River, and the discharge is of the same magnitude. On the basis of cost allocations used by U. S. Army Corps of Engineers, the Dalles collection system cost $7,000,000 with facilities for the water supply costing another $3,600,000. If less than conventional facilities are to be considered because of the size of the runs, a much cheaper system could be developed for the Passamaquoddy powerhouse, utilizing fixed entrance ports and a centralized water supply system (See Fig. 4). This would cost in the neighbourhood of $2,000,000, and would deliver the fish to one fishway of the minimum dimensions indicated previously.

Without the collection system, because of the length of the powerhouse, there could be no guarantee that fish would all pass upstream even with a fishway at each end of the powerhouse. However, since fishways at these points without the collection system would be comparatively cheap, and would undoubtedly have some value in maintaining at least part of the run, they might be considered as the very minimum facilities that could be provided. These fishways would be as shown in Fig. 5 without the collection system shown, and would cost approximately $100,000 each, or $200,000 each if an auxiliary water supply is provided for attraction at the entrance.

It should be pointed out here that passage of anadromous fish is possible to a degree at all points in the project with the exception of the powerhouse, so that this would appear to be the first location where facilities should be considered.

FISH PASSAGE INTO UPPER POOL

Through the 40 Filling Gates at Letite Passage

While it is possible that anadromous fish will be swept into the

Upper Pool through the filling gates, it is not believed they will be attracted to the area of the gates in any numbers. If this is the case, no fish passage facilities need be provided. If, however, there is enough leakage through the gates to attract fish and cause them to delay and injure themselves, two courses of action would be possible. First, the navigation lock could be so designed as to permit a continuous discharge of water with the lock lowered. It could then be used as a fish lock to pass fish along with shipping or separately if no shipping were present. Secondly, a fishway could be built at one end of the gate structure as shown in Fig. 6. This fishway would require 20 pools of the minimum dimensions indicated earlier and would cost about $100,000. An auxiliary water supply to augment the small flow from the fishway for attraction purposes would be desirable which would cost an additional $100,000.

Through the 50 Filling Gates at Indian River

The same comments would apply here, except that fish are more likely to be in this area because of the presence of less saline water from the emptying gates. Here again fish facilities might not be necessary if continuous leakage is not extensive. If it is extensive, fish attracted to the emptying gates but unable to pass into the Lower Pool during the high stage of the tidal cycle, could be attracted to the leakage from the filling gates and be held there. In this case a fishway similar to that shown for Letite Passage in location and cost would be required..

Downstream Passage at Powerhouse

There is one feature of the project which it is not possible to make recommendations for at the present time. This is the possibility of adult fish entering the Upper Pool which are returning to spawn in streams tributary to the Lower Pool. This is possible even with no facilities at the filling gates. It is assumed that they could find their way to the Lower Pool via the turbines, but the loss, if any, cannot be predicted. It might be possible to make tests to determine this however. If losses were known to be significant, consideration could be given to the development of a headrace screen with bypass to ensure safe passage. This is not recommended without tests to prove its need, however. In addition no provision is considered to exclude upstream migrants from the draft tubes, since this would inevitably interfere with the downstream migration.

SUMMARY

The fish facilities to be considered and their costs are listed below in the order of importance. The first item has been indicated to be the one essential item needed to guarantee any degree of maintenance of anadromous fish runs to the tributaries of the Upper Pool. The items following assure more successful passage by degrees. The last item covering fishways at the filling gate structures are only required if sufficient leakage occurs through these gates to attract fish and cause them to be delayed and injured.

