SECTION A

A-1

RELATION OF TEMPERATURE TO FISH ABUNDANCE AND DISTRIBUTION IN THE SOUTHERN NEW ENGLAND AREA.[1]

By

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ABSTRACT

Information is presented on the distribution of a number of species of southern New England fishes that typically migrate offshore during the winter months. Depth and temperature preferences are discussed. Seasonal changes in the abundance of eight species on an inshore fishing ground, the Southwest Ground near Block Island, are described for the period 1956-58. The relation of these changes to temperature is discussed. The seasonal changes observed on the Southwest Ground demonstrate that these species tend to be most abundant on inshore grounds when water temperatures are the same as those in which they occur most abundantly offshore. Some of the factors that complicate the analysis of seasonal changes in abundance are briefly discussed. These include size, sex, and the effect of temperature or other hydrographic events such as the fall overturn on availability.

INTRODUCTION

The first United States Commissioner of Fisheries, S. F. Baird, undertook an investigation of the life histories of various commercial species common to the southern New England area by soliciting the testimony of knowledgeable fishermen, trap operators and others. To the question concerning the seasonal movements of scup, Mr W. E. Whalley of Newport, Rhode Island, replied as follows:

> "They expected them in February, and got the seines ready. They had them in the water in March. I always judge by the dandelions; when I see the first dandelion, scup come in; I watch the buds, and when the buds are swelled full, then our traps go in. When the dandelion goes out of bloom and goes to seed, the scup are gone; that is true one year with another, though they vary with the season. I am guided by the blossoms of other kinds of plants for other fish. When high blackberries are in bloom, we catch striped bass that weigh from twelve to twenty pounds; when the blue violets are in blossom—they come early—you can catch the small scoot-bass. That has always been my rule, that has been handed down by my forefathers".

Although this testimony is nearly 100 yr old, it is not easy to improve upon it today.

Fishery biologists tacitly agree that temperature is an important factor in the determination of general distribution and seasonal abundance. It is difficult however to demonstrate and quantify the role of temperature, simply because of the lack of concomitant fishery and temperature data for most marine areas; and because of the difficulty of establishing the causality involved n implied relationships. While much still remains to be desired, the general temperature cycle s well known and abundant fishery data exist for the southern New England area, sufficient at east to justify a study of the relation of temperature to variations in seasonal abundance.

Early in the 1950's, a sizeable industrial trawl fishery developed in New England, particularly at Point Judith, Rhode Island. This fishery was unusual in that all fish taken in the trawl were anded. Food fish were sorted out and sold at the local cooperative, and the rest of the catch old at a nearby reduction plant. The general aspects of this fishery have been reported upon by dwards and Lux (1958). The species composition of that portion of the catch sold for reduction n 1957 and 1958 has been reported by Edwards (1958) and Edwards and Lawday (1960). By 1960 this ishery virtually ceased to exist at Point Judith. The fishing activities had however been carefully documented for the period July 1955-60 inclusive.

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DIVERSITY INDEX STUDIES

The first attempt to interpret the industrial trawl fishery data involved the calculation of various indices of species diversity, especially Fisher's (Fisher, *et al.*, 1943) alpha[3]. There was a relation between bottom temperature and alpha, particularly on those fishing grounds nearest to land. The values of alpha obtained for one of these, the Southwest Ground, are given in Table 1. Combining samples, as for example the bimonthly combinations given in Table 1 or the combining of samples from nearby grounds of the same depth, tended to strengthen the relation between temperature and alpha, and suggested as well that very large samples were required to obtain reliable values for individual grounds or smaller units of time. As it was, over 55,000 fish were involved in the Southwest Ground samples used for the analysis summarized in Table 1.

TABLE 1. ALPHAS FOR SOUTHWEST GROUND, FOR 1956-58, BY MONTH, FOR ALL MONTHLY SAMPLES COMBINED, AND FOR EACH BIMONTHLY PERIOD, ALL SAMPLES COMBINED.

	1956	1957	1958	Average alpha	Alpha, all samples combined	Alpha bimonthly values, all samples combined		Bottom water temp- erature °C
Jan.	2.16	3.13	--	2.65	2.55	+Feb.	2.45	6.0
Febr.	1.76	1.98	2.53	2.09	2.01	+Mar.	2.39	3.8
Mar.	2.69	2.36	2.48	2.51	2.42	+Apr.	2.92	3.3
Apr.	3.54	2.67	2.69	2.97	2.80	+May	3.07	4.8
May	2.80	2.78	2.89	2.82	3.00	+June	3.32	7.0
June	2.80	2.56	3.31	2.89	3.30	+July	3.68	11.2
July	2.93	3.23	2.87	3.01	3.55	+Aug.	3.78	12.0
Aug.	2.65	2.86	2.36	2.62	3.22	+Sept.	3.77	13.3
Sept.	2.90	3.09	3.18	3.06	3.38	+Oct.	3.59	14.2
Oct.	2.82	3.26	3.01	3.03	3.58	+Nov.	3.91	14.2
Nov.	2.46	2.28	3.09	2.61	3.35	+Dec.	3.20	12.6
Dec.	2.60	2.41	2.47	2.49	2.45	+Jan.	2.77	7.0

SOUTHERN NEW ENGLAND SPECIES

In very broad terms, the species in the southern New England area may be divided into two groups. The first is a summer or warm water complex, and includes the red hake (*Urophycis chuss*), silver hake (*Merluccius bilinearis*), scup (*Stenotomus chrysops*), butterfish (*Poronotus triacanthus*), fluke, or summer flounder (*Paralichthys dentatus*), angler (*Lophius americanus*) and about twenty additional species of lesser abundance. Most of these species migrate offshore and southward to the edge of the Continental Shelf during the winter months. During the cold months of the year, a second group of species, fewer in number and considerably smaller in biomass, dominate the grounds. The group includes, among others, the cod (*Gadus morhua*), ocean pout (*Macrozoarces americanus*), yellowtail flounder (*Limanda ferruginea*) and the longhorned sculpin (*Myoxocephalus octodecimspinosus*). During the warmer months of the year these species either move offshore or eastward toward the Gulf of Maine.

WINTER DISTRIBUTION

The fishes characteristically occurring inshore during the warm months of the year migrate offshore and southward during the winter months as mentioned above. During winter months as shown in Fig. 1., inshore water temperatures approach 0°C. Temperatures increase rapidly with depth, reaching a maximum of 12° to 14°C. between 100 and 125 m. This warm water zone is characteristic of the shelf edge from Cape Cod to Cape Hatteras. Beyond the warm zone temperatures slowly decrease as depth increases, but seldom decrease to much less than 6°C. at 250 m.

The numbers of individuals of some of the species collected at the time the data for Fig. 1 were obtained are given in Table 2. More extensive distributional data were obtained in 1959 on

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[3] $S = \alpha \ln (N/\alpha+1)$, where S is the number of species and N the total number of individuals.

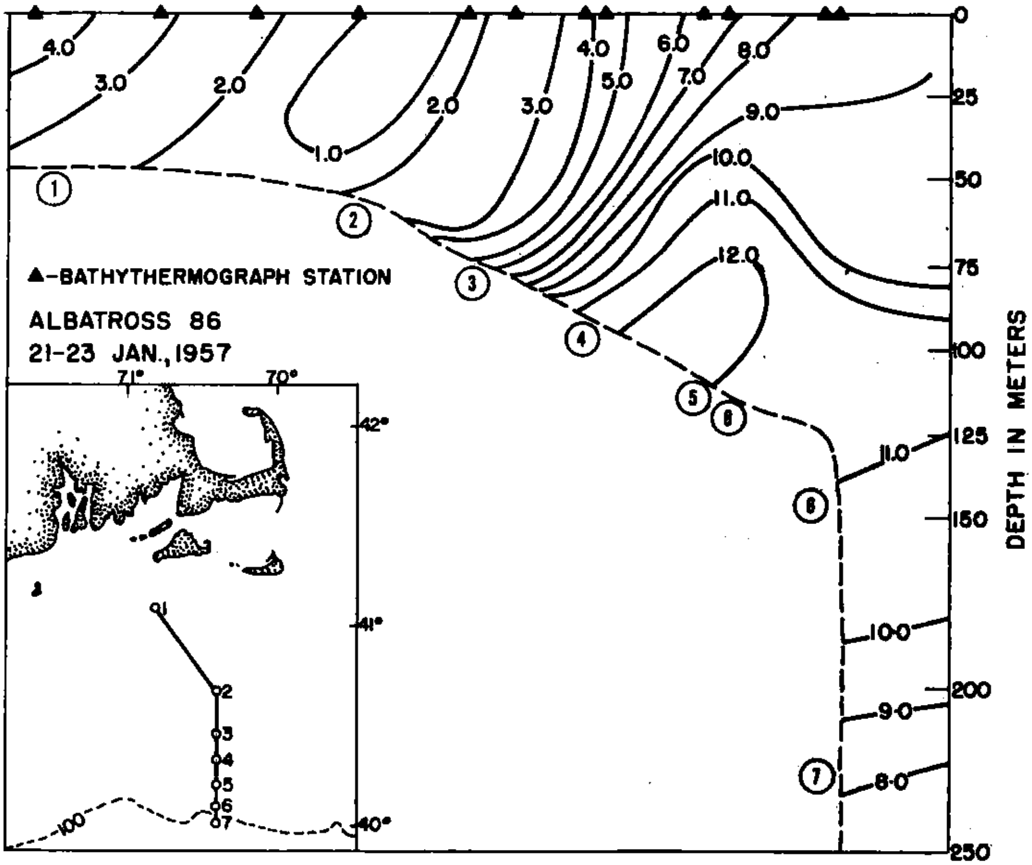

Fig. 1. Water temperatures and fishing station locations (circled), based on data collected on *Albatross III* cruise 86, 21-23 January, 1957. Transect runs south from Martha's Vineyard.

lbatross III Cruise 126 (Edwards, *et al.* 1961). These data are presented diagrammatically in Fig. . The values given represent the relative (percent) number per tow for each temperature interval iven. The number of tows was insufficient to break down the data for temperatures less than 10°C.

Two species, the scup and fluke, were most abundant in the warmer water and both were more bundant on the shoaler side of the warm water zone. The fluke was not often taken on this par- icular cruise and the data obtained indicate a sample bias toward colder water not in accord with ther observations, as for example those of Cruise 86 given in Table 2.

The butterfish was most abundant in waters with a temperature of about 11° C , regardless of epth. Similarly distributed, but with a preference for even colder water (9° to 10°C), the red ake also appeared to disregard depth.

While the angler was most frequently taken in water of any depth with temperatures from 8° to °C , it was clearly more abundant at depths of 125-200 m. Silver hake as well tended to be more bundant in deeper water but generally did not occur where temperatures were much below 9°C except or young-of-the-year silver hake which were taken only in the relatively cold shoal water. A eneral tendency for this species to prefer progressively warmer water as it increases in size was bserved.

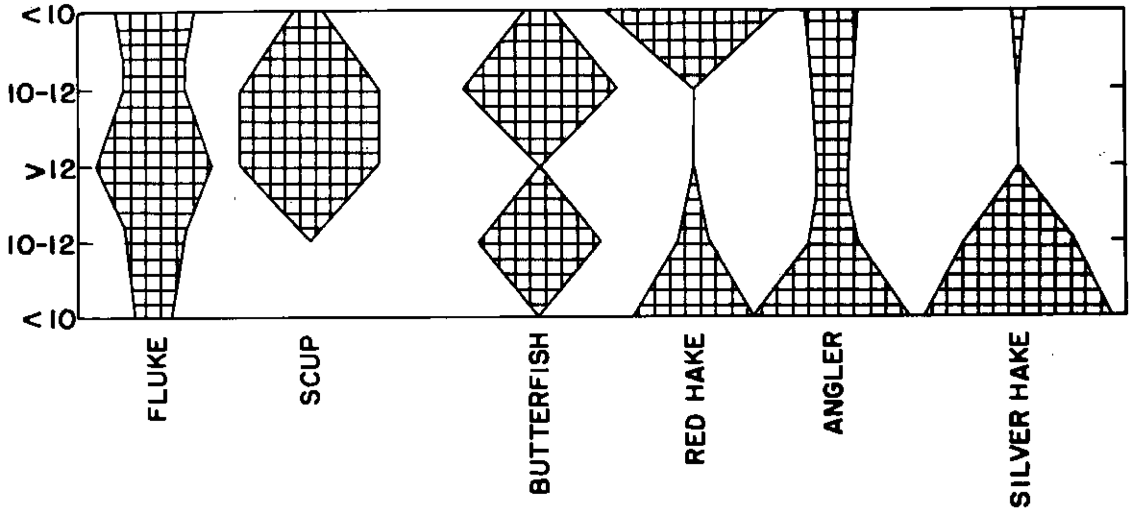

Fig. 2. Diagrammatic presentation of the relative (percentage) catch/tow data. Depth increases from top to bottom, the warmest water occurs between 100-125 m.

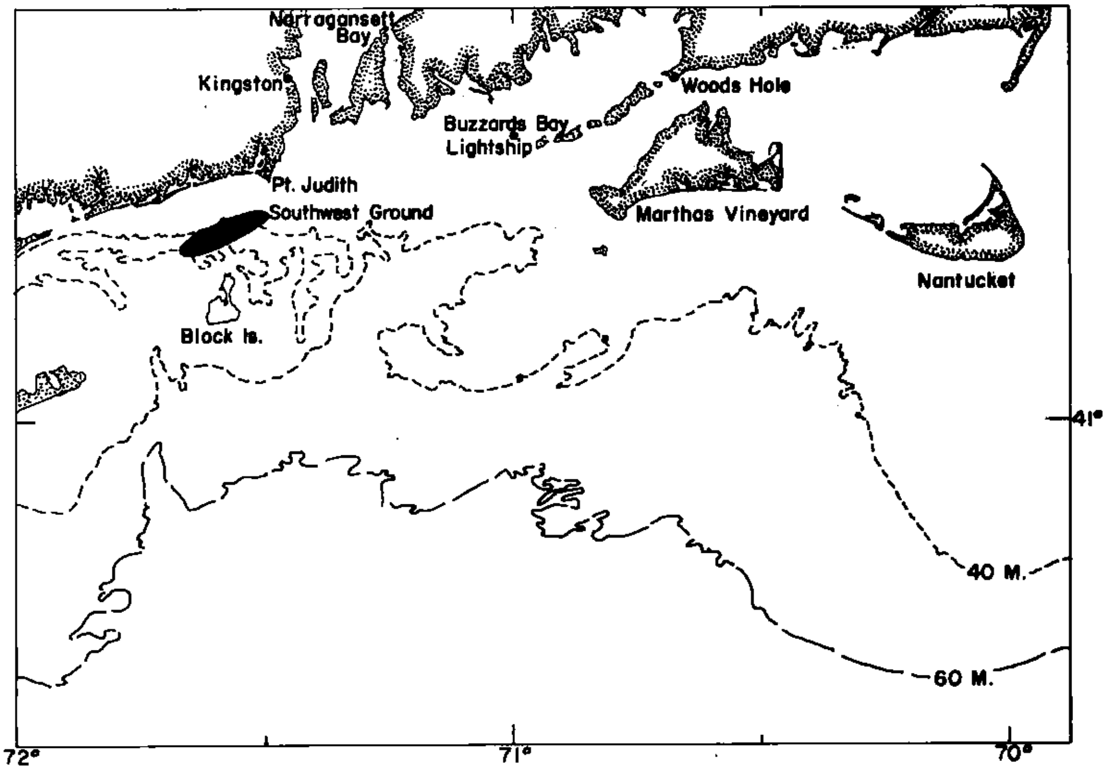

Fig. 3. Map of the southern New England area showing location of Southwest Ground and surface temperature stations.

TABLE 2. NUMBERS OF SELECTED SPECIES CAUGHT AT STATIONS SHOWN ON FIG.1. ASTERISK INDICATES YOUNG-OF-THE-YEAR.

	STATION NUMBER							
	1	2	3	4	5	8	6	7
Bottom temperature °C	2.8	2.2	6.7	11.1	11.9	11.6	11.0	8.4
Depth (m)	50	60	70	85	110	115	145	230
Fluke				12	5			
Scup				19	1			
Butterfish				695	21			
Red hake		18	102	1				
Silver hake	*6	*560	223	11		1		28
Angler	2	6	7	1		1		6
Cod		9						
Ocean pout	1	2						

SEASONAL CHANGES ON THE SOUTHWEST GROUND

Water temperatures.

The Southwest Ground (Fig. 3) lies between Block Island and the coast of Rhode Island. The depths fished by commercial fishermen varied from 40 to 50 m. The seasonal cycle of temperature for waters 50 m in depth in this immediate area is shown in Fig. 4. Temperature minima of about 3°C occur in late February or early March, and maxima of about 20°C at the surface in August and 15°C at the bottom in September and October. Overturn begins toward the end of September and usually is complete by the end of October. Intrusions of colder bottom water in late summer almost certainly occur from time to time.

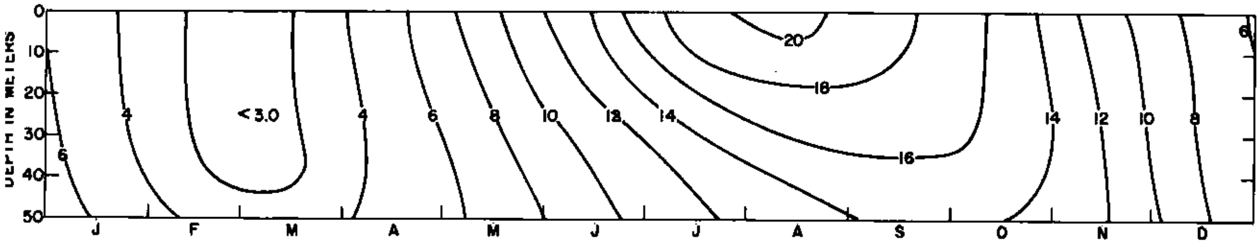

Fig. 4. Seasonal cycle of temperature for waters 50 meters in depth north of Block Island. Based on all bathythermograph data available for the period 1941-1960.

Fishery data will be presented below for the years 1956-58. The only consistently useful temperature data for this period are to be found in the surface temperature and lightship observations reported by Bumpus (1957) and Day (1959*a*, *b*). The year 1957 was a relatively warm year throughout the area south of Cape Cod. Day noted several instances of cold bottom water intrusion along the middle Atlantic coast in 1957. The data for 1958 show a tendency toward much colder water than was recorded in the previous several years. Surface temperatures at Woods Hole show the same general trends as do those at the Buzzards Bay Lightship and Kingston, Rhode Island. The records for the latter two stations are, unfortunately, incomplete for the period 1956-58.

Woods Hole surface temperature deviations for the period 1956-58 are presented in Fig. 5. The data have been smoothed by 3's to emphasize trends and reduce strictly local variations.

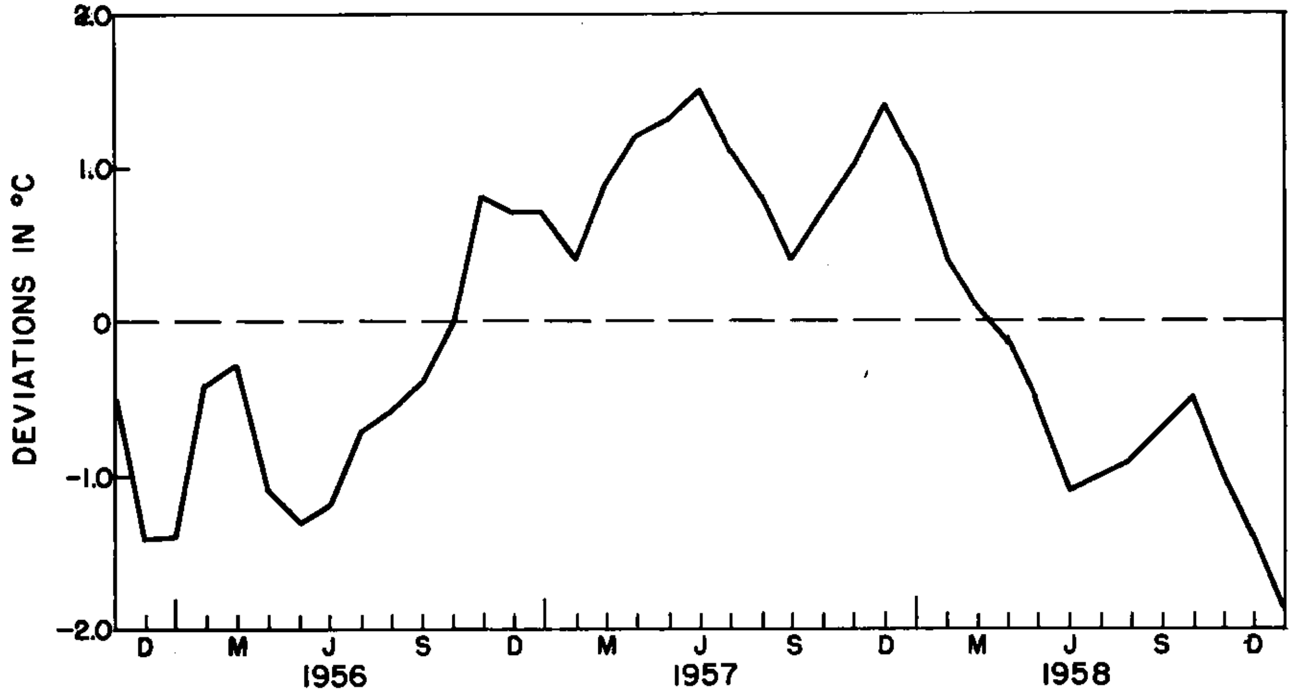

Fig. 5. Monthly deviations of Woods Hole surface temperatures, smoothed by 3's, for the period November 1955 to January 1959.

To the extent that these Woods Hole temperature deviations may also represent trends on the Southwest Ground, the following points should be kept in mind in connection with the discussions that follow. The year 1956 began relatively cold but warmed up gradually and ended with above normal temperatures. Conditions during 1957 were consistently warmer than normal. The sharp decline in the deviations for the summer months may indicate that the cold water intrusions mentioned earlier occurred in the southern New England area as well. The combination of warmer than average surface conditions and intrusions of colder bottom water would tend to delay overturn. Beginning with temperatures significantly above normal, 1958 temperatures became progressively colder than average and the year ended with below normal temperatures. It may be assumed that bottom temperatures varied in much the same manner except for that period (June - September) when thermal stratification was marked.

Catch/hour data

Table 3 lists the average monthly catch/hour for the eight species discussed below. Data are presented for the period 1956-58. The Southwest Ground is fished only during daylight hours; thus no adjustment was required for diurnal variations in availability. The vessels that prosecuted this fishery were all small otter trawlers, mostly less than 20 m in length. The codends of the trawls were invariably lined with netting having a stretched mesh size of 5 - 6 cm.

For the purposes of discussion, these data were transformed into relative (percentage) catch/hour figures for each year separately to eliminate the bias caused by variation in year class strength.

Fluke;Fig. 6,7

Fluke first arrive in moderate abundance in May and June and are most abundant on the Southwest Ground at the time of maximum bottom temperatures as shown in Fig. 6a. The data for each year separately show essentially the same changes, September in each case showing maximal relative abundance. Fish were on the grounds for the longest period in 1957, arriving in measurable numbers in March. They were present for the shortest period in 1958. In the spring these fish move through the grounds to other areas that are both shoaler and warmer at this time. As temperatures increase, the fluke gradually leaves the shoaler waters and the abundance again slowly increases on the Southwest Ground. At or about the time of overturn (data to establish the exact dates of overturn for the Southwest Ground do not exist) there is usually a marked increase in the catch/hour for a short period of time after which fluke rapidly depart from the ground. The bar diagram of the changes in catch/hour on a 5 day period basis, Fig. 7, illustrates this point. The somewhat anomalous data for 1957 are especially interesting in view of the postulated delay of overturn.

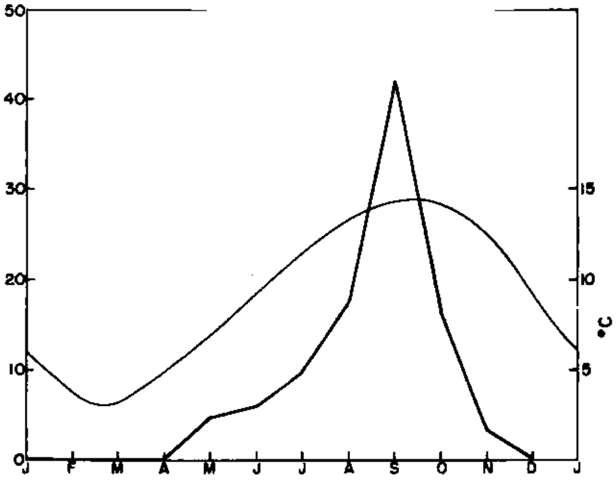

Fig. 6a. Seasonal changes in fluke abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

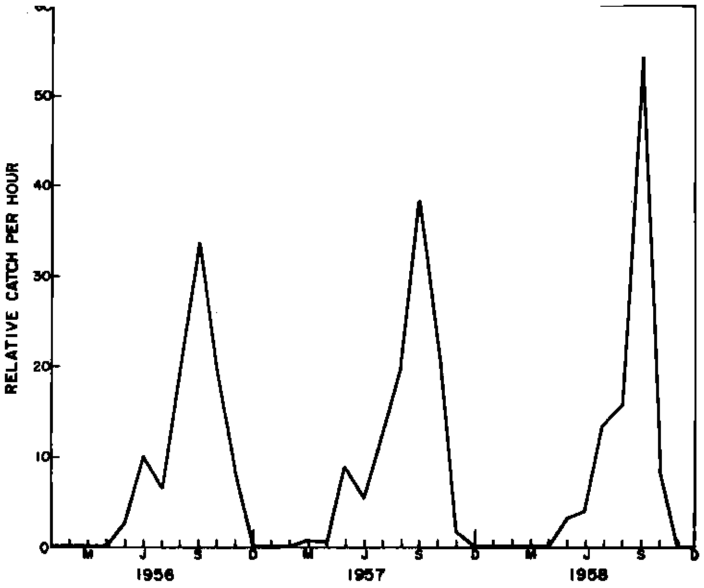

Fig. 6b. Yearly variation in seasonal changes of fluke abundance.

Scup; Fig. 8

The scup shows approximately the same seasonal abundance changes as the fluke. They first appear in number in April or May, at which time they are on their way to inshore spawning grounds where the water temperatures average 8° to 10°C. They move into deeper water as the season progresses and are most abundant at the time of highest bottom temperatures. Again as was the case with the fluke, they were present for the longest period of time in 1957. The offshore migration of the scup also begins at about the time of overturn and they are virtually gone from inshore grounds in November.

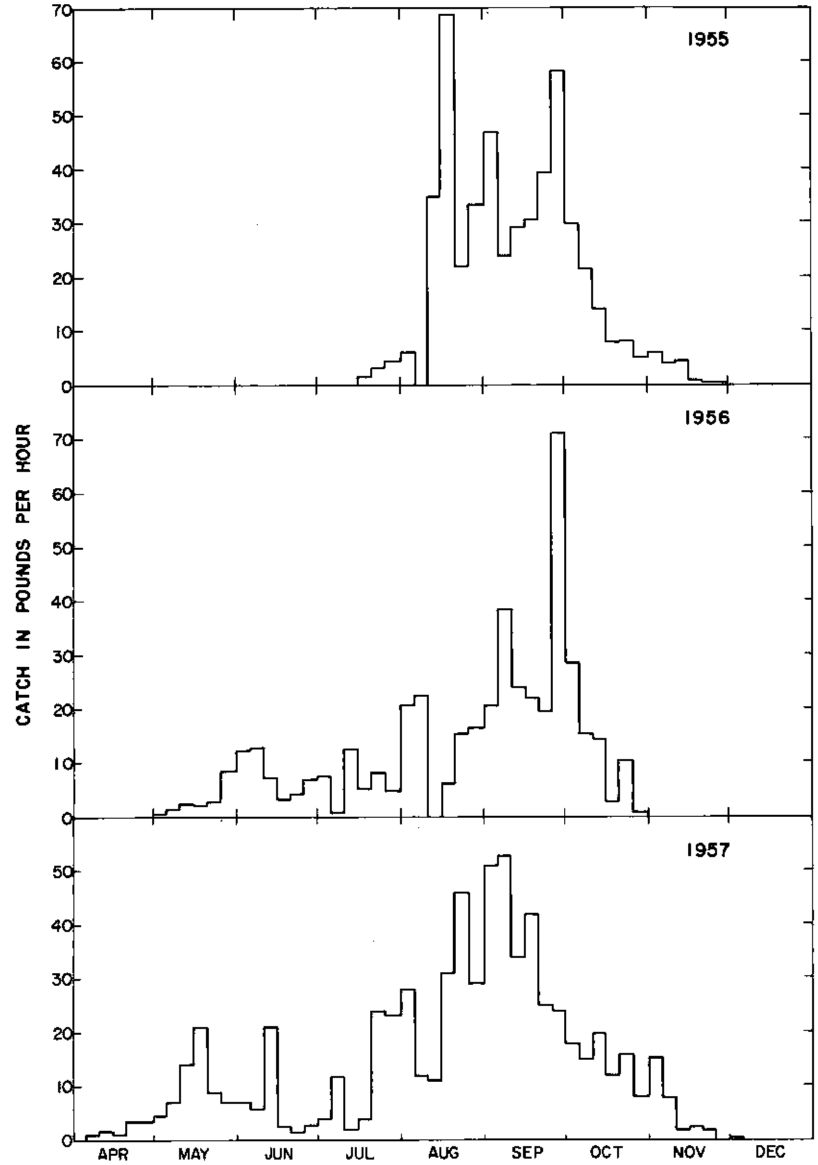

Fig. 7. Variation in the catch/hour of fluke on the Southwest Ground by 5 day periods, July 1955-December 1957.

Butterfish; Fig. 9

The butterfish is a widely ranging, quasi-pelagic species. Unlike the scup and fluke it frequently occurs in considerable numbers during the summer in the Gulf of Maine to the north and east. Historically its occurrence on the Southwest Ground is more erratic than any of the other principal species. Butterfish reach their peak seasonal abundance in November when the water temperature at the bottom is around 12°C. This species showed up earliest (April) in 1957 and generally was more abundant throughout the season in this year.

TABLE 3. CATCH PER HOUR TO NEAREST POUND OF VARIOUS SPECIES ON THE SOUTHWEST GROUND, BY MONTH, 1956 THROUGH 1958.

Species		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Fluke	'56	--	--	--	+	2	8	6	15	28	17	7	+
	'57	+	--	1	+	7	4	1	16	30	19	1	--
	'58	--	--	--	+	3	4	13	14	50	8	+	--
	Average	--	--	+	+	4	5	9	15	36	14	3	+
Scup	'56	--	--	--	--	13	4	17	21	41	76	1	+
	'57	--	--	--	1	6	4	5	12	8	15	2	--
	'58	--	--	--	--	19	26	33	52	82	33	1	+
	Average	--	--	--	+	13	12	18	28	44	41	1	+
Butterfish	'56	--	--	--	--	+	4	3	6	2	3	45	19
	'57	+	--	--	+	+	3	3	12	36	46	158	4
	'58	+	--	--	--	+	2	1	10	3	7	4	16
	Average	+	--	--	+	+	3	2	9	14	19	69	13
Silver hake	'56	40	--	+	1	183	269	504	557	987	1048	1889	817
	'57	292	285	30	79	356	735	423	865	731	841	624	414
	'58	98	8	3	1	145	187	300	558	603	552	338	507
	Average	144	98	11	27	228	397	409	660	774	814	951	579
Red hake	'56	5	--	--	4	512	334	127	256	378	451	580	194
	'57	30	17	10	42	364	529	175	289	70	81	119	43
	'58	--	5	4	9	513	279	117	128	363	456	1167	291
	Average	12	7	5	18	463	381	140	224	270	329	622	176
Angler	'56	75	--	19	8	86	123	101	16	54	30	35	167
	'57	60	71	79	57	25	124	88	129	--	47	109	378
	'58	319	24	18	35	169	209	232	114	125	128	161	157
	Average	151	32	39	33	93	152	140	86	60	68	102	234
Ocean pout	'56	51	220	392	103	186	37	--	--	--	--	--	172
	'57	223	478	445	296	307	42	16	+	--	--	--	4
	'58	44	378	440	463	212	38	22	+	2	--	5	6
	Average	106	359	429	288	235	39	13	+	1	--	2	61
Cod	'56	40	61	56	11	6	4	+	--	+	1	60	41
	'57	25	26	25	9	1	+	+	--	--	+	46	48
	'58	41	71	39	30	9	+	+	+	+	6	70	74
	Average	35	53	40	16	5	1	+	+	+	2	59	54

Silver hake; Fig. 10

Seasonal changes in relative abundance closely follow the seasonal temperature changes. Peak abundance is indicated for November but it should be noted (Table 3) that this may be the result of an atypical situation in November 1956. As mentioned before, the larger the silver hake, the warmer the water they appear to prefer. In 1956 the maximum lengths of silver hake sampled on the inshore grounds near Point Judith were as follows:

Jan. - Mar.	28 cm
Apr. - June	40 cm
July - Aug.	50 cm
Sept. - Dec.	40 cm

The fish were on the Southwest Ground for the shortest period in 1956, and year round in 1957 and 1958.

This species also occurs in the Gulf of Maine in commercial quantities during the summer months. During the early 1950's when water temperatures generally showed marked deviations on the warm side, occasional catches of silver hake were recorded from the Gulf of Maine during the winter months. Usually they depart this area early in the fall.

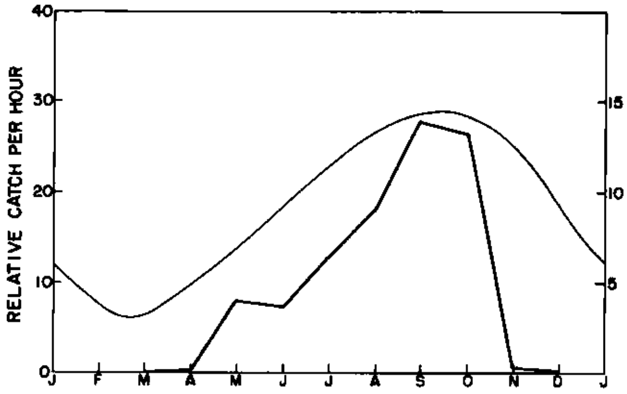

Fig. 8a. Seasonal changes in scup abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

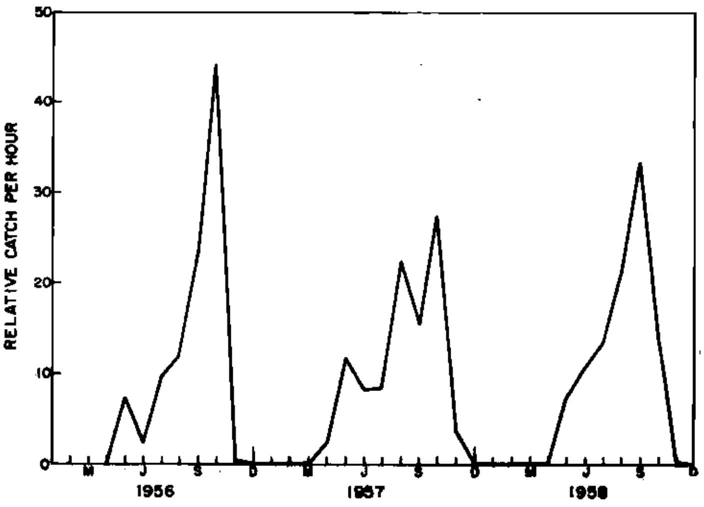

Fig. 8b. Yearly variation in seasonal changes of scup abundance.

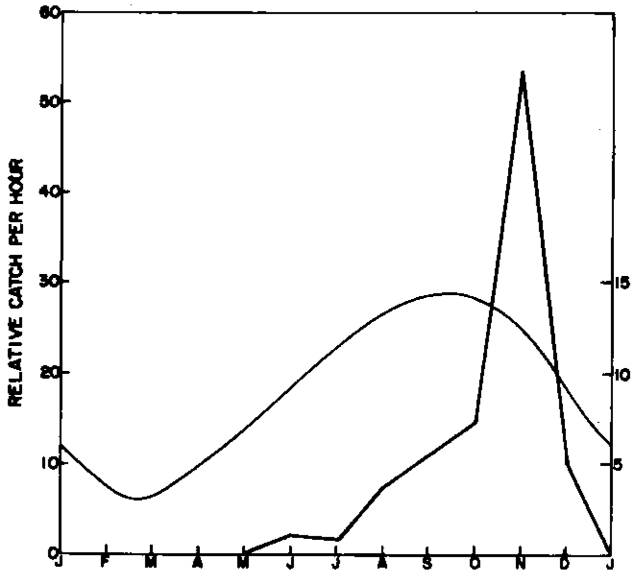

Fig. 9a. Seasonal changes in butterfish abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

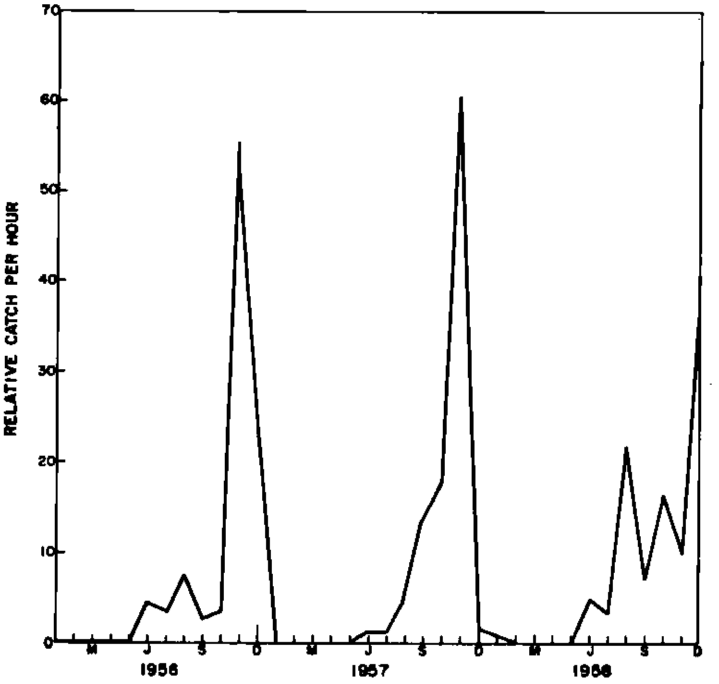

Fig. 9b. Yearly variation in seasonal changes of butterfish abundance.

Red Hake; Fig. 11

Red hake move into the Southwest Ground in great abundance late in April or early in May. As the waters warm this species tends to move into deeper, colder water to return again in number following the time of overturn. The species was on the ground throughout 1957, although generally less abundant than in 1956 or 1958. It did not return to the ground in number in the fall of 1957, probably because of the atypical hydrographic events of the year.

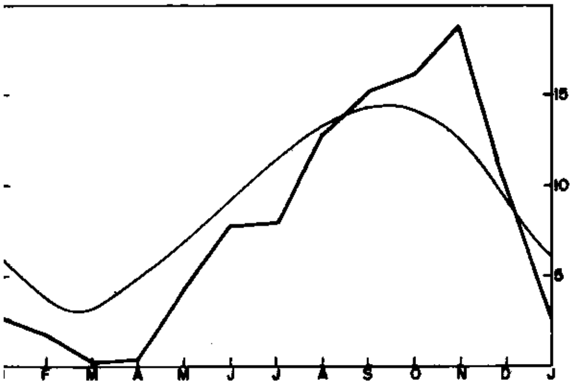

Fig. 10a. Seasonal changes in silver hake abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

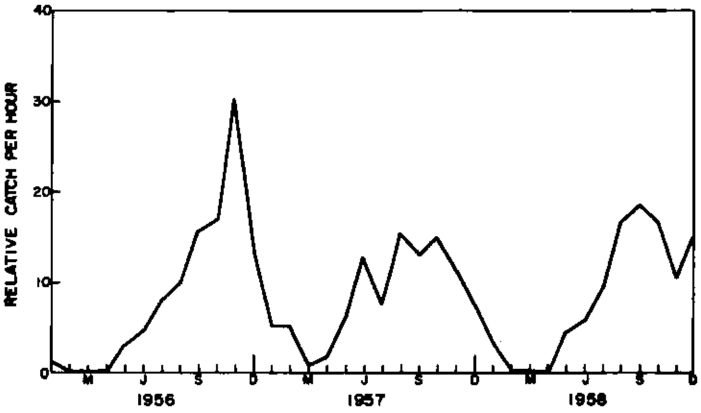

Fig. 10b. Yearly variation in seasonal changes of silver hake abundance.

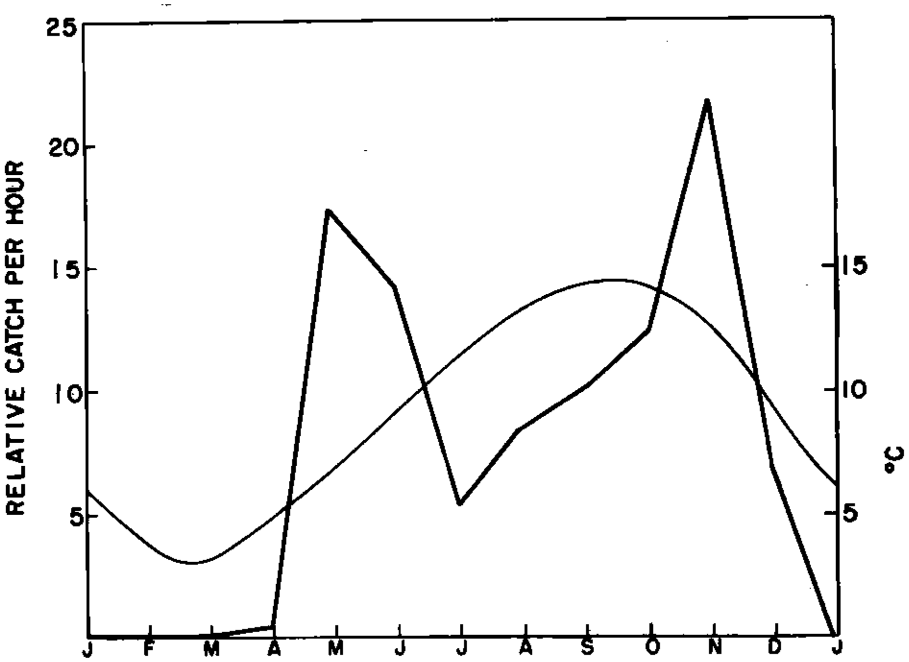

Fig. 11a. Seasonal changes in red hake abundance on the Southwest Ground, for the period 1956 through 1958, and average bottom temperature.

Angler; Fig. 12

The angler shows essentially the same type of seasonal variation in abundance as the red hake but with a preference for colder water. It is most abundant when the temperatures are about 9°C. It was present throughout 1958, the year that began relatively warm and finished on the cold side. It was entirely absent from the ground in September of 1957.

Both the angler and the red hake may occur on the ground throughout some years. Both as well occur as far north at least as the Grand Bank off Newfoundland.

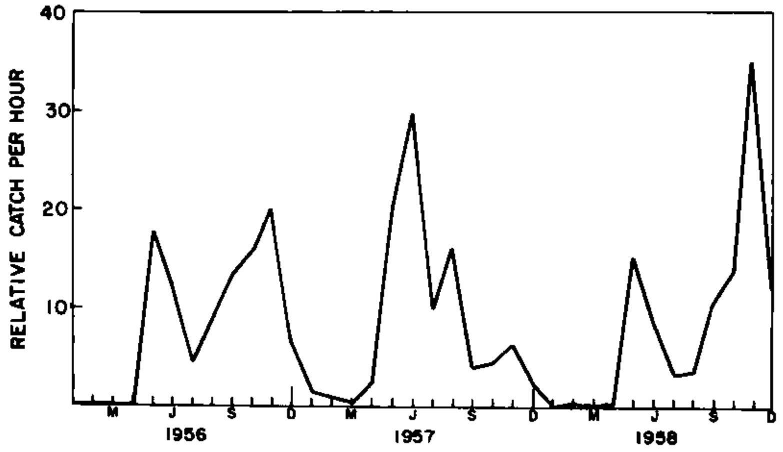

Fig. 11b. Yearly variation in seasonal changes of red hake abundance.

Ocean pout; Fig. 13

The ocean pout is clearly most abundant when water temperatures reach their minimum. They were present longest in 1958, but most abundant in terms of catch/hour in 1957. There is no substantial evidence, observational or otherwise, to suggest that the ocean pout undertakes migrations of any consequence. Olsen and Merriman (1949) have presented evidence that ocean pout are to be found on rougher, rocky bottoms, where they spawn in the summer and fall. It is suggested therefore that the changes observed may represent merely a local shift in habitat in response to temperature changes.

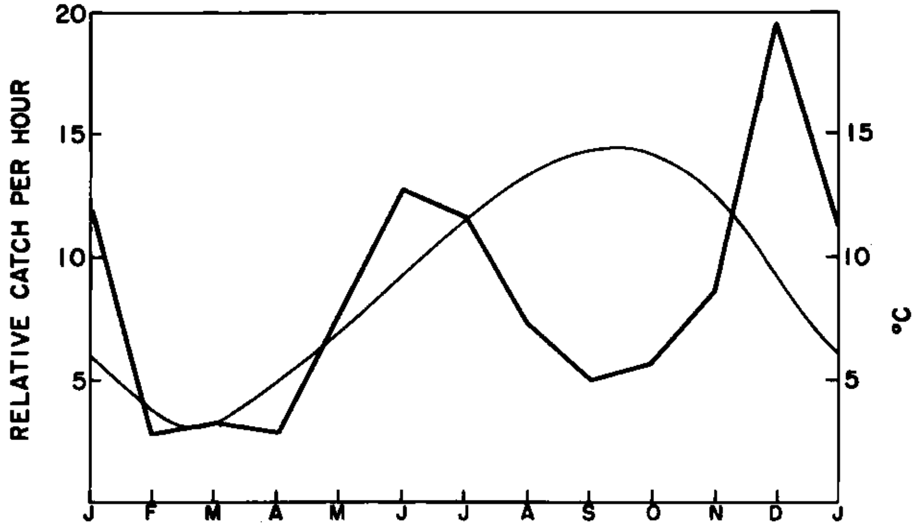

Fig. 12a. Seasonal changes in angler abundance on the Southwest Ground for the period 1956 through 1958, and average bottom temperature.

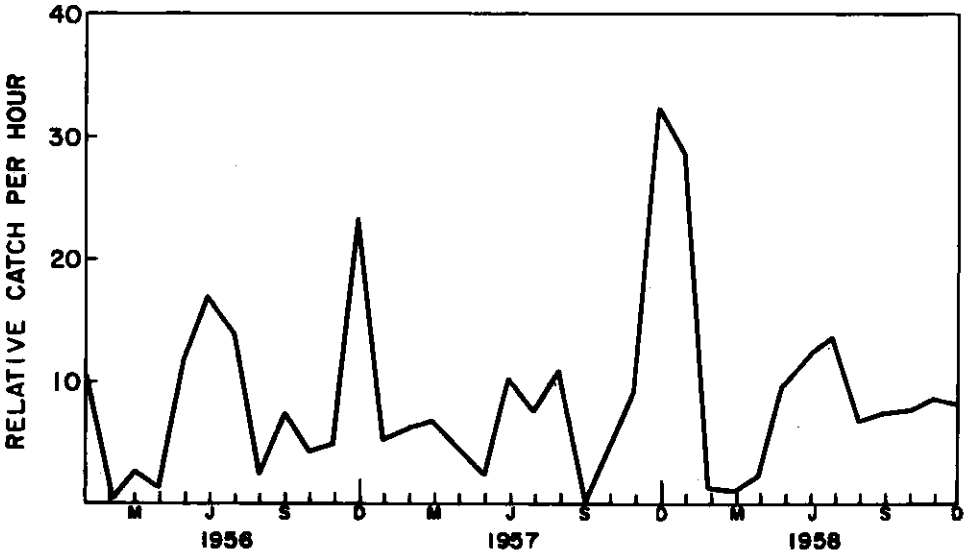

Fig. 12b. Yearly variation in seasonal changes of angler abundance.

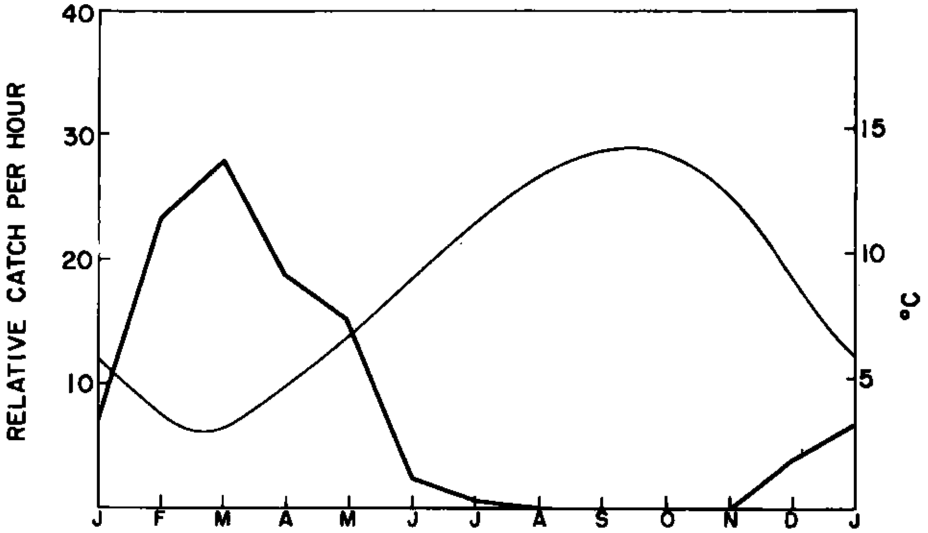

Fig. 13a. Seasonal changes in ocean pout abundance on the Southwest Ground for the period 1956 through 1958, and average bottom temperature.

Cod; Fig. 14

The cod shows essentially the same changes in seasonal abundance as the ocean pout, with the difference however that these changes are clearly associated with movements. The first peak in abundance represents a migratory wave that can be followed to the southern coast of New Jersey where these fish spawn. This group of fish arrives about 1 month after overturn. Occurring with these fish are other cod, possibly a local subgroup, which remain in the area throughout the winter (Bigelow and Schroeder, 1953, p. 186). The cod returning from the New Jersey spawning grounds do not pass through the inshore fishing grounds and thus do not show up on the Southwest Ground. The catch/hour in 1957 was considerably below that of the other 2 yr. Cod were present throughout 1958.

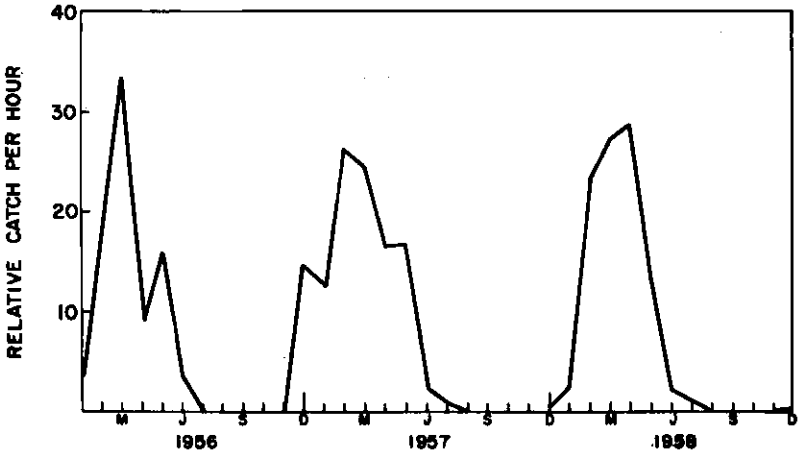

Fig. 13b. Yearly variation in seasonal changes of ocean pout abundance.

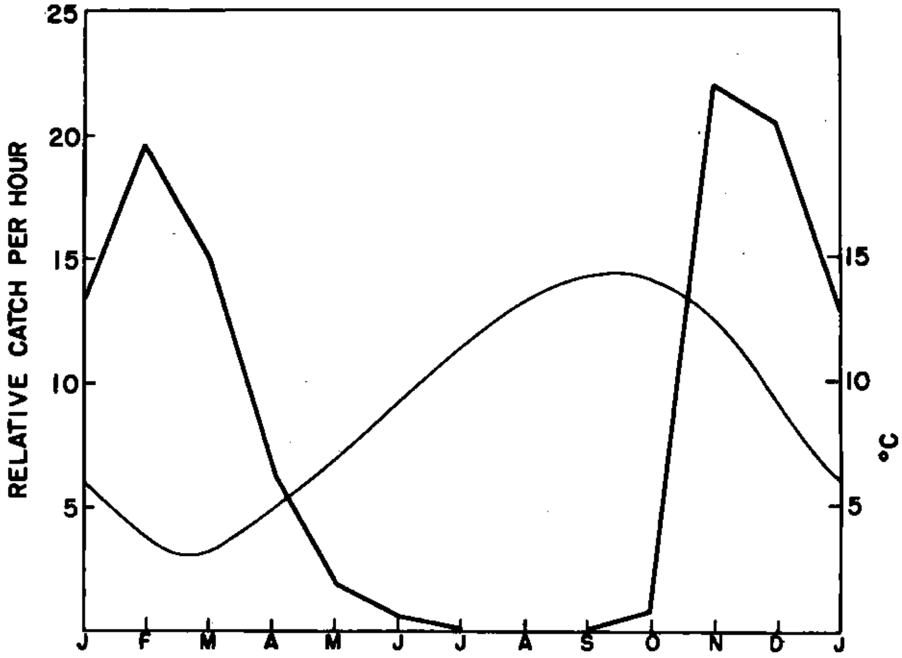

Fig. 14a. Seasonal changes in cod abundance on the Southwest Ground for the period 1956 through 1958, and average bottom temperature.

DISCUSSION

The eight species discussed above illustrate the range of seasonal variations in relative abundance observed on the Southwest Ground. More than 25 species including skates and dogfish, were taken by the industrial trawl fishery on southern New England grounds and landed in quantities greater than 1,000 metric tons a year. With the exception of the winter flounder, skates, and dogfish, these others also show seasonal changes in abundance that one might hypothesize on the basis of winter distributional data. The winter flounder inhabits the bays and estuaries of this coast where it may be found during the colder months of the year. The seasonal changes observed on the Southwest Ground would lead one to believe that it was a fish with preferences similar to those of the red hake or angler. It is however actually moving offshore as temperatures increase. The

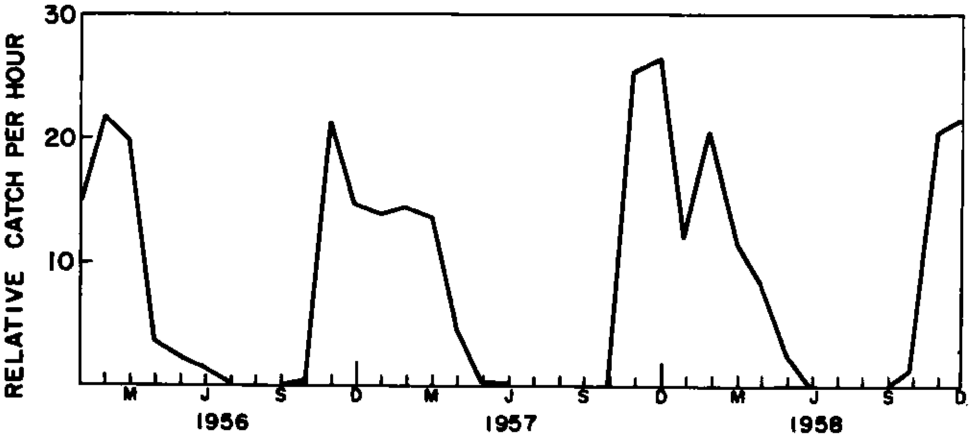

Fig. 14b. Yearly variation in seasonal changes of cod abundance.

analysis of the seasonal movements of skates and dogfish is complicated by differential movements on the parts of the two sexes. Such differential movement of the sexes may also be a factor in bony fish species but is easy to overlook since they are not so readily sexed.

The analysis of seasonal changes in abundance is further complicated by apparent changes in temperature preference on the part of different age groups. As was mentioned earlier, such appears to be the case with the silver hake and there are subtle indications in our data for other species that the phenomenon may be general. Size (or age) and sex are factors that should be considered in the experimental design of any future work.

Although the data presented here suggest that most, if not all, typical Middle Atlantic species tend to seek approximately the same temperature whether inshore in the summer or offshore in the winter, the question of availability has not been resolved. For most species the lack of fish in research vessel and commercial catches does reflect that the species has in fact left an area entirely. In others, as for example the ocean pout, the changes in seasonal abundance appear to represent a local shift to a different habitat that is not adequately sampled by the commercial fleet. The dramatic rise in catch/hour seen in the fluke at the time of overturn and that occurs within a 5 day period can only be interpreted as a change in availability whether due to aggregation or other behavioural change, or a shift in local habitat. Whatever the reason, it raises a question that must be resolved for each species. Most of the species discussed here show marked changes in availability between day and night. Fortunately, as mentioned earlier, the data presented in this paper may be presumed reasonably free of bias due to diurnal variations in abundance, since the Southwest Ground is seldom, if ever, fished after dark.

Most species arrive and depart in a relatively abrupt manner. Between arrival and departure the changes in abundance observed are more gradual and suggest that the fish are moving about the general area in a relatively passive manner with changes in relative abundance reflecting the general suitability of the area.

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A-2

SEASONAL DISTRIBUTION OF COD (*GADUS MORHUA* L.) ALONG THE CANADIAN ATLANTIC COAST IN RELATION TO WATER TEMPERATURE[1]

By

Yves Jean[2]

ABSTRACT

Seasonal relationships between size, bottom temperature and distribution of cod are described for the western Gulf of St. Lawrence and Nova Scotia Banks.

In summer, in the western Gulf of St. Lawrence, cod are distributed from 35 to 145 m at bottom temperatures from 0° to 6°C. They are most abundant at about 100 m where the temperature is around 1°C. In winter they are concentrated in 130 - 180 m along the western slope of the Laurentian Channel at bottom temperatures from 1° to 3°C.

On the Nova Scotia Banks cod are less abundant than in the Gulf of St. Lawrence. They are found mainly around Banquereau, Middle Ground and the northern edges of Sable Island Bank. Further to the west cod are replaced by haddock as the dominant species. Nova Scotia Banks cod are found in shallower and warmer waters than Gulf cod, both in summer and winter. In summer they are present from 65 to 110 m at bottom temperatures varying from about 1° to 8°C. In winter they are taken primarily at 90 - 135 m at bottom temperatures from 2° to 4°C.

Area and depth distributions of commercial catches reflect the seasonal pattern of cod migrations and distributions demonstrated in surveys and tagging studies.

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[1] Originally Contribution No. A-7, ICNAF Environmental Symposium, Rome 27 January-1 February 1964. Published *in extenso* in the J. Fish. Res. Bd. Canada, 21(3): 429-460, 1964.

[2] Fisheries Research Board of Canada, Biological Station, St. Andrews, N.B.

A-3

DISTRIBUTION OF HADDOCK OFF THE EASTERN CANADIAN MAINLAND IN RELATION TO SEASON, DEPTH AND BOTTOM TEMPERATURE[1]

By

F.D. McCracken[2]

CONTENTS

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[1] Originally Contribution No. A-8, ICNAF Environmental Symposium, Rome 27 January-1 February 1964.

[2] Fisheries Research Board of Canada, Biological Station, St. Andrews, N.B.

ABSTRACT

Haddock stocks off the outer coast of Nova Scotia (ICNAF Subarea 4) are discrete from those of the Grand Banks (ICNAF Subarea 3). Those off the central and eastern part of the Nova Scotia region (ICNAF Divisions 4V and 4W) do not appear to mix extensively with those off the western portion (ICNAF Division 4X).

Otter trawling for haddock produces greatest landings from Division 4W mainly from February to April, and smaller but important landings from Divisions 4V-T mainly in May-July.

In winter, research-vessel survey hauls caught greatest numbers of haddock of all sizes in southern Division 4W (Sable Island-Emerald Bank region) at depths of 70 - 125 m and temperatures of about 4° to 6°C. On top of the banks at depths less than 70 m and temperatures below 2°C haddock were virtually absent. To the eastward in Division 4V haddock were mainly small (<40 cm fork length), less abundant, and occurred considerably deeper (100-250 m) at temperatures around 3° to 4°C.

In summer, haddock return to shallower water and are distributed more widely throughout the region. Haddock, mainly large, migrate inshore to shallower waters off Cape Breton in Divisions 4V and 4T. Others merely move to shallows on top of the banks where small fish (<40 cm) and a few larger fish (>40 cm) are most numerous at depths of 35 - 70 m and at temperatures around 6° to 8°C.

INTRODUCTION

Haddock, *Melanogrammus aeglefinus* L., are found off the North American coast from Georges Bank to the southern Gulf of St. Lawrence, St. Pierre and Grand Banks.

Migrations and interrelationships of haddock stocks off the Canadian Atlantic mainland have been described by Needler (1930) from tagging results and statistics of the commercial fishery. Needler (1931) also presented information about the life-history of the haddock in this region, and McKenzie (1946) described in detail the Canadian fishery there during the late 1930's. Subsequent tagging (McKenzie, personal communication; McCracken, 1956, 1960, 1963) has filled in various gaps in the study of haddock migrations and interrelationships.

These studies relied mainly on records of commercial fishing. The data have limitations, particularly those for the earlier period when much of the fishery was conducted by hook and line, and only large fish were caught and landed. More recent commercial fishing has been mainly by otter trawl, which captures haddock over a greater size range and more extended area, and the new records are free of some of the shortcomings of the old.

This paper presents data on the recent commercial fishery along with the results of Fisheries Research Board of Canada systematic research-vessel surveys, which began in the Gulf of St. Lawrence in 1957 and on offshore banks in 1958. These surveys have the advantage of taking small haddock and fishing in areas at seasons not covered by the commercial fishery. Observations during surveys also relate hydrography to specific areas and catches.

The results presented here will emphasize seasonal changes in distribution of haddock related to area, depth, temperature, and size of fish.

MATERIALS AND METHODS

Data presented in this paper have been compiled from results of research-vessel surveys, log records kept by commercial fishing vessels, and statistics of landings published by the International Commission for the Northwest Atlantic Fisheries (ICNAF). The research-vessel surveys were conducted at various times from 1958 to 1962, both in "winter" and "summer". Jean (1964) has presented details of the vessels and gear used. They were the 25-m *Harengus*, towing a manila No. 36 otter trawl with an 18.3-m headline, for summer surveys, and the 53-m *A. T. Cameron*, towing a manila No. 41 otter trawl with 24-m headline, for winter surveys. In all cases the codend was either covered or lined with 25-30 mm mesh netting.

In 1960 comparative fishing trials were carried out by the two vessels at the same time and place. These showed that, on the average, the *A. T. Cameron* caught twice as many haddock per tow as the *Harengus*. For comparability, *A. T. Cameron* catches have therefore been reduced by a factor of 0.5.

During the 1958 summer and winter surveys two hauls were made at about a half of the fishing stations. Thereafter only single hauls were made. Virtually all haddock in the *Harengus* catches and most of those taken by the *A. T. Cameron* were measured. For sampling some large catches by the *A. T. Cameron* fish were placed in baskets, usually in lots of 3 or 5, and a basket from each succeeding lot was chosen at random for measurement. Fish in the last lot of baskets were normally mixed between baskets before the sample basket was chosen. Paloheimo and Dickie (1963) have demonstrated some bias in this method of sampling; however, none of the *Harengus* catches and only about 20% of the *A. T. Cameron* catches could be affected.

At each fishing station surface and bottom water temperatures were taken along with a bathythermograph cast. Records so obtained have been used to relate temperature and haddock distribution.

Statistics of landings used here are those reported to ICNAF by its member countries and published in its Statistical Bulletin. Distribution of Canadian catches by otter trawlers was obtained from log records kept by captains of these vessels and collected by our field staff.

HADDOCK STOCKS AND THE FISHERY

1. Division of stocks

The haddock stocks considered in this paper are those occurring off central and eastern Nova Scotia and in the southern corner of the Gulf of St. Lawrence. This region has been designated as Divisions 4T, 4V, and 4W of Subarea 4 by ICNAF (Fig. 1). Haddock of this region are separate from those of Subarea 3 (Grand Banks and St. Pierre Bank off southern Newfoundland). Needler (1930) and McCracken (1956, 1960) have shown that the deep-water Laurentian Channel which divides these two subareas is an effective barrier to haddock migrations. Vertebral counts by Clark and Vladykov (1960) (54.1 for eastern and central Nova Scotia banks and 52.9 for St. Pierre Bank) support the conclusion that these stocks are separate.

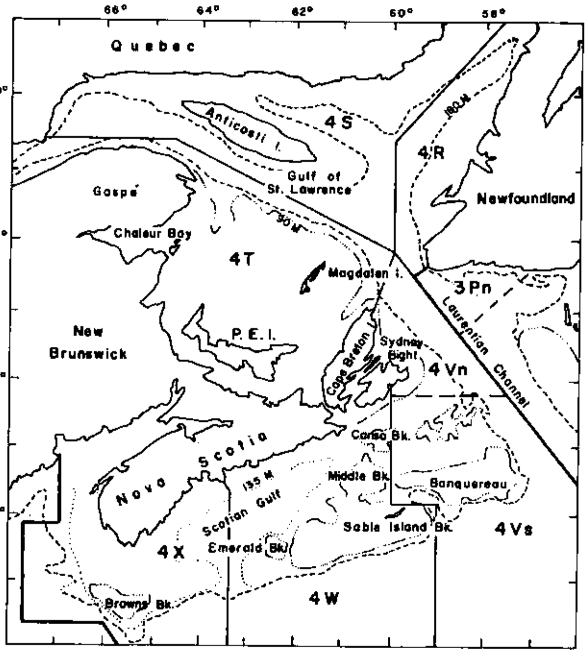

Fig. 1. Map of ICNAF Subarea 4 (including 3Pn and part of 3Ps) showing banks, deeps, and localities mentioned in the text.

Tagging results (Needler, 1930; McCracken, 1956, 1960) indicate only limited mingling of haddock stocks between central and eastern Nova Scotia (4V, 4W) and those of western Nova Scotia (4X). The conclusions from tagging are supported by differences in haddock vertebral counts shown by Clark and Vladykov (1960) for haddock from Divisions 4V-W and 4X. The deep, warm-water Scotian Gulf appears to be the main barrier.

Taggings within Divisions 4T, 4V, and 4W indicate extensive intermixing of commercial-size haddock (40 cm fork length and over). Haddock caught and tagged off inshore Cape Breton (4V) in spring (Needler, 1930) were retaken later that season in the southern Gulf of St. Lawrence (4T). The following winter haddock from the same tagging were recaptured on offshore Sable Island Bank (4W). Similarly, haddock tagged in September in the southern Gulf of St. Lawrence (4T) (McCracken, 1960) were retaken in spring and autumn off Cape Breton (4V) and in winter on offshore banks (4W). Uniform vertebral counts (Clark and Vladykov, 1960) provide further evidence that a single stock occupies all Subarea 4 regions east of the Scotian Gulf. Further evidence for a single stock in Divisions 4T, 4V, and 4W is provided by statistics of landings, seasonal distribution of commercial fishing effort, and results of research-vessel tows.

2. Statistics of landings

Average annual commercial haddock landings by 3-month periods from Subarea 4 for the years 1958-60 are presented in Table 1. They demonstrate the importance of central (4W) and western (4X) Nova Scotia areas in the haddock fishery. Most of the landings came from these two Divisions, and during 1958-60 slightly more were landed from 4W than from 4X. For the region under discussion in this paper (4T, 4V, 4W), 4W (central Nova Scotia) accounted for about 70% of the total landings; 4T (the southern Gulf of St. Lawrence) for about 10%; and 4V (eastern Nova Scotia) for about 20%.

TABLE 1. AVERAGE ANNUAL HADDOCK LANDINGS IN METRIC TONS, ROUND FRESH, BY DIVISIONS, OF SUBAREA 4, FEBRUARY 1958 - JANUARY 1961.

Division	4T		4V		4W		4X		Total	
Period	Can.	For.	Can.	For.	Can.	For.	Can.	For.	Canadian	Foreign
					Otter trawl					
Feb-Apr	19	...	452	197	9549	1258	591	6624	10611	8079
May-July	1409	22	1197	129	1804	159	1498	1069	5908	1379
Aug-Oct	712	...	575	42	3081	169	1848	514	6216	725
Nov-Jan	233	...	621	87	3246	135	324	306	4424	528
Totals	2373	22	2845	455	17680	1721	4261	8513	27159	10711
					Other gears					
Feb-Apr	...	...	31	985	459	915	1297	...	1787	1900
May-July	46	4	330	364	34	34	1297	...	2078	402
Aug-Oct	75	7	161	927	96	96	1263	...	1767	1030
Nov-Jan	33	39	181	157	58	58	911	...	1387	254
Totals	154	50	703	2433	1394	1103	4750		7019	3586
GRAND TOTAL	2639		6436		21898		17524		48475	

For the region 4T-V-W, landings by Canadian vessels predominated, making up about 80% of the total for all nations. Otter trawls accounted for most of the Canadian haddock landings from Divisions 4T-V-W. "Other" Canadian gears were mainly inshore traps operated on the coast of Cape Breton in 4V and 4W. Most haddock landings by other countries can be classified as being produced by towed gear. Haddock taken by "other" foreign gears were mainly from Spanish pair trawlers operating in Divisions 4V and 4W.

TABLE 2. AVERAGE ANNUAL CANADIAN OTTER TRAWL EFFORT BY DIVISIONS, OF SUBAREA 4, FEBRUARY 1958-JANUARY 1961.

Division	4T	4Vn	4Vs	4W	4X	
Period	hr	hr	hr	hr	hr	Total
Feb-Apr	771	1831	2216	17417	1729	23964
May-July	56201	3963	3486	8037	11043	82730
Aug-Oct	57238	985	1643	8271	7287	75424
Nov-Jan	14884	1790	1964	11157	...	29795
Totals	129094	8569	9309	44882	20059	21193

Average annual effort in hours fished by Canadian otter trawlers in areas 4T-4X, from February 1958 to January 1961, by 3-month intervals, is presented in Table 2. These effort data may be compared with haddock landings in Table 1 to show relative abundance of haddock in each of the Divisions. In 4T a large number of hours fished by Canadian otter trawlers from May to October did not produce large landings of haddock. Since haddock is in great demand, the low landings indicate scarcity of haddock in this Division. In the winter period (February-April) relatively large Canadian effort in Division 4V produced small landings compared with the return per unit effort in Division 4W, and indicates much higher abundance of haddock in 4W at that season. For the remainder of the year the difference between 4V and 4W is not so marked.

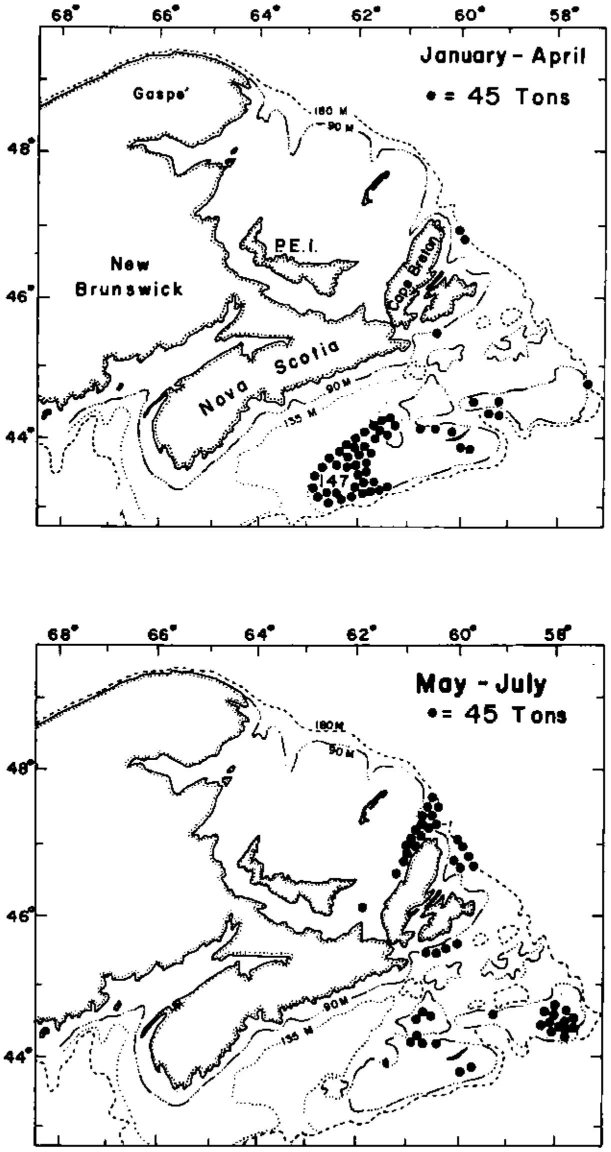

Fig. 2. Distribution of catches of haddock by Canadian otter trawlers in Divisions 4T, 4V, and 4W in January-April and May-July,1959; from log records.

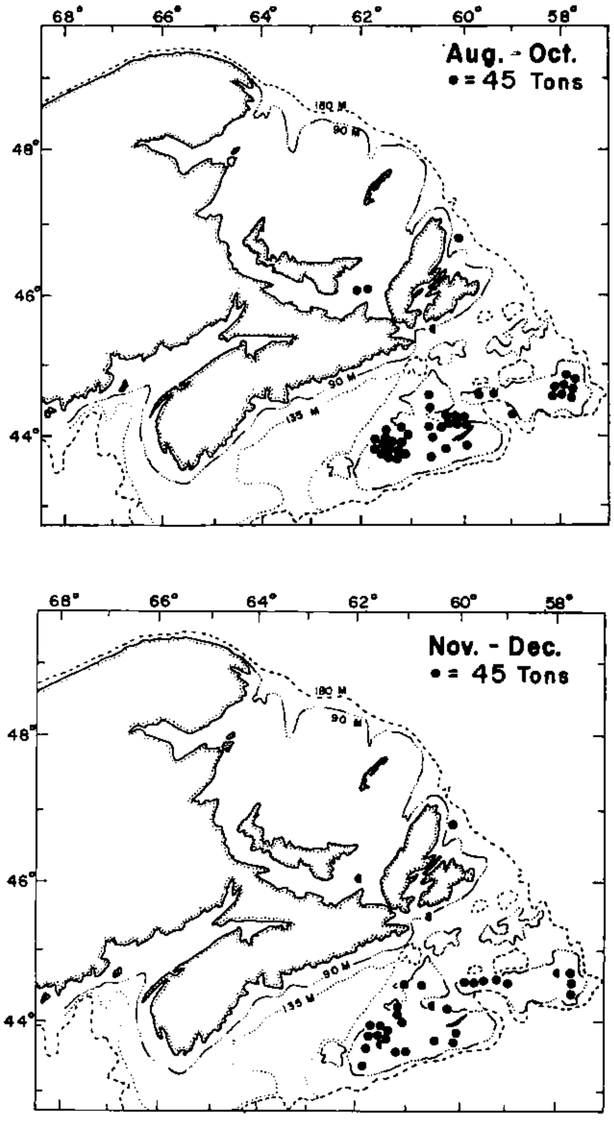

Fig. 3. Distribution of catches of haddock by Canadian otter trawlers in Divisions 4T, 4V, and 4W in August-October and November-December,1959; from log records.

The seasonal nature of the catches presents an interesting pattern, which is generally repeated from year-to year. Records for Division 4W show that the bulk of haddock landings was made in the February-April period. Seasonal differences were less marked in 4V, although most of the landings were made in May-October. Canadian landings from 4V were greatest in May-July. Those from Division 4T were also greatest in the May-July period, although a substantial portion was also landed in August-October.

3. Distribution of commercial catches

Representative 1959 log records for Canadian otter trawlers fishing commercial-size haddock (over 40 cm fork length) are summarized in Fig. 2 and 3. Catches in winter and early spring months (January through April) were mainly from offshore banks (Sable Island and Emerald Banks, 4W), although by April a few catches were made off Cape Breton and on Banquereau (4V).

In May-July, catches were being made around Sable Island and on top of Middle Ground (4W), on top of Banquereau in shallow water and in deep water off the east coast of Cape Breton (4V) and in the deep-water gully on the west coast of Cape Breton (4T). At the same time, statistics records show catches being taken by inshore traps operating on the east coast of Cape Breton (4V and 4W). In other words, the haddock catches were spread throughout the central and eastern Nova Scotia region.

In the August-December period a few haddock were taken off Cape Breton and in the eastern end of Northumberland Strait (4T). However, the bulk of landings still came from the offshore banks, Banquereau and Sable Island. The amounts of haddock taken by otter trawls in the shallow water of 4T vary widely from year to year. Some years much larger amounts are taken than are shown for this period in 1959.

Since otter trawls are the most important gear used, their catches in 4T-V-W indicate the seasonal changes in distribution of the fishery. In winter it centres on offshore banks in 4W and moves inshore in 4V and 4T during spring and autumn. The fact that McKenzie (1946) found the same seasonal distribution of the fishery in 1938-40 suggests that this pattern has existed for a long time. However, landings from the inshore eastern Nova Scotia area in spring were even more important then because trap fishing was more common.

Otter-trawler log records show that haddock fishing is largely confined to depths less than 185 m throughout the year; that the summer fishery tends to be in shallow water, less than 90 m; and that the winter fishery is generally deeper than 90 m with some east-west variation. As will be shown from research-vessel surveys, the fishery reflects the seasonal pattern of haddock distribution.

RESEARCH-VESSEL SURVEYS

1. Distribution by area and season

Research-vessel surveys in 4T-V-W have been carried out in the winters of 1959-62 and in the summers of 1958-60. Results for 1960 and 1962 have been chosen to illustrate winter haddock distribution because, in those years, the survey covered the widest areas. To supplement these, the results of winter hauls from eastern Banquereau in 1959, mainly on top of the bank, have been added to the 1960 data. Results for the 1959 survey have been chosen to illustrate summer distribution, again because these covered the widest area.

1.1. Winter

Winter distribution of haddock in 4T-V-W (Gaspé to Sable Island and Emerald Banks) as deduced by research-vessel catches is shown in Fig. 4 and 5. Both small (<40 cm) and large (>40 cm) haddock were scarce in the Gulf of St. Lawrence (4T) and off the east coast of Cape Breton (4Vn). Those taken were confined to deep water along the edge of the Laurentian Channel. The area off western Cape Breton, where a spring fishery occurs, was not covered by the surveys. However, it is known from January 1962 commercial codfishing efforts in this area that haddock were virtually absent. It seems likely that this is the usual winter situation. Around Banquereau (4Vs) small catches of haddock were taken from deeper water along the southern edge of the bank and in the deeper water region between Banquereau and Sable Island Bank. None were taken on top of the bank. Haddock of all sizes were most numerous around the western end of Sable Island Bank and around

Emerald Bank in the southwestern part of Division 4W. This is also the distribution indicated by winter catches of the commercial fleet (Fig. 2).

Winter research-vessel catches of both small and large haddock were mainly confined to depths less than 185 m on the Scotian Shelf. Around Emerald and Sable Island Banks (4W) most were deeper than 75 m. In the Banquereau region (4Vs) most were deeper than 90 m. Along the Laurentian Channel (4Vn) those haddock taken ranged considerably deeper, about 135-230 m.

Most of the haddock from the Laurentian Channel and Banquereau region were small fish (<40 cm). Around Emerald Bank and western Sable Island Bank large haddock (>40 cm) made up a much larger proportion of the winter research-vessel catch. Again, this is indicated by the distribution of the winter fishery for commercial sizes (>40 cm).

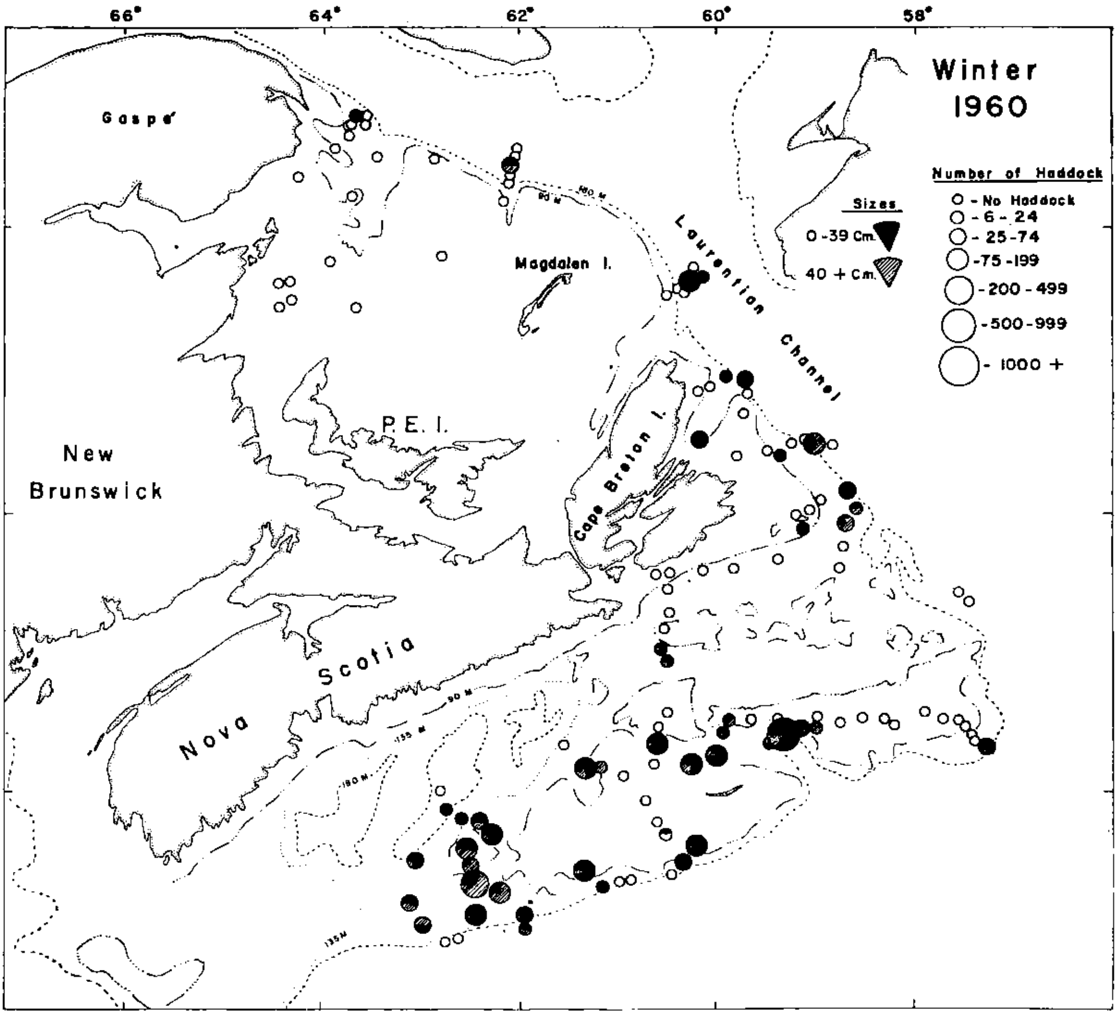

Fig. 4. Distribution of haddock catches by research vessels along the Canadian mainland in the winter of 1960.