1. Minimum facilities at power house	
Fishways 2 @ 100,000	$ 200,000
Auxiliary water supply 2 @ 100,000	200,000
2. Conventional facilities at powerhouse	
Powerhouse collection system	2,000,000
One fishway plus auxiliary water	200,000
3. Emptying gate fishway	
Cost of one gate bay plus	500,000
4. Filling gate fishways	
Fishway Indian River	100,000
Fishway Letite Passage	100,000
Auxiliary water supply 2 @ 100,000	200,000
5. Future screen at powerhouse	(no estimate)

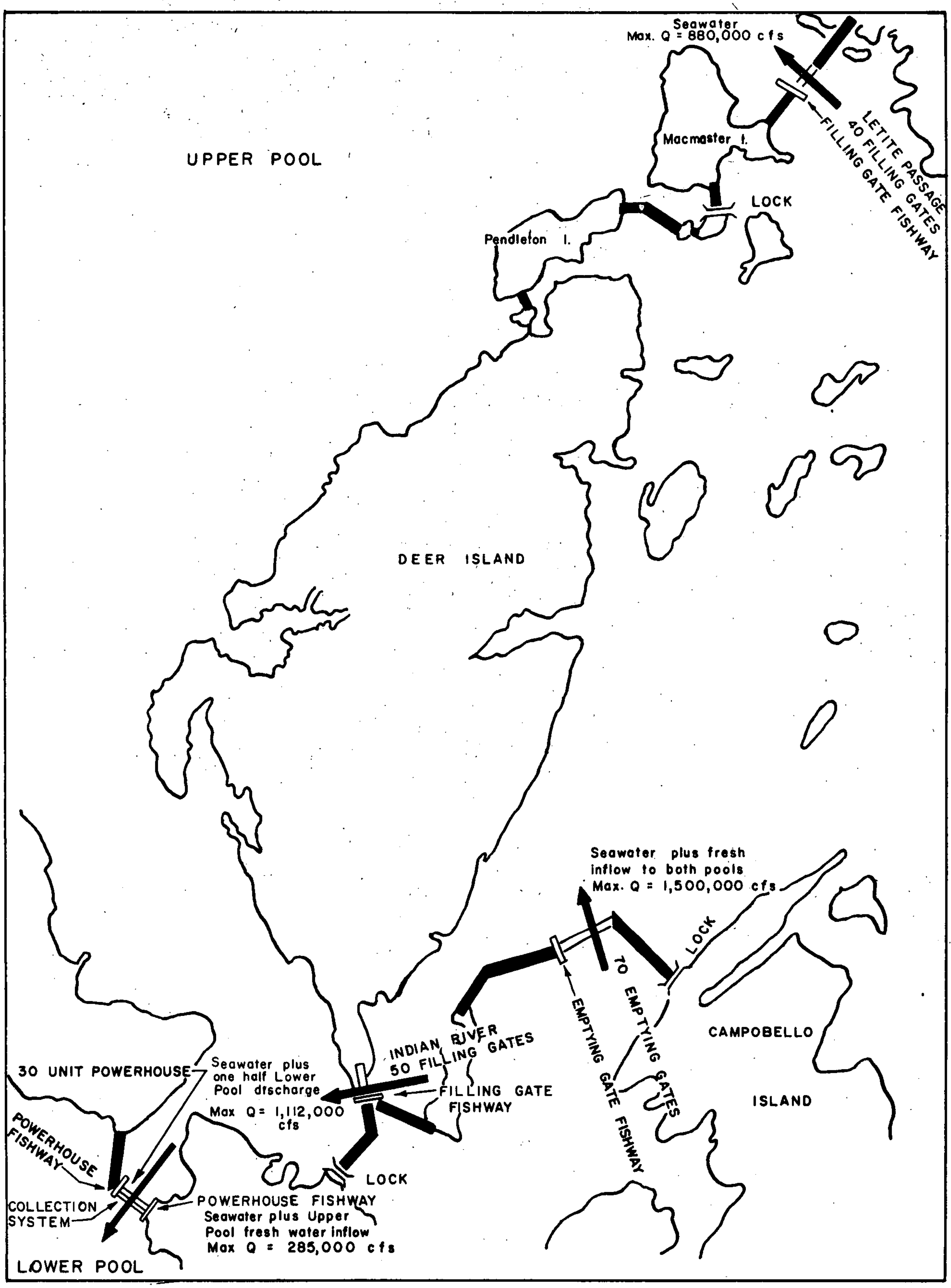

Figure 1. General layout showing location of facilities described in report.