1.2. Spring and summer

The 1959 spring and summer research-vessel survey results give a less satisfactory picture than the winter surveys. They are deficient both in timing and area covered. The offshore bank surveys (Banquereau to Emerald) were made in midsummer and, although they covered a large portion of the offshore region, they did not cover the inshore waters of eastern Nova Scotia. The spring surveys off Cape Breton were carried out much earlier and covered only the east coast although there is a spring haddock fishery on the west coast as well. In the Gulf of St. Lawrence the principal area covered in spring and summer was that off Gaspé and northern New Brunswick. Because of these deficiencies, the 1959 research-vessel survey data have had to be supplemented by results of samples of commercial landings and by results of some earlier research-vessel catches in the western Cape Breton region.

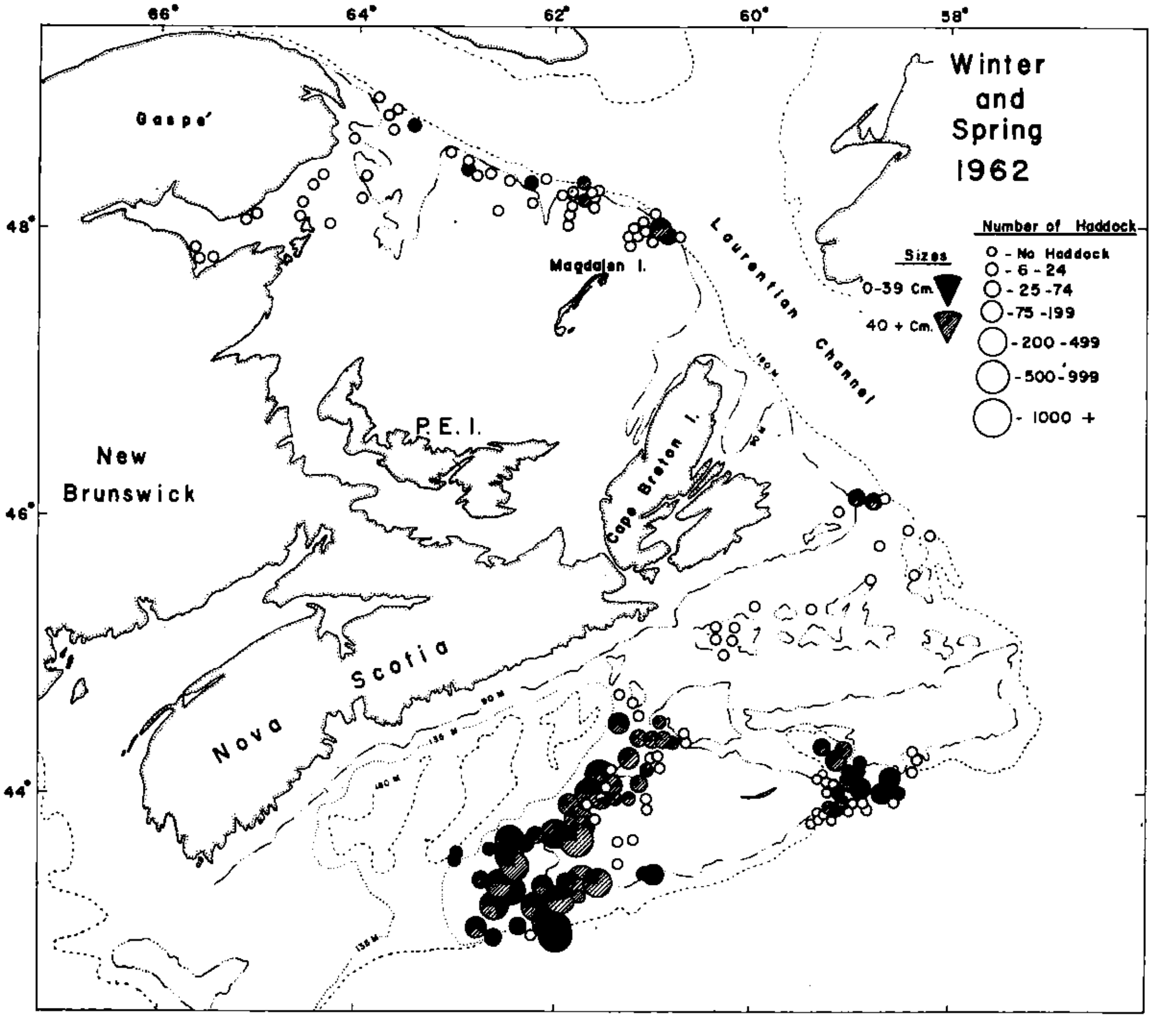

Fig. 5. Distribution of haddock catches by research vessels along the Canadian mainland in the winter (offshore banks) and spring (Gulf of St. Lawrence) of 1962.

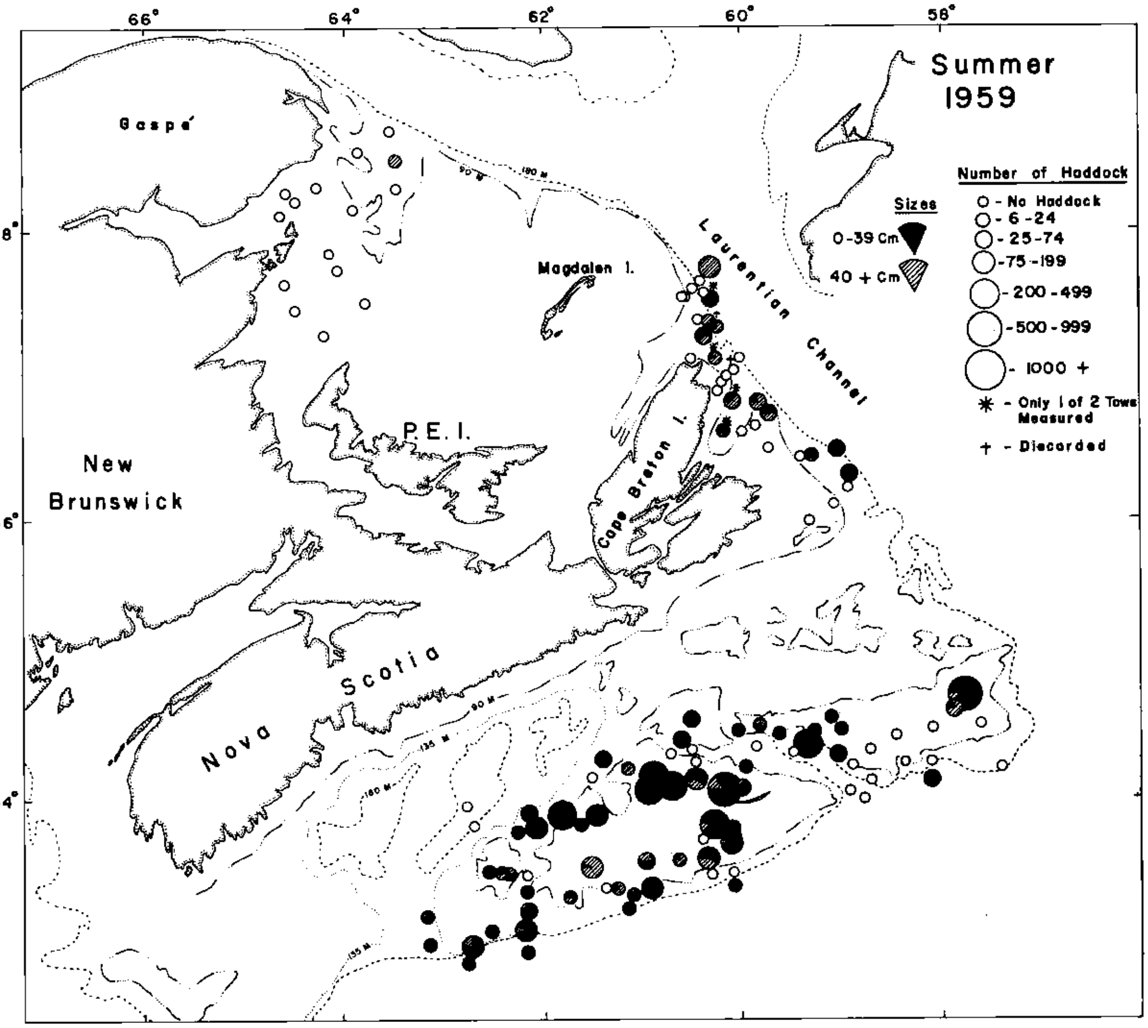

Fig. 6. Distribution of haddock catches by research vessels along the Canadian mainland in the spring and summer of 1959.

The spring research catches in the western Gulf of St. Lawrence took almost no haddock (Fig.6). Landings and log records of commercial vessels also indicated that haddock are virtually absent from this region. Occasional small catches are made, particularly in late summer months and in shallow water around northern New Brunswick (unpublished data). However, the survey results combined with commercial fishing data indicate that haddock are uncommon throughout the south-western Gulf, except for the southern corner around eastern Prince Edward Island and western Cape Breton. Off the east coast of Cape Breton spring survey hauls took small catches of haddock, mainly at depths between 90-185 m along the Laurentian Channel. Sampling was not carried out inshore in this region. However, it is known that at this time traps alongshore on the east coast of Cape Breton were taking haddock. In the offshore Nova Scotia areas, haddock were caught in fair numbers from Banquereau to Emerald Bank. Largest catches came from on top of the banks from depths less than 75 m, particularly around Sable Island and on Banquereau. Although a few haddock were taken throughout the area from deep water (90-185 m), the general distribution was in shallow water, thus contrasting with that in winter when haddock are regularly most abundant at the 90-185 m depths and absent from the shallows.

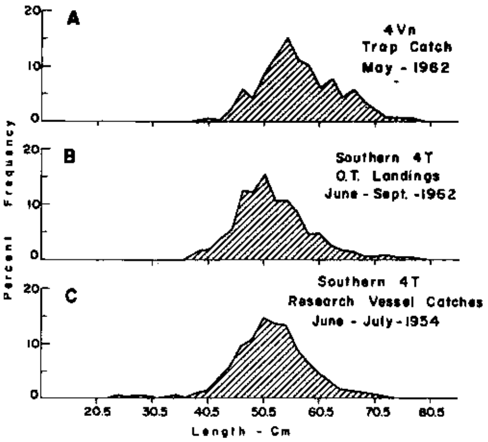

Fig. 7. Size composition of haddock in commercial landings and research-vessel catches from inshore Cape Breton and the southern Gulf of St. Lawrence.

A. Trap-caught haddock, Cape Breton, May 1962.

B. Haddock landings of commercial otter trawlers in July and September 1962 from the southern Gulf.

C. Haddock catches by research vessel in June and July 1954 from the southern Gulf of St. Lawrence.

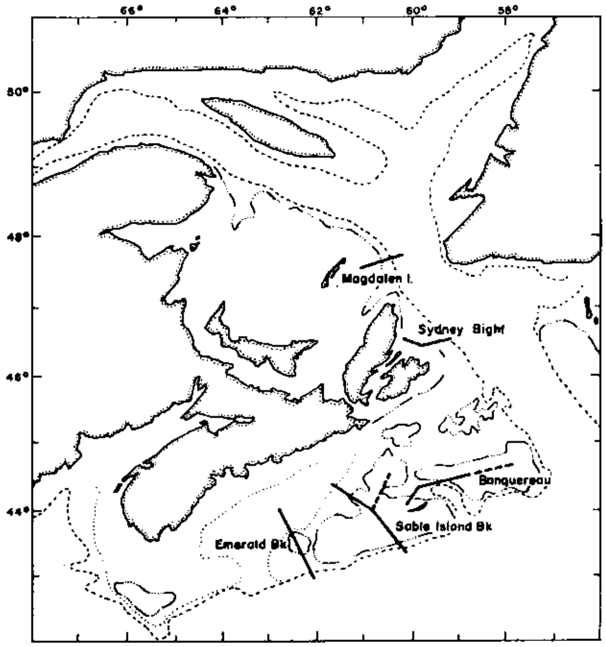

Fig. 8. Location of sections used in comparing distribution of haddock by depth and temperature.

With few exceptions, small haddock (<40 cm) predominated in all the offshore banks catches, both in shallow and deep water. This contrasts with winter conditions when large haddock (>40 cm) predominated in many of the hauls around Sable Island and Emerald Banks. Spring catches in deep water off the east coast of Cape Breton were a mixture of small and large haddock. The survey results suggest that most haddock in inshore Cape Breton and southern Gulf of St. Lawrence waters in spring and summer are large fish. Samples of commercial haddock catches (no fish discarded) from an inshore trap off eastern Cape Breton in May 1962 show that haddock taken were mainly over 45 cm (Fig. 7A). Samples from landed catches of the commercial otter-trawl fishery in the eastern end of Northumberland Strait (southern 4T) in July and September 1962 included only haddock that were over 43 cm long (Fig. 7B). Discard estimates for this region were extremely low in 1962 and 1963 (less than 2% by count; unpublished data). From this it appears that the haddock in the area were practically all large fish. Dragging in the Northumberland Strait region during June to July 1954, using a net with covered codend (during mesh-selection experiments), produced mainly large haddock over 40 cm (Fig. 7C). Thus, we conclude that haddock in these inshore waters during summer are mainly large. Tagging results (Needler, 1930; McCracken, 1963) show that these are part of the winter offshore stocks.

2. Distribution related to depth and temperature

Results of research-vessel fishing along the Laurentian Channel, off the Magdalen Islands and eastern Cape Breton, in the Banquereau region, and in the vicinity of Sable Island and Emerald Banks, have been chosen to show haddock distribution by depth more clearly, and to relate distribution to temperature. While research-vessel surveys in these regions have been carried out for a number of years, those chosen to illustrate summer conditions in the Banquereau region were done in 1959, and those to illustrate winter, spring, and summer in all other areas were done in 1960. The locations of sections chosen are shown in Fig. 8.

2.1. Winter

In January 1960, off the Magdalen Islands in the Gulf of St. Lawrence, haddock were confined to deep water (240-275 m) at temperatures of about 4°C (Fig. 9). They were absent from depths less than 200 m and temperatures of less than 3°C. Catches were light and composed largely of small fish (<40 cm).

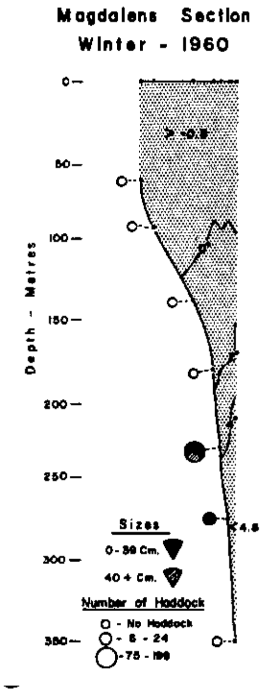

Fig. 9. Distribution of small and large haddock by depth and bottom temperature east of Magdalen Islands winter 1960.

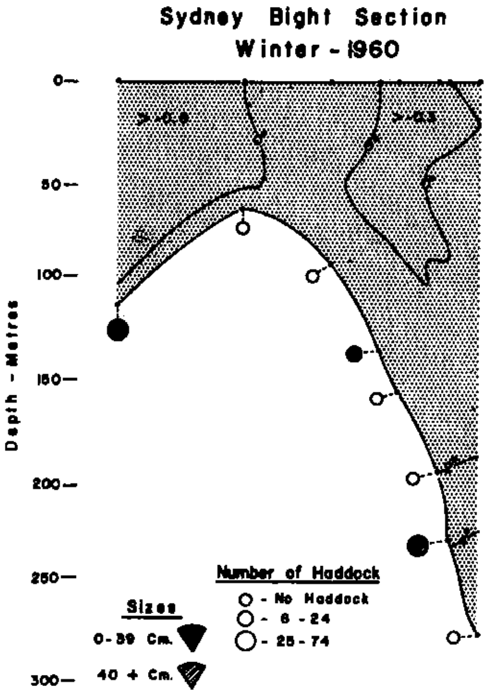

Fig. 10. Distribution of small and large haddock by depth and bottom temperature in Sydney Bight (east Cape Breton), winter 1960.

In the Sydney Bight winter section, eastern Cape Breton, haddock were found at 125 m at a temperature of <1°C (Fig. 10). Catches were light and composed mostly of small fish. In depths about 225 m and at temperatures of about 4°C, catches were also light but contained both small and large haddock.

Along the southwestern end of Banquereau, no haddock were found at depths less than 75 m and bottom temperatures below 2°C (Fig. 11). But good catches of both small and large fish were taken at 90-150 m and at temperatures between 3.5° and 4°C along the steep slope of Banquereau. Only small numbers were taken in the deeper, warmer water of the "gully". Small fish predominated in the catches at depths of 110-135 m and at temperatures of about 4°C on the Sable Island side of the "gully".

In the section across Sable Island Bank there were no haddock at depths less than 75 m and bottom temperatures below about 3.5°C (Fig. 12). However, fair catches of small haddock were taken at depths of 75-110 m and temperatures of 4° to 6°C on both the seaward and shoreward slopes of Sable Island Bank. The largest catches were taken on the seaward slope.

In the Emerald Bank region good haddock catches were made at depths of 75-110 m and temperatures of 4° to 8°C (Fig. 13). On the shoreward slope of the bank mainly small fish occurred in temperatures of 4° to 6°C. Large fish predominated in catches from the "plain" (80-100 m) extending across and south of Emerald Bank where temperatures ranged from about 4.5° to 8°C. Small fish were most numerous again at the seaward edge of this plain at depths around 110-130 m and temperatures of about 7°C.

Thus, in winter, the haddock in the eastward area are mainly small fish and found in deeper water and at lower temperatures than those in the westward area.

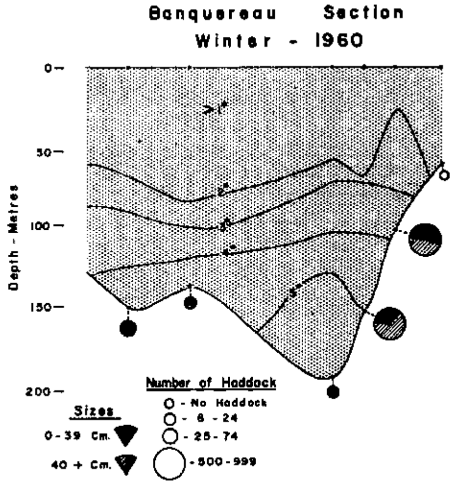

Fig.11. Distribution of small and large haddock by depth and bottom temperature in the western Banquereau region, winter 1960.

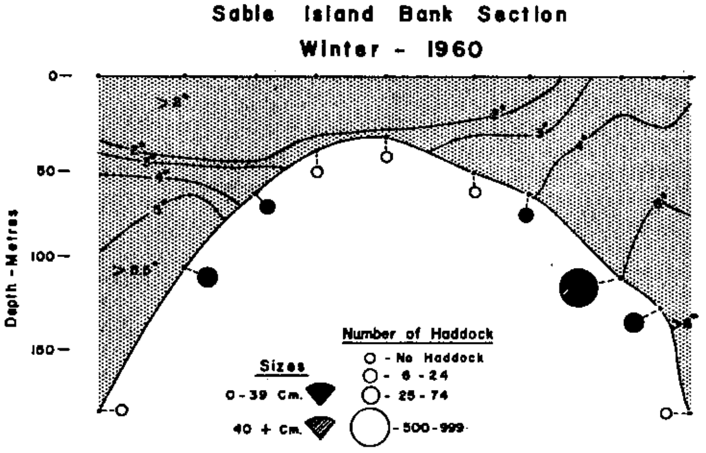

Fig. 12. Distribution of small and large haddock by depth and bottom temperature in the Sable Island Bank region, winter 1960.

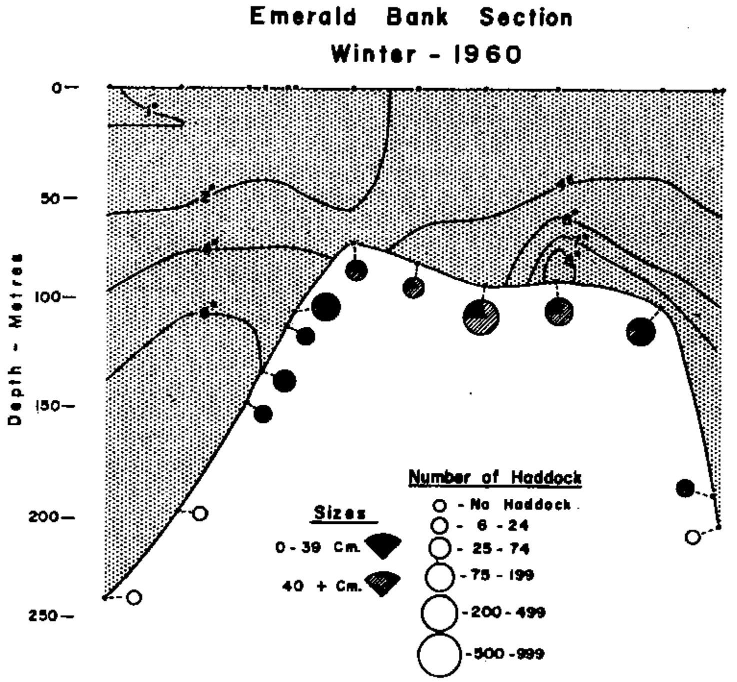

Fig. 13. Distribution of small and large haddock by depth and bottom temperature in the Emerald Bank region, winter 1960.

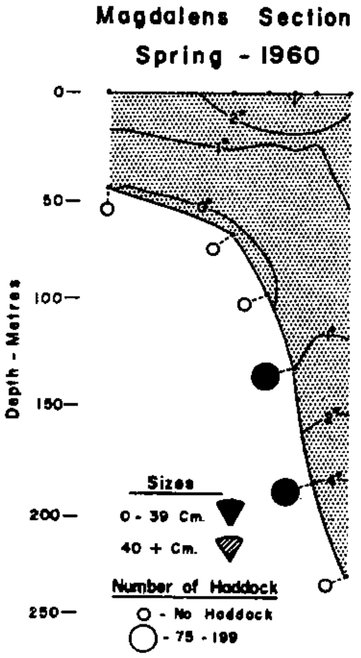

Fig. 14. Distribution of small and large haddock by depth and bottom temperature east of Magdalen Islands, spring 1960.

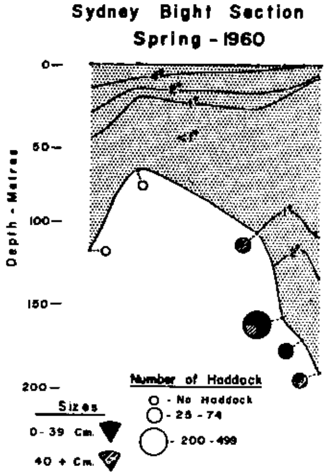

Fig. 15. Distribution of small and large haddock by depth and bottom temperature in Sydney Bight (east Cape Breton), spring 1960.

2.2 Spring and summer

Research-vessel surveys in the various regions during spring and summer were carried out over a longer period than those in winter. Surveys off eastern Nova Scotia and in the Gulf of St. Lawrence were done in May while those on offshore banks were done in July.

Off the Magdalen Islands in May, haddock had moved into slightly shallower water than in winter but small fish were still being taken from depths of 130-185 m at temperatures between 1° and 4°C (Fig.14). They were absent from the coldest, shallowest water (<1°C) at depths of about 45 to 110 m.

In the section off Sydney Bight, haddock catches were larger than in winter and there was a greater proportion of larger fish (>40 cm). They were taken from shallower water (110-190 m) and colder water temperatures (1° to 3°C) than in winter (Fig. 15).

A section across Banquereau in the summer of 1959 (July) showed that haddock were numerous in the shallow, warm-water region at the eastern end of the bank. They were mainly small fish (<40 cm) and were taken from depths of 35-45 m and at temperatures of 5° to 7°C (Fig. 16). There were no haddock of any size over much of the bank at depths around 55-75 m and temperatures under 3°C. On the southwestern slope of Banquereau small fish were found at all depths between 75 and 135 m and temperatures around 2°C. On the Sable Island side of the deep gully between Banquereau and Sable Island largest catches of predominantly small fish were made in shallow water less than 55 m at temperatures of 6° to 8°C.

On top of Sable Island Bank largest catches of haddock were taken at depths of 35-65 m and temperatures of 6° to 10°C(Fig.17). These summer catches were much larger than the winter, shallow-water catches, and small fish (<40 cm) predominated. In further contrast to winter conditions, there were few haddock on the slopes of the banks at depths greater than 65 m.

Around Emerald Bank, which is further to the westward, the summer catches were light compared to winter, and there were practically no haddock on the Scotian Gulf side of the bank at all depths exceeding 80 m, even though temperatures there were from 4° to 6°C(Fig. 18). Light catches of both small (<40 cm) and large (>40 cm) fish were taken on the plain and slopes seaward of Emerald Bank from 100 to 185 m and temperatures from 7° to 10°C.

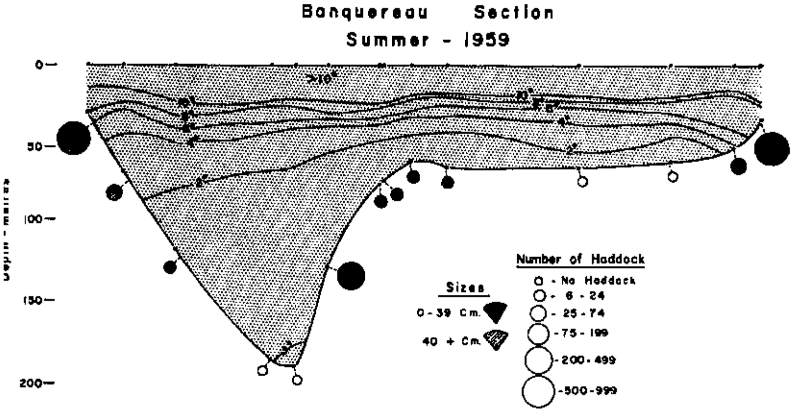

Fig. 16. Distribution of small and large haddock by depth and bottom temperature in the Banquereau region, summer 1959.

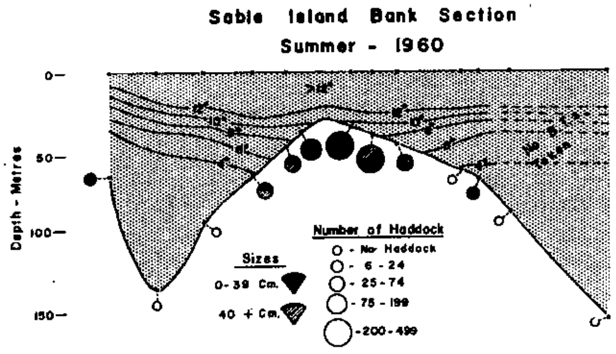

Fig. 17. Distribution of small and large haddock by depth and bottom temperature in the Sable Island Bank region, summer 1960.

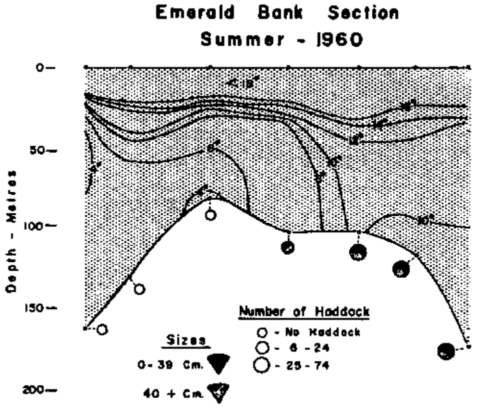

Fig. 18. Distribution of small and large haddock by depth and bottom temperature in the Emerald Bank region, summer 1960.

Thus, summer distribution of haddock on all offshore banks had changed markedly since winter. To the westward the concentrations of commercial-size haddock were no longer found in the Emerald Bank region, and small fish were now most abundant in the shallow, warm-water layer of Sable Island Bank. To the eastward; catches of small haddock had increased by spring and the fish had moved to somewhat shallower water. There were few large haddock at any of the stations fished in the offshore region. It seems likely, as shown by tagging results and statistics of the commercial fishery, that many of the large fish had moved inshore to the eastward off Cape Breton and into the southern Gulf of St. Lawrence. Those remaining offshore were distributed over a much wider area across the top of the banks than in winter.

3. Variation in distribution between years and seasons

The Sable Island-Emerald Bank region where haddock were most numerous has a complex topography (Fig. 1). The Scotian Gulf separates these offshore banks from the inshore grounds. To the eastward the banks deepen into a gully between Middle Bank and Banquereau, and to the westward depth increases gradually in the vicinity of Emerald Bank. Bottom temperatures at similar depths in this region may be widely different, and it is difficult to obtain relationships that are common to the different regions. Sections across the bank, already presented, show some differences in haddock catches for the shoreward and seaward sides of the banks. Further grouping of research-vessel haddock catches in relation to depth and temperature provides interesting comparisons between years and seasons.

Average haddock catches by size and age in the Sable Island-Emerald Bank region for four depth zones for the winters of 1959-60 and the summer of 1959 are presented in Fig. 19 and 20.

3.1 Depth zone <70 metres

In the winters of both 1959 and 1960, bottom temperatures in March-April at these depths were less than 3.5°C and survey catches of haddock were light. In 1959, bottom temperatures were generally below 1.5°C and no haddock were caught. In 1960, bottom temperatures were slightly higher, about 2° to 3°C, and a few small (under 20 cm) and larger (40-50 cm) haddock were taken. Mainly these were fish of ages 1-5 yr. In the summer of 1959 haddock catches were greatest at these depths, in temperatures of about 3° to 7°C. Smaller haddock (<40 cm) of ages 2-4 predominated in the catches.

3.2 Depth zone 70-125 metres

In the winters of both 1959 and 1960, greatest catches of haddock were taken in this depth range. In 1959, larger fish, over 40 cm and ages 5-7, were found throughout this depth range, with somewhat greater numbers in the warmer water (3.5° to 7°C) to the westward. To the eastward, where

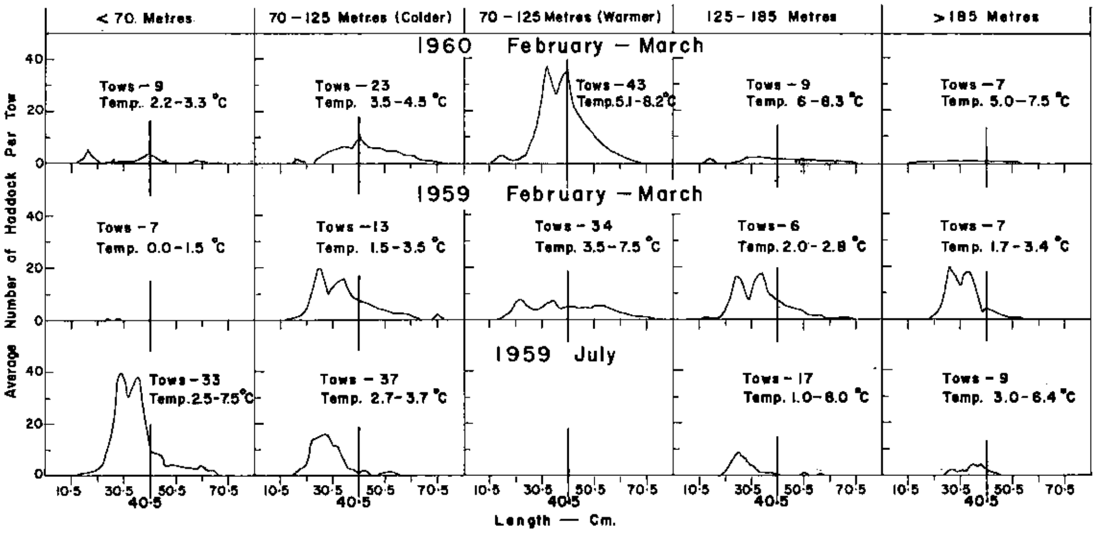

Fig. 19. Average catches and sizes of haddock by depth zones in the Sable Island-Emerald Bank region in winters of 1959 and 1960 and summer of 1959.

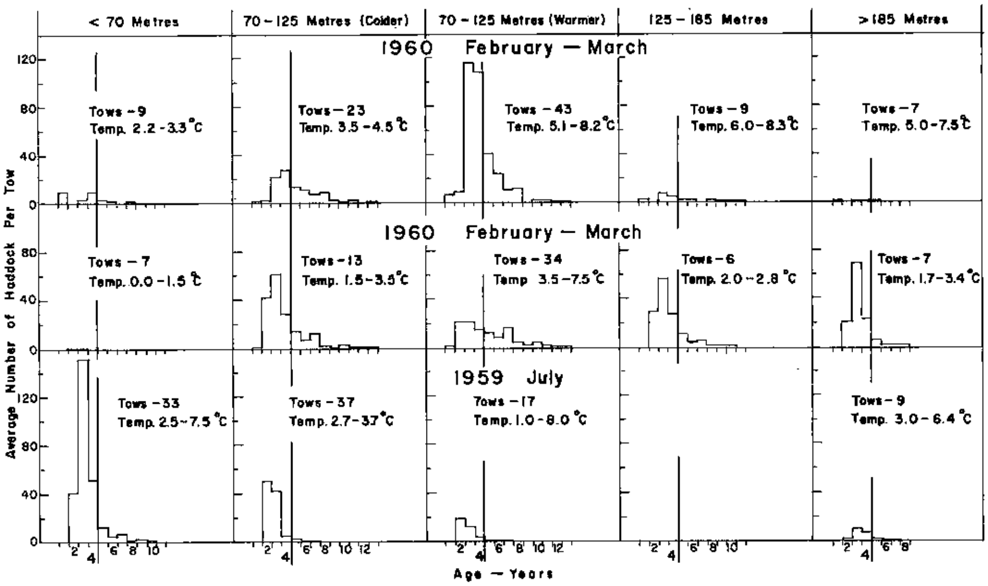

Fig. 20. Average catches and ages of haddock by depth zones in the Sable Island-Emerald Bank region in winters of 1959 and 1960 and summer of 1959.

temperatures were lower than 3.5°C, large numbers of small haddock (20-40 cm) of ages 2-4 were taken. In 1960, with temperatures all above 3.5°C in this depth range, large haddock, over 40 cm and ages 5-8, were taken throughout. Small haddock, under 40 cm, ages 2-4, were most numerous in the warmer waters (5° to 8°C) rather than in the colder water as in 1959. In the summer of 1959 haddock catches were light in this depth range and were mainly of small fish, 20-30 cm long and 2-3 yr of age. However, a few large fish (>40 cm) occurred in nearly every tow.

3.3 Depth zone 125-185 metres

In the winter of 1959 there were large numbers of small fish, 20-40 cm and ages 2-4, in this depth range along the seaward slope of the banks. Bottom temperatures were low (2° to 3°C). A few larger haddock (>40 cm) were also present. In the winter of 1960, when the water was warmer (6° to 8°C) at these depths, only small catches of mixed sizes were obtained. In the summer of 1959 a few hauls at this depth caught small numbers of small haddock, 20-30 cm and ages 2 and 3.

3.4 Depth zone >185 metres

In the winter of 1959, small haddock, 20-40 cm and 2-4 yr of age, were taken in fair quantities at depths greater than 185 m and at bottom temperatures of about 2° to 3.5°C. However, in 1960, haddock were virtually absent from these depths. In summer a few haddock about 30-40 cm in length were taken there at temperatures around 6°C.

In summary, we see that in the Sable Island-Emerald Bank region seasonal differences in haddock distribution are very clear. In summer, small and large haddock are most numerous in the shallow waters where they are virtually absent in winter; and, throughout the region, at all depths, larger haddock, over 40 cm and ages 5-7, are much less abundant than in winter.

The variation in haddock distribution at the same season for different years is less simple. In 1959, when bottom temperatures were colder on top of the banks and colder temperatures also extended further westward than in 1960, haddock were found in much deeper water. Principally these were small fish, under 40 cm and about 2-4 yr of age. In 1959 even fewer haddock were taken in the cold water on top of the bank than in 1960. In both years larger fish (>40 cm) were most numerous in middle depths (70-125 m) and at moderate temperatures (4° to 6°C). Small fish, 20-40 cm, were also numerous in the intermediate depth zone in both years. However, in 1959, they were found in colder parts of this depth zone, and in 1960 the warmer parts. In both instances, these small haddock were found to the eastward around Sable Island Bank close to where they had been most numerous in summer.

DISCUSSION

Considering haddock catches in the 4T-V-W region both by research vessels and commercial otter trawlers, it is clear that season, temperature, depth, and size are major factors determining haddock distribution and migrations.

Within this region, summer and winter distribution of both large and small haddock differs markedly. This can be accounted for only by migration. In May-June, large fish leave their centre of winter abundance around Sable Island and Emerald Banks. Indications are that many move to shallower inshore regions to the east and north, where they spend the summer. About the same time, small haddock leave the deep water at the edges of the banks and move into shallow water on top of the banks and spend the summer there.

In November-December, large haddock leave inshore regions for deeper offshore areas, moving south and west to reach these regions. About the same time, small haddock and those few large haddock which were found on tops of offshore banks in July-August, leave the shallows and move into deeper water on the edges.

What controls the timing of these migrations is not elucidated by this study. Both the spring and fall migrations occur while rapid seasonal changes are taking place. These movements of large fish out of the southern Gulf of St. Lawrence and movements of both large and small fish off the tops of the banks both begin before temperatures fall very low. Nevertheless, temperature appears to play an important part since the autumn and early winter migration is much more pronounced from the northeastern, cold-water areas than from the more westward. Georges Bank is an example where haddock never leave the shallows (< 100 m) in winter (Schuck, 1952). Browns Bank shows a similar situation. Haddock are found there in good quantities on top of the bank at depths less than 100 m in March (McCracken, unpublished). In both the Georges and Browns Banks regions, winter bottom temperatures on top of the banks are several degrees higher than those found on Banquereau and Sable Island Bank.

The depth and temperature at which haddock are found in winter grades from deeper, colder water to the north towards shallower, warmer water to the south. Off Cape Breton, haddock were most numerous around 200 m at temperatures around 3.4°C; around Banquereau the depth range was 100-150 m at temperatures around 4° to 5°C; and off Emerald Bank at depths of 70-100 m and temperatures of 4° to 8°C. Thus, the distribution of haddock in winter appears to be a combined function of temperature and depth. Where colder water extends deep they are forced to move deep, but where cold water is more shallow they tend only to move into intermediate depths. Templeman (1960) describes the marked concentration of haddock on Grand Bank in the winter of 1959, "in a narrow band at depths of 220 to 255 metres". Haddock were apparently avoiding the colder water above but were also resisting moving into deep water even though it was warmer and, as a result, they were very much concentrated. In the same year (1959) when cold water went much deeper in the Sable Island Bank region, haddock, particularly small fish (<40 cm), extended into deeper water, and more of the larger fish moved to the westward around Emerald Bank where the water was warmer. The fact that mainly small haddock remain in the eastern region during winter suggests that small fish may have a greater tolerance than large for greater depths and lower temperatures.

It is also apparent that the distribution of haddock plays an important part in the fishery. Concentration of haddock in the warmer-water region off western Sable Island Bank and Emerald Bank in the February-April period is the main basis of the Canadian late-winter fishery in Division 4W. When haddock spread into the shallows in spring and summer and migrate into inshore regions, they appear to be too dispersed for profitable fishing.

Variations in temperature from year to year and resulting differences in degree of concentration of haddock can produce pronounced changes in catch per effort without much change in either stock size or recruitment. This fact must be taken into account in estimating population sizes from catch-per-effort data in predicting fishing conditions and in devising management regulations.

ACKNOWLEDGEMENTS

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A-4

COD AND LOW TEMPERATURE IN ST. MARY'S BAY, NEWFOUNDLAND

By

Wilfred Templeman[1] and A. M. Fleming[1]

ABSTRACT

In St. Mary's Bay Newfoundland in 1957 bottom temperatures at 125 - 150 m in February were -1.4°C and in April -1.3°C. In February no large cod were present although there were many small cod mostly 14-21 cm in length.

Large cod were moderately numerous in January when the bottom temperature was 1.4°C. By April there were still large numbers of small cod of the same sizes and a few large cod had returned. The cod, especially the small ones were actively feeding at this time.

INTRODUCTION

There are enough apparently contradictory statements in the literature about the ability of cod, *Gadus morhua* L., to live at temperatures of -1.0°C and lower that additional evidence on this subject is desirable.