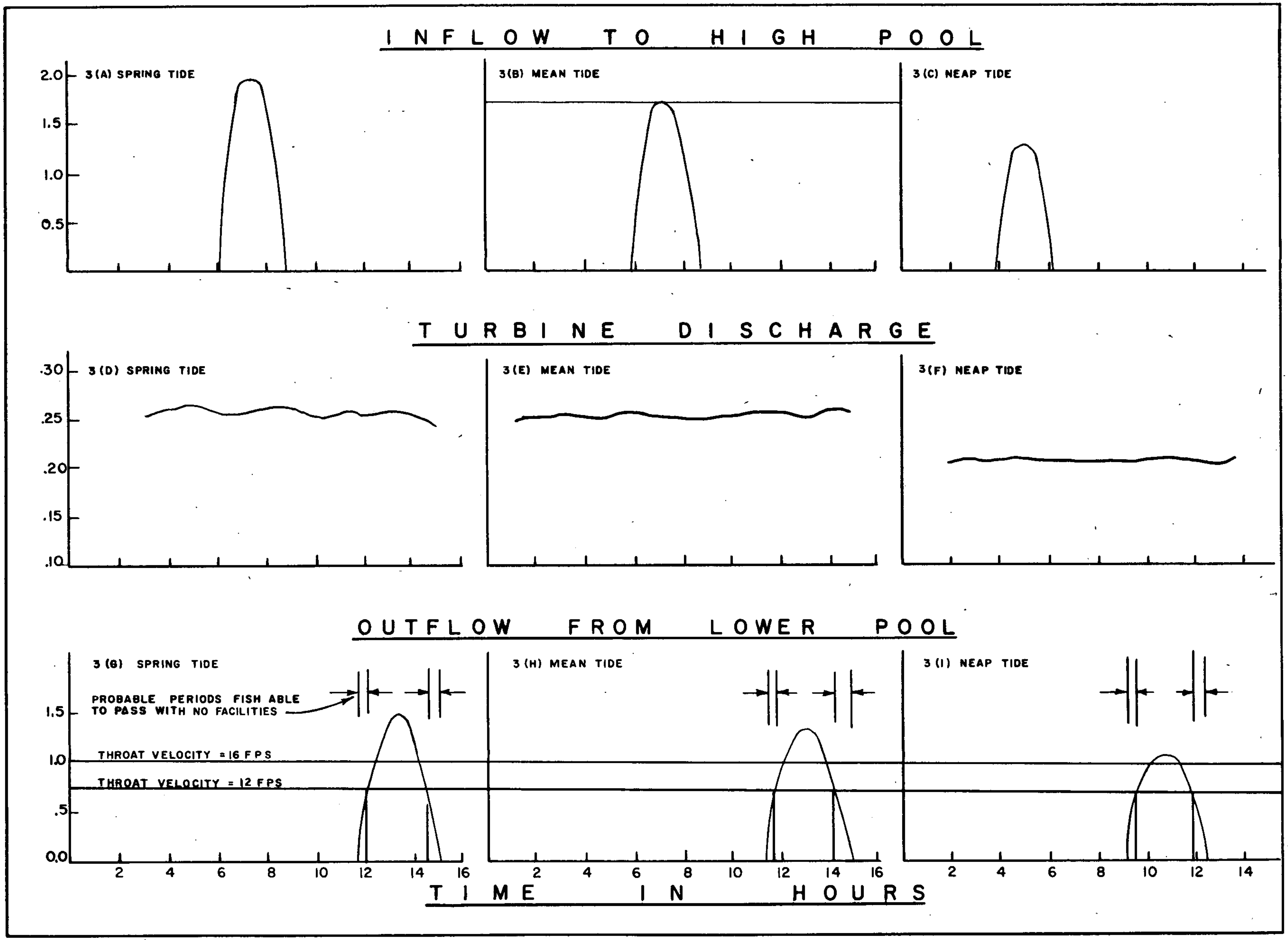

Figure 2. Flow conditions through high pool, through turbines, and out of low pool, for spring tide, mean tide and neap tide, with periods of fish passage.

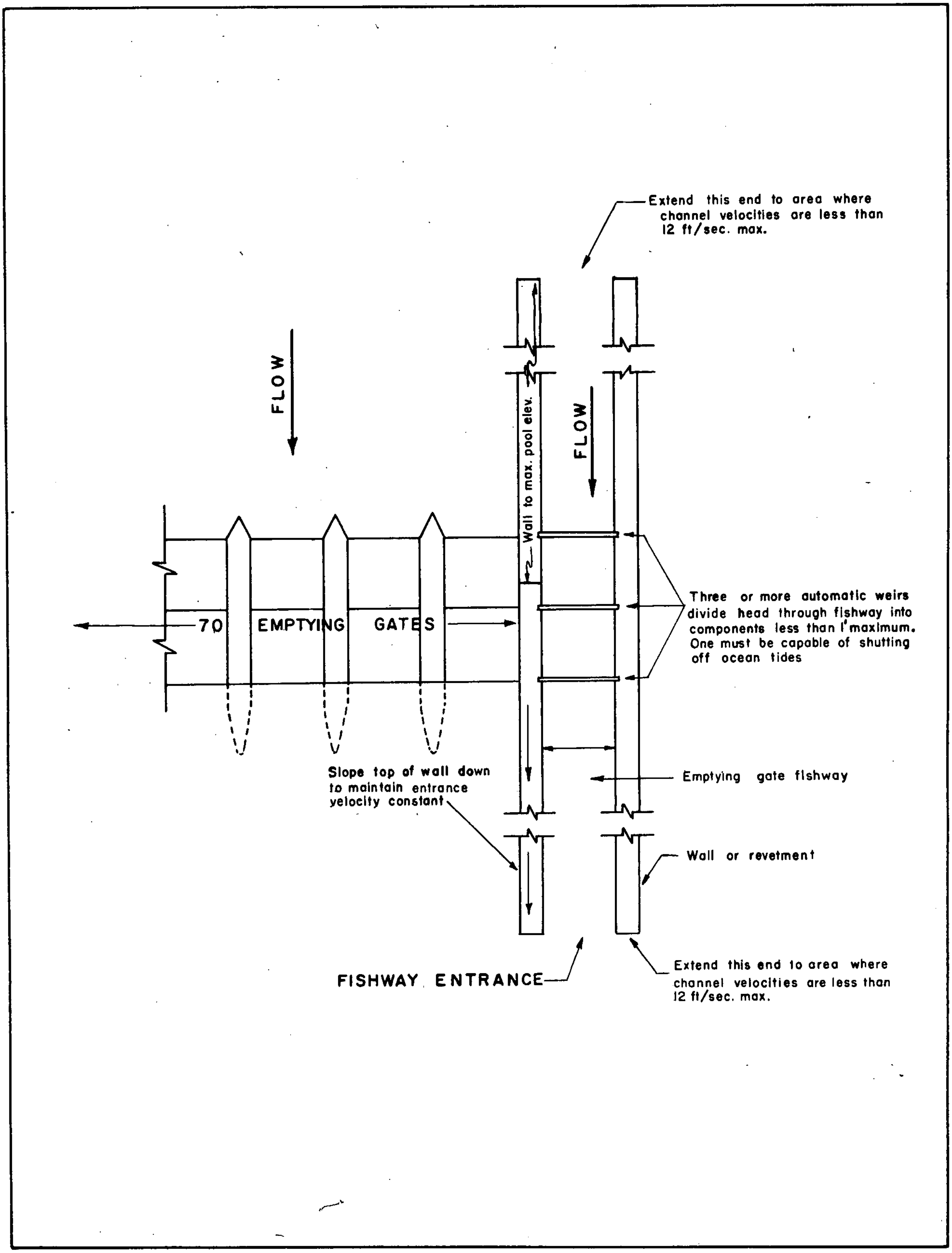

Figure 3. Fishway at 70 emptying gates.