Cod are resistant to low temperatures. This is shown by the scarcity of reports of dead cod in the Newfoundland area, despite the fact that we have many reports of the death in winter to early spring of large numbers of capelin, haddock, dogfish and Greenland halibut. On the east coast of Newfoundland in late winter and early spring temperatures of the water down to 150 m or more often fall below -1.0°C and sometimes to -1.7 to -1.8°C. Usually the larger cod, at least evade these low temperatures by passing deeper. However, cod must be trapped in some east coast bays and coastal areas in deep holes where water temperatures fall to low levels, but which have no deep passage seaward through which the cod can escape.

For the few records of mass mortalities of cod in the Newfoundland Area, no direct observations of water temperatures are available. Collins (1884) mentions large quantities of cod floating at the surface over an area of at least 10-16 sq km (4-6 sq miles) at Cape Charles, Labrador on 1 August 1876. Local fishermen picked up and cured over 300 quintals (ca. 60 metric tons round fish). These deaths were attributed to the presence of numerous icebergs grounded in the vicinity. The Evening Telegram, St. John's, Newfoundland of 15 May 1934 (Thompson,1943) reported large quantities of dead cod seen floating at the surface for a distance of over 30 km in the northern part of the Gulf of St. Lawrence early in May 1934.

Simpson (1953) reports the presence of dead cod and other fishes in the North Sea during the cold winter-early spring of 1947, not only in areas where the bottom temperatures in March reached 0°C but also over a wide area where temperatures could not have fallen below 1.5°C. This author also says that small cod were caught at the piers in Lowestoft throughout late February and early March 1947, when the sea temperature was below 0.5°C for 18 days (including 7 days below 0°C) with a minimum of -0.4°C and there were no reports of dead cod or other species.

Dannevig (1930) records that cod and other fishes died on the Norwegian coast at temperatures probably from about -1.1 to -1.4°C, but that 2 cod which were impounded near the wharf for a month or more lived through temperatures as low as -1.4°C. Dannevig also conducted an experiment with cod 20-30 cm long which were taken from the sea, where the temperature was 3.5°C, and placed in a tank of water at 0.6 to 0.7°C but with the temperature being continually reduced. After 35 min when the temperature had reached -0.9°C, the cod were shivering and after 45 min with the temperature lowered to -1.1°C, all the cod were floating upside down with 4 dead and 1 showing some sign of life.

Nielsen (1893) reports the death of a cod in about 12 min after being transferred from the holding pound of the cod hatchery at Dildo, Trinity Bay, Newfoundland, at 32°F (0°C) to the spawning pound of the hatchery where the water was 31°F (-0.6°C). Also, on 6 and 7 February 1893 when temperatures at the holding pounds dropped to 29° and 30°F (-1.7 to -1.1°C) all the cod in pounds

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died.

Earll (1880) reports that all mature cod retained for hatchery purposes at Gloucester, Massachussetts, died in January 1879 when the temperature of the water fell to 30°F (-1.1°C).

Thompson (1943) says that, during the 1931 research cruise of the *Cape Agulhas* in the Newfoundland area, a few cod were captured at bottom temperatures as low as -1.6°C. No details of locality, depth or date are given and we have not been able to verify this statement from the yearly reports or the original records of the 1931 cruise.

Martin (1961) says that very small cod (0 and 1 age-groups) were still present in shallow water off Shippegan Island, New Brunswick in January, at a bottom temperature of -1.5°C.

ST. MARY'S BAY

Between 16 November and 29 May 1957 the research vessels *Marinus* and *Investigator II* made a series of half-hour bottom hauls with an otter trawl in St. Mary's Bay, Newfoundland, in the central area of the bay, mainly between 125 and 150 m (Table 1). The lower part of the codend was lined and the upper part covered with nylon shrimp netting so as to retain the small fish.

The sets in St. Mary's Bay were not planned as cod research but were part of sampling cruises to Hermitage Bay for redfish and to St. Mary's Bay for American plaice. Consequently information on the sizes of cod present in the earlier sets is not as complete as would be desirable.

TABLE 1. ABUNDANCE OF COD IN RELATION TO WATER TEMPERATURE IN ST. MARY'S BAY, NEWFOUNDLAND, 1956 AND 1957. (THE *Marinus* USED A NO. 35 TRAWL WITH A 15.3 M HEADLINE AND THE *Investigator II* A NO. 36 TRAWL WITH AN 18.3 M HEADLINE.)

Ship	Year	Date	Time† dragging	Depth	Bottom temp.	Cod per hour's dragging*			
						Small (below ca. 44 cm)	Scrod (ca. 44-52 cm)	Market (ca. 53-85 cm)	Large (ca. 86 cm and over)
			hr	*m*	°*C*	*avg no.*	*avg no.*	*avg no.*	*avg no.*
Marinus	1956	Nov.16	1 (2)	128-146	0.29	135	...	40	...
Investigator II	1957	Jan.16	2.5(3)	132-146	1.37	1	...	(210)	
Marinus	1957	Feb.26	2 (4)	124-150	-1.40,-1.37, -1.40	(210)	...	...	...
Marinus	1957	Apr. 9	1 (2)	124-132	-1.33	687 (70)	...	3 (20)	3 (45)
Marinus	1957	Apr. 9	0.3(1)	198	-1.38	(45)	...	...	...
Marinus	1957	May 29	1 (2)	95-128	-0.48 to -0.67	770 (145)	...	6 (45)	8 (120)

† no. of sets in parentheses

* lb. per hr in parentheses

Bottom temperatures (usually at a few metres above the bottom) were taken with Negretti and Zambra deep-sea reversing thermometers attached to Nansen bottles and a 36 kg weight. Two reversing thermometers were always used at the same time. The thermometers were provided with National Physical Laboratory (Great Britain) certificates and all temperatures are corrected temperatures. It is possible to feel reasonably confident that actual temperatures in the bottom layers were as low as those recorded. On 9 April, for example, when cod were caught at 124-132 m, temperatures were -1.33 and -1.38°C at 110 and 188 m. On 26 February, with 4 sets giving essentially the same kind of catches in 124-132, 124-146, 139-150 and 146-150 m, temperatures of -1.37, -1.40 and -1.40° C were recorded in 3 different set locations in actual thermometer depths of 132, 123 and 142 m. Salinities at the 100-140 m depths were between 32.3 and 32.7 $o/_{oo}$.

Bottom temperatures were 0.29°C in November and some larger (1.1-4.5 kg) cod as well as greater numbers of small cod were present.

In January, with bottom temperature 1.37°C, modest amounts of the larger cod from 1.1 to over 4.5 kg were present, but very few small cod.

On 26 February the bottom temperature was -1.4°C. (Actually, 1957 was a cold winter in the Newfoundland area and by the end of February temperatures in St. Mary's Bay from surface to about 150 m would have been -1.4°C or lower. Two miles off Cape Spear near St. John's on 1 March 1957 temperatures were -1.7°C from surface to 100 m and -1.4°C at 150 m and on 5 April 1957 -1.6°C from surface to 100 m and -1.7°C from 150 m to bottom at 170 m). No cod of commercial size were present but small cod were numerous, one 35 cm with the remainder all below 30 cm in length and almost all 14-21 cm in length.

On 9 April, with bottom temperature -1.33°C, there were fewer small cod taken than in February and only a few larger cod had returned. In deeper water at 198 m where the temperature was -1.38°C there were, also, fairly large numbers of small cod but no large cod. The cod were almost all below 20 cm (616 out of 693) and only 6 were over 50 cm (Table 2). The cod were feeding at this time, and stomachs especially in the small cod, were quite full mainly of euphausiids and amphipods with an occasional polychaete worm. Stomachs of the larger cod contained relatively smaller amounts mainly of spider crabs, some amphipods and small fish remains.

TABLE 2. LENGTH FREQUENCIES OF COD (ENTIRE CATCHES), ST. MARY'S BAY, NEWFOUNDLAND.

Total length snout-mid-fork	*Marinus* 2 sets 9 April 1957 124-132 m -1.33°C	*Marinus* 1 set 29 May 1957 95 m -0.48°C
cm	*no.*	*no.*
8-10	4	10
11-20	612	312
21-30	62	148
31-40	9	8
41-50	0	2
51-60	1	2
61-70	1	0
71-80	0	0
81-90	1	5
91-100	3	2
Total	693	489

By the end of May, in slightly shallower water with bottom temperatures -0.5 to -0.7°C, large numbers of small cod were present, almost all 15-23 cm in length, and small numbers of larger cod (Table 2).

DISCUSSION

Simpson (1908), for large cod caught near bottom by handline in about 90 m, and with the surface temperature of 11.1 to 11.6°C usually only 0.1 to 0.2°C higher than the bottom temperature, found rectal temperatures 0.40°C higher and muscle temperatures on a smaller number of specimens 0.46°C higher than the bottom temperature. Temperatures were measured immediately after capture so that the effect of struggle in increasing the temperature was included. Dogfish, flounders and haddock, however, allowed to remain alive in a tank of sea water for an hour after capture before taking their temperature, had body temperatures no higher than those of their tank water environment.

Britton (1924) using a thermometer and a rectal insertion found temperatures of living cod to average 0.7°C higher than the bottom temperatures of 7.9 to 10.0°C in 31 m from which they had just been lifted. Fish already dead on being landed showed rectal temperatures equal to those of the deep water from which they were taken. Thus, although the surface water was 1 to 4°C higher than the deep-water temperature, it apparently was not responsible for the increased temperatures of the fish. These cod would have done a good deal of struggling, with consequent increase in temperature, while the line was being hauled. In shallow water of 4 m, 13.8°C, temperatures of other bottom fishes were 0.4°C above their environmental temperatures and temperatures of bottom fishes taken from a shallow tank at 14.9 to 15.5°C were 0.1°C above those of their environment. Only larger specimens, generally 1.4-4.5 kg were used.

Clausen (1934) used thermocouples in the stomachs of 10 species of freshwater fish and found that although fish temperatures and water temperatures were approximately the same any stimulation resulted in an increase in temperature of the fish.

Morrow and Mauro (1950) mention many authors who, using thermo-electric methods and small fish, found only insignificant differences between fish temperature and water temperature, and also that several authors have shown that stimulation of fish from handling on being caught in a net results in an increase in their temperature.

Allowing for the increase in temperature resulting from violent struggling on capture of cod, such as those studied by Simpson and Britton there is little to encouraee the belief that cod living normally for a long period of time at low temperature have a body temperature more than 0.1°C higher than the surrounding water.

Scholander *et al.* (1957) using fish from Hebron Fjord, Labrador found that fishes such as the Arctic cod, *Boreogadus saida,* from the bottom water with temperatures of -1.73 to -1.75°C all year round, had plasma freezing points of -0.9 to -1.0°C in both summer and winter and thus, granting that the body temperatures of the fishes were the same as that of the environment, were supercooled by -0.7 to -0.8°C. These fish rapidly froze to death when brought to the surface at the same temperature as that at the bottom and put in contact with ice which seeded the fish with ice crystals. Fishes such as the Greenland cod, *Gadus ogac*, normally living under the ice in the shallow water where the temperature was -1.75°C in winter, had a plasma freezing point of -1.5°C in winter and -0.8°C in summer when the water temperatures were 4 to 7°C. These fish did not freeze in winter at -1.75°C even if they were touched by the ice but in summer turned belly up and ice masses filled their eyes at -1.0°C. It was repeatedly found that even large specimens of Greenland cod and sculpin had a body temperature within 0.1°C of the sea water.

Doudoroff (1945), for the hardy marine species *Fundulus parvipinnis*, inhaviting shallow bays and estuaries of California, found that death, at slowly lethal low temperatures in sea water of normal salinity, was preceded by dehydration of the tissues and delayed but not prevented by dilution of the sea water to 45% of its normal salinity. Osmoregulative failure was indicated as the cause of slow death at low temperatures but not of rapid death at still lower temperatures which may have been caused by respiratory disturbances.

Woodhead and Woodhead (1959) found a condition of osmotic imbalance in cod of the Barents Sea. Cod caught from October to June at bottom temperatures below 2°C had slightly higher amounts of blood salt (chlorides) than those caught at temperatures above 2°C. The fish taken below 2°C were caught at temperatures from 0 to below 2°C. In July and September, freezing point depressions and blood salts were at their normal values in cod from bottom water both above and below 2°C. These authors say that the cod lose their ability to survive in water below 2°C at the beginning of

October and that their results may explain the deaths of cod encountered in the North Sea (Simpson, 1953) at temperatures from 0 to 1.5°C.

Scholander *et al.* (1957) found in summer that chlorides (halides) made up about 80% of the osmotic pressure in both deep and shallow water fishes. In shallow water winter fishes living at -1.7°C or lower, and with a very large freezing point depression of about -1.5°C, the chlorides produced only half the freezing point depression. Thus the chlorides were increased relatively little in winter at these very low temperatures. Also, if fishes were transferred in summer from the warm surface water to bottom water at -1.73°C the total concentration of osmotic substances increased but the chlorides rose relatively less than the other substances.

The North Sea deaths of some of the cod population at temperatures of 0 to 1.5°C or over, were from a group of cod not normally encountering cold water and may have been due to chill or to osmoregulative failure in some of the cod, such as that found at low temperatures for *Fundulus* by Doudoroff (1945) and for cod by Woodhead and Woodhead (1959). The deaths of cod in coastal water and in shallow water or experimental tanks at temperatures of about -1.1°C were presumably due to quick chilling without time for gradual acclimatization, and in some cases to ice-seeding.

The St. Mary's Bay cod in moderately deep water could in many years encounter temperatures as low as -1.0°C or lower. Decrease of temperature in winter would be relatively slow, allowing for gradual acclimatization, and their ability to withstand temperatures of -1.4°C is very likely due to ability to maintain life when supercooled as were the Hebron Fjord deep water fishes. Small cod were probably more adapted than larger cod to these very low temperatures.

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A-5

MASS MORTALITIES OF MARINE FISHES IN THE NEWFOUNDLAND AREA PRESUMABLY DUE TO LOW TEMPERATURE

By

Wilfred Templeman[1]

ABSTRACT

Large numbers of cod have died off Labrador, in the northern part of the Gulf of St. Lawrence and smaller numbers in Trinity Bay probably due to cold. In proportion, however, to the great numbers of cod present in the Newfoundland area the reported deaths of cod are rare due to their ability to withstand cold, if time is available for acclimatization to it, and the tendency of the cod to retreat to deeper water in winter.

In proportion to the relative numbers of cod and haddock there are many more occurrences of haddock deaths in winter-spring in cold coastal surface waters. Haddock remaining overwinter in Newfoundland coastal areas apparently have less ability to withstand cold and a greater tendency than cod to enter shallow water too early in the year where they are destroyed by chilling or ice-seeding in the case of supercooled fish.

On two occasions in late March-early April, Greenland halibut died in large numbers in Trinity Bay. Although the deaths were most likely due to cold and related to the pelagic feeding on capelin well off the bottom in colder water, there is some doubt because there are no similar reports of Greenland halibut deaths from more northerly bays with Greenland halibut populations.

There are many occurrences of capelin deaths and most appear to be from ice-seeding of supercooled fish, at the surface. The pelagic life of these fish and their ability to live in the cold upper layer are responsible for their nearness to the surface in winter where they may enter the surface layer containing abundant ice crystals. It is possible that whales or more usually harp seal herds may at times drive capelin schools to the surface in winter and early spring.

Spiny dogfish in the Newfoundland area are migrants from southwards and with their higher temperature requirements than most native fishes have died in large numbers apparently from cold. The mechanism is presumably not supercooling and ice seeding but a disturbance of the nervous mechanism with loss of balance and great reduction of muscular and respiratory activities at low temperatures.

Mackerel were reported to have driven ashore on two occasions and at least one of these occurrences was probably due to cold.

INTRODUCTION

Well authenticated reports of mass mortalities of sea fishes in the North Atlantic due to low temperature have been reported by many authors especially by Dannevig (1930*a*, 1930*b*) and Johansen (1929) for cod and other fishes of southern Norway and Denmark, and by Lumby and Atkinson (1929) and Simpson (1953) for cod and other fishes of the North Sea. Although temperatures causing death on the Norwegian Coast were below 0°C, in the North Sea most of the deaths occurred in areas where the bottom temperatures probably did not fall below 1.5°C.

In many other instances of deaths of cod by cold at temperatures below 0°C in semi-natural situations (Nielsen, 1892, 1893, for the cod spawning pounds at Dildo, Newfoundland; and Earll, 1880 and Carswell, 1889, for the hatchery retaining pounds at Gloucester and at Woods Hole, Massachusetts), conditions were unnatural. The cod held in shallow pounds near the surface were

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killed by rapid lowering of water temperature and had no opportunity to respond naturally to falling temperatures by going deeper to warmer water.

Mass mortalities in Greenland in winter and spring of redfish (Jensen, 1922) and of redfish, cod, wolffish and lumpfish (Jensen, 1939) have been ascribed to unusually cold water. Collins (1884) reports the deaths of immense quantities of haddock in early December 1789 from the Arcto-Norwegian area. These dead haddock were seen floating in the sea off the coasts of Lapland and Norway on a voyage from Archangel to Leith. The subject of mass mortalities in the sea, from various causes, has been the subject of an excellent review by Brongersma-Sanders (1957).

In the Newfoundland-Labrador area, the coastal shelf area of Labrador and most of the west and east coasts of Newfoundland, including the bays, are covered by ice each winter. Also, sea temperatures over these parts of the coast have fallen by February-March to below 0°C to a depth of over 170 m and often to -1.5°C and even to -1.7°C, or slightly lower, over a great part of this depth. (See Fig. 1 for average temperatures off St. John's in the southern part of the area under discussion, and Fig. 2 for a section from St. John's to the Grand Bank in March after a cold winter).

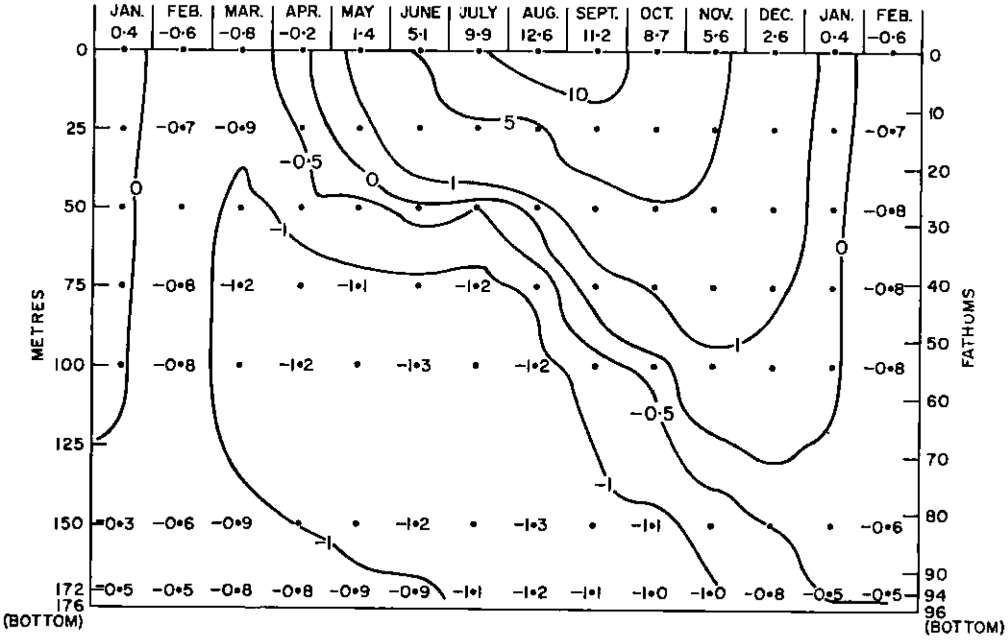

Fig. 1. Average sea temperatures (°C) at Station 27, 3.2 km (2 nautical miles) off Cape Spear, near St. John's, Nfld. (Average mid-monthly temperatures at the depths indicated, for 1950-62. Position of station, 47°31'50"N, 52°35'10"W, 176 m).

At Station 27, 3.2 km off Cape Spear near St. John's, (Fig. 1) average temperatures in February, March, April in °C (taken at each 25 m level surface to bottom in 176 m) were:

1950, -1.1, -1.6, -1.3;	1951, -0.5, -0.7, -0.2;	1952, -0.5, -0.8, -0.6;
1953, -0.1, -0.4, -0.5;	1954, -0.9, -1.0, -1.0;	1955, -0.2, -1.1, -1.2;
1956, -0.1, -0.5, -0.7;	1957, -1.4, -1.6, -1.3;	1958, -0.2, -0.4, -0.3;
1959, -1.4, -1.6, -1.2;	1960, -0.7, -0.7, -0.7;	1961, -1.5, -1.5, -1.3;
1962, -0.4, -1.3, -1.0;	1963, -0.3, -1.1, -1.0.	

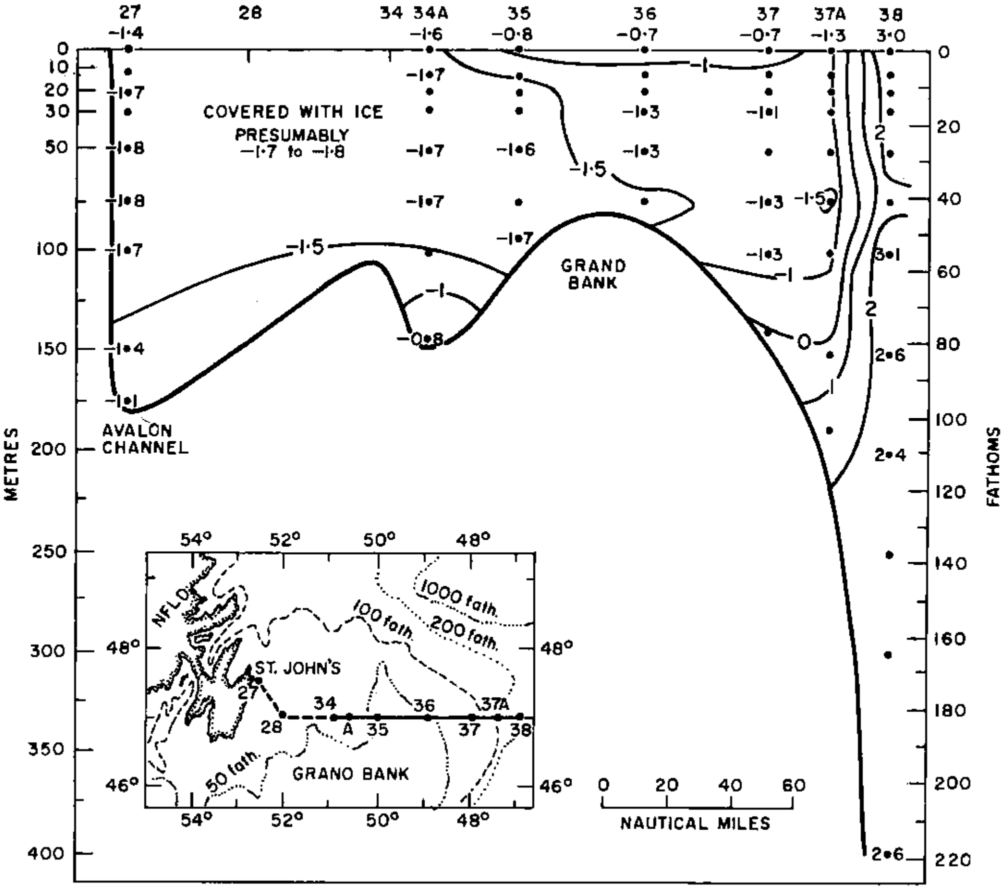

Fig. 2. Temperature section (°C) from Station 27 off Cape Spear across the Avalon Channel and the Northern Grand Bank, March 25-27, 1961.

In this period the coldest years judging from these southerly east coast records were 1950, 1957, 1959 and 1961. In all other years temperatures were low enough in the upper layers or could have been low enough at the surface in the more northerly bays to produce the recorded deaths.

It is not surprising, therefore, that there are winter-spring deaths of fish which can clearly be attributed to cold. There are other mass deaths in winter-spring where the evidence is not quite so clear. We have, over the years, collected many of these records from the Newfoundland area of mass or individual mortalities of fish in nature, examined some of the fish and come to conclusions on the cause of death. It is unfortunate that water temperatures are not available at the time of death but in many cases the evidence is clear and the accounts of the deaths may stimulate future investigation.

Cod and capelin are normal residents of the whole Newfoundland and Labrador continental shelf area. Greenland halibut, haddock, dogfish and mackerel are more restricted in distribution, the main populations of the latter three retreating southward in winter.

The location of the many Newfoundland place names mentioned in this paper is shown in Fig. 3.

COD *Gadus morhua* L.

Collins (1884) says that Captain Kirby, at Cape Charles, on the coast of Labrador on 1 August, 1876 saw an immense number of cod floating at the surface over an area of at least 10-16 sq km (4-6 sq miles). More than 300 quintals (ca. 60 metric tons round fish) were picked up and cured by local fishermen. At the time of this occurrence an unusual number of icebergs were grounded in the vicinity.

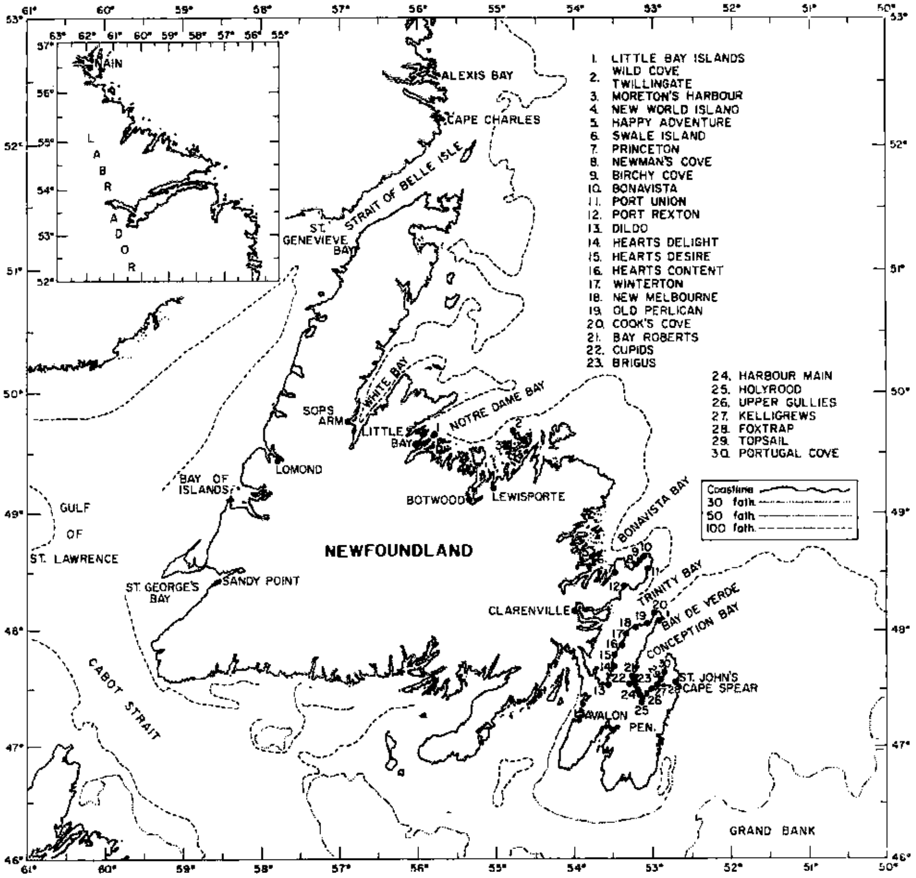

Fig. 3. Place names, Newfoundland area.

As many as 7 or 8 large bergs were within an area of 6-8 km (4-5 miles) and 40 bergs were in sight from the hills of Cape Charles. The local fishermen were of the opinion that the excessive coldness of the water, caused by the proximity of so much ice had killed the fish.

The St. John's Evening Telegram, 15 May, 1934, reported that Captain Tremblay, Master of the S.S. *North Voyageur*, stated that he steamed through over 32 km (20 miles) of dead codfish early in May 1934. This occurred in the northern part of the Gulf of St. Lawrence from 49°49'N, 59°10'W to 49°04'N, 58°40'W.

Mr P.J. Bannister, fishery officer, reported that off Port Rexton, Trinity Bay on 22 March 1960, numerous dead baby cod were floating on top of the water. There was a thin layer of white ice on the fish and they could not get to the bottom. The same observer in February 1948 coming from Swale Island to Happy Adventure, Bonavista Bay noticed a large cod floating on the surface. The fish was covered with a layer of ice. He says that the fish was taken, put in a pan and when the ice had melted it jumped out of the pan, very much alive. The fish was eaten with no ill effects.

HADDOCK *Melanogrammus aeglefinus* (L)

The St. John's Daily News, on 22 February 1957 reports (from their old files) that in May 1906 a shoal of haddock came in from Trinity Bay and hundreds of them went ashore on the beach at Clarenville.

The St. John's Evening Telegram of 16 March 1912 records that at Portugal Cove, Conception Bay, on 15 March thousands of haddock swam into the cove through a lake of water in the ice. These fish died and floated on the surface. The people of the village who went out in small boats each obtained 500 - 1,000 lbs. Such a happening had never before occurred in Portugal Cove.

A letter from Mr J. Strong of Little Bay Islands on 11 April 1957 informed us that 2 haddock, 15 and 35 cm long, were found dead near the shore. At this time the whole sea area out to about 160 km was covered with ice. Another haddock 28 cm long in good condition was found dead near Twillingate on 28 March 1960, by Mr E. Drover. Again on 7 May 1961, Mr Strong reported finding, at Little Bay, 5 dead haddock about 25-45 cm long. The bay was at the time covered with ice.

On 5 June 1959, fishery officer Nichols reported that thousands of small haddock were floating and being washed ashore in the Sops Arm area of White Bay.

Fishery officer P.J. Bannister, reported that off Port Rexton, Trinity Bay, on 22 March 1960, numerous dead haddock were floating on the surface of the water. There was a thin layer of white ice on the fish.

GREENLAND HALIBUT *Reinhardtius hippoglossoides* (Walbaum)

On 8 April 1943, Greenland halibut (called turbot in Newfoundland) came to the surface and died in large numbers on the eastern side of Trinity Bay.

During the week of 26 March-2 April 1959, mass deaths of Greenland halibut occurred again in Trinity Bay. The following account of this occurrence is mainly from the report of a survey by Mr A.G. Kelland, technician at the St. John's Station. At Old Perlican it is estimated that large numbers of Greenland halibut were killed. Slob ice was present and most of the Greenland halibut were seen dead but in good condition in shallow water on the bottom. One man salted a barrel of these fish and they were reported to be of average size and in good condition. In the same period at Winterton, about a dozen dead Greenland halibut were picked up floating at the surface in fresh condition and not frozen. Mr Kelland ate some of these and the taste was excellent. There were reports of similar numbers of dead Greenland halibut washed on shore at Hearts Delight and Hearts Desire.

CAPELIN *Mallotus villosus* (Müller)

Templeman (1948) notes mortalities of capelin during winter in Labrador. In the deep fjords of northern Labrador near Nain great cracks appear in the surface ice in winter and these run across the fjord every few miles throughout its length. Capelin rise into the open water in these cracks and apparently freeze when they reach the cold surface water. As much as two barrels of capelin have been obtained from one crack in an hour or two. Also in southern Labrador in March and April 1941 capelin were obtained in open cracks in the ice of Alexis Bay. These fish were plentiful and were used as dogfood.

On 8 April 1943, when, as we have reported, large numbers of dead Greenland halibut were washed ashore in Trinity Bay large numbers of dead capelin were noted in the same area. Similarly, in Mr Kelland's report of the deaths of Greenland halibut in Trinity Bay, 26 March - 2 April 1959, small quantities of fresh dead capelin were washed ashore at the same time.

Seven of these were examined at the St. John's Station by Mr T.K. Pitt and were adult capelin 14-17 cm long which would spawn in 1959. The normal amount of fat was present and the condition of the internal organs gave no indication of the cause of death. Four stomachs were empty, two had remains of euphausiids or mysids and one contained digested material. The male capelin did not possess spawning ridges. Capelin in this condition are usually called "whitefish" by Newfoundland fishermen.

On 13 April 1950, a fisherman, Mr Walter Baggs, noted fair quantities of dead capelin floating on the surface of the sea just north of St. John's. These capelin were in good condition, *i.e.* recently killed. Some were brought in and eaten. They were of the size which would spawn in the same year.

On 19 March 1960, Mr E. Drover of Twillingate saw hundreds of newly dead capelin floating near the beach on the western side of Twillingate. Over a stretch of 50 m of beach he picked up several gallons. These capelin were in excellent condition and were eaten.

Mr P.J. Bannister, fishery officer, reported that, on 22 March 1960, numerous capelin were floating at the surface off Port Rexton, Trinity Bay. There was a thin layer of white ice on the bodies of these fish and although when they were being collected a few were alive enough that they flicked away, the ice prevented them from escaping toward the bottom.

On 1 March 1963, very large numbers of floating dead capelin appeared among the slob ice in the Newman's Cove and Birchy Cove area Bonavista Bay. The Bay was full of slob ice pressed closely to shore. Thousands of capelin could be seen on the ice and intermingled with and below the slob ice. Local people collected large numbers for food. Probably at least several millions of capelin were killed here. Two men secured two barrels of capelin in one hole in the ice. These capelin were excellently fresh and were eaten in large numbers in the Newman's Cove and Bonavista area.

The author examined 6 of these capelin at Bonavista several weeks later. They were about 16-20 cm long, a bright silvery colour on the belly and bluish grey on the back. The bellies were more silvery and the back and the whole fish not as dark in colour as later, in late June-early July, when the fish are in shallow water near the beaches to spawn. The spawning ridges had not appeared on the males but the males could be separated externally from the females by the greater size of the anal fin. Eggs in the ovaries of the females could barely be seen with the naked eye.

SPINY DOGFISH *Squalus acanthias* L.

Templeman (1944) reports that, in the week preceeding 11 January 1939, at Sandy Point, St. George's Bay, a large number of spiny dogfish (called dogfish in remainder of paper) were washed ashore after heavy northwest gales which lasted for 3 days and produced a heavy sea in this area.

Mainly from 20-26 February 1951, large numbers of dogfish were driven ashore at many places in Conception Bay. At Cupids on 20 February 1951, they were observed by a technician of the St. John's Station, Mr B.W. Andrews, who was stationed in the area and who reported as follows: I first noticed these dogfish in Cupids harbour early morning 20 February. There was no wind or sea and new slob ice was forming in the harbour. The dogfish were noticed in the water near the beach - some alive, all belly-up and waving their tails, and others dead but all afloat on the surface. All died eventually. They could be seen all along 3 km of beach about 1 every 20 m. All the dogfish were small and lean, much different from the usual run in size and stoutness.

Also from the local branch of the Department of Fisheries of Canada information was obtained that numbers of small dogfish drove ashore and were found on the beach at Harbour Main on Sunday 25 February 1951.

Fishery officer Badcock of Bay Roberts reported that hundreds of small dogfish were ashore there on 5 March, or earlier, 1951 and many dead and dying dogfish were also reported from Brigus on 20 February from Kelligrews and Harbour Main.

Additionally Mr Donald Andrews reported large numbers of dying dogfish driving onshore at Foxtrap in Conception Bay on 5 April 1951. These were all small dogfish, alive but stupid and without sense of direction. They could be thrown off the beaches but would come in again.

Twelve of these dogfish selected at random from Cupids on 20 February and 3 from Bay Roberts on 5 March were examined by the author. Nine were immature males 57-65 cm in greatest total length and 6 were immature females, 5 being 58-66 cm and one 70 cm in greatest total length. All stomachs were empty.

In the winter of 1952 large numbers of dogfish died in Notre Dame Bay. The following information of this occurrence was supplied by Mr S.A. Knight of Moreton's Harbour: During the month of January 1952 large numbers of dogfish drifted ashore on the southern side of Notre Dame Bay in the area from Twillingate to Lewisporte and Mr Knight believes that conditions were generally the same all around the bay. Large numbers of small to medium sized dogfish drifted in at Wild Cove on New World Island early in January. The fish were in a stunned condition usually belly-up with only slight movement of the fins. A gale of northeast wind was blowing at the time and the fish drifted onto the beaches. The St. John's Daily News of 8 February 1952, reported from its Botwood correspondent that every hole of water in the ice near beaches and wharves was filled with dead and dying dogfish.

In the winter of 1954 large numbers of dogfish were noticed dead or dying at the surface and washed ashore on the beaches of Trinity and Conception Bays. The Federal Department of Fisheries (Newfoundland area) reported on 11 February 1954, that dogfish had been driving ashore at Old Perlican in Trinity Bay since January. There were scores around the beach and some came in on 10 February. There was a little life in them when they came in but not enough to keep them from being washed up on the beaches. Mr Earl Frost, technician at the St. John's Station, reported on 23 February 1954, that numbers of dogfish were washed ashore early in February at Old Perlican, Cook's Cove and New Melbourne, Trinity Bay, with the greatest number at Cook's Cove. Also at these places large numbers were seen on the surface in a stunned condition. Dogfish also washed ashore at Bay de Verde, Conception Bay on 15-18 February among the slob ice. They appeared half-dead and floated on the surface of the water before being driven ashore.

On 25 February 1954 Mr A.G. Kelland, technician at the St. John's Station, investigated reports of dogfish washing ashore in Conception Bay. On Topsail Beach 35 dogfish were noted and 5 on the beach at Upper Gullies. At Holyrood several hundred dogfish were on the beach. On these beaches most had been washed ashore on 23-24 February and these were in good condition but some were beginning to decay and had been washed ashore earlier. A local resident of Holyrood said that the first dogfish he noted on and near the beach was on 24 February. Some were floating on the surface barely alive and others were washed ashore dead. At Holyrood 203 dogfish were measured and 110 females 56-75 cm in greatest total length were all immature whereas of 93 males 56-78 cm long many of the larger males were mature. All 9 males and 7 females examined had empty stomachs.

The St. John's Daily News on 15 March 1954, reported that on the west coast of Newfoundland thousands of dead dogfish were being drifted ashore on the coastline between Lomond and St. Genevieve Bay.

Also the Fisherman's Advocate of Port Union, reported on 26 March 1954, that at Princeton, Bonavista Bay, in common with other places around the coast, dogfish had been plentiful and found dead on the beaches during the early winter.

MACKEREL *Scomber scombrus* L.

In the St. John's Daily News of 2 February 1952, it was reported that thousands of mackerel, *Scomber scombrus* L., had driven ashore in Notre Dame Bay beginning about 20 December 1951.

Mr B.W. Andrews, technician of the St. John's Station, reported that on the night of 27 December 1951, small numbers of mackerel with an average weight of 1 kg came ashore on the beach at Cupids, Conception Bay.

DISCUSSION

1. Cod

The deaths described are in situations and times when they could most likely be ascribed to cold water although the occurrence reported for August on the Labrador Coast must be very unusual. In view of the large numbers of cod in the Newfoundland area there are few records of mass deaths. Small cod in this area, when acclimatized slowly, can live in water at least as low as -1.4°C and larger cod commonly to -0.5°C and in small numbers to -1.3°C or lower (Templeman and Fleming, this symposium). In winter, in the Newfoundland area, cod of mature and large immature sizes tend to seek deeper water below the influence of the winter chilling and hence are usually in water above 0°C and often between 2 and 3.5°C. In late winter-early spring (Fig. 1, 2) water temperatures may be the same or almost the same, -1.0 to about -1.7°C, from surface to bottom down to 150 m or more and as low as -1.8°C on the surface where ice crystals are then forming. Occasional cod caught in this cold layer might come to the surface and being seeded by contact with ice crystals, their body fluids would change from their supercooled liquid condition to a frozen condition (Scholander *et al.*,1957). Also, although mature cod may live in deep water at above 0°C in winter after spawning, in the Labrador area mainly on the seaward slope of the continental shelf, many of them become pelagic in late spring-early summer and enter shallow water of the coastal region. In the Gulf of St. Lawrence, cod, which winter in the deep water near the Newfoundland side of Cabot Strait, move rapidly northward in late spring and enter shallow water as far northward as the Strait of Belle Isle. It is probable that a rapid change from deep warm to shallow cold water in the latter situation resulted in the mass mortalities recorded for the Gulf of St. Lawrence. The mortalities of Labrador cod in August have been ascribed to cold water due to the presence of icebergs. Although again death from cold water is a likely cause there is some doubt because icebergs are common on the Labrador Coast and no other mass deaths have been reported from iceberg melting.

2. Haddock

Haddock are accustomed to living at a temperature one to several degrees higher than cod. Consequently, it is to be expected that their resistance to low temperatures will be correspondingly less than that of cod.

The most northerly large spawning population of haddock on the continental shelf east of Newfoundland and Labrador lives mainly on the southern Grand Bank, returning to the southwestern slope in winter and mainly spawning there, and in summer spreading northeastward over the Grand Bank but still mainly over the southern half of this bank. Some of these Grand Bank haddock and occasionally large numbers in their northward passage reach the coast of Newfoundland, especially the Avalon Peninsula, in late June and early July, and in July and August work northward along the east coast of Newfoundland. A few migrate as far as Notre Dame Bay and occasional individuals, either by way of the east coast of Newfoundland or from another small population along the west coast of Newfoundland, reach southern Labrador. Presumably most of these haddock retreat southward in autumn, but at least some remain and spend the winter with the cod in the deep warmer water below the cold layer. From their natural winter abode in the deeper water on the southwestern slope of the Grand Bank haddock move northeastward into shallower water from April to June as water temperatures rise in the shallow water of the bank. There is, however, a tendency at this time to move northward even if water remains fairly cold but in these months the bottom water of the southern shallow-water part of the Grand Bank is usually 1 to 4°C and occasionally 0 to 2°C (Templeman and Hodder, this symposium). The surface temperatures on the southern Grand Bank at this time are slightly higher than the bottom temperatures and there are no records of mass mortalities from cold. Northward, however, along the coasts of Newfoundland where some haddock which migrated northward from the Grand Bank in previous years spend the winter in deep water, the haddock apparently have the same instinct to move into shallower water fairly early in spring and may be killed by cold water especially in presence of ice crystals. It is likely that some of the winter kills are of haddock caught in bays of only moderate depth and in passing to the surface when the water becomes chilled below -1°C are killed by ice-seeding in the surface layer. Also many of the haddock, instead of passing into the deeper water to the east, may be trying during the winter to retreat southward pelagically in shallow water which becomes too cold for survival.