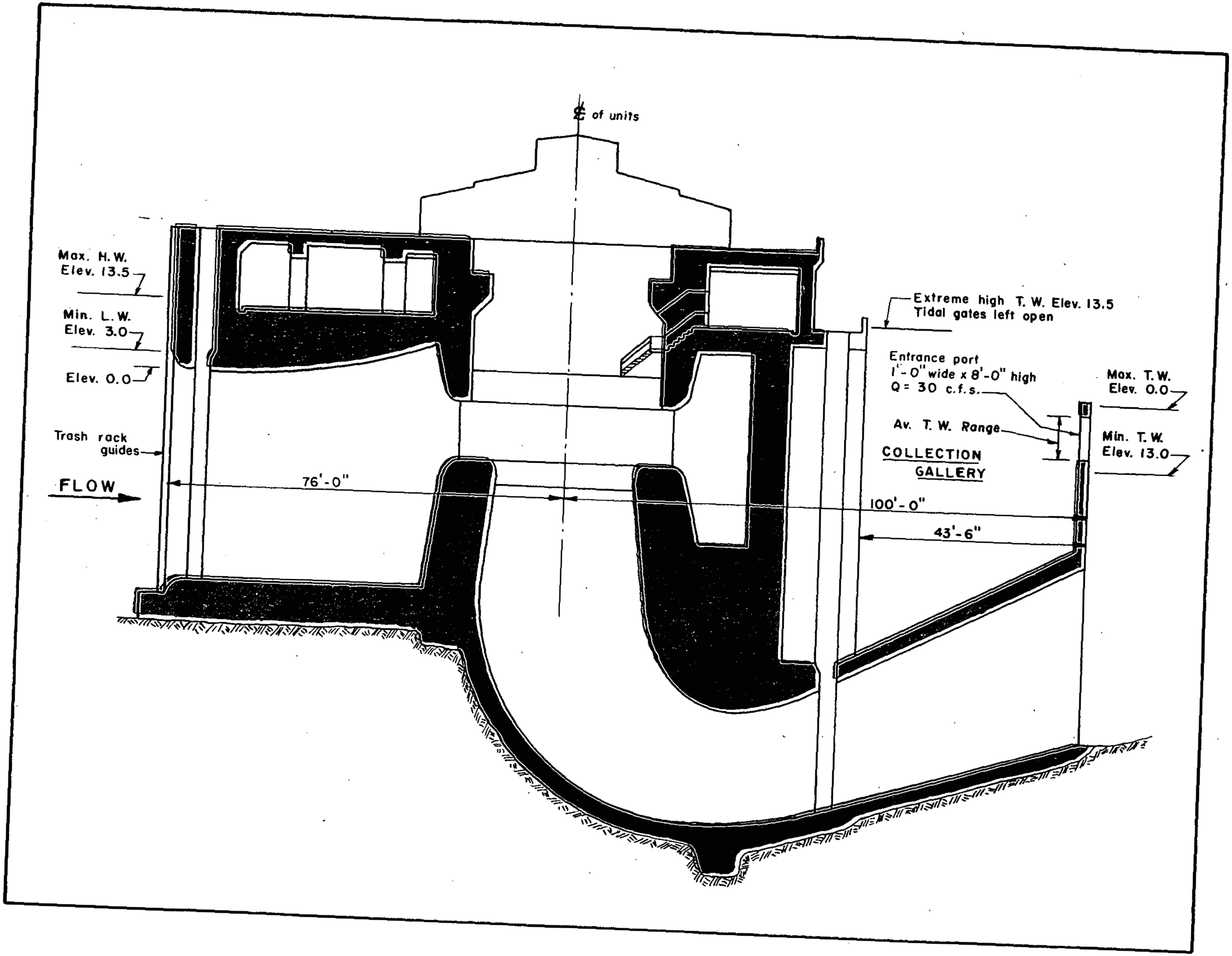

Figure 4. Powerhouse collection system.