Only a very small number of haddock winter off the Newfoundland east coast (probably not more than 1 haddock to at least 10,000 cod). In spite of this disparity in numbers present there are more records from this area of haddock than of cod mortalities which can definitely be attributed to cold water. It is probable that the natural behaviour of the haddock is not suited to over-winter survival in numbers on the east coast of Newfoundland and thus no coastal spawning populations have developed here.

3. Greenland Halibut

Although Greenland halibut are abundant in many other deep bays of the Newfoundland area all the accounts of deaths of Greenland halibut are from Trinity Bay. This is not the coldest bay and in the more northerly White Bay and the bays and arms of Notre Dame Bay the cold water should extend more deeply and on the average be colder.

Trinity Bay is a deep water bay with a threshold depth at its mouth of about 230-265 m and water as deep as 330 m off Old Perlican and over 370 m off Winterton and Hearts Desire. The Greenland halibut in Trinity Bay in summer and autumn are almost all below 180 m and the larger ones and the greater numbers below 280 m. In an otter-trawl survey of this bay by the *Investigator II* in late November-early December 1953 the largest quantities of Greenland halibut, 350-1,180 kg per hour's towing, were between 300 and 400 m and bottom temperatures of 0.4 to 0.8°C. Greater depths were not investigated due to lack of towing warp. In this bay at the depths inhabited by the larger Greenland halibut temperatures should not fall below 0°C in winter and spring. The upper layer of water down to 150 m or deeper should in almost all winters fall below 0°C by February-March and in very cold winters reach -1.5 to -1.8°C for at least a considerable part of this depth with as low as -1.75°C and ice crystals and ice at the surface. (At the usual winter salinity near St. John's of slightly over 32 o/oo the freezing point of sea water and formation of ice crystals is at -1.75° C). The depth of the entrance to the bay is also great enough that there should not be oxygen depletion.

The pelagic capelin which can inhabit water below 0°C is one of the chief foods of the Greenland halibut and is a favoured bait for them. Jensen (1935) records that in the West Greenland fjords the Greenland halibut often move into the intermediate layer in numbers and feed on capelin as much as 100 m off the bottom in a depth of 300 m. Here they are often caught pelagically and abundantly by the Greenlanders using handlines only 200 m long. It is very likely, therefore, that in Trinity Bay schools of Greenland halibut carry out similar vertical migrations moving up from the deeper water of above 0°C temperatures into colder water above. Thus, in years when water temperatures are low and the cold water extends deeper than usual they may move suddenly into water so cold that they may be stunned and lose control of their movements and finally be killed by the cold water or by ice-seeding at the surface. This might especially occur when strong northerly winds send the colder water deeper than usual on the southern side of the narrow bay.

There remains the problem why Greenland halibut, lacking an air bladder, should float at the surface. These are rather fat fish and (in summer at least) have about 10-12% fat in their flesh which helps to lighten them. Passage toward the surface should cause a good deal of gas to come out of the blood and be retained in the tissues and the very cold surface water is fairly dense in spite of the approximately 32 o/oo coastal salinity. Any formation of surface ice on the fish, which has not been reported for the Greenland halibut, but has been reported for some of the other fishes, would also help to float the fish. After a while at the surface the sea-birds pick away the guts and liver and the fish then apparently sinks unless it has meanwhile become frozen into the ice.

There must, however, remain an element of doubt that low temperatures were the cause of the mortalities of Greenland halibut because of the absence of information on such deaths from more northerly bays where temperatures should be lower and low temperatures extend deeper. In favour of cold being the cause of death is the record that on both occasions when Greenland halibut died, capelin died also, and many of our instances of capelin dying have certainly been due to cold, most likely to ice-seeding of supercooled fish.

4. Capelin

That capelin can live in very low temperatures is apparent from the fact that they occur in numbers as far north as Hudson Bay. They are pelagic, cold water fish commonly found in the Newfoundland area in winter, near and in the cold upper layer. It is not surprising, therefore, that at times during late winter and early spring when temperatures are approximately the same and often below -1.0°C in the upper 150 m near the coast that some schools of capelin may come into the immediate shallow water near the shore or at the surface where temperatures of -1.7 to -1.8°C and great quantities of ice crystals are available to seed them with ice and kill them. The general occurrence of capelin deaths described seems to suit this kind of situation. The ice which often covers the fish keeps the capelin floating and even if some life remains prevents them from passing deeper.

In the surface kills of capelin (also of some haddock and baby cod) reported by Mr Bannister from Trinity Bay, 22 March 1960, 6 large baleen whales were at the surface in the vicinity and it was thought that these whales which, off Newfoundland, feed partly on capelin might have driven the capelin and other fishes to the surface where they iced up and died. It is possible that in spring the numerous harp seals may occasionally also drive some capelin into the icy surface layer or the inshore shallow water area. Many of the occurrences, however, are very likely mass movements of the capelin into the shallow water and surface environment at a time when these situations are fatal due to the presence of ice crystals.

5. Spiny Dogfish

These are rather warm water fish not liberating their young in the Newfoundland area. In summer they migrate northward along the Newfoundland coast as far as southern Labrador. In their migrations northward around the east coast of Newfoundland dogfish move in the warmer surface layer rather than in the deeper and colder water occupied by cod. In the autumn the mature females pass southward out of the Newfoundland area to produce young on the continental shelf of the United States (Templeman, 1944). Large numbers of dogfish of intermediate size — immature females, immature males and mature males — sometimes remain in the bays. Here they often find themselves in shallow holes or harbours when too low temperatures develop. Being a warmer water fish than cod and capelin they probably cannot survive at as low a temperature as these fish. Conception Bay, from which many of our reports of dogfish deaths in winter have come, has a deep central hole below 170 m but the threshold at the entrance of the bay is shallower than 170 m. Thus all the water of the bay can fall below 0°C during the winter, the first 170 m, at least, below -1.0°C and the surface to -1.7 to -1.8°C. In early December 1953 the bottom water in the deep hole of this bay was at a uniform -0.9°C in all depths from 180-265 m. The deaths of dogfish cannot be attributed to ice-seeding at the surface of supercooled fish since the body fluids of elasmobranchs are isotonic with sea water and these dogfish before dying have presumably risen from deeper waters of higher salinity. The surface floatation and deaths are very likely produced by loss of muscular and respiratory control and possibly from other causes such as osmoregulative failure (Doudoroff, 1945; Pitkow, 1960).

Although in the dogfish there is no air bladder and the flesh not fatty the oily liver would often assist in floatation once the animal has lost its power to swim more deeply.

These overwinter deaths from cold may be an important factor in preventing the establishment of native populations of dogfish in the Newfoundland area.

6. Mackerel

The two accounts of mackerel going ashore on the beaches in December are not detailed enough to indicate whether or not they were killed before going ashore. The Notre Dame Bay occurrence, however, was accompanied by massive deaths of dogfish at the same time and was presumably the effect of cold. Mackerel are rather warm-water fish and only occur in the eastern Newfoundland area in quantity in the warmer periods of years. They are apparently migrants into this area rather than regular inhabitants and might be expected to be affected detrimentally by low temperatures.

7. Other Fishes

Redfish, *Sebastes mentella* Travin are present in moderate numbers in some deep Newfoundland bays, such as Trinity Bay and Notre Dame Bay, and are relatively abundant in the Gulf of St. Lawrence. It is surprising that no mortalities of redfish in winter-spring are reported from these or other Newfoundland Areas although winter deaths of large numbers of redfish probably from cold are reported from the fjords of West Greenland (Jensen, 1922, 1939; Templeman, 1959). Redfish are normally below 180 m in the east coast Newfoundland bays, even in summer, and tend to go deeper in winter. The bays are deep and very low temperatures probably do not reach deeply enough to kill redfish which, although most prevalent in the Newfoundland area at temperatures above 3°C, are sometimes caught in small numbers in water of 1°C or less.

Herring, *Clupea harengus* L. are present in great quantities in winter in ice-covered bays such as Bay of Islands and Trinity Bay and yet we have no report of herring deaths which are likely to have been caused by cold.

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A-6

RESEARCH VESSEL CATCHES OF COD IN THE HAMILTON INLET BANK AREA IN RELATION TO DEPTH AND TEMPERATURE [1]

By

Wilfred Templeman and A. W. May [2]

ABSTRACT

The interrelationships of distribution and abundance of cod in the Hamilton Inlet Bank area ith depth and temperature have been studied by analysis of catch, depth and temperature data from esearch vessels, generally fishing at pre-determined positions and depths.

Surveys in April and May of 1963 revealed large concentrations of spawning and post-spawning od on the extreme eastern slope of the bank in depths of 225 - 330 m at temperatures mainly beween 2.5 and 3.1°C. The larger, mature fish were most abundant in deeper warm water, while the maller, immature fish generally inhabited shallower and cooler water. It is apparent that in winter ost mature cod of this area move as far away from the coast as possible and accumulate on the eastrn continental slope for spawning, since they are not found in abundance closer to shore in similar epths and otherwise suitable temperatures.

Following, but not immediately after spawning, these concentrations begin to break up, and by ate June many of these cod have found their way inshore, and are fished throughout the summer at ariable temperatures with a range of at least -0.8 to 8.7°C. Those remaining offshore are found ainly in shallower (165-250 m) cooler (-1.0 to 2.0°C) water close to and on the central part of he bank, occasionally concentrating to feed, and by late summer may be restricted in movement due o temperature barriers or to feeding.

Concentrations found in late autumn on the southwestern slope of the bank may be gathering or movement eastward to the spawning area.

INTRODUCTION

Between 1950 and 1963 the Fisheries Research Board of Canada research vessels *Investigator 11* nd *A.T. Cameron* carried out bottom trawling surveys on Hamilton Inlet Bank and on the eastern and outheastern slopes of this bank. The *Investigator 11* a 25-m, 250-h.p. vessel used a No. 36 otter-rawl with an 18.3-m headline. The *A.T. Cameron* a 54-m, 1000-h.p. vessel used a No. 41 otter-trawl ith a 24.1-m headline. The codend in each case was lined or covered with small-meshed netting. his was of 29- or 35-mm external stretched mesh size, except for an *A.T. Cameron* cruise in August 962, when 2-inch mesh courlene was used as a cover. Both ships trawled at about the same speed f 3½ knots. Except where otherwise indicated the period of towing on bottom for each set was 30 in. On the slope of the bank the vessels always towed along a depth contour, attempting to keep he same depth in any one set. A bottom temperature was taken at the end of each set, usually bout 4 m from the bottom, using 2 reversing thermometers on a Nansen or Knudsen water bottle, and 36-kg weight. In all the more recent work temperatures have been corrected for thermometer and uxiliary error but, in these waters of low temperature, corrections are as a rule small—in the econd decimal place. Also, in all the work by the *A.T. Cameron* in depths to 275 m, an additional heck was made by a bathythermograph cast, at each station, to bottom or about 1 m above bottom. emperatures from the thermometers and bathythermograph slide were compared and adjustments made o the bottom temperatures where necessary. Below 275 m temperatures are usually rising slowly nd the effect of the thermometers being several metres off bottom is not significant in relation o the wide temperature scales used in this contribution. Unless otherwise noted all temperatures eferred to in this contribution are bottom temperatures.

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Fisheries Research Board of Canada Biological Station, St. John's, Nfld.

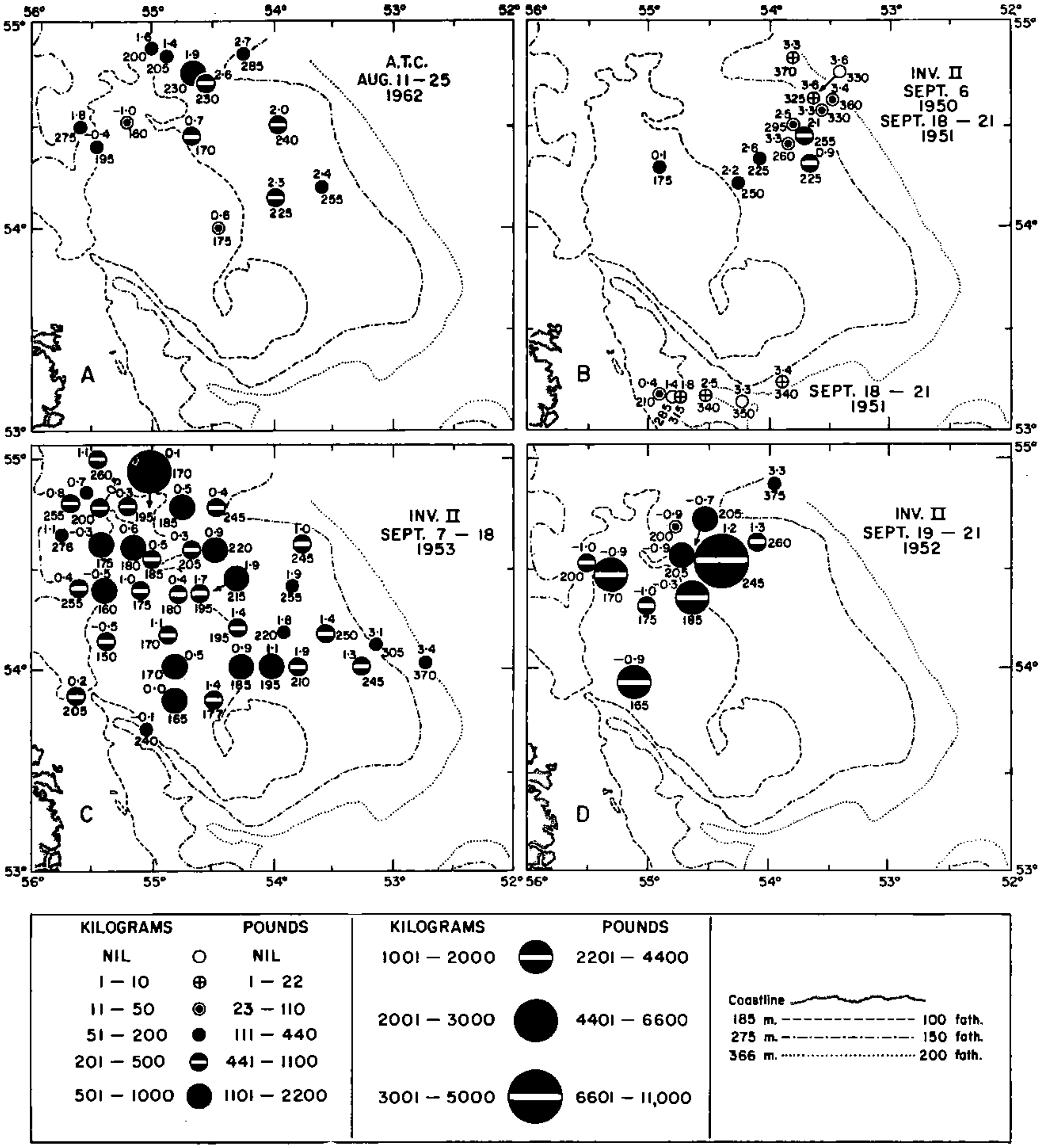


Fig. 1. Cod catches per half-hour tow by the *A.T. Cameron* and the *Investigator 11* on Hamilton Inlet Bank and its slopes, 9 April-11 August, 1958, 1960 and 1963. (Bottom temperatures in °C and depths in m are inserted near the catch symbols which are for whole cod.)

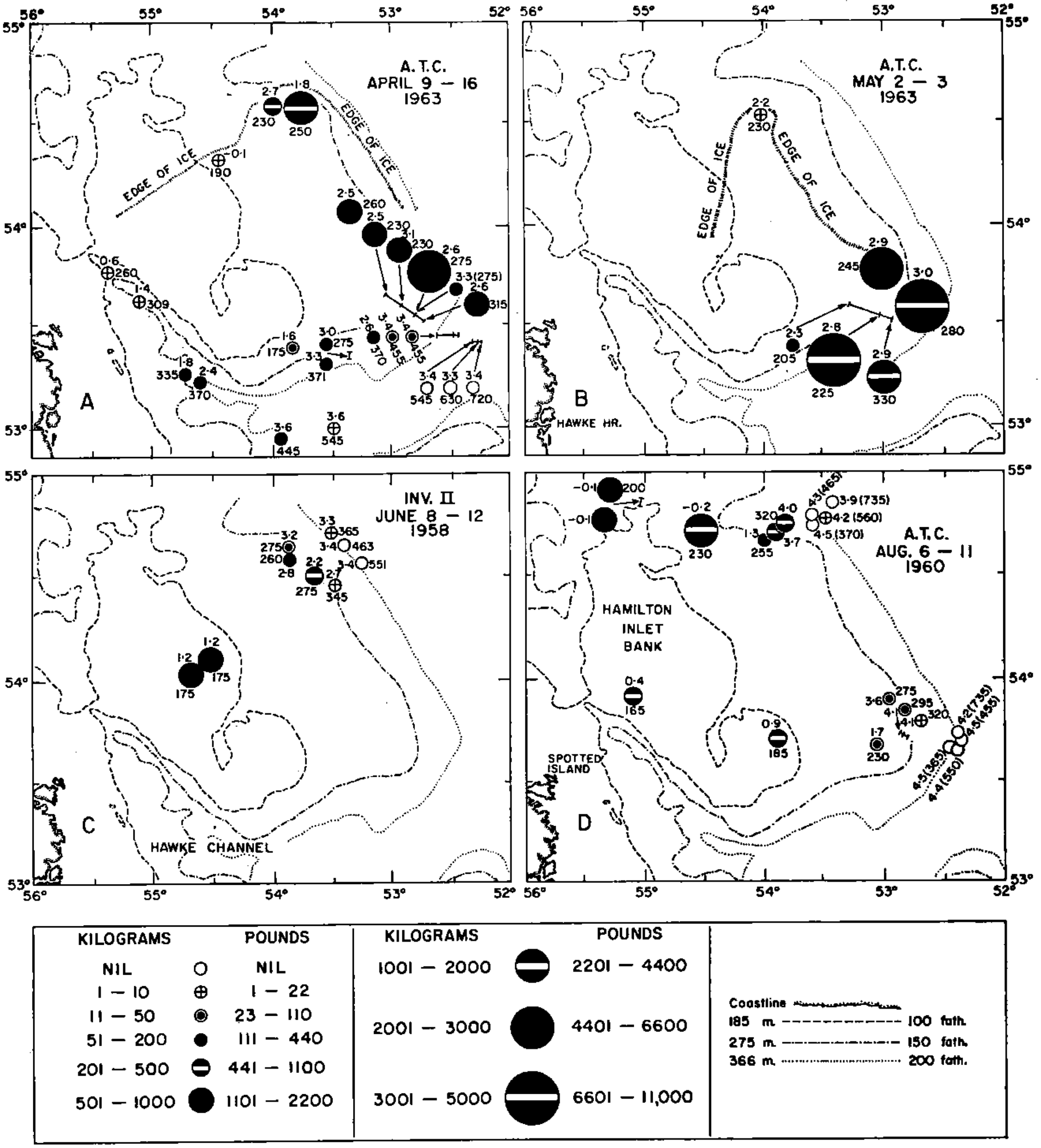


Fig. 2. Cod catches per half-hour tow by the *A.T. Cameron* and the *Investigator 11* on Hamilton Inlet Bank and its slopes, 11 August-21 September, 1951, 1952, 1953, and 1962. (Bottom temperatures in °C and depths in m are inserted near the catch symbols which are for whole cod.)

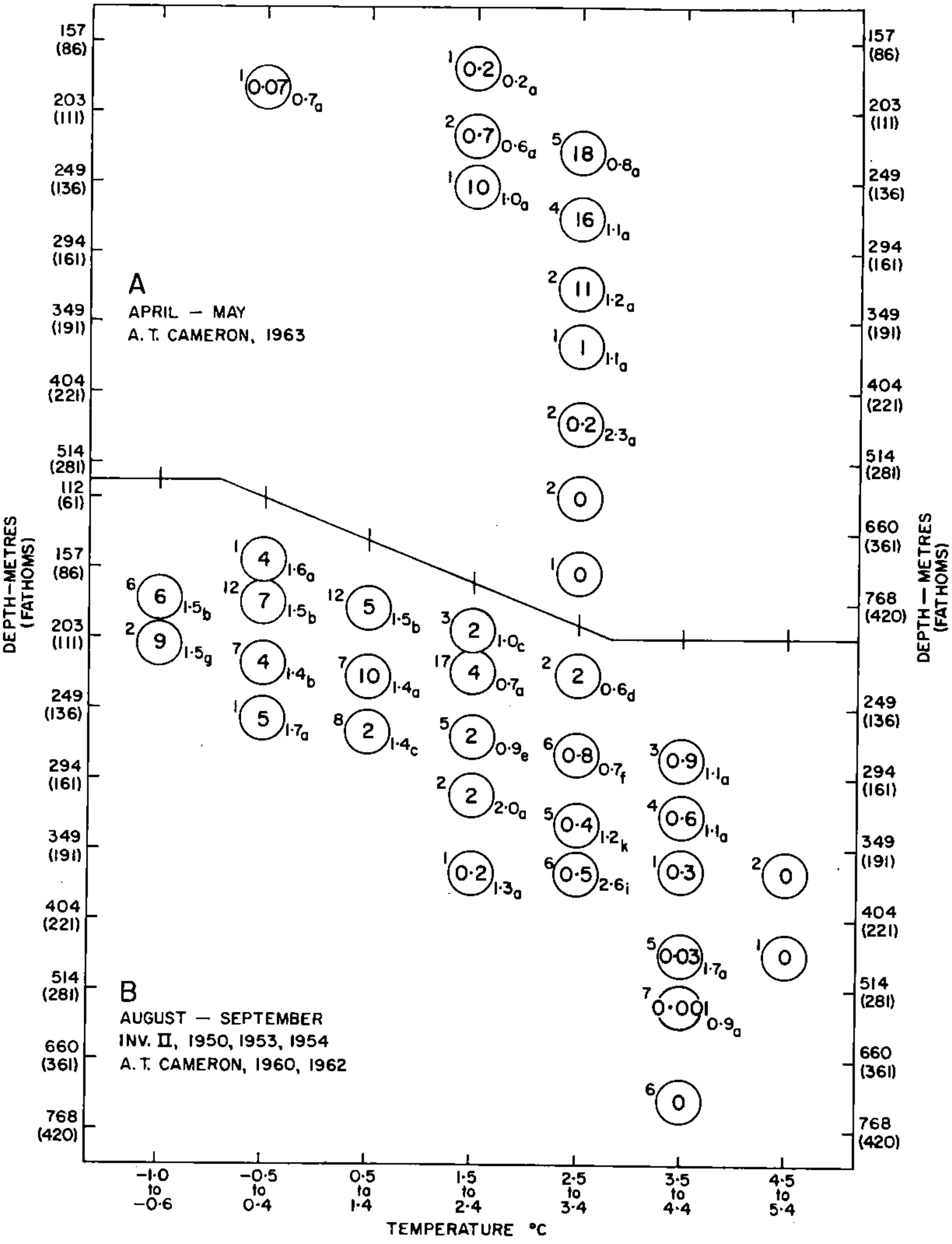


Fig. 3. Average catches of whole cod in the Hamilton Inlet Bank area in relation to depth and bottom temperature. (The figure in the circle is the average catch in hundreds of kg. At the upper left of the circle is the number of sets included in the average. At the lower right is the average weight of the whole cod in kg. The letter index to the lower right of the weight, indicates the percentage of the cod catch represented in the averages for average weight: a, 100; b, 90-99; c, 80-89; d, 70-79; e, 60-69; f, 50-59; g, 40-49; h, 30-39; i, 20-29; j, 10-19; k, 1-9.)

In paired haul comparisons of the *A.T. Cameron* and *Investigator 11* during 4 cruises involving a total of 101 sets the *Investigator 11* caught 80% as much cod as the *A.T. Cameron* although the *A.T. Cameron* caught over twice as much haddock as the smaller ship. Assuming that on Hamilton Inlet Bank the August and September concentrations and distributions are similar, and allowing for the additional catching power of the *A.T. Cameron*, it appears likely that the *Investigator 11* catches in September 1952 and 1953 (Fig. 2C, 2D) and even the *A.T. Cameron* catches of August 1960 (Fig. 1D) indicate a greater cod population on Hamilton Inlet Bank than in August 1962, judging by the *A.T. Cameron* catches at the later period (Fig. 2A). Because the *Investigator 11* surveys were in the earlier part of the period under consideration when cod were more plentiful, and the *A.T. Cameron's* surveys in the latter period when a large fishery was developing in this area, it has not been found necessary to separate the *Investigator 11* and the *A.T. Cameron* catches in Fig. 3.

The sets were made at pre-determined positions without reference to abundance of fish as indicated by echo-sounder. However, most of the larger catches of the *A.T. Cameron* in April-May 1963 (Fig. 1A, 1B) and the two 200-m catches of the *A.T. Cameron* in August 1960 (Fig. 1D) were made in areas where commercial trawlers were fishing. All sets were made in daylight.

A.T. CAMERON AND *INVESTIGATOR 11* SURVEYS

1. Spring

In early April 1963 (Fig. 1A) the *A.T. Cameron* found heavy concentrations of cod on the eastern and southeastern slopes of Hamilton Inlet Bank. The heaviest concentrations on the southeastern slope during 9-12 April were in 275 m at 2.6°C, and on the northern part of the eastern slope at 250 m and 1.8°C. On the southeastern slope trawling was extended to 720 m, but only a few cod were found deeper than 370 m (2.6 to 3.4°C), and none between 545 - 720 m (3.3 to 3.4°C). On the northern part of the slope the fishing was at the edge of the ice and it was not possible to trawl deeper. Sets in shallower water (175-190 m) and at lower temperatures (-0.1 to 1.6°C) on the eastern edge of the bank produced only a few small cod. Sets in deeper water in the western part of Hawke Channel at low temperatures (0.6 to 1.8°C) also produced few cod.

On 2-3 May, 1963, very large catches of post-spawning cod were obtained on the southeastern slope (Fig. 1B) just south of the ice edge at 225-280 m (2.8 to 3.0°C). These spawning and post-spawning concentrations in April-early May appear to be on the extreme eastern edge of the slope, and in 1963 were chiefly at depths between 225 - 330 m at temperatures from 2.5 to 3.1°C (Fig.1-5). The larger mature fish were in the deeper water and higher temperatures, and smaller immature fish predominated in shallower water and lower temperatures (Fig. 3-5).

2. Summer to early Autumn

From August to early September (Fig. 1-3) and probably also in June (Fig. 1C), the cod were concentrated on and near Hamilton Inlet Bank rather than on the seaward border of the eastern slope, and in shallower water and lower temperatures than in the spawning and immediate post-spawning period in April-May. The larger catches were generally in depth ranges of 165 - 250 m and at temperatures from -1.0 to 2.0°C and cod were usually scarce below 300 m. At the higher temperature ranges (Fig. 3B) there was a tendency for cod to be more plentiful at the shallower depths. At similar depths they were more abundant in the lower temperature ranges, most large mean catches occurring below 1.5°C and almost all below 2.5°C. At locations with significant numbers of cod in the same depth range, there was usually a decrease in fish size with increase in temperature. There was, however, little difference in size at any depths within the -1.0 to 1.4°C range. At the higher temperature ranges the scarce fish from the deep water were often on the average larger than those from the greater populations of the shallower water in the same temperature range (Fig. 3B).

3. Cod Catches in Relation to Temperature Sections

3.1 Spring. For some recent surveys temperature sections are available with the catch data (Fig. 4,5) and it is worthwhile to consider these data in detail. In the 9 April-3 May period (Fig. 4, 5A) all the large catches of 501-1000 kg and over per half hour were in temperatures of 1.8 to 3.1°C, and all the very large catches of 2001-3000 kg and over in temperatures of 2.6 to 3.0°C. Bottom temperatures adjacent in a shoreward and shallower direction to the positions of these large catches were 2 and 1°C and these would not be a barrier to cod during the feeding season. Temperatures of the water layers immediately above the large catches, however, were usually changing

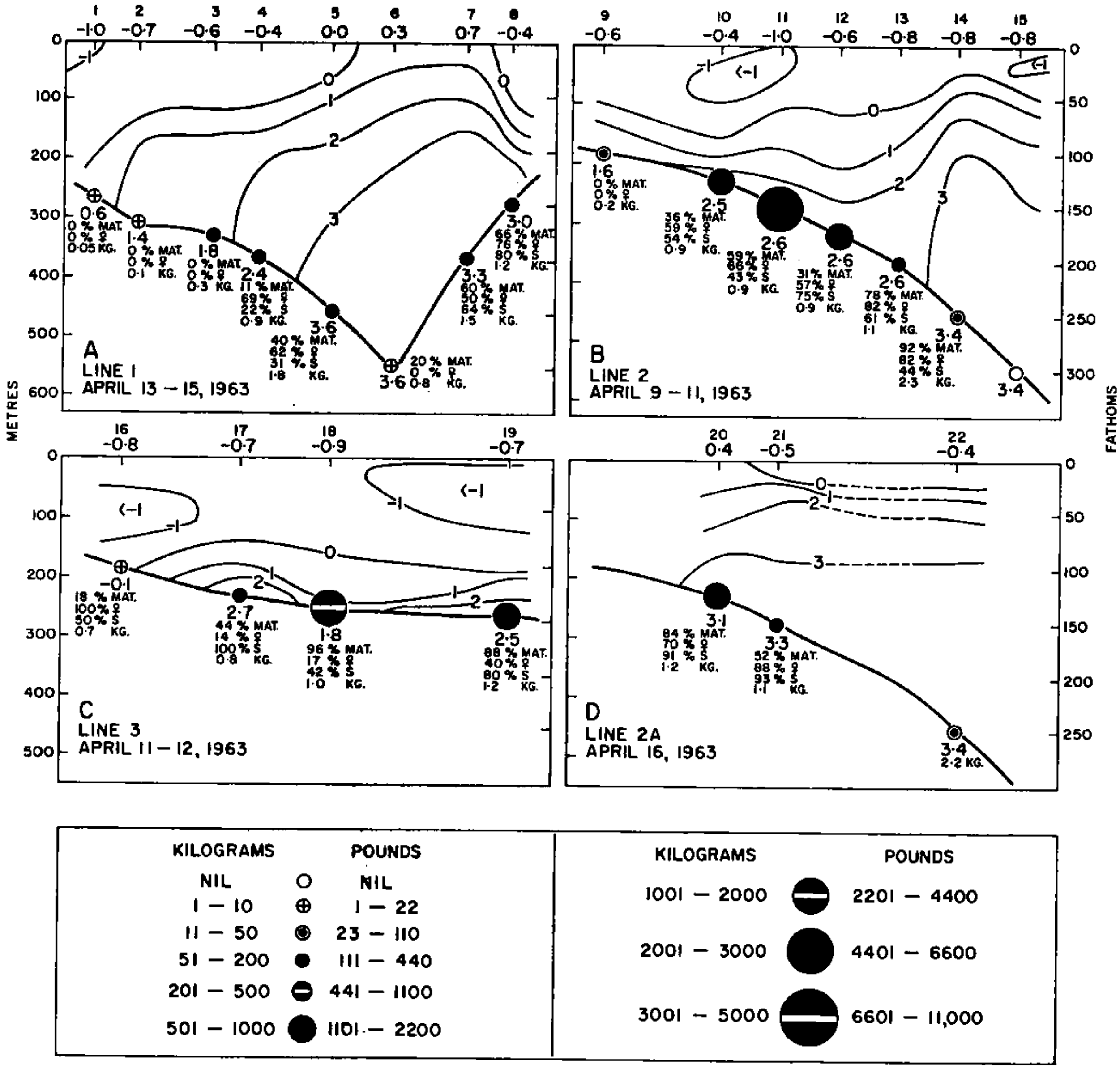
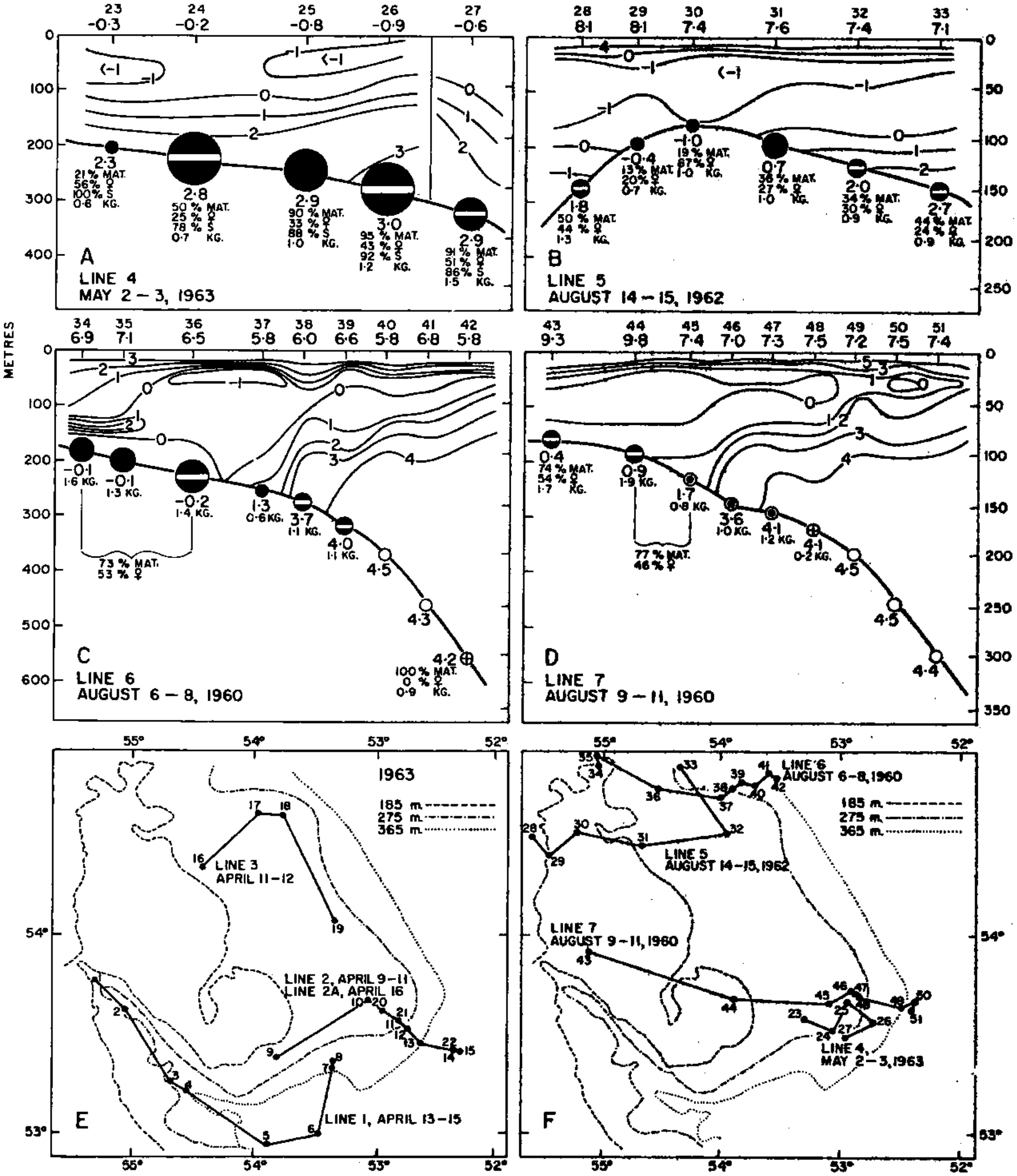


Fig. 4. Cod catches by the *A.T. Cameron* per half-hour tow on bottom in relation to temperature sections, bottom temperature °C, percentage of cod sexually mature (Mat.), percentage of females among the mature cod, percent spent (S), and average weight of the whole cod in kg. (The positions of the various lines and sets are shown in Fig. 5.)

quickly enough to 2, 1 and 0°C that movement upward may have been temporarily restricted and thus have made the cod more available near bottom. It must be remembered here that the vertical scale is greatly exaggerated and if drawn in the same proportion as the horizontal scale would only have a depth of a fraction of a millimetre. Hence the overlying isotherms were relatively very much closer together than appear in these figures. In this period the cod were feeding very little except on viscera, heads and backbones of cod being discarded by trawlers. There was no evidence from the net catches that any other food was abundant on or near bottom (Templeman, this symposium).

On 9-11 April 1963, (Fig. 4B) a large catch of cod (2,450 kg) was obtained on Line 2 in Set 11 at 275 m and 2.6°C, and a smaller catch (530 kg) at 230 m and 2.5°C. On 16 April (Fig. 4D) and in



ig. 5. Cod catches by the *A.T. Cameron* per half-hour tow on bottom in relation to temperature sections, bottom temperature °C, percentage of cod sexually mature (Mat.), percentage of females among the mature cod, percent spent (S), and average weight of the whole cod in kg. (The values of the catch symbols are shown in Fig. 4).

Set 21 at the same depth and position as Set 11, but at a higher temperature (3.3°C), only 160 kg of cod were caught. At 225 m in Set 20 at approximately the same position as Set 10 but at a higher temperature, the catch was approximately the same as in Set 10 (860 kg). In the intervening period there had been a 3-day storm of northeast wind, 35-80 km per hour, which had apparently caused upwelling of deep warm water from Hawke Channel over the shallower rim of the channel toward the north and probably caused cod to move shallower. Many European trawlers were fishing cod at and near the 275 m depth in this area on 9-11 April but by 16 April they had disappeared toward the northward apparently because of the lack of cod at the usual depths. On 2-3 May 1963, 90-100 trawlers were observed fishing the seaward tip of the southeastern slope of Hamilton Inlet Bank within a radar range of 10 nautical miles in the vicinity of the large catches shown in Fig. 1B and 5A and the large concentrations seen in the echo-sounder records (Fig. 6-8).

In the regions of heavy concentration on the southeastern slope during 9-11 April, 43-75% of the females had completed spawning, and 42-80% had completed spawning on the more northerly line on the eastern slope during 11-12 April. Spawning was proceeding rapidly since by 16 April returning to the same line southeast of the bank, 91% of the females in the only large catch were spent. In Hawke Channel to the west of Hamilton Inlet Bank only 22-31% were spent in the 2 small catches which contained mature females. On 2-3 May, on Line 4, on the southeastern part of the slope (Fig. 5A), in the same area as the fishing on 11-12 April and 16 April, 78-92% of the females were spent. In the Hamilton Inlet Bank area generally in April and May the pre-spawning mature cod were usually the largest fish. On all lines cod sizes and the percentages of mature cod, and in the areas of concentration the percentage of females among the mature cod, usually increased with depth and increasing temperatures.

3.2 August. At this time (Fig. 5B, 5C and 5D) all catches of 501-1000 kg and over per half hour were at lower temperatures (0.7 to -0.2°C) than in the spring, but smaller catches of 201-500 kg of cod were still made in deeper water at temperatures up to 3.7 to 4.0°C.

In August most cod tend to occupy shallower situations than in winter and the reasons for the concentrations are likely to be food abundance and temperature barriers. In Fig. 5B the concentration at 0.7°C at Set 31 on the eastern slope may be hindered from moving west to the shallowest water of the bank by the 0 to -1°C temperatures along the bottom. At the same time the 0 to -1°C temperatures overhead, together with the tendency at this time for the cod to move shallower, may act to trap the fish in this position and restrict their vertical movements.

In Fig. 5C the cod concentrations in Sets 34-36 at -0.2 to -0.1°C could not be restricted in position by the temperatures in the vicinity of 0°C immediately overhead. They were, however, feeding heavily on capelin which presumably caused the concentrations to accumulate and be retained in position. Similarly the smaller concentrations at 3.7 to 4.0°C in deeper water at Sets 38 and 39 were not restricted by the overhead ceiling, but may have been restricted by the rapidly declining temperatures to the west. Dispersion was restricted here also by heavy feeding on scaled lancet fish, *Paralepis coregonoides borealis* Reinhardt (Templeman, this symposium).

The largest cod in August 1960 (Fig. 5C and 5D) on the eastern slope of Hamilton Inlet Bank were in the shallowest (but still deep) water at the lowest temperatures. In August 1962 (Fig. 5B) this was also true in a limited degree for the portion of the section on the eastern slope of the bank but not for that on the western slope.

4 Echo-sounder Observations, May 2-3, 1963.

Simrad echo-sounder records were obtained during and between most of the sets shown in Fig. 1B and 5A and these reveal the distribution of fish in relation to the bottom. Figure 6 shows echo recordings made during the set at 245 m (Set 25), and afterward while steaming at 8 knots in a southeasterly direction until a depth of 300 m was recorded. In each case there are scattered recordings well off bottom with occasional heavy concentrations showing near bottom. Figure 7 gives the picture between 200 and 230 m, or between Sets 23 and 24 of Fig. 5A. Here fish are observed to be very close to bottom all along the recording to a depth of approximately 220 m. At this point the fish appear to be moving off bottom, and for the remainder of the trace are seen to hold this depth, although the bottom drops away to 230 m. A set was made at this point (Set 24 in Fig. 5A) and the resulting echo recording shown in Fig. 8. Some heavy patches are seen close to bottom, with concentrations off bottom also in about 220 m. Figure 8 also shows the echo recording made while steaming between Sets 24 and 27, *i.e.* from about 230 to 310 m. Here we see that fish are beginning to leave bottom between 260 and 280 m, remaining mainly in this depth range as the bottom falls away.