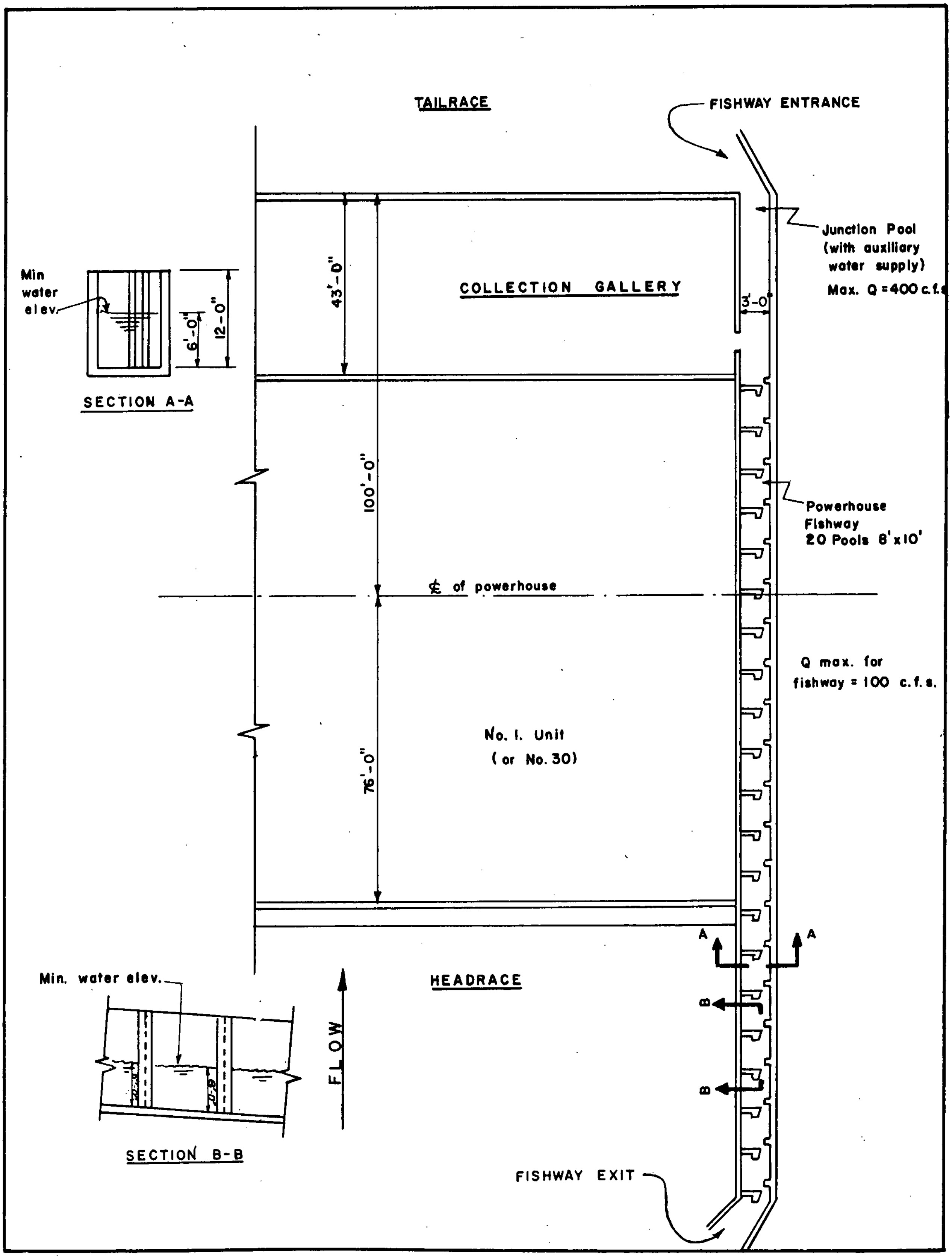

Figure 5. Powerhouse fishway and collection gallery.

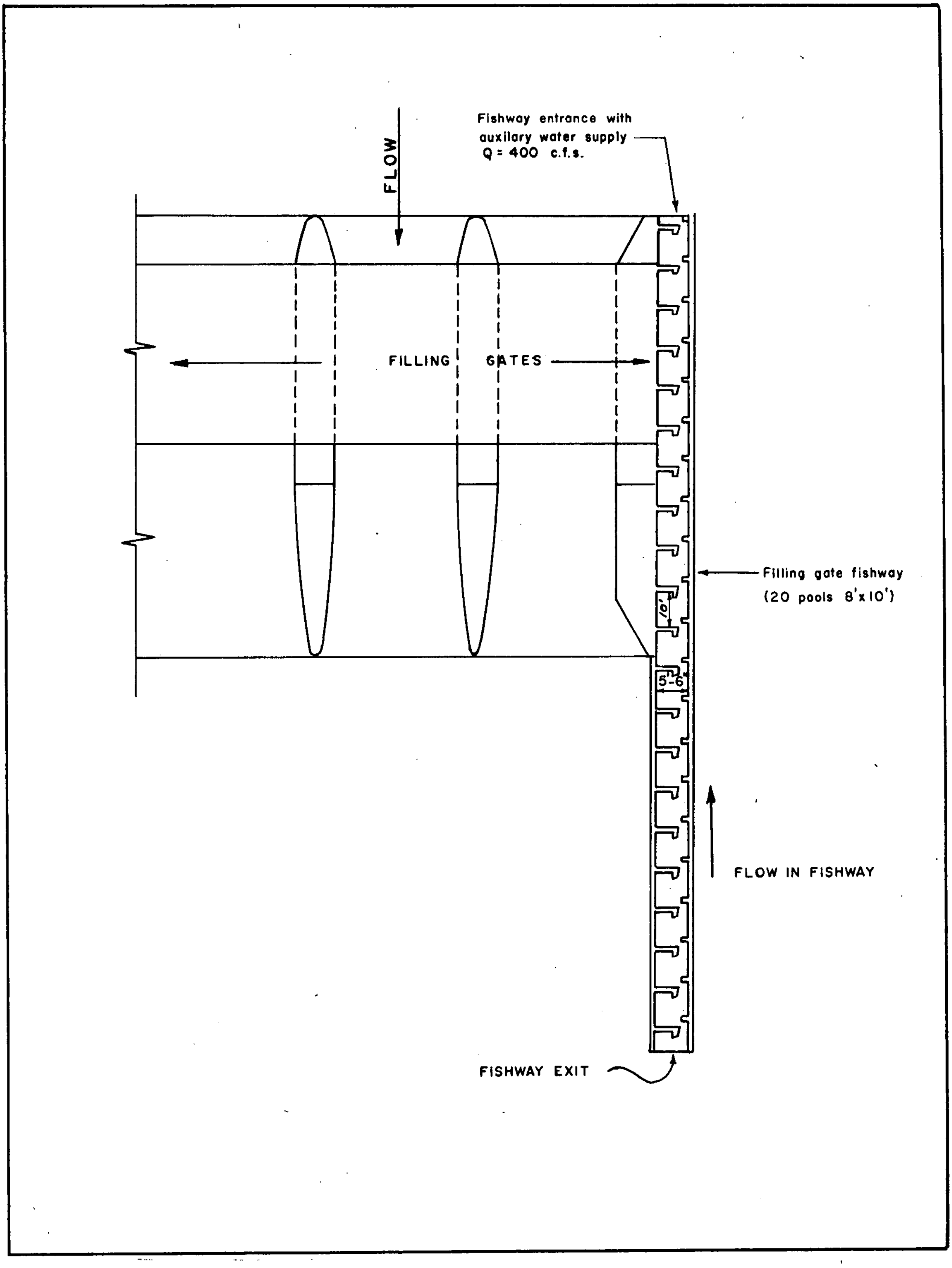

Figure 6. Fishway for filling gates.