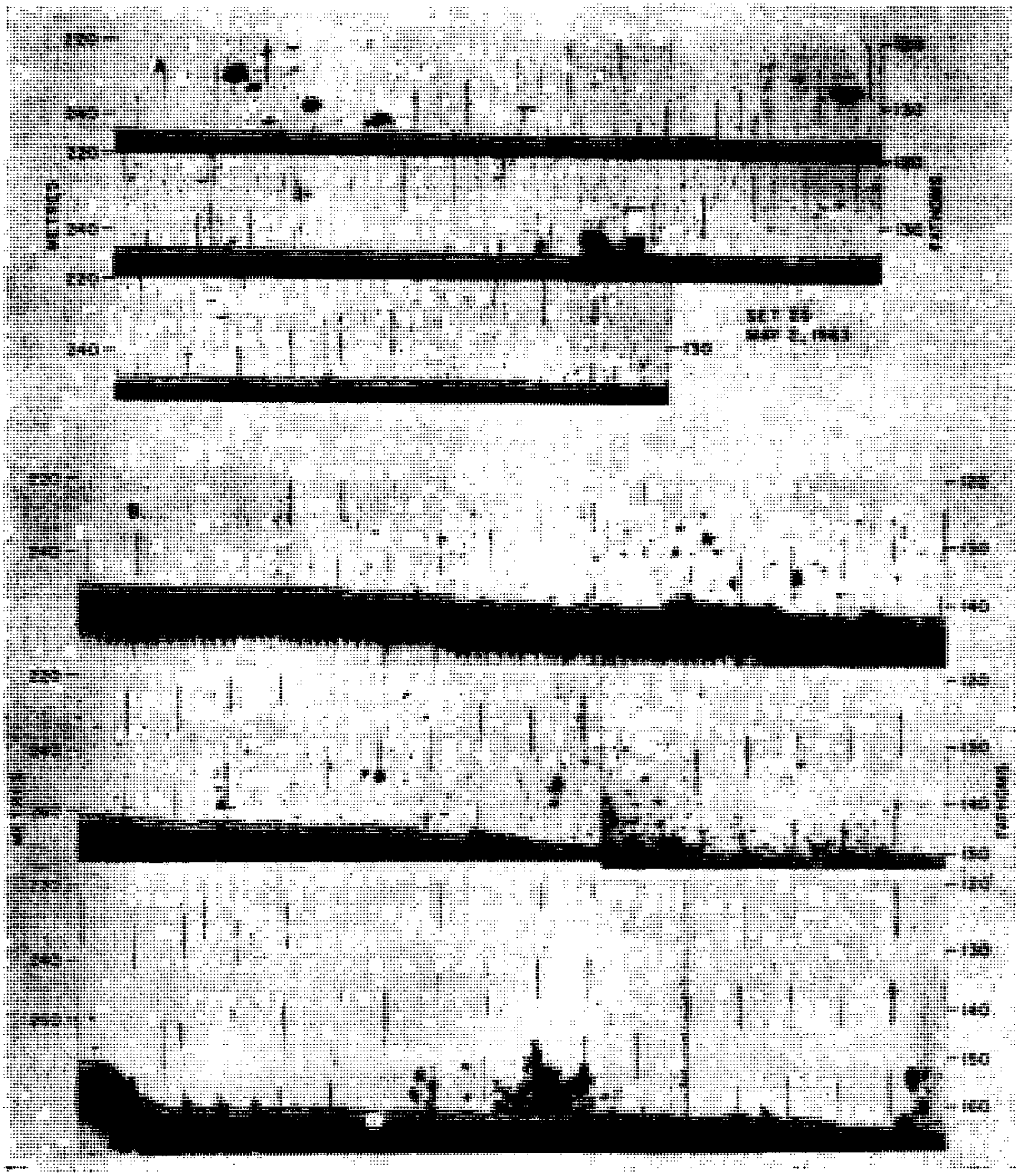


Fig. 6. Simrad echo-sounder records (A) during Set 25 (Fig. 5A, 5F) at 3.5 knots and (B) while steaming to the southeast at 8 knots from the end position of Set 25 to the 300 m contour, 2 May, 1963. The cod catch in Set 25 was 2560 kg per half-hour tow at a depth of 245 m.

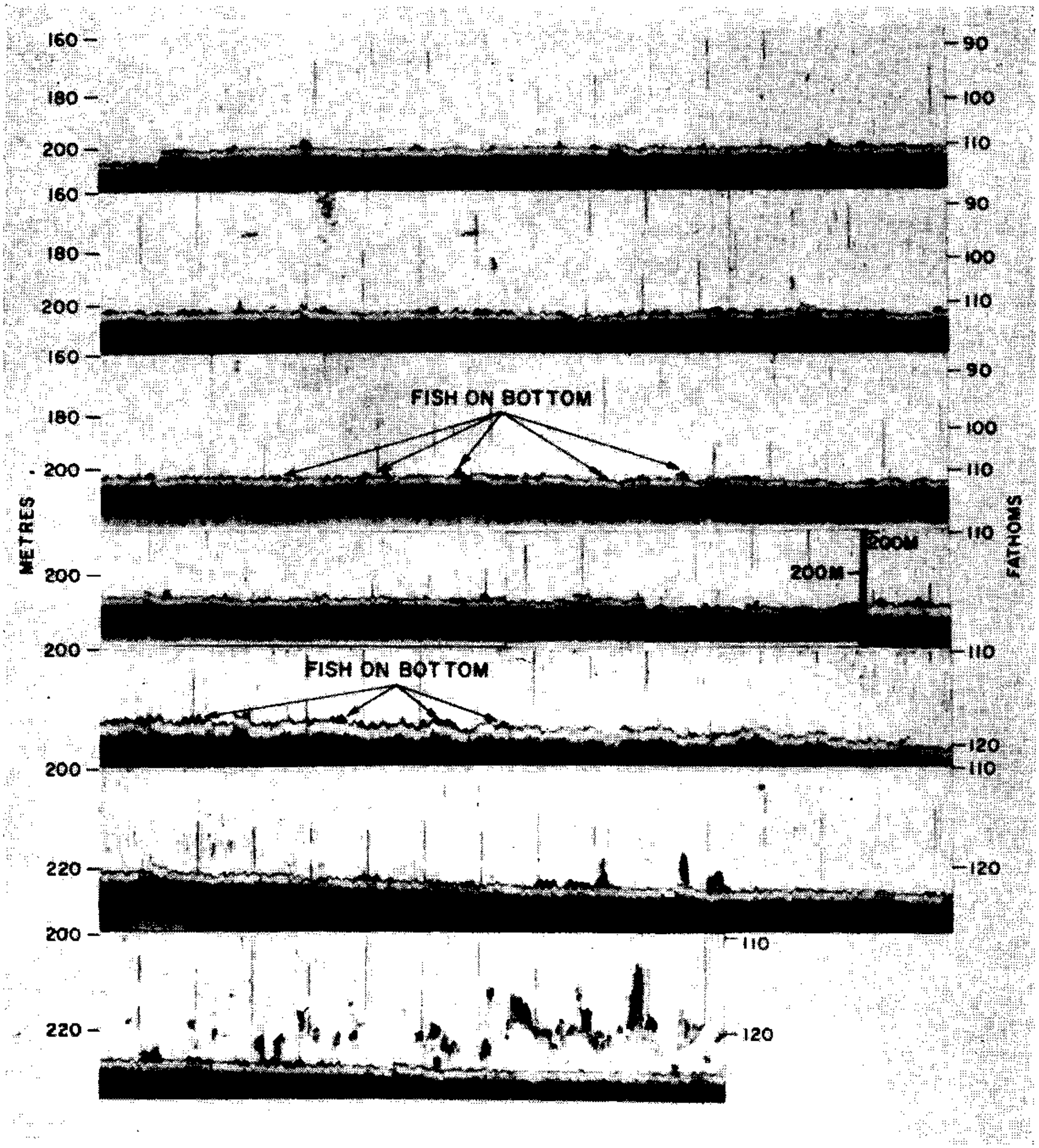


Fig. 7. Simrad echo-sounder record made while steaming at 10 knots between Sets 23 and 24 (Fig. 5A, 5F), 3 May, 1963. The cod catches per half-hour tow in Sets 23 and 24 were 140 kg and 4830 kg respectively at depths of 205 and 225 m.

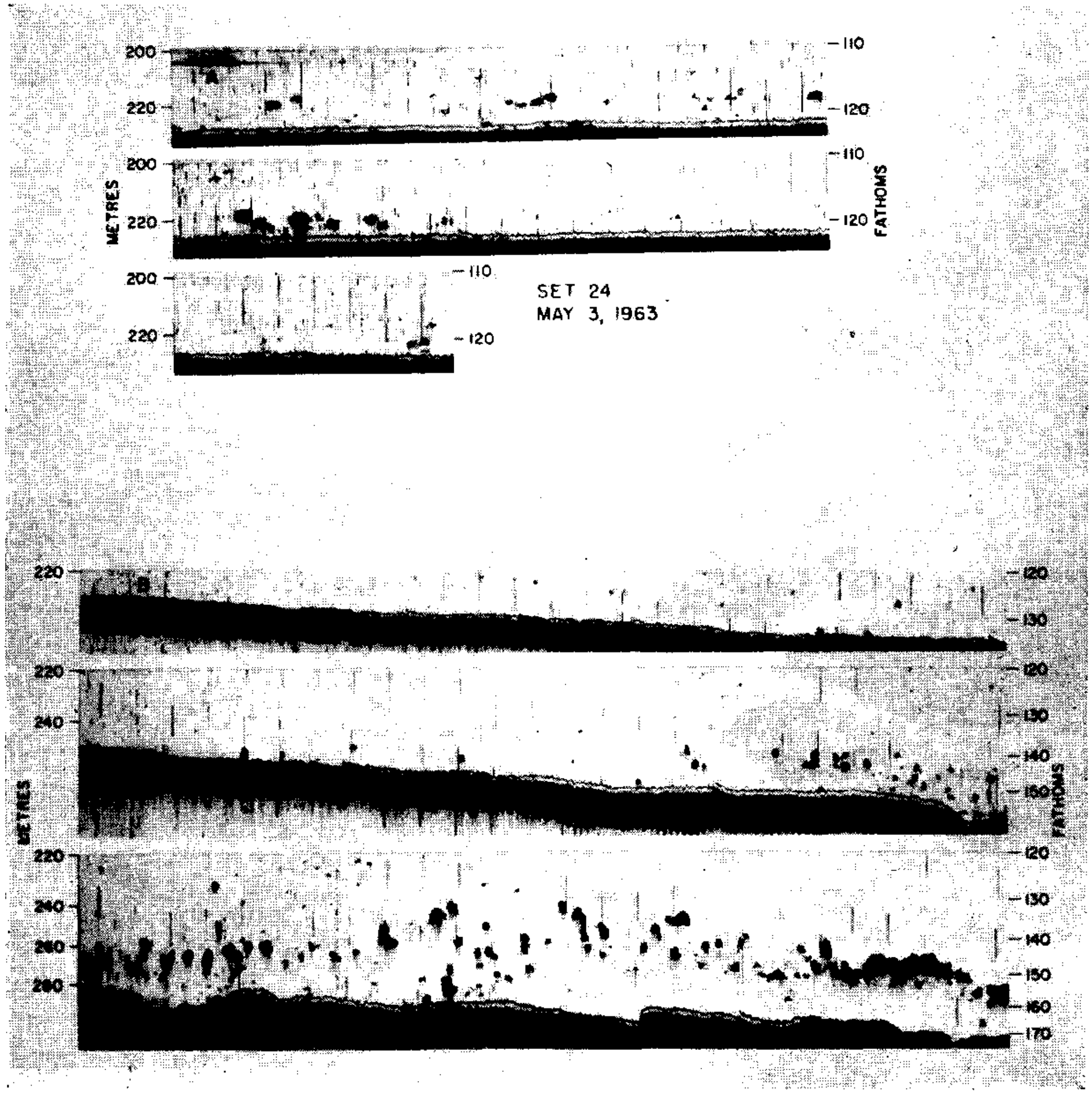


Fig. 8. Simrad echo-sounder records (A) during Set 24 (Fig. 5A, 5F) at 3.5 knots and (B) while steaming at 10 knots between Sets 24 and 27, 3 May, 1963. The cod catches per half-hour tow in Sets 24 and 27 were 4830 kg and 1590 kg respectively at depths of 225 and 330 m.

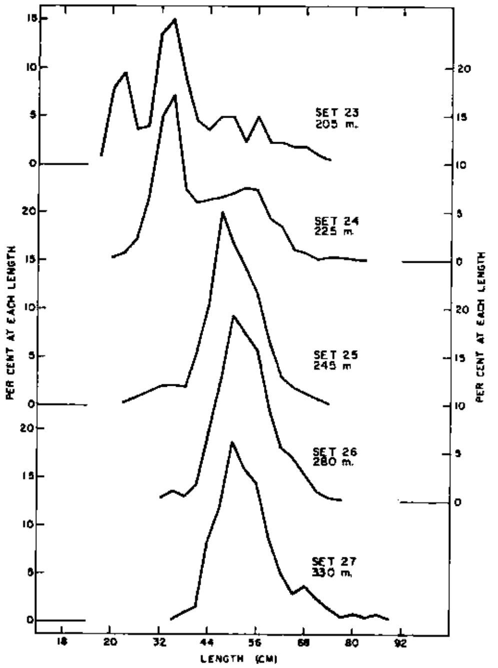


Fig. 9. Length frequencies by depth of cod taken on the southeastern slope of Hamilton Inlet Bank, 2-3 May,1963. Set positions are shown in Fig. 1B and 5F.

Fish can also be seen close to bottom as a thickening of the bottom line, as well as scattered between 220 and 260 m. The echo sounder was also used to search for cod in the surface layers, but none were found. Several attempts to jig cod at various depths in the upper 50 m were likewise unsuccessful.

There would thus appear to be two centres of abundance among the cod distributed along the edge of the bank, one represented by Set 24 (223 m) and the other by Set 26 (278 m). In each case there is a tendency for the fish to be distributed off bottom, beginning at about 220 m for the former group and 260-280 m for the latter. The reason for these two centres of abundance is illustrated in Fig. 9, which shows a marked correlation between depth and size of fish in the catch. In fact the fish can be separated on the basis of size into two distinct groups, one consisting mainly of fish less than 40 cm long (Sets 23 and 24) and the other of fish greater than 40 cm long (Sets 25-27). From the echo-sounder recordings it is apparent that both these groups are beginning to move off bottom at about the same time.

The off-bottom movement is probably related to a subsequent migration inshore as described by Templeman and Fleming (1956) for the Bonavista area. Since these are post-spawning concentrations (though many immature fish are also present at the shallower depths) this upward movement probably begins as a search for food, the bulk of the mature fish having completed spawning. In this area however, natural food appeared very scarce, and occasional examination of stomachs showed that the only significant food item was cod offal. More than 90 vessels were fishing in this area at the time and these of course were the source of the offal. It is possible that without this source of food the cod might have already dispersed and the very fact that trawlers were fishing in the area helped to keep the concentration intact. Certainly there were no temperature barriers to prevent horizontal dispersion. Eventually, many or most of these cod would presumably find their way inshore in time for the inshore fishery which in southern Labrador begins toward the end of June.

On 29 July, 1951 a large pelagic cod school was found by the *Investigator II* close to shore near Seal Islands, Labrador (Fig. 10). Temperatures were 7.3°C at the surface, 5.5°C at 25 m where the fish were located and -1.10°C near bottom at 50 m. These mid-water cod at 25 m, probably just above the thermocline, were jigged from the *Investigator II* as fast as they could be pulled in.

5. Notes on the Inshore Labrador Cod Fishery

In the Strait of Belle Isle the fishery is carried out by trap, linetrawl, and jigger (although a few gillnets are also in use) and begins about mid-June. The fishery in southern Labrador is carried on almost entirely by trap and jigger, beginning during the last week of June and the first week of July. The fishery in northern Labrador is almost entirely an Eskimo handline fishery, with some traps in the Nain area, and begins about mid-July. In former years fishing was carried on in the far north beginning late July to early August. The fishery goes on to about October in most areas, generally by means of handline.

Traps are set in depths of 10-30 m. Recorded bottom temperatures at these depths during 1959-62 ranged from 6.3 to -0.8°C. Surface temperatures at the same time ranged from 4.2 to 14.5°C. Temperatures recorded in July and August while jigging fish in depths of 7-70 m, ranged from 8.7°C at the former depth to -1.1°C at the latter. Fish seem to jig best in fairly high temperatures (about 4 to 9°C). The cold intermediate layer is close to the surface in inshore Labrador in early and mid-July, temperatures below 0°C being encountered at about 15-18 m.

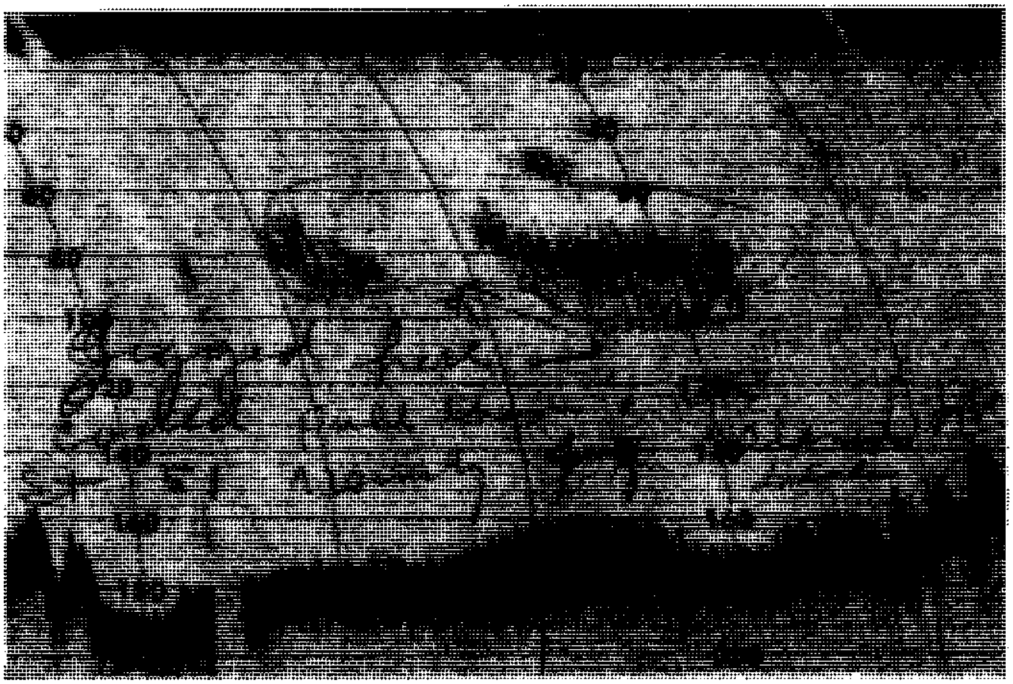


Fig. 10. Echo-sounder record of a pelagic school of cod (circled area) close to shore at 53°14'N, 55°39'W near Seal Islands, Labrador on 29 July 1951. (The echo-sounder record is in feet. 1 ft = 0.3 m. The handwritten comments were entered on the record at sea).

. Additional Autumn Data

In April our small catches and the absence of the fishing fleet indicate no concentrations of od in Hawke Channel and on the northern border of this channel west and southwest of Hamilton nlet Bank. However, in the autumn there is some evidence of cod concentrations here although not early as great as the winter-spring concentrations on the eastern slopes of this Corlett nd Ramster (MS,1963) report that in a cruise of the *Ernest Holt* to Labrador from 22 November to December 1962, a good catch of 1,510 kg of cod was obtained in the channel northwest of Hamilton nlet Bank at about 55°20'N 56°30'W in 210-220 m at 2.5°C. In this same cruise on the southwestern lope of Hamilton Inlet Bank (the northern slope of Hawke Channel) at about 53°27'N (reported as 5°27'N in the MS), 54°40'W the best catch of cod was over 1,540 kg per hour in 310-365 m with verage catches of 1,040 kg per hour in 300-375 m. Bottom temperatures were about 3°C. 'Eight arge trawlers were fishing in this area. Most of the cod were feeding on the pelagic amphipod, *hemisto*, with some shrimp, *Pandalus*, and spider crabs, *Chionoecetes*.

In a cruise of the *A.T. Cameron* on the southern Labrador Shelf in September 1963 (too late to e included in detail in the figures and text of this paper) covering depths where available from ess than 180-730 m, the best catch of cod (1,420 kg per half hour) was obtained on 15 September t 295 m, 1.4°C at 53°20'N, 54°29'W. This position is close to the area of Hawke Channel south-est of Hamilton Inlet Bank where the *Ernest Holt* obtained similar catches in late November,1962.

On the southeastern slope of Hawke Channel in the same general area as in April (Fig. 4E, ine 2) the only significant catches of cod were 480 kg and 690 kg at 220 and 271 m, 3.1° and 3.7° . Also in this cruise on 11-12 September on the northeastern slope of Hamilton Inlet Bank, in a ine from 54°51'N,55°04'W to 54°51'N,53°22'W and depths ranging from 192 to 805 m the best catch of od (690 kg) was in the shallowest set at 192 m and 0.6°C.

Also in October in a brief survey along a line from 53°58'N,55°04'W to 53°19'N,54°22'W from 54 m (-0.5°C) to 284 m (0.9°C) and extending from the top of the southern half of Hamilton Inlet ank to Hawke Channel the best catches of cod (1,600, 2,325 and 1,770 kg per hour) were on top of the bank in the southern quarter at 161, 168 and 165 m at 1.3, 1.1 and 0.4°C. At 53°32'N, 54° 40'W on 6 October in 146 m, where the *A.T. Cameron* obtained 1,720 kg of cod in an hour's dragging (0.5°C), 40-50 European trawlers were fishing in the neighbourhood. Again on 8 October in the general area of 53°25'N, 54°15'W at 152-174 m, with catches by the *A.T. Cameron* of 710, 210 and 1,340 kg of cod per hour (1.0 to 1.7°C), 22 European trawlers were observed in a radius of 6 nautical miles on the radar. Most of the cod on the plateau of the bank, at moderately low temperatures in this October cruise, were feeding heavily on capelin.

DISCUSSION AND CONCLUSIONS

Lee (1952), for the Bear Island area, found that in May and June the greatest otter-trawl catches were at bottom temperatures between 3 and 5°C, in August-November between 3.5 and 4°C and in winter between 1.75 and 3°C. The lower limit of 1.75°C for good catches applied to the area west of 21°E, and east of this meridian paying catches were taken in the summer months at temperatures as low as -0.3°C. No cod were taken at bottom temperatures below -0.6°C. These fish were feeding heavily on capelin and krill whereas those concentrated at higher temperatures west of this meridian were either feeding lightly to moderately or not feeding.

Thompson (1943) obtained the greatest otter-trawl catches of cod on the southern Grand Bank, February-May, 1934-36, between 0 and 6°C. In early autumn, 1935, large catches of cod were obtained on the eastern and northeastern Grand Bank at temperatures from -0.5 to 0.2°C. In the 1931 research cruise a few cod were captured at as low a temperature as -1.6°C. Whiteley *et al.* (1932) in otter-trawl hauls in the coastal area of Newfoundland and Labrador, August-September 1931, found cod most plentiful at temperatures above 3°C.

Martin (1961) found January otter-trawl research vessel catches of commercial-sized cod in the southwestern Gulf of St. Lawrence and in the Laurentian Channel off Cape Breton concentrated between 180-230 m at bottom temperatures of 2 to 4°C. In the same month very small cod (0 and 1 age-groups) were still present in their summer locations in the shallow water in the Gulf of St. Lawrence at a bottom temperature of -1.5°C. Medium-sized cod of about 40-70 cm were caught in approximately equal quantities at depths from 27 to 230 m and temperatures from 0 to 4°C in May, and in 27 and 110 m at 3 to -1°C in June. In autumn these medium-sized cod were mainly in 90-130 m at 0 to 1°C while smaller cod at this time were mainly in shallow water at 6 to 8°C. Again Martin (1963) in the winter and early spring of 1962 found cod of commercial size in the southwestern Gulf of St. Lawrence in deep water, 145-230 m, along the western edge of the Laurentian Channel with the largest catches off Cape Breton at 1 to 3°C.

Pechenik and Noskov (1962) say that in the early part of 1961 cod occurred in stable concentrations and were fished successfully on the southeastern slopes of Hamilton Inlet Bank at depths of 285-360 m and temperatures of 3 to 3.75°C. Noskov *et al.* (1963) report dense shoals of post-spawning cod in April 1962 with catches of 4-6 tons per hour's trawling between 59° and 58°N on the northern Labrador Shelf at 400-500 m. In Division 2J in the spring of 1962 day-time catches were smaller than at night, the cod being off the bottom in the day-time feeding on planktonic organisms and near bottom feeding on benthic forms at night.

McKenzie (MS, 1951) found good cod catches with line gear over a wide range of bottom temperatures in the Nova Scotian and New Brunswick coastal areas: at Shelburne, 2 to 9°C; at Cape Breton, 0 to 6°C with a good catch also at 16°C; and at Halifax Harbour (in reported fishing) 0.25 to 11°C with two fairly good catches at 13.5 and 15.0°C. In this area the largest cod were taken at intermediate temperatures with smaller cod at the highest or lowest temperatures. The jig was much more effective than baited hooks at the high temperatures. Also in experimental line trawling off Halifax good catches were made in 1932 between 0.5 and 4°C with decreases above 4°C, and in 1932 good catches at 1 to 6°C with a decline in catch and more catch failures after 5°C but with a good catch also at 10 and at 12°C. A sudden influx of warm water (a sudden rise from 7 to 15°C at Halifax and 5 to 14°C at Shelburne) reduced successful line fishing in the shallower water to a near zero catch, but good fishing could be obtained in deeper and cooler water beyond the over-warmed area.

Rasmussen (1950, 1952) described fishing at Spitzbergen, Bear Island and West Greenland as profitable for Norwegian longliners only where bottom temperatures were 2°C or higher. Rasmussen (1954, 1955) for the pelagic longline fishery in Holsteinsborg Deep in West Greenland found the greatest catches of cod below the thermocline. In 1953 the greatest catches were between 100 -

35 m at a temperature of 2.2 to 2.3°C and in 1954 at 120-140 m at temperatures of 0.8 to 0.9°C.

Templeman and Fleming (1956, 1963) found that good bottom longline catches, in deep water of 00 m and deeper off the east coast of Newfoundland and Labrador in May-November, generally occur- ed when there was a temperature of at least 0.1 to 0.5°C at one end of the longline. Catches were till of commercial quantity when the longline was in the range of temperatures from 0.6 to 1.0°C t one end to 2.1 to 2.5°C at the other. In the cold water layer at intermediate depths cod catches ere usually low when the bottom temperature was below -0.5 and extremely low at -1.5°C. In the in- hore shallow water layer commercial catches were obtained at temperatures from 0 to 4°C.

Tremblay (1942) in experiments with a lognline set at different bottom temperatures from 1 to °C in Bay Chaleur of the Gulf of St. Lawrence found the greatest catches at 8°C. Catches rose at irst gradually and then rapidly from 2 to 8°C and declined rapdily from 8 to 9°C. Catches at 4 nd 9°C were only about one-fifth those at 8°C.

In the Newfoundland and Labrador inshore area large quantities of cod are caught in cod traps et close to the shore in depths usually of 18-37 m but sometimes less, especially in Labrador. leggs (1931) at Raleigh, at the northern tip of Newfoundland, found the best catches in cod traps o occur in July at temperatures between 8 and 10°C.

Thompson (1943) says that in 1934, owing to the prevailing high-water temperatures of 8 to °C in the coastal region from Trinity Bay to Cape Race, the inshore trap fishery yielded poor re- ults but that farther north—*e.g.* at Fogo—the water was colder (2 to 3°C at a depth of 25 m) nd an excellent trap fishery resulted. On the east side of the Strait of Belle Isle the water as of the usual high temperature (8 to 9°C) and the trap fishery was the best for many years. At ay Bulls, near St. John's, a group using 4 deep cod traps obtained 2,000 quintals of cod in 1932, ,000 in 1933 and 500 in 1934, with July and August temperatures in these years of 1.5 and 2.0°C, .3 and 4.7°C and 6.5 and 6.2°C. These temperatures were at 25 m (approximately the mid-depth of ne trap) and bottom temperatures would have been lower. Apparently, as mentioned by Thompson, in n area with temperatures usually high in summer, such as the eastern side of the Strait of Belle sle, trap catches are successful at high temperatures. Where temperatures in 18-37 m are usually ow in summer, as on the east coast of Newfoundland, a rise of several degrees beyond the usually ow temperature may greatly reduce the trap catch.

Rasmussen (1955), in recording the largest catches of Norwegian longlines in pelagic fishing n Holsteinsborg Deep at 2.2 to 2.3°C in 1953 and at 0.8 to 0.9°C in 1954, says that the cod are pparently not attracted by the temperature but by the large quantities of food organisms such as apelin and sandeels existing below the thermocline.

Our Labrador data add to the evidence that cod in winter go deeper to higher temperatures and ccumulate in large pre-spawning, spawning and post-spawning masses not necessarily in areas with a lentiful food supply. In our sets these temperatures were 1.8 to 3.1°C and for very large catches .6 to 3.0°C. The Labrador area does not have very high temperatures in the slope water, the high- st in most years being below 4°C. The offshore movement of these cod seems to be instinctive and ne great mass of these mature fish appear to move for spawning as far away from the coast as pos- ible to the seaward slope of the continental shelf. To the west, in an area of Hawke Channel west f Hamilton Inlet Bank and closer to the coast where there are often abundant cod in the autumn, ery few cod were found in depths and temperatures which would have been suitable in summer and the ew cod present were small and mainly immature.

The cod which proceed inshore to the shallow waters near the coast are found in late June-July varying temperatures, usually above 0°C, and are often plentiful at temperatures considerably igher than any to be found in the deep slope water where they spend the winter and spring. In the mmer and early autumn the greatest masses of offshore cod are on or close to Hamilton Inlet Bank shallower depths and lower temperatures than in winter, and when great concentrations are en- ountered they are usually feeding on capelin. Other smaller concentrations in deeper water of igher temperature on the eastern slope are feeding on fish inhabiting these warmer waters. In the ne year investigated this was chiefly the scaled lancet fish *Paralepis coregonoides borealis*.

The late autumn concentrations in Hawke Channel and on the southwestern slope of Hamilton Inlet nk, at higher temperatures similar to those at which the spawning cod are found in spring, may be ginning to gather for movement eastward to form pre-spawning concentrations along the northern lope of Hawke Channel and the eastern slope of Hamilton Inlet Bank.

Many of these cod of the offshore spawning area are known from tagging results (Sidorenko and Postolaky, MS, 1963, and unpublished data of the St. John's Station) to be, in summer, coastal (inshore) cod of Labrador and the northeast coast of Newfoundland. On the Labrador coast these cod arrive in quantity in the shallow water near the southern coast of Labrador in late June to early July and progressively northward along the coast to late July and early August in northern Labrador.

The echo-sounder records and the failure to jig cod in the surface layers in early May indicate that the fish at this time are not in the shallow water surface layer, in which they live while inshore, but there is a great amount of vertical migration which may be preliminary to presumably pelagic coastward movement.

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ABOUT POSSIBLE FISHING/TEMPERATURE OF WATER RELATIONSHIP[1]

By

Orestes Cendrero[2]

ABSTRACT

A note on a possible fishing/temperature of water relationship in the Grand Bank area was submitted to the Thirteenth Annual Meeting of ICNAF as part of the Spanish Research Report. This paper gives a more detailed description of the observations used in that report. They were made from a Spanish pair trawler in February-April 1963 and it is argued that these preliminary observations indicate that a satisfactory relationship might not be found.

MATERIAL AND METHODS

Temperatures were recorded by the means of a Negretti & Zambra reversing thermometer fixed on a Nansen bottle. Water samples were not collected for salinity.

The thermometer was cast immediately after the haul, as the fish were being taken on board the ship and the latter was standing still, provided weather and other conditions allowed.

All observations took place aboard the commercial pair trawler *Playa de Ondarreta* throughout February, March and the first half of April 1963. Weather made it impossible to make observations every day, and on many days only once a day.

RESULTS

Table 1 summarizes all the temperatures recorded, the fish caught in each haul in kg per hour, and the dates and zones where the observations were made. The quantities of fish include both stored and discarded fish and are those of cod only.

The table shows that temperatures ranged from 1° to 5° C, except for the 8.5°C recorded on 26 March. Probably the temperature was not that high on that day, and maybe a wrong working of the thermometer gave an incorrect reading, but it could not be checked.

Although it may be a little premature to say so, a relationship between the temperature at the bottom and the quantity of fish caught is not likely to exist, or at least does not seem to exist from the observations carried out.

The following fact, which happened fairly often, makes us think so. When the trawl was dragging no fish were detected, either by the loop or by the echosounder. Nevertheless, after a normal tow (about 4·hr) a catch of 50 or 60 baskets was hauled in, *i.e.*, some 8-10 metric tons. Since this catch was a good catch the skipper had the net shot again to drag along the same place, steaming the other way about. After three or four more hours towing, just 2 or 3 baskets were caught. No fish were detected in either case. The gap between the two hauls had not been longer than 2 hr, not enough for the temperature to change significantly, and in fact it had not (*e.g.*, 9 March).

Why was there no good catch in the second haul? Why was there a good catch on one day and not on the following day at the same place, the temperatures being about the same? In our opinion, there are many other and more significant factors which determine the occurrence of cod.

No doubt cod like other animals have a range of temperatures in which they are at ease. But this range must be rather wide and we do not think that cod would move even a little distance from a place because of being subjected to a wide variation of temperature within the range if there were other reasons such as spawning zone, occurrence of food to make them stay. On the other hand, a preferred temperature would not mean necessarily the presence of cod if other

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preferred conditions were lacking.

TABLE 1. COD CATCH AND BOTTOM TEMPERATURE.

Date	Position	ICNAF Division	Bottom temperature (°C)	Total catch (kg)	Catch (kg/hr)
Feb.					
4	46°05'N-57°05'W	3Ps	1.2	9,760	1,956
5	46°21'N-57°11'W	3Ps	1.5	3,667	1,048
9	46°05'N-57°10'W	3Ps	2.0	2,445	652
14	43°45'N-59°15'W	4W	2.5	12,388	2,751
17	43°55'N-59°04'W	4W	3.0	10,269	2,738
23	43°35'N-60°47'W	4W	3.0	35,448	6,445
27	43°25'N-60°45'W	4W	2.8	1,630	466
28	43°21'N-61°12'W	4W	3.2	7,335	2,256
Mar.					
3	43°18'N-61°15'W	4W	1.8	5,705	1,630
5	43°19'N-61°17'W	4W	0.8	163	50
6	43°25'N-61°20'W	4W	5.0	31,296	13,765
9	43°27'N-61°37'W	4W	2.3	35,406	10,894
9	43°27'N-61°37'W	4W	2.3	6,601	2,031
10	43°31'N-61°34'W	4W	2.4	978	326
10	43°09'N-61°42'W	4W	5.8	25,917	7,405
11	43°30'N-61°95'W	4W	0.8	3,952	1,317
12	43°25'N-61°40'W	4W	2.2	5,868	1,805
12	43°25'N-61°40'W	4W	3.2	20	13
16	43°37'N-60°50'W	4W	2.1	2,445	611
18	43°28'N-61°40'W	4W	3.2	1,956	434
19	43°28'N-61°40'W	4W	3.6	4,025	1,254
19	43°28'N-61°40'W	4W	2.2	6,520	1,373
20	43°28'N-61°40'W	4W	4.0	5,216	1,159
21	43°27'N-61°48'W	4W	2.2	10,595	2,119
26	43°05'N-61°52'W	4W	8.5	1,304	348
28	44°29'N-59°40'W	4Vs	1.6	5,064	2,532
30	44°03'N-58°50'W	4Vs	1.0	4,890	931
31	44°27'N-59°16'W	4Vs	1.0	3,260	1,630
Apr.					
3	44°00'N-59°03'W	4Vs	3.4	9,880	2,821
4	43°40'N-60°10'W	4W	3.6	2,758	788
5	43°44'N-59°28'W	4W	2.7	5,705	1,426
6	44°00'N-59°09'W	4W	2.1	40,750	13,583
6	44°00'N-59°09'W	4W	1.8	8,350	1,965
7	44°01'N-59°07'W	4W	2.7	3,260	1,087
8	44°05'N-59°12'W	4W	1.8	2,445	611
8	44°03'N-58°53'W	4Vs	0.9	47,825	27,368
8	44°03'N-58°53'W	4Vs	1.2	3,260	1,304
12	43°57'N-58°49'W	4Vs	2.0	3,260	815
13	43°59'N-59°06'W	4W	2.0	2,495	998
16	43°26'N-61°30'W	4W	3.7	16,855	9,631
17	43°21'N-61°35'W	4W	4.8	27,710	7,389
18	43°25'N-61°35'W	4W	4.2	14,355	3,854
18	43°31'N-61°33'W	4W	4.2	5,379	1,289

Vertical migrations of cod support this theory. Cod rise to near the surface at night, and also when there is capelin *(Mallotus villosus)* about despite the fact that temperatures at the surface are quite often 2° or 3°C higher than those at the bottom.

A final reason for having obtained a poor catch where just a few hours before 8 or 10 tons were caught, may be that the trawl frightened the fish and they swam away to a safer place.

Other Spanish workers (Rodriguez Martin & Lopez Costa, 1954; Rodriguez Martin & Rojo Lucio, 1953; Rodriguez Martin, 1956) have given a very small range of temperatures for cod, defining practically what could be called a "cod temperature". We believe the latter cannot be defined so exactly and that, if it exists, it ranges from 1° to perhaps 8° or 10°C. Further observations will be made to assess this point.

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A-8

DISTRIBUTION OF HADDOCK ON THE GRAND BANK IN RELATION TO SEASON, DEPTH AND TEMPERATURE[1]

By

Wilfred Templeman and V.M. Hodder[2]

CONTENTS

ABSTRACT

Haddock on the southwest Grand Bank spend late winter and early spring in the deep water of the southwest slope, usually between 120-275 m (65-150 fathoms) and at temperatures mainly between 2.5 and 9°C in the more central rather than the northern and southern extremes of the slope. By April the haddock tend to move shallower toward the plateau of the bank. This movement continues in May and in summer, the rate of progression onto the bank depending on the presence of temperatures usually approaching or beyond the 2°C level. Apparently the winter and early spring movement of haddock to warm deep water is necessary to escape the low temperatures of the water over the plateau of the bank but, also, must be partly due to a natural tendency to go deeper at this time because they usually descend deeper than is necessary to escape the low temperatures of the shallower water. Similarly the April-June movement to shallower water at first usually places the haddock in colder water than that in which they spent the winter. This, also, is therefore a natural movement not necessitated by changes in deep water temperatures.

The movement toward shallow water begins before spawning which occurs chiefly in May and June, and the direction of movement to summering areas on the bank is generally northeastward and eastward, agreeing with the distribution of the warmer water.

There is doubtless some pelagic movement over cold water which seems to account for the occasional large early-summer northwestward migration to the east coast of Newfoundland.

The greatest concentrations in summer are in the shallowest area of the southern part of the bank, the Southeast Shoal. When the haddock population is large very great quantities are concentrated on this shoal in the vicinity of capelin spawning grounds where they feed on capelin eggs and capelin.

The movement to shallower water which occurs in April-June is also usually a movement to colder water but with occasional exceptions the larger quantities are in temperatures of close to 2°C and

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[1] Originally Contribution No. A-6, ICNAF Environmental Symposium, Rome, 27 January-1 February, 1964.

[2] Fisheries Research Board of Canada, Biological Station, St. John's, Newfoundland.

over. Later in the year and in warm years, temperatures are higher and haddock concentrations are at higher temperatures.

The cold tongue of water from the eastern branch of the Labrador Current extends as a bottom or intermediate layer, strongly in some months and years and weakly in others, westward along the southwest slope of the bank. The area of bottom occupied by the cold tongue may be shallower or deeper than that occupied by the main haddock population and sometimes the cold tongue separates the haddock population into 2 parts with usually only a few individual haddock or no haddock in the colder parts of the tongue below 1 and especially below 0°C. Sometimes it seems partly to separate and partly to engulf and on other occasions to engulf haddock concentrations.

On the Grand Bank temperatures low enough to restrict haddock movement are common but usually bottom temperatures are not high enough to form more than a temporary restraint to movement. The best otter-trawl catches on the Grand Bank between February-June are usually made at temperatures between 2 and 8°C but within this range the most favourable temperatures for haddock concentrations vary in different years, months and depths.

INTRODUCTION

For many years, mostly from April to June but occasionally earlier, the research vessels *Investigator II* and *A.T. Cameron* have carried out otter-trawl surveys of the haddock (*Melanogrammus aeglefinus* (L.)) population on the southern Grand Bank. The *Investigator II* used a No. 36 trawl with an 18.3 m headline and the *A.T. Cameron* a No. 41-5 trawl with a 24.1 m headline. The towing speed of both ships is 3 1/2 knots. A number of comparisons of relative catches of haddock by the *Investigator II* and the *A.T. Cameron* have been made but the results are varying enough that conversions of the catches by the *Investigator II* to the *A.T. Cameron* level have not been made in the data presented. The *A.T. Cameron* catches approximately 2 1/4 - 3 times as much haddock per set as the *Investigator II* and the latter ship has been relatively ineffective for haddock at depths of 185 m (100 fathoms) and greater. Before 1951 a small mesh codend with meshes averaging about 70 mm internal stretched diameter was used. From 1951 onward either a codend liner or cover of 35 or 29 mm external stretched mesb was used for survey sets. For mesh selection cruises, also, only data from otter trawls with codend meshes about 70 mm internal stretched diameter have been included. All catches used in this paper are per 30-min drag on bottom.

Bottom temperatures and in recent years surface to bottom temperatures have always been taken at each tow. On the slope of the bank the tows were made along the contour maintaining the required depth as far as possible. Bottom temperatures were taken at actual thermometer depths about 4 m above the bottom using 2 reversing thermometers attached to Nansen bottles and a 36 kg weight. All temperatures are corrected for thermometer and auxiliary thermometer variation. Temperatures for 1958 and later are adjusted to bathythermograph temperatures either at the bottom or about 1 m from the bottom, the bottom thermometers still being used to check the bathythermograph readings. In this paper unless otherwise indicated all temperatures are bottom temperatures.

Since 1952 surveys have been along the same lines extending southwest-northeast and at the same depths and stations approximately in the same locations on the line (Fig. 1). Stations on lines B, D, F and H were always occupied, and those on lines A, C, E and G were sometimes omitted or not fully completed.

DISTRIBUTION OF HADDOCK ON THE GRAND BANK

1: Survey Cruises

On the southern Grand Bank during the late winter and early spring months (with occasional exceptions in and after warm winters) and in some years to early May, bottom temperatures over the plateau of the bank in depths less than 90 m (50 fathoms) usually range from about 0 to 1.5°C toward the north to 2°C and often below this temperature at many stations as far south as the 90-m (50-fathom) contour. At this time haddock concentrations do not occur on the bank but on the southwest slope usually at temperatures higher than 2°C (Fig. 2A, 2B, 2C). The greatest concentrations are usually in the more central rather than the extreme northern and southern parts of the southwest slope.

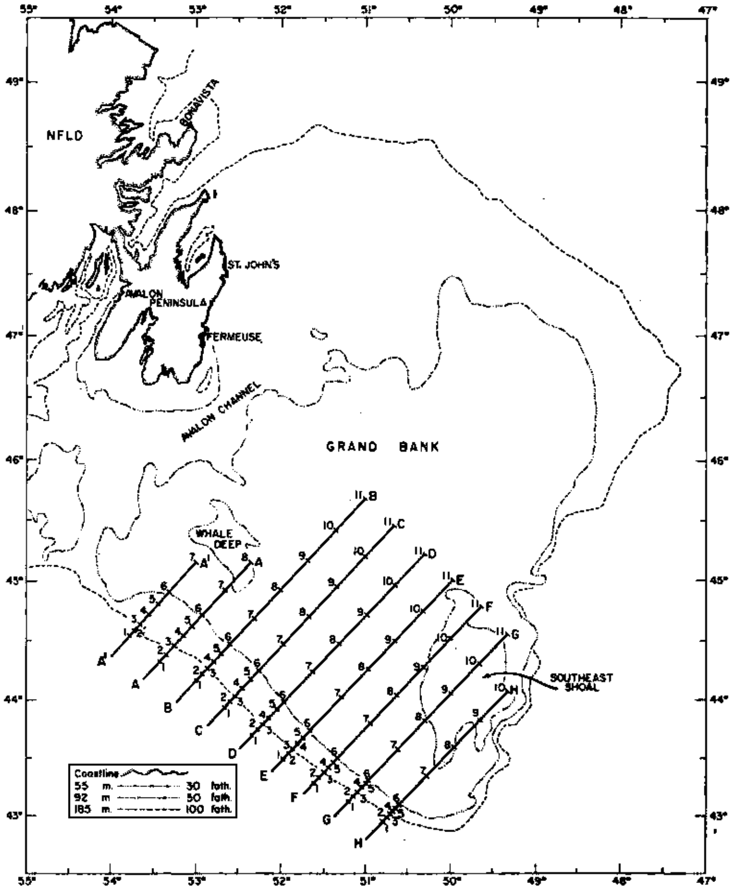

Fig. 1. Survey lines and stations on the southern Grand Bank (ICNAF Subarea 3).

Later in April and May, with rising temperatures on the bank, haddock pass onto the surface or plateau of the bank including the shallow Southeast Shoal. Concentrations on the bank are not great unless the bottom water is approaching 2°C and higher (Fig. 2C, 2D). The large concentrations are usually at temperatures greater than 2°C (Fig. 3). With the passage of haddock onto the plateau of the bank only occasional concentrations remain deeper than the 90-m (50-fathom) contour (Fig. 3), whereas in the earlier part of the year (Fig. 2A, 2B) almost all the haddock were deeper than this contour.

With increasing temperatures on the bank the haddock move still further away from the deep water of the southwest slope northeastward across the southern part of the bank (Fig. 4A, 4D).

When in April to June temperatures below 3°C occupy most of the southern part of the bank, there may be some haddock concentrations on the plateau of the bank at temperatures as low as or slightly lower than 2°C, but good concentrations may still remain on or near the southwest slope (Fig. 3A, 3B, 4C). When, however, in May and June still higher temperatures are present on the bank plateau most of the concentrations follow the tongue of high-temperature water from the central part of the southwest slope toward the Southeast Shoal. At this time most but not all haddock concentrations on the plateau of the bank are in water of higher temperature, usually between 3 and 6°C, but occasionally good catches are obtained in water where the temperature is as low as 2°C or slightly lower and as high as 8°C (Fig. 4). When these developments or incursions of higher-temperature water and the accompanying incursions of haddock are well underway over the bank plateau the haddock populations of the southwest slope are reduced to very low levels (Fig. 4A, 4D).

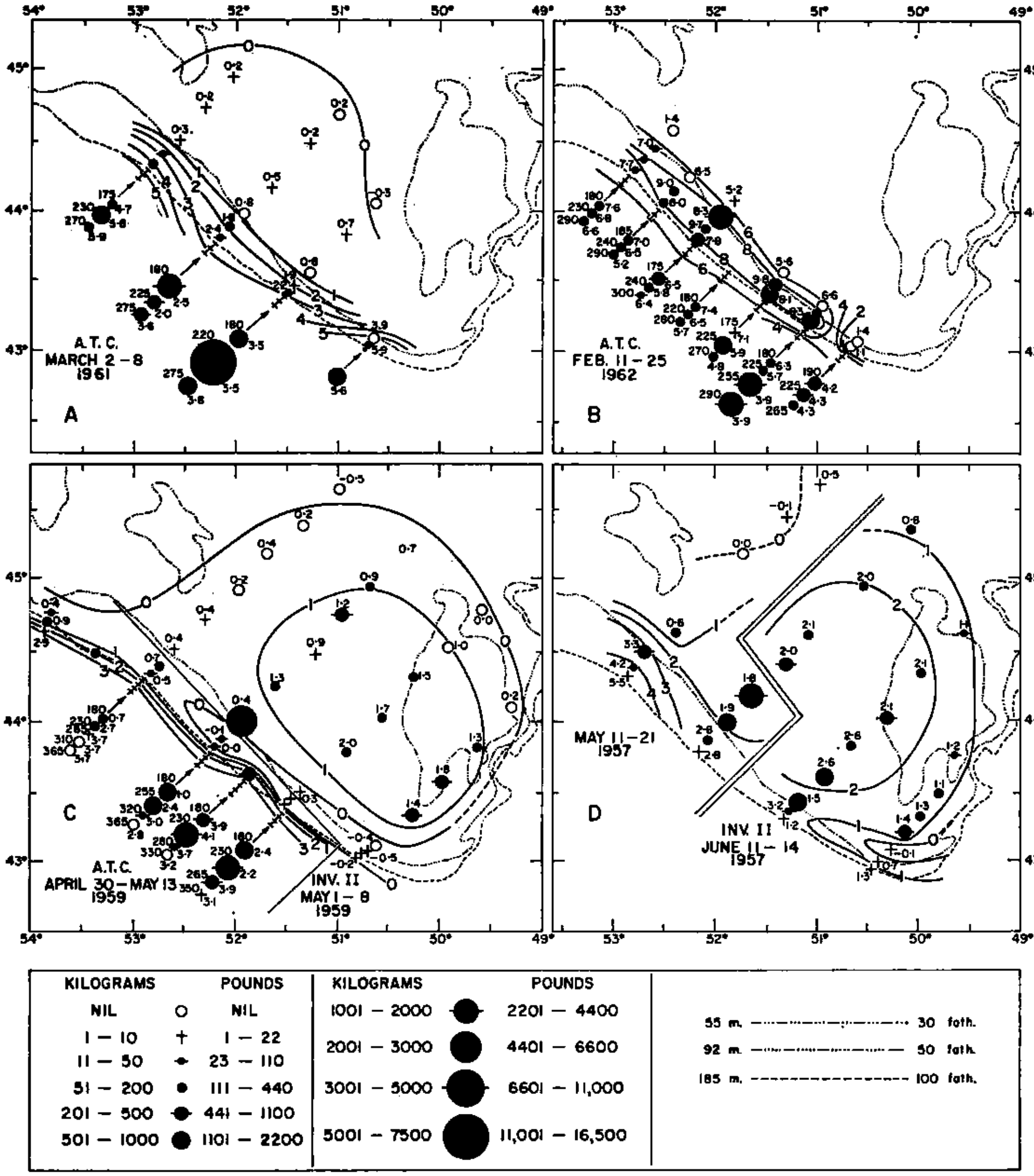

Fig. 2. Distribution of haddock on the southern Grand Bank in relation to bottom temperature. (On the slope depths in metres are given to the left of the catch symbols. In this and in all subsequent figures catches are in kilograms per half-hour tow on bottom, temperatures are in °C).

Figures 5 and 6 show in more detail some of the depth, temperature and catch relationships along individual lines (of Fig. 1) from February to June. On Line B, the most western of the 4 lines illustrated (Fig. 5), because of the influence of the cold western branch of the Labrador Current passing through the Avalon Channel, temperatures usually remain below 2°C and often below 1°C on the bank plateau. However, by April-June haddock have moved from the deeper water and the concentrations are usually located at the 90-m (50-fathom) contour (Station 6) or slightly shallower at Station 7 and in one case at Station 8. The movement occurs earlier and progresses farther when temperatures in the shallow water are higher (in the vicinity of 2°C or higher). The

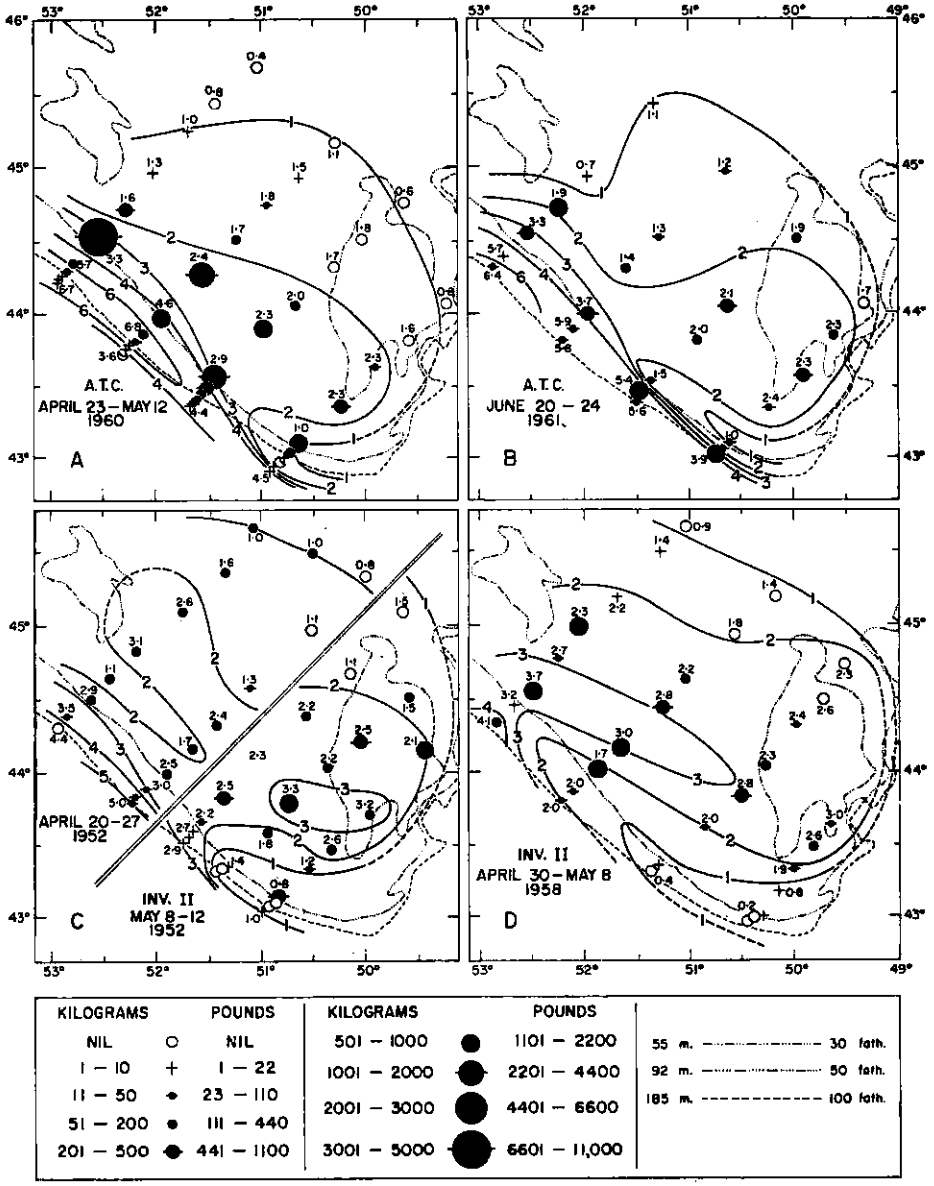

Fig. 3. Distribution of haddock on the southern Grand Bank in relation to bottom temperature.

largest catch on the plateau of the bank shallower than 90 m (50 fathoms) occurred in June 1955 when a temperature of 4.5°C was present at Station 7. Occasionally, when temperatures during this time of year are higher than 1°C over that part of the bank covered by the 3 northern stations (9-11), small quantities of haddock are caught at these stations, but when temperatures are below 1°C few or no haddock are usually present.

Somewhat eastward on Line D (Fig. 5) the progression of the haddock from the southwest slope to the plateau of the bank can be noted from March to June, the larger catches being usually associated with temperatures of about 2°C and over. The largest catch in the shallower water at Station 9 in June 1955 was at the highest temperature for this station (5.4°C). There was, however, a large catch at Station 6 in May 1959 at only 0.4°C just above the cold tongue of water from the eastern branch of the Labrador Current (see Fig. 8 and later section). Temperatures were very high in February 1962 and in consequence the haddock concentration was probably shallower than usual for this month.

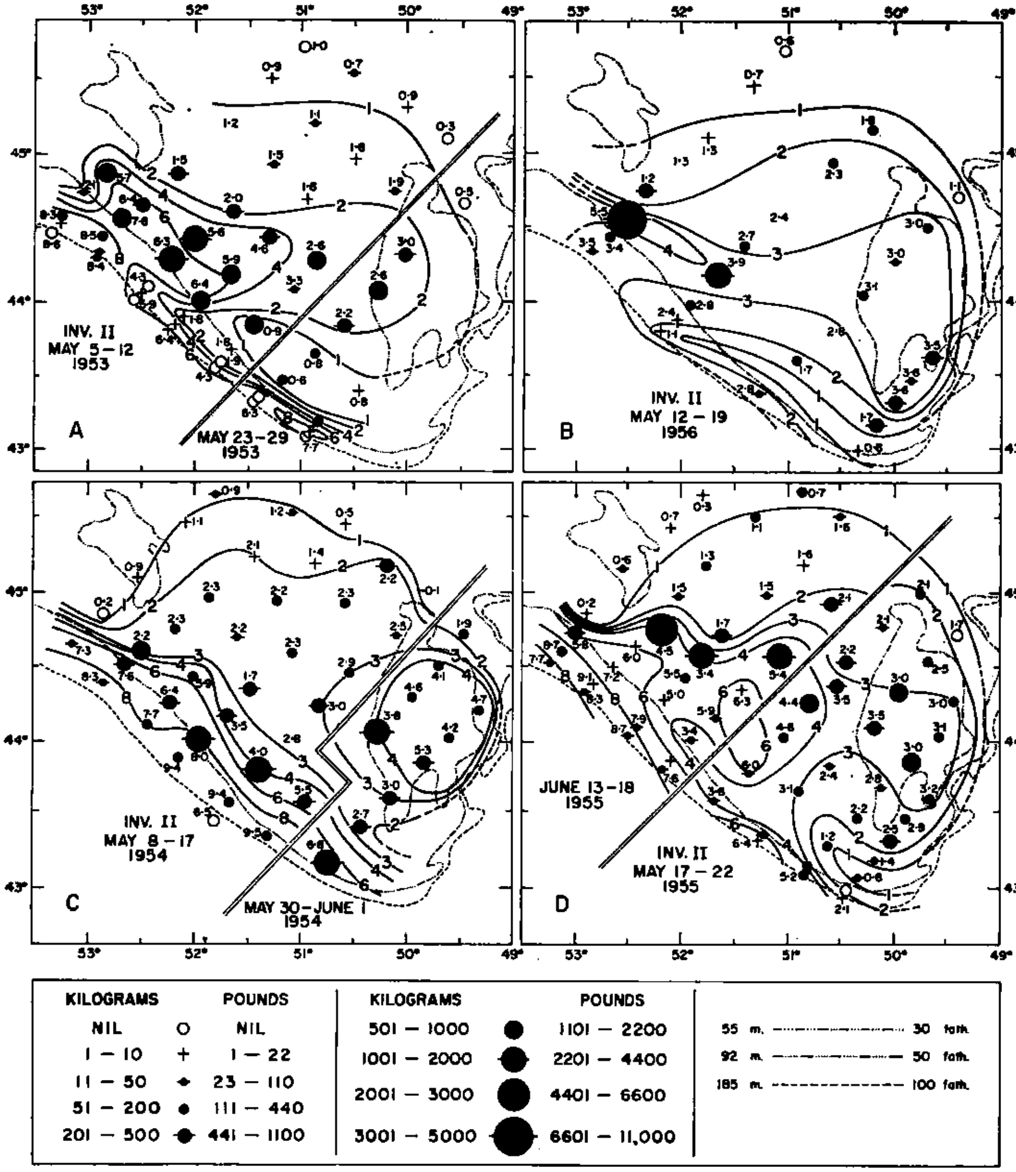

Fig. 4. Distribution of haddock on the southern Grand Bank in relation to bottom temperature.

Still further east on Lines F and H (Fig. 6) the location of the haddock in deep warmer water of the slope in the early part of the year can be noted, as well as the movement of the haddock northward over the plateau of the bank as the water temperatures increase. Good catches in the shallow water are again usually associated with temperatures above 2°C. On Line F the very high temperatures of February 1962 allowed haddock to occur in quantity shallower on the slope than in March 1961 when the water on the bank was much colder.

2: Haddock Concentrations in Relation to Temperatures of the Water Mass

For some recent years it is possible to show haddock distribution over the southern Grand Bank not only in relation to bottom temperatures as in Fig. 5 and 6 but also in relation to the temperature of water masses as determined from bathythermograph traces (Fig. 7, 8).

In February 1962 (Fig. 7) high temperatures were present on the southwest slope of the Grand

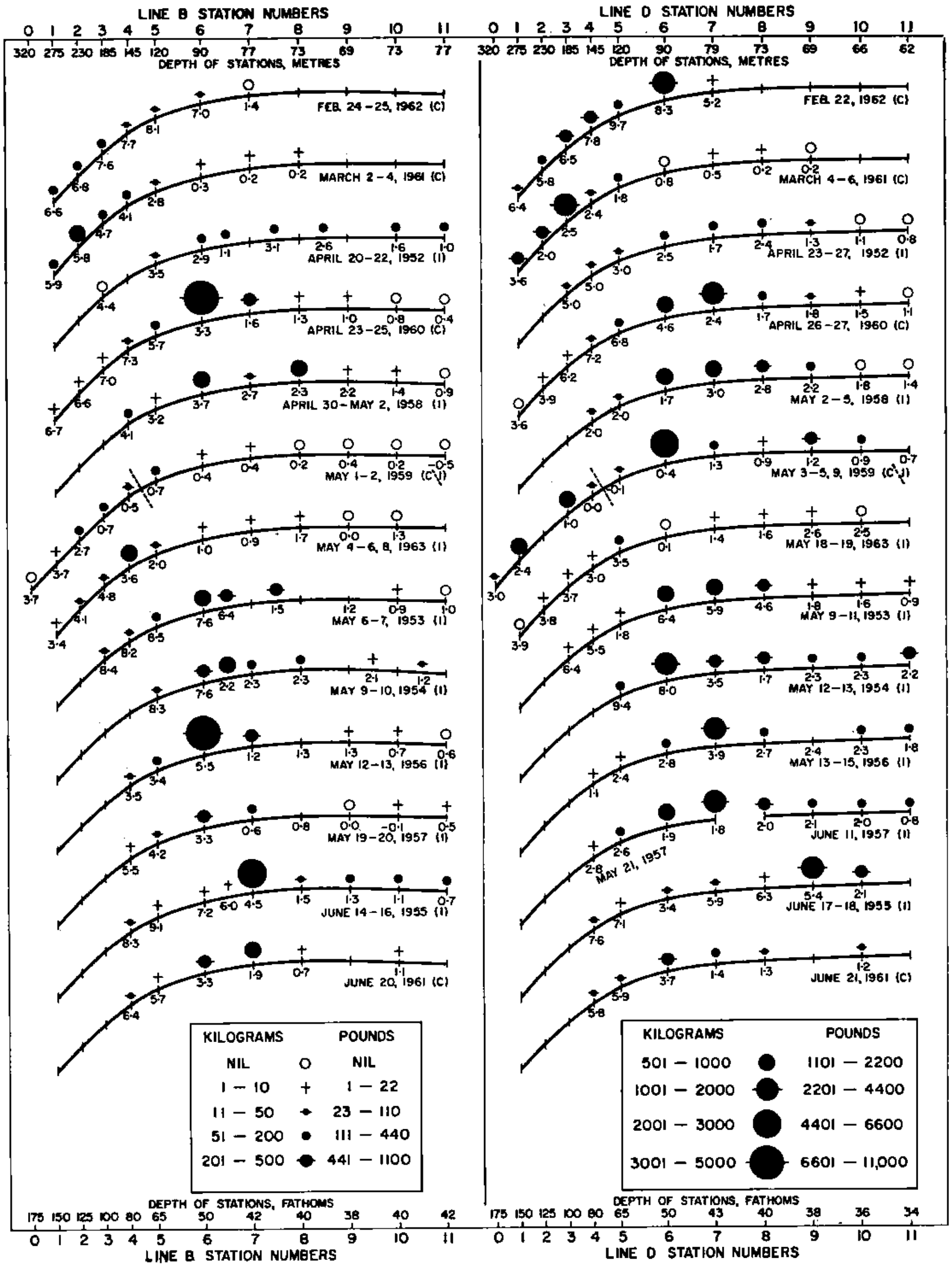

Fig. 5. Haddock catches per half-hour tow on bottom on survey lines B and D, February-June 1952-63, by the *A.T. Cameron* (C) and the *Investigator II* (I). (The location of the lines and stations is shown in Fig. 1.)

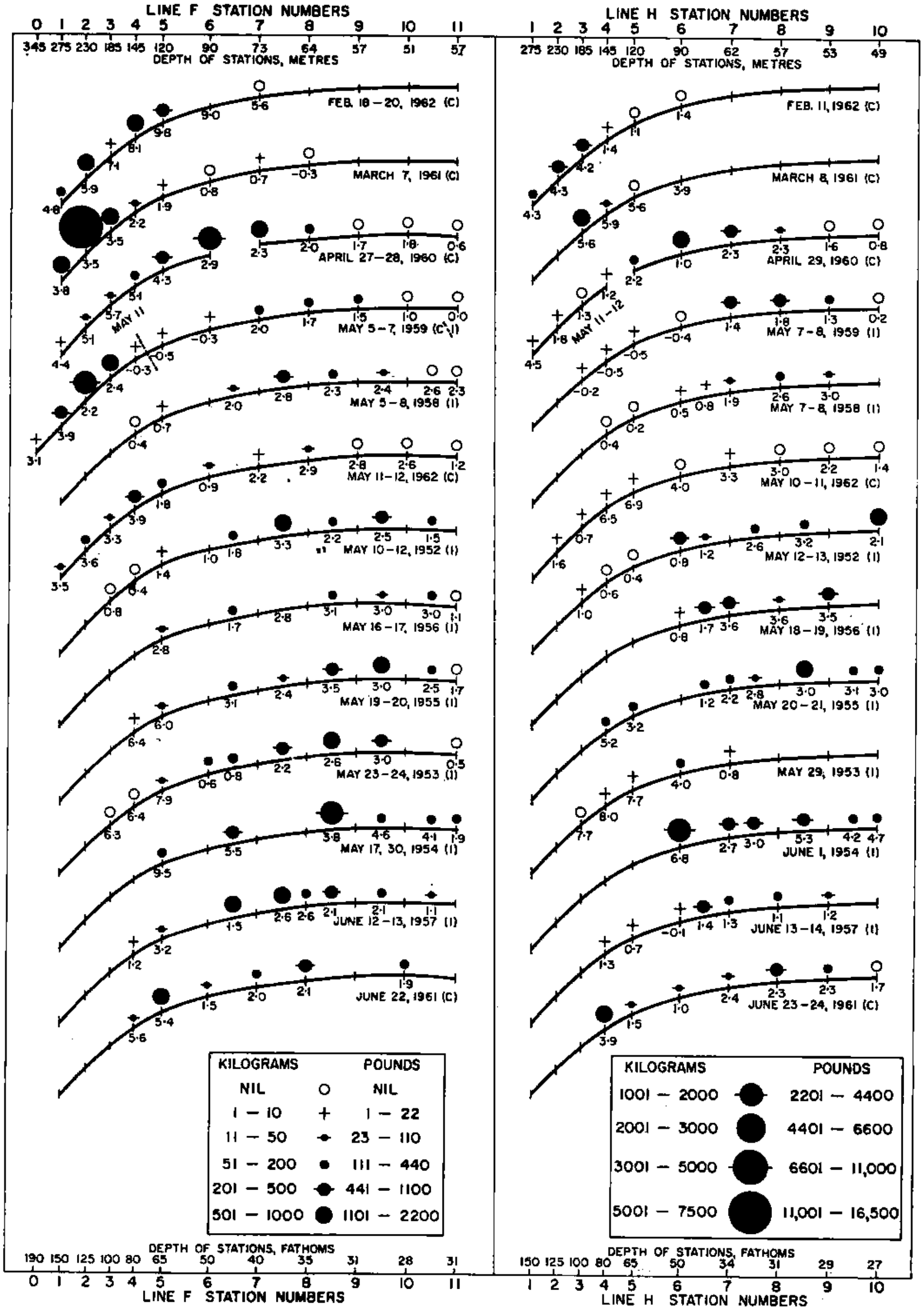

Fig. 6. Haddock catches per half-hour tow on bottom on survey lines F and H, February-June 1952-62 by the *A.T. Cameron* (C) and the *Investigator II* (I). (The location of the lines and stations is shown in Fig. 1.)

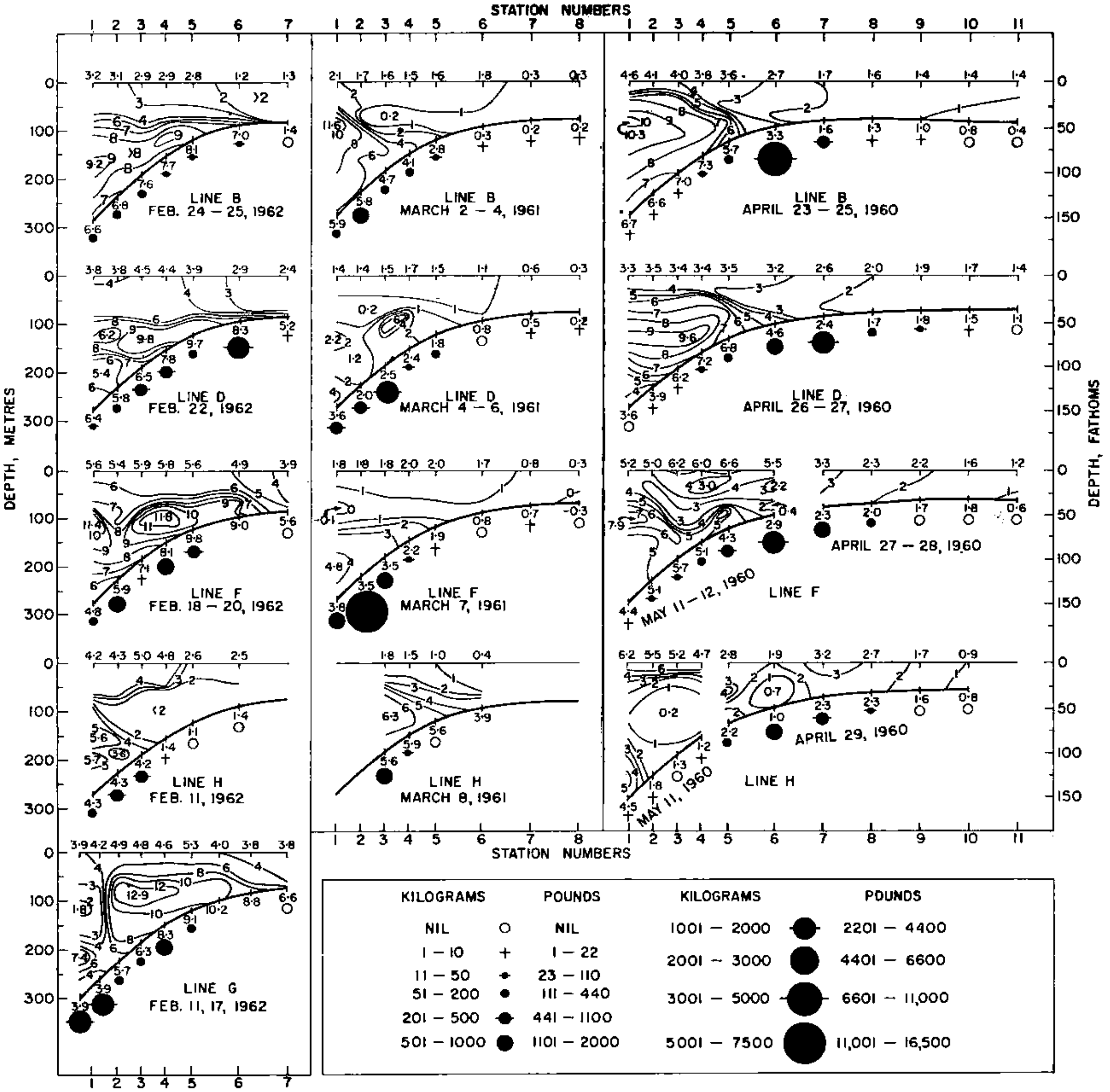

Fig. 7. Haddock catches per half-hour tow on bottom on survey lines B,D,F,G and H, February 1962, March 1961 and April 1960, by the *A.T. Cameron* in relation to temperature sections constructed from bathythermograph records taken at the fishing stations. (The location of these lines and stations is shown in Fig. 1.)

Bank and the haddock were in water with these high temperatures. The largest catches were obtained on Lines D, F and G, in water from 3.9 to 8.3°C. In general the haddock were located below the 90-m (50-fathom) contour, but in one case (Line D) a concentration was found as shallow as 90 m (50 fathoms) at a high temperature of 8.3°C. On Line H where temperatures were lower the best but not large catches were taken in 185 m (100 fathoms) at 4.2°C and in 230 m (125 fathoms) at 4.3°C. Even where suitably high temperatures of 5.1 to 7.0°C existed in water shallower than 120 m (65 fathoms) on Lines B-G, few haddock were taken, except for the 1 large catch on Line D, Station 6.

In March 1961 (Fig. 7) only a few individual haddock or none were present at stations in depths shallower than m (65 fathoms) and at temperatures between 0.8 and -0.3°C. All catches of significant size were obtained in 185-275 m (100-150 fathoms) at 2.5 to 5.8°C. Shallower sets between

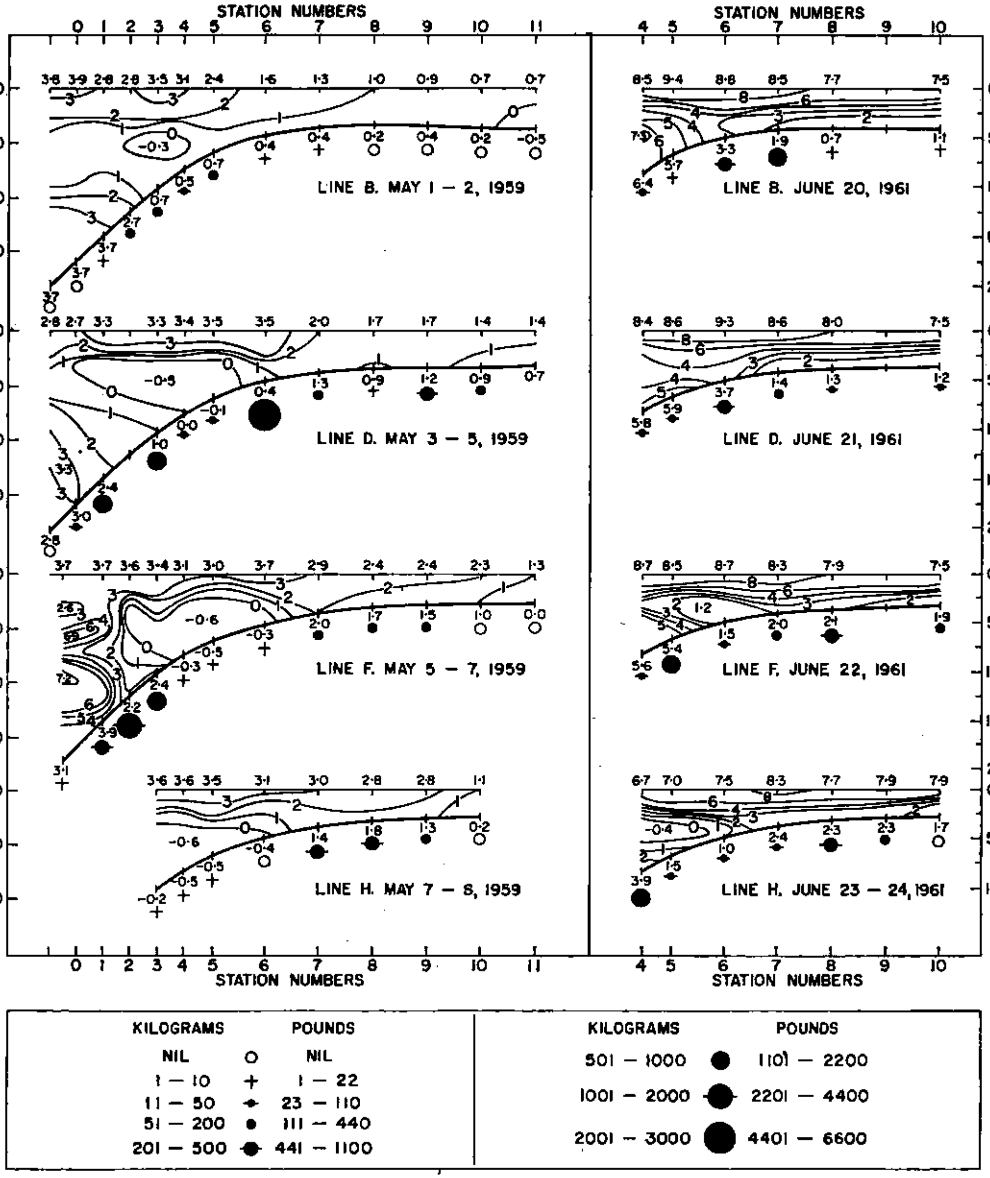

Fig. 8. Haddock catches per half-hour tow on bottom on survey lines B,D,F and H, May 1959 and June 1961, in relation to temperature sections constructed from bathythermograph records taken at the fishing stations. (The location of these lines and stations is shown in Fig. 1. Stations 5 to 11 on all lines in 1959 were occupied by the *Investigator II*; all others were by the *A.T. Cameron*.

120-145 m (65-80 fathoms) within this temperature range (5 sets between 2.8 and 5.9°C) and also 2 other sets between 2.2 and 2.4°C produced few haddock.

Thus in March and probably in February haddock were on the southwest slope rather than on the plateau of the bank, and they were lying deeper than was necessary to evade low temperatures. At this time there is evidently a tendency for the haddock to lie in deeper water where on the average temperatures are higher, rather than to seek the shallowest limits of favourable temperatures.

In April-May 1960 (Fig. 7) the haddock were definitely shallower than in February and particularly March and all good catches were obtained at Stations 6 and 7 in 90 and 77-m (50 and 42 fathoms),

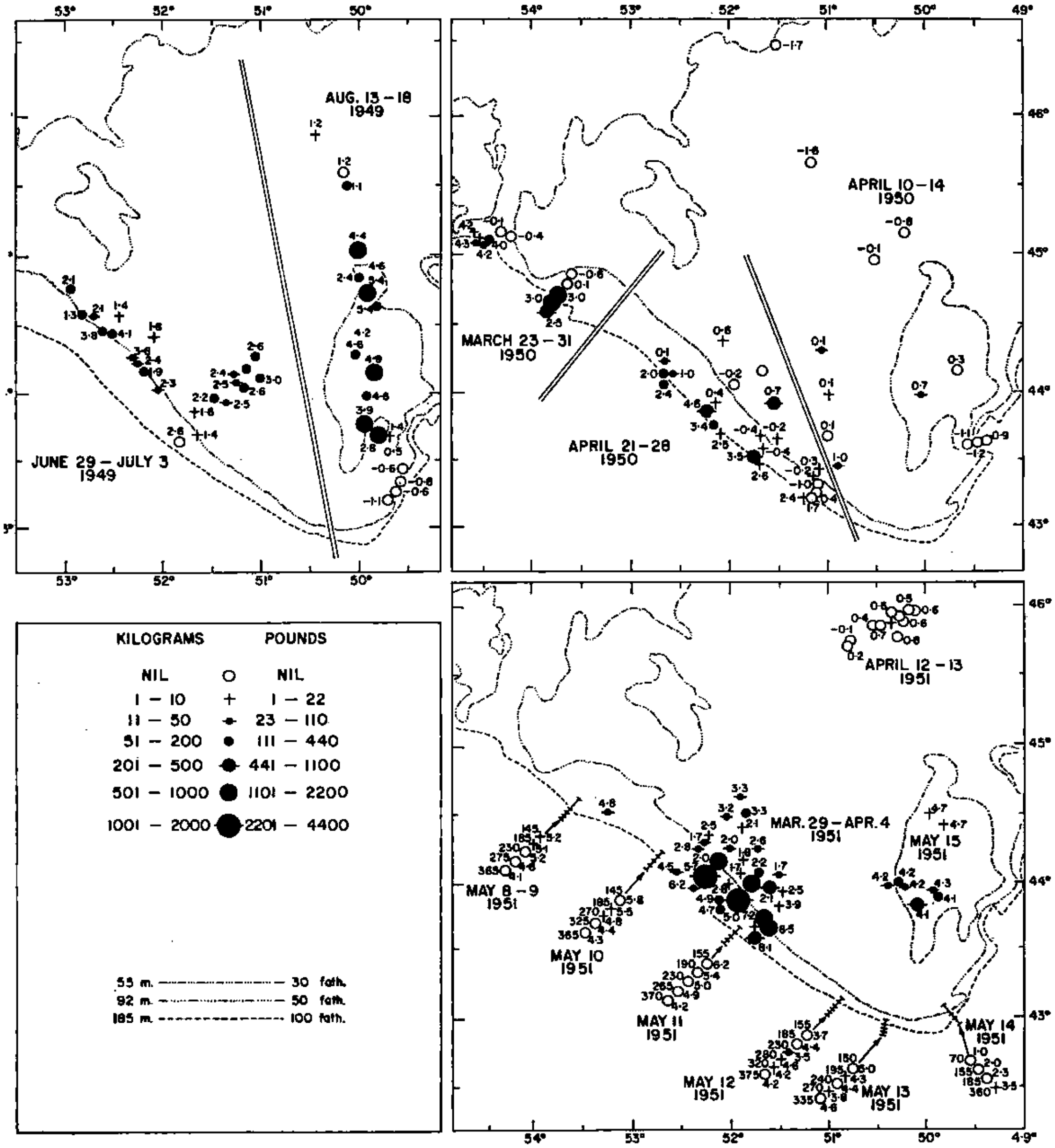

Fig. 9. Distribution of haddock on the Grand Bank in survey cruises of the *Investigator II*, March-August, 1949-51.

3 large catches at 2.4 to 3.3°C and 3 moderate catches at 1.0, 2.3, and 4.6°C. Two of the largest catches were taken at locations where there was a rapid change in water temperature of at least 1°C immediately above the bottom. (See also several instances of this kind in Fig. 7, 1962 D, F and G). These ceilings of water with a different temperature could have restricted the vertical range of the haddock and made them more readily available to a bottom trawl. The haddock concentrations were approaching but not penetrating the 2°C isotherm.

In May 1959 (Fig. 8) in all sections there was a mass of cold water, with temperatures between -0.6 and 0°C at intermediate depths, covering a wide area of the southwest slope in the 3 eastern sections (Lines D, F and H). This cold layer (or tongue), an extension of the eastern branch of the Labrador Current, projects westward around the tail of the bank and penetrates for varying distances along the southwest slope (Fig. 2, 3, and 4). The concentrations of haddock occurred on the slope below and on the shallower plateau of the bank above the cold layer but only a few individuals were found in sets in the cold layer at temperatures below 0°C. Most of the good catches in the deeper water were at temperatures from 2.2 to 4.1°C (see also Fig. 2C), but on Line D there was a good catch at 1.0°C immediately deeper than the cold tongue and an excellent catch at 0.4°C immediately shallower than the cold tongue. The good catches deeper than the cold layer sometimes had very cold water immediately overhead (Fig. 8, 1959, Lines D and F, Station 3). The deep-water concentrations of haddock at this time were engaged in their northward migration to shallower water and had moved northward close to the cold layer but had not entered it. On Line H the survey sets were not made deeply enough to sample the haddock of the warm water deeper than the cold tongue. (This is unfortunately true also for the more easterly lines in a number of situations and occasions in Fig. 5-8).

In June 1961 (Fig. 8) the cold tongue was neither as extensive nor as cold as in May 1959. Its effect, however, where it is well developed on the most easterly sections (Lines F and H), is again to separate the haddock into deep and shallow concentrations at higher temperatures (2.1 to 5.4°C) with only small quantities in the cold tongue at 1.0 to 2.0°C. On Lines B and D the haddock had moved partially but not wholly onto the plateau of the bank at temperatures of 1.9 to 3.7°C, their movement onto the bank being restricted by temperatures below 2°C.

There were several instances where haddock concentrations were found at moderately high temperatures along the slope immediately deeper than water masses, in which several degree isotherms of lower temperatures were crowded closely together (Fig. 8, 1961, Line D, Station 6; Line F, Station 5 and Line H, Station 4; Fig. 7, 1962, Line D, Station 6). There are many other examples in Fig. 5-8 where great changes from larger to smaller catches occur in the vicinity of sharp temperature changes. In some cases the abrupt catch and temperature changes occur above and below the cold tongue of water extending westward along the southwest slope from the eastern branch of the Labrador Current, this unfavourable environment separating shallow and deep-water concentrations both at more favourable temperatures.

The barrier effect of an impinging abrupt rise or fall in temperature needs to be interpreted also in relation to the most likely natural direction of movement of the haddock, deeper in winter-early spring and shallower in April-July. In winter-early spring (February-March in our figures), when haddock are moving deeper, the barriers should be at greater depths than the haddock concentrations. Deep-water temperatures below the winter-early spring haddock concentrations on the slope of the southwest Grand Bank are not extremely high or low and are within the favourable range for haddock at shallower depths on the slope. Consequently the barrier in the deep water is usually depth rather than temperature. The haddock upon reaching a certain depth presumably become concentrated due to a resistance to going deeper.

When the sharply differing temperature, serving as a temporary barrier, is within the favourable temperature range, such a barrier can only be temporary, functioning while the fish are becoming adjusted to the impinging higher or lower temperature.

3: Supplementary Results from Early Cruises

Before the repetitive surveys at approximately the same stations on the southern half of the Grand Bank were begun in 1952 there were some less extensive surveys by the *Investigator II* (Fig. 9) which help to fill some of the time and space gaps in the data from the survey cruises of recent years.

In March and April 1950 (Fig. 9) cold water below 1°C and much even below 0°C extended deeper than usual along the southwest slope. Haddock catches at these lower temperatures along the slope and in shallower water were usually zero or negligible, except for one modest catch just north of the 90-m (50-fathom) contour at 0.7°C. The best catches, although small, were obtained on the southwest slope below the cold water at temperatures between 2.5 and 4.6°C in depths from 145 to 240 m (80 to 130 fathoms), the latter being the lower limit of fishing.

In late March-early April 1951 (Fig. 9), when temperatures on the plateau and on the southwestern slope of the bank were considerably higher than in 1950, the largest catches of haddock were obtained in shallower water than in 1950 on and above the upper part of the slope in depths of 80-100 m (45-55 fathoms) at temperatures between 2.0 and 7.2°C. In early April no haddock were caught in many sets on the northern central area of the bank at -0.1 to 0.7°C, and in May no haddock or negligible quantities of haddock were found in the deep water of the southwestern slope in depths of 155-375 m (80-205 fathoms) at 3.5 to 6.2°C. By May 15, although temperatures were much higher than

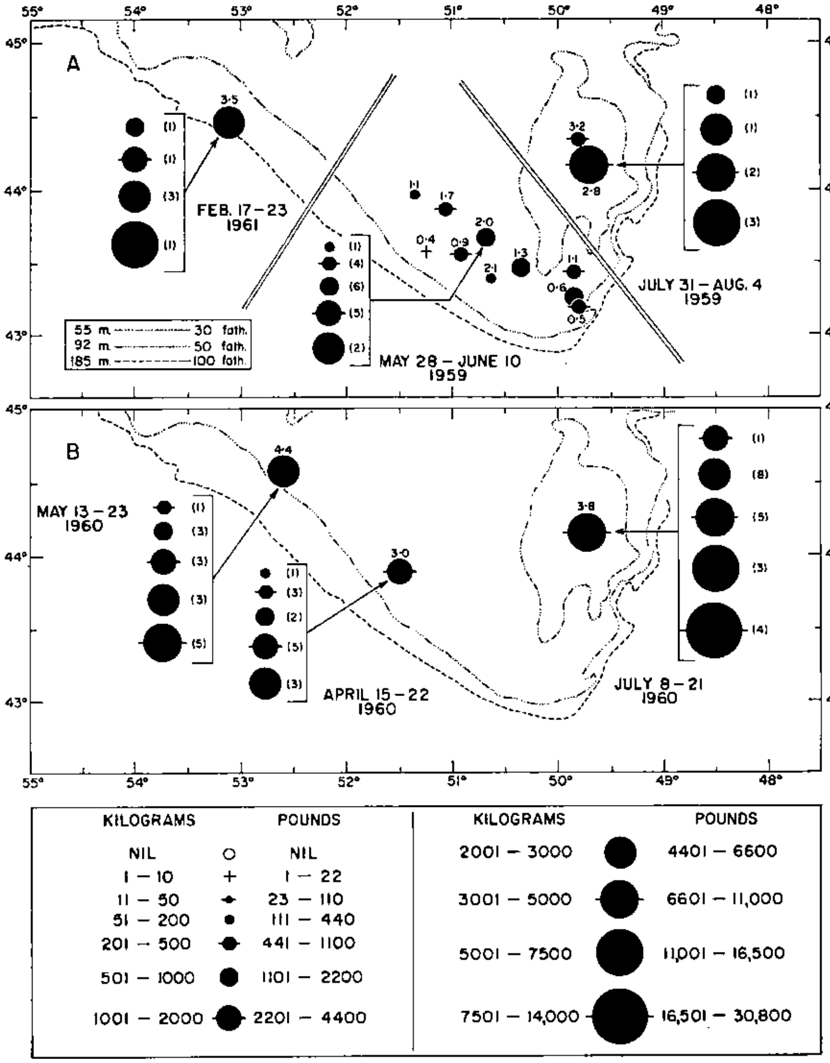

Fig. 10. Haddock catches per half-hour tow on bottom by *A.T.Cameron* from mesh selection cruises on the southern Grand Bank, February-August, 1959-61. (The figures in parentheses represent the number of tows and the arrow points to the average catch which is shown at the fishing location.)

usual, 4.1 to 4.7°C, only small quantities of haddock were present on the Southeast Shoal.

In late June and early July 1949 (Fig. 9) small quantities of haddock were found at most stations on the southwestern part of the plateau of the bank in 66-113 m (36-62 fathoms) at 1.3 to 4.1°C. In August considerably larger catches were made on and near the Southeast Shoal in depths of 46.-60 m (25-33 fathoms) at temperatures from 3.9 to 5.4°C and in one case at 2.8°C.

4: Mesh Selection Cruises

In addition to the survey cruises, several mesh selection cruises for haddock were made, some of the results of which are given in Fig. 10. During these cruises, after preliminary searches to find suitable quantities of haddock, many tows were made in the same area. These were usually 1-hr tows and occasionally, when catches were very large, 40-min tows. The catches have been reduced to the half-hour level to agree with the results of the survey cruises.

In February 1961 large catches were taken in 155-170 m (85-93 fathoms) on the slope south of Whale Deep at 3.5°C, and in May 1960 similar catches were obtained just north of the same location in 85 m (47 fathoms) at 4.4°C. In April 1960 and May-June 1959 only modest catches were obtained on the bank plateau just north of the 90-m (50-fathom) contour at 0.6 to 3.0°C.

In July-August 1959 and in July 1960 very large catches were obtained at 2.8 and 3.8°C on the Southeast Shoal in 46 m (25 fathoms). These large catches were taken in a capelin spawning area where the haddock were feeding heavily on capelin eggs and capelin (Templeman and Pitt MS, 1951; FRBC, 1952, Pitt, 1958, Noskov, MS, 1962).

5: Pelagic Movements

Although most feeding of haddock is on bottom organisms, it appears possible that on some occasions, at least, haddock may move long distances pelagically. Often in late June and early July there is some movement of Grand Bank haddock coastward to the Avalon Peninsula and northward reaching Bonavista usually in late July and early August. The quantity of haddock decreases as the movement northward progressea and small numbers have been taken at least as far north as Notre Dame Bay. In some years this coastward movement of haddock schools is very great. For example, at Fermeuse on 29 June-3 July 1959, most codtraps obtained 900-1,400 kg of haddock per haul and 1 trap had a catch of 9,000 kg. This migration occurs across the Avalon Channel which usually has a good deal of bottom or intermediate water below -1.0°C. Judging from the usual scarcity of cod (a fish which generally lives at lower temperatures than haddock) in these temperatures of -1.0°C and lower, it appears certain that these haddock travel pelagically across the Avalon Channel in the warmer surface layer. In their normal abode on the bank haddock are much more bottom related and less pelagic than cod. When they are caught together with cod in codtraps on the east coast of Newfoundland, however, their pelagic habit at this time is evident from their tendency to take up their position nearer the surface and in warmer water than the cod. Bottom temperatures on the bank were unusually low in early May 1959 (Fig. 2C) and haddock concentrations were retained longer than usual and mainly lay deeper than the barrier of the cold tongue. It appears likely that large quantities, in order to move shallower, rose into the warmer surface layer and dispersed pelagically in such numbers that large schools reached the southeastern coast of Newfoundland.

It is very likely, also, that some of the haddock migrations between the slope and the shallower parts of the bank are pelagic as such movements in more superficial warmer water would at times appear to be necessary if the haddock are not to pass through below 0°C water of the cold tongue.

DISCUSSION AND CONCLUSIONS

On the Grand Bank in winter haddock become concentrated at greater depths, often at 185-230 m (100-125 fathoms) and in lesser but sometimes significant quantities as deep as 275 m (150 fathoms), than on the Scotian Shelf where the winter concentrations occur at 80-130 m (45-70 fathoms) (Martin, 1960, 1961).

From otter-trawl surveys of Georges Bank by the *Albatross III* in the spring of 1950, during the spawning season most haddock of all ages occurred in water shallower than 55 m (30 fathoms) with only very small quantities in deeper water. At greater depths haddock gradually decreased in numbers but there was a secondary increase in numbers of larger haddock in the 112-165 m (61-90 fathom) range. Similar surveys in the summers of 1948-50 showed that the smaller haddock (ages 2-4) were principally in depths of 55-110 m (30-60 fathoms) whereas the older haddock were most numerous in water of 166-275 m (91-150 fathoms). Very few haddock of any age were found in the 112-165 m (61-90 fathom) depths in summer (Colton, 1955).

Presumably, as assumed by Colton, many of the large haddock of the Georges Bank area remain in deep water until late winter and rise into shallower water during the spawning season which occurs mainly in February-April (Bigelow and Welsh, 1925; Walford, 1938). The Grand Bank haddock begin to move towards the shallower water in April and spawn mainly in May and June.

Noskov (MS, 1962) shows the Soviet fishery for haddock on the Grand Bank in 1961 to have taken place on the shallower part of the southwest slope and on the southwest fringe of the plateau of the bank in April-June and mainly on the western part of the Southeast Shoal but also a little to the west of this shoal in July-November.

In the Bay of Fundy McKenzie (1932) found that the best catches of haddock on bottom longlines occurred in July-August at bottom temperatures of about 8°C but catches fell rapidly to near zero with temperatures of 9 to 11°C. In early winter catches increased again when the bottom temperature fell to about 4°C but were again reduced to near zero as the temperature fell to 2°C and lower. In experimental fishing near St. Andrews no haddock were caught with longline in water colder than 2.4°C. The greatest catches were made when the bottom water was between 7.3 and 10°C and catches almost as great were sometimes made when the bottom temperature was 11.9°C. On other occasions no haddock were taken with longline at 11.7°C although otter trawling in the same area showed that haddock were numerous.

Martin (1960, 1961) found largest catches of haddock of commercial size on the Nova Scotian Shelf in winter to occur in the vicinity of Sable Island and Emerald Banks in 80-130 m (45-70 fathoms) at bottom temperatures from 3 to 5°C. At bottom temperatures of 1 to 3°C small haddock predominated but there were no haddock in the shallow water on the tops of the banks where temperatures were less than 1°C. In cold years the haddock lay deeper and were more concentrated. In summer small haddock were most abundant in warm shallower water less than 55 m (30 fathoms) on top of the banks with bottom temperatures above 7°C.

Thompson (1939), from otter trawling on the southwest slope and edge of the Grand Bank by the research vessel *Cape Agulhas* in March-May 1934 and 1935, found the greatest average catches of haddock at 4 to 7°C.

A consideration of Fig. 5 and 6 shows that in different years, months and depths there is considerable variation in the temperatures at which the best catches of haddock are made but on the southern Grand Bank between February-June the best catches are usually obtained at bottom temperatures between 2 and 8°C. In any one month and place, however, only a limited part of this range of bottom temperatures is generally available. Consequently, haddock, if present, must usually occupy a more limited temperature range.

Haddock in late winter and early spring inhabit the southwest slope of the Grand Bank at greater depths than are required merely to evade low temperatures. Preceding spawning haddock desert the high temperatures of the deeper water, which are very favourable during winter, and move shallower usually into lower temperatures. Presumably the retention of haddock eggs and larvae on the bank is favoured by this northeastward pre-spawning migration away from the very deep water south and west of the slope. It is apparent that Grand Bank temperatures either in the deep or the shallow water are not usually high enough to be limiting for haddock, although they may doubtless form a temporary barrier to haddock already in low temperatures until they become accustomed to the impinging higher temperature water.

By April-June, when the haddock are moving northeastward from the southwest slope of the bank, the eastern Grand Bank branch of the Labrador Current usually has a well-developed tongue of water below 1°C extending westward along the shallower fringe of the southwest slope to about 51°W (Fig. 2D, 3A, 3B, 4D) or even farther westward to about 51°30'W - 52°30'W (Fig. 2C, 3C, 3D, 4A, 4B). The cold tongue of water, judging from Fig. 2-8, attains a greater development in May and June than in earlier months. Depending on the time of development of the cold tongue in relation to the existence of haddock on the slope or the passage of haddock to the shallower plateau of the bank, the following hypotheses are possible: the cold tongue may pass above or below the main haddock concentrations or may push through the concentrations with the haddock moving both deeper and shallower away from the cold tongue, thus separating them into concentrations above and below the cold tongue. Haddock concentrations are rarely found in the central coldest part of this cold tongue, but sometimes they are found at temperatures below 1.5 and even below 1°C on the fringes of the cold tongue. It is possible that in such cases the haddock concentrations have not migrated into the cold tongue but have moved both deeper and shallower away from it and thus become separated, but that sometimes the cold tongue has moved rapidly enough to engulf the haddock concentrations on its fringes and they have become acclimatized to the cold water before they could escape it. In such cases haddock concentrations occur deeper and shallower than the cold tongue at unusually low temperatures as in Fig. 2C, and Fig. 8, 1959 (Line D, Stations 6 and 3). On other occasions (Fig. 3A, 4A) the cold tongue seems to engulf the southern part of a haddock concentration on one or more of the eastern lines. The apparent separation of haddock by a cold layer of water at intermediate depths into concentrations in warmer water both shallower and deeper than the cold layer is similar to that found by Templeman and Fleming (1956) for cod on the east coast of Newfoundland.

Temperatures on the Grand Bank are often low enough, from less than 0 to 2°C, to interfere with northward movement of haddock over the bank plateau. Consequently, even in summer, apart from the pelagic coastward and coastal movements, large concentrations of haddock are found on the southern rather than on the northern parts of the bank.

In some months and years (Fig. 4A, 4B, 4D, 3D) there is an apparent intrusion of warmer slope water onto the bank from the southwest slope region, usually between 53° and 51°W. Often the haddock are included with or follow the pattern of the warm water intrusion. At other times (Fig. 2C, 2D, 3A, 4C) there may be an influx of warm slope water at various levels or there may equally well be warming from the surface. The intrusion or warm water mass has either a broad base on the southwest slope (Fig. 4C, 4D) or the base may be narrow forming a warm water tongue (Fig. 4A, 4B). The width of the base is largely determined by the extent of development of the cold tongue passing westward along the southwest slope and edge of the bank. With the intrusion (if it occurs) and the cold tongue both being deflected in their natural direction to the right, the haddock are directed by the isotherms of favourable temperature toward the shallowest part of the southern Grand Bank, the Southeast Shoal. The extent, shape, temperature, and other characteristics of this warm water mass during the spawning season in May and June and the resulting distribution of haddock at spawning time should have a considerable influence on the survival and retention on the bank of haddock eggs and larvae. In 1955 when haddock were well established on the plateau of the bank in May and June, with very few on the slope (Fig. 4D) there was the most successful year-class survival of haddock between 1950-1962. (For success of other haddock year-classes see Templeman, this symposium).

From lack of information on food and feeding of haddock in the Grand Bank area it has not been possible here to assess the relative effects of food and temperature in producing haddock concentrations. However, as in the instance given of the great haddock concentrations on the capelin spawning grounds of the Southeast Shoal, there can be no question that, especially after spawning, food as well as temperature will be important factors in concentrating haddock. Judging, however, by the work of Homans and Vladykov (1954) for haddock of the Nova Scotian area and allowing for later spawning (mainly in May-June) on the Grand Bank it is unlikely that the pre-spawning haddock on the southwest slope are concentrated mainly by food.

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A-9

DISTRIBUTION OF HADDOCK ON ST. PIERRE BANK (ICNAF DIVISION 3Ps) BY SEASON, DEPTH AND TEMPERATURE[1]

By

Wilfred Templeman and V. M. Hodder[2]

ABSTRACT

The largest catches of haddock from research vessel operations on St. Pierre Bank from late ay to early July 1951-54 were in the shallow water. On the average the largest shallow-water atches were taken at temperatures between 2.5 and 7.0°C but a few large catches occurred at tempratures from 1.4 to as low as 0.7°C. Catches in the deep water were very low and the small num ers of generally larger fish at depths below 119 m were usually at the higher temperatures between .5 and 6.4°C.

Information from Newfoundland trawlers during the years of great abundance of young fish of ne 1949 year-class showed that haddock were available in quantity on top of the bank in 37-72 m nd usually less than 60 m from June to January. In February-April the commercial fishing was conntrated on the western slope of the bank generally between 146-220 m.

Temperature surveys indicate that the bottom water on top of the bank usually ranges from less nan 0° to 1°C in March-April, whereas at the same time on the western slope of the bank at 175 m nd deeper bottom temperatures were usually from 3 to over 6°C.

The retreat of haddock from the shallow water in January-February and the return to shallow ater again in May-June are apparently in response to low temperatures on top of the bank in winter nd early spring and to the subsequent warming in late spring and early summer.

INTRODUCTION

Surveys of St. Pierre Bank by bottom otter trawl have been carried out for many years, mainly n late spring, by the research vessels *Investigator II* and *A.T. Cameron*. Details of the ships, rawls, and hydrographic methods are set out in Templeman and Hodder (this symposium). Unless therwise noted all temperatures mentioned in this paper are bottom temperatures.

Statistics of landings, location of fishing and effort have also been obtained for Newfound and trawlers fishing on St. Pierre Bank since 1953 and for several Newfoundland trawlers before nat time.

Only occasionally is St. Pierre Bank a major source of haddock. Before the autumn of 1953, nen the unusually successful 1949 year-class had reached small commercial size, haddock fishing y Newfoundland trawlers in this area was sporadic although some successful fishing for haddock as carried out in deep water in spring and early summer of the years after 1946. From the autumn f 1953 to the spring of 1956 there was excellent fishing on St. Pierre Bank for the very numerous 949 year-class. Since 1956 there has been little commercial haddock fishing on this bank.

DISTRIBUTION OF RESEARCH VESSEL CATCHES

. 1951-54

In the years 1951-54 the *Investigator II* obtained some large catches of haddock on St. Pierre ank (Fig. 1), almost all from the unusually large 1949 year-class. Although fishing was usually arried out in depths to 185 m and occasionally deeper, the large catches (greater than 1000 kg per

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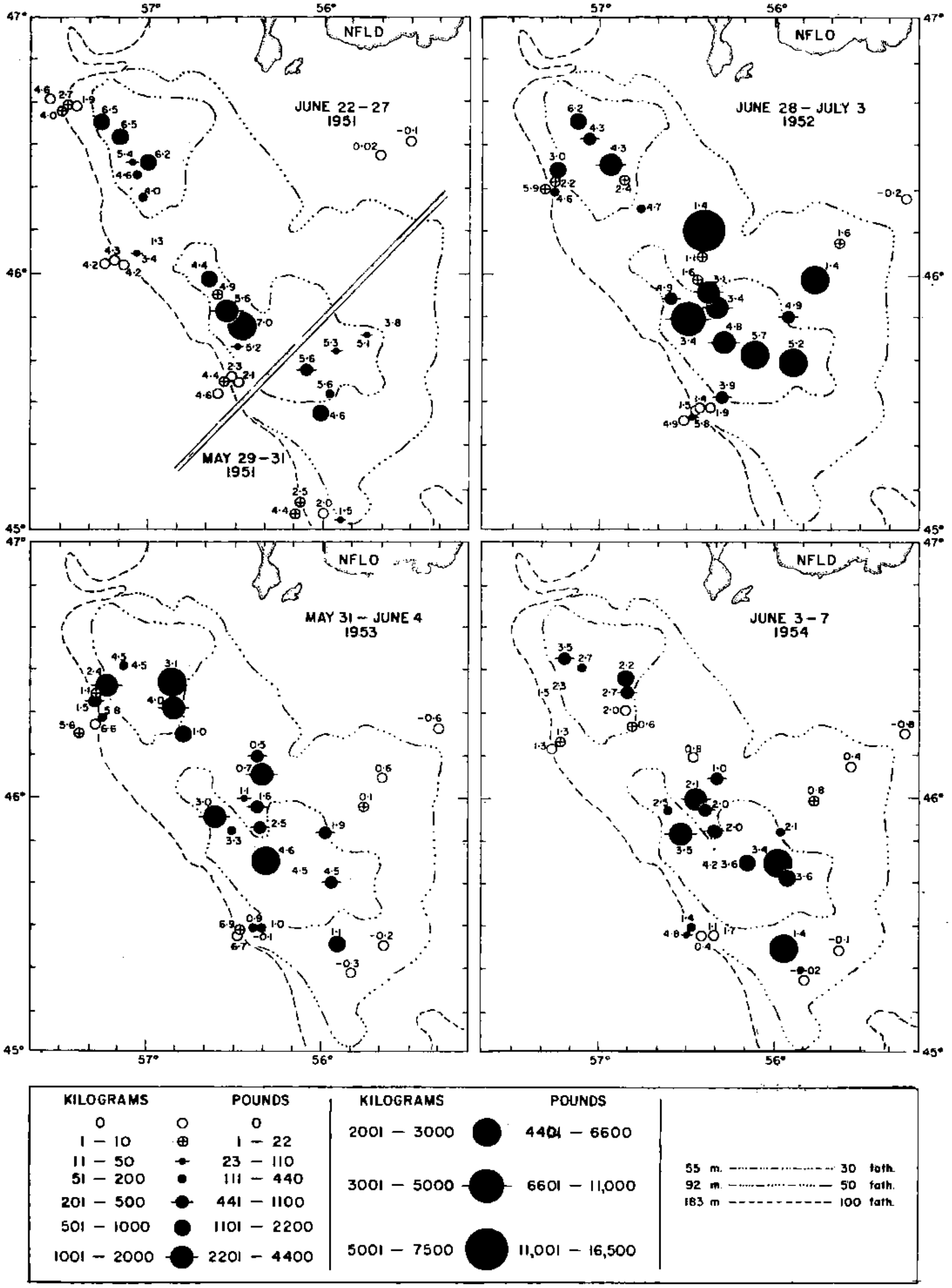

Fig. 1. Distribution of haddock from otter-trawl catches by the *Investigator II* on St. Pierre Bank, 1951-54, in relation to bottom temperature. (Catches are in kg of whole haddock per half-hour tow on bottom and temperatures are in °C.)

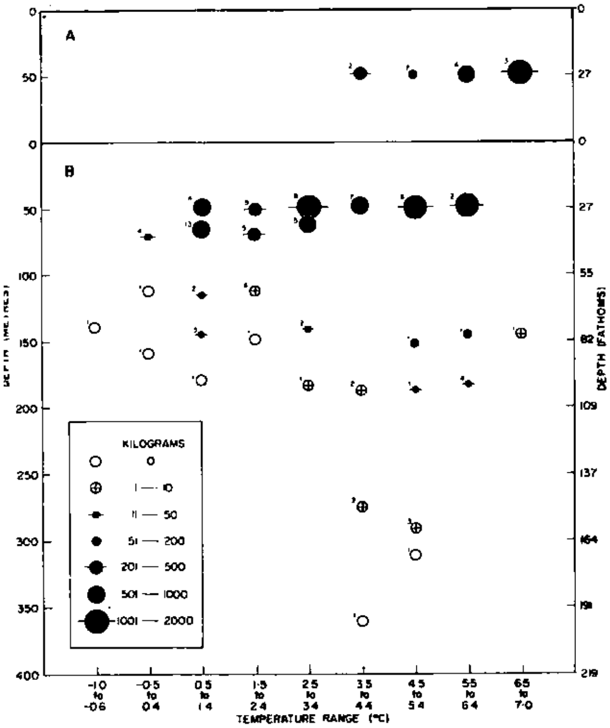

Fig. 2. Average catches of whole haddock per half-hour tow by the *Investigator II* on St. Pierre Bank in May-early July 1951-54 in relation to depth and bottom temperature. (At the upper left of each symbol is the number of sets involved in the average. A = 1951. B = 1952-54 for the shallowest depth range and 1951-54 for the remainder.)

hour tow) were all taken in shallow water on the plateaus of the bank mainly between 44-66 m. In May and June 1951 (a warm year) large numbers of haddock (mainly 2-yr-old fish) were obtained at high temperatures of 4.4 to 7.0°C. Between 28 June and 3 July 1952, although most of the good catches (chiefly of 3-yr-old fish) were taken at temperatures of 3.1 to 5.7°C, two large catches (one the largest for the survey) were taken at 1.4°C. From 31 May to 4 June 1953, good catches of mainly 4-yr-old haddock were taken chiefly between 2.4 and 4.6° C. Again on 3-7 June, 1954, some good catches of chiefly 5-yr-old fish were taken at temperatures from 1.4 to 3.5°C. Many sets in deeper water, both in cold water at intermediate depths (70-180 m) and in deeper warm water between 180-300 m produced zero or negligible catches.

In Fig. 2. where the catches are averaged in relation to depth and temperature range, it can be seen that the best fishing, mainly on haddock 2-5 yr old of the 1949 year-class, occurred in average depths of 45-50 m. In 1952-54 the largest catches, on the average, were obtained at temperatures between 2.5 and 6.4°C, whereas in 1951 (Fig. 2A), a warmer year, the haddock (mainly 2-yr-old fish) were most plentiful at the highest temperatures (5.5 to 7.0°C). At average depths of 60-70 m catches were reduced; the available temperature range was narrower and the largest catches were between 0.5 and 3.4°C. Catches at deeper levels were very low and the small numbers of generally larger fish at levels below 119 m tended to be at the higher temperatures between 2.5 and 6.4°C.

2. 1957-60

In recent years, 1957-60, survey sets on St. Pierre Bank mainly in May and June by both the *Investigator II* and the *A.T. Cameron* have produced negligible catches (Fig. 3). In this period, although temperatures on the shallower parts of the bank were generally suitable for haddock, the best of the very small catches were usually on the western slope of the bank, either in the deep warmer water of about 180 m or deeper or in the intermediate colder water usually at about 145 m. This scarcity is due to the great reduction in the haddock population on St. Pierre Bank following the heavy exploitation during 1954-56 and the poor year-class survival since 1949.

HADDOCK DISTRIBUTION AS INDICATED BY THE COMMERCIAL FISHERY

1. The Commercial Fishery

The commercial fishery by Newfoundland trawlers on St. Pierre Bank in 1954-56 was mainly for haddock of the 1949 year-class. From June to January (Fig. 4, 5) fishing was concentrated in shallow water between 37-72 m. At first most of the fishing occurred in the shallowest part of this range where bottom temperatures in late spring and summer are highest. As the year advanced fishing gradually progressed downward to 55-60 m in December and January. The downward movement to deeper water appeared to occur very rapidly in January, so that from February to April haddock were caught on the western slope of the bank usually between 146-220 m.

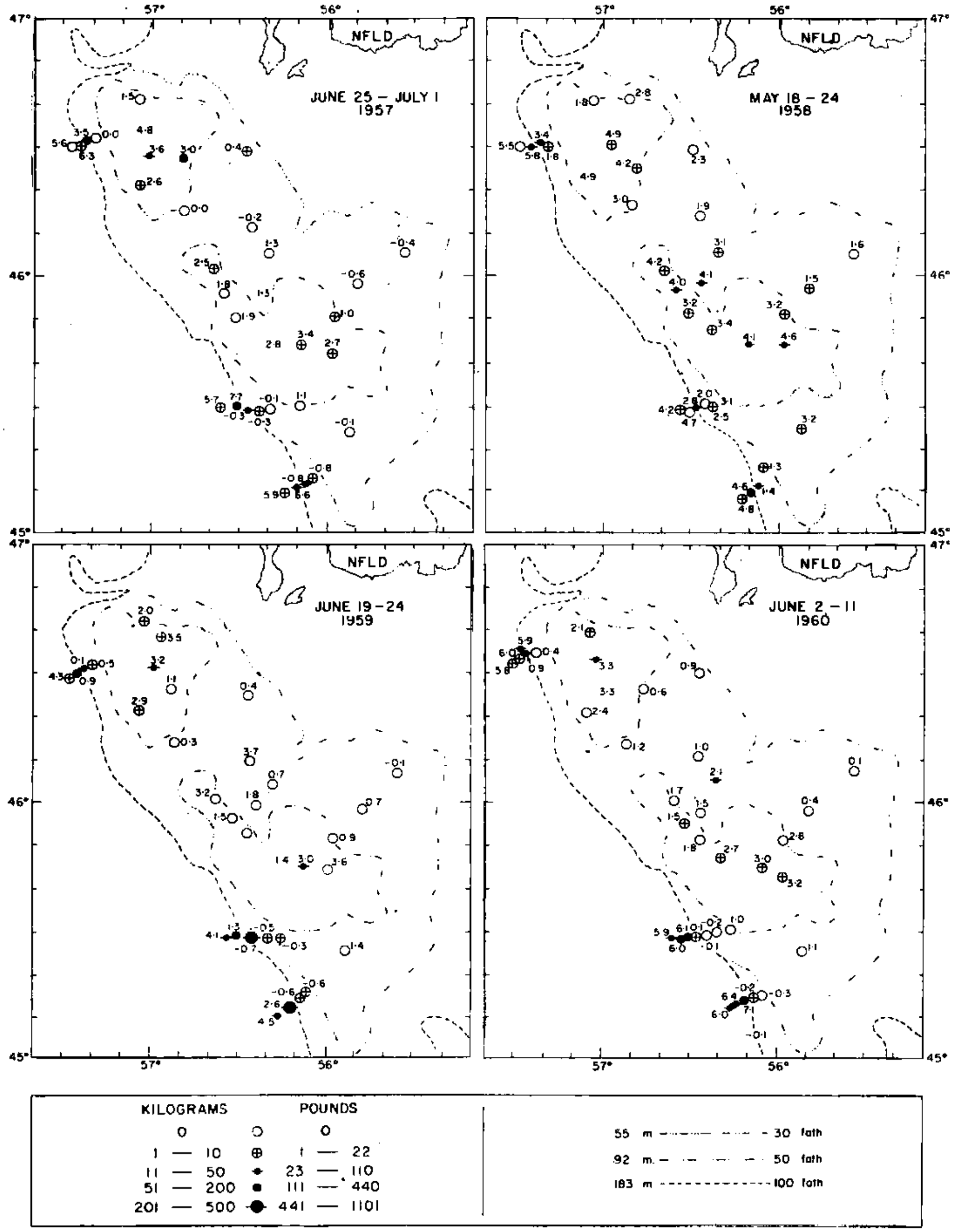

Fig. 3. Distribution of haddock from otter-trawl catches by the *Investigator II* 1957-59 and by the *A.T. Cameron* 1960, in relation to bottom temperature. (Catches are in kg of whole haddock per half-hour tow on bottom and temperatures are in °C.)

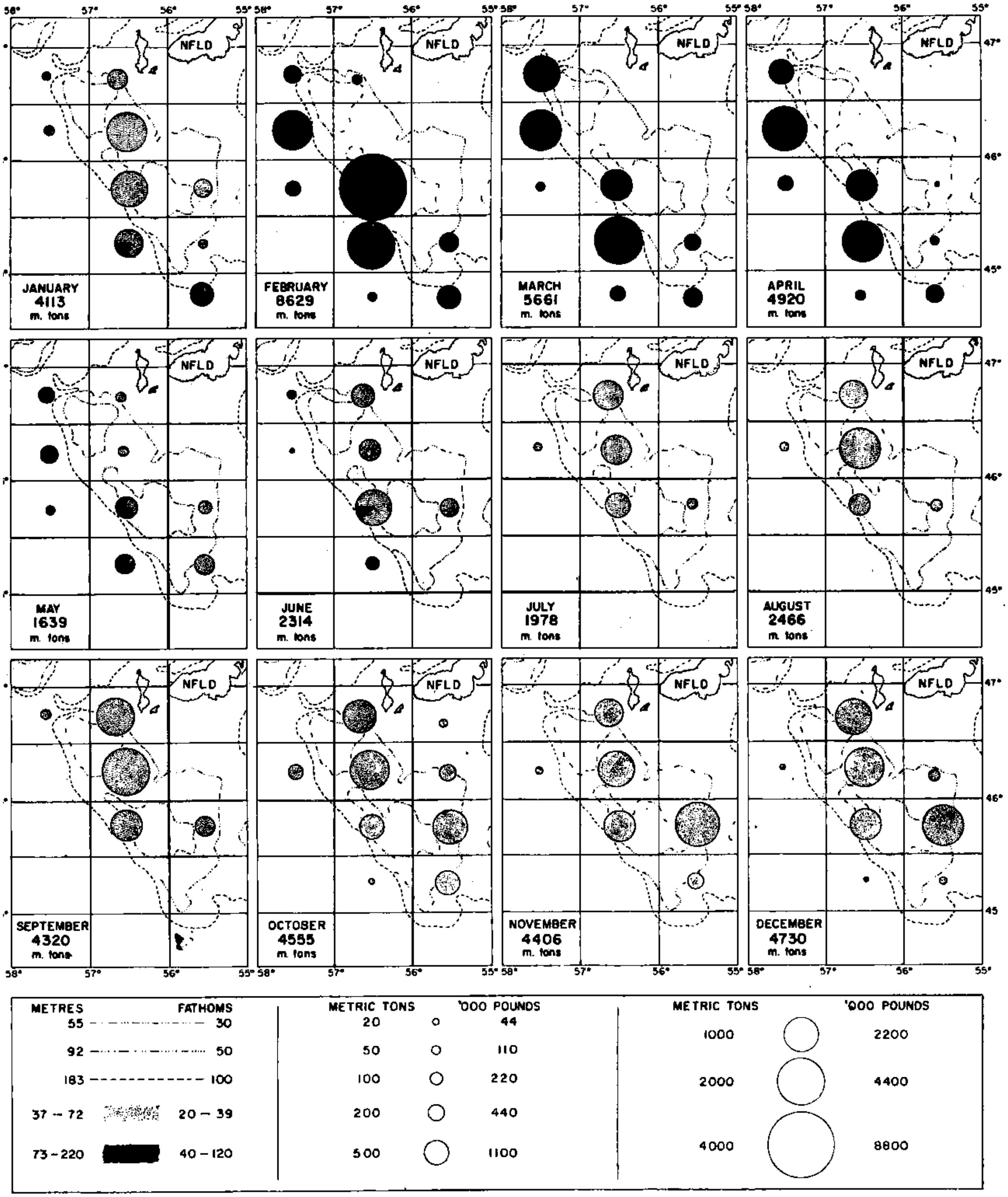

Fig. 4. Monthly distribution of haddock landings by Newfoundland trawlers (151-400 tons) in 1954-56 by 1° longitude, 1/2° latitude rectangles and depth range. (The symbols are in relation to the size of the landings and are placed in the middle of the appropriate rectangle.)

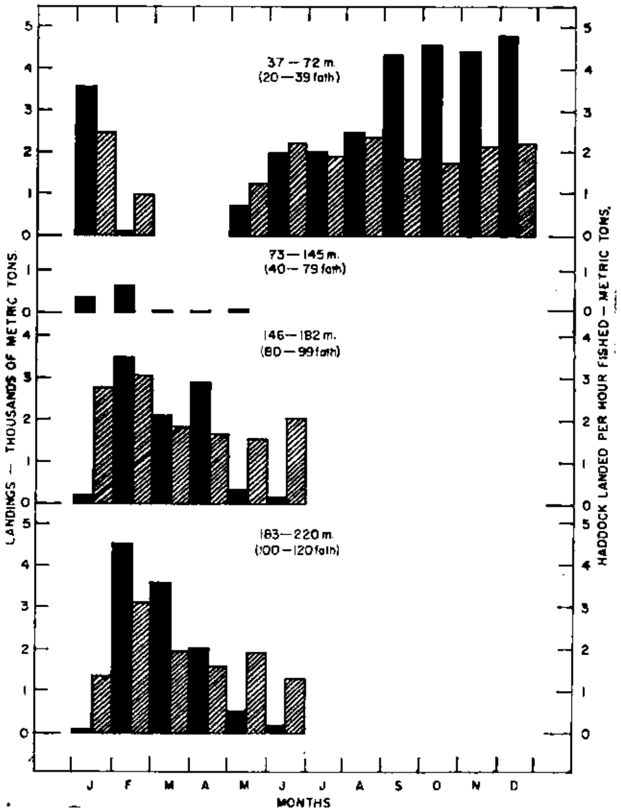

Fig. 5. Average monthly landings and landings per unit effort of whole haddock by Newfoundland trawlers (151-400 tons) at various depth ranges on St. Pierre Bank, 1954-56. (Black bars represent landings and cross-hatched bars the landings per unit effort.)

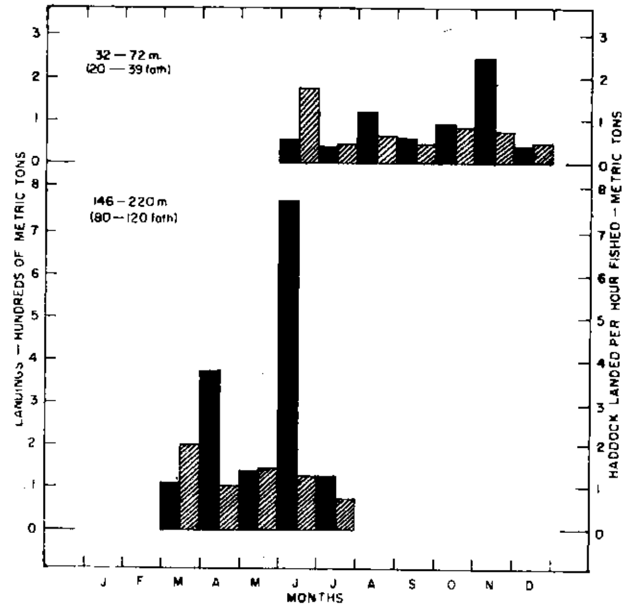

Fig. 6. Average monthly landings and landings per unit effort of whole haddock by several Newfoundland trawlers (151-400 tons) at various depth ranges on St. Pierre Bank, 1946-50. (Black bars represent landings and cross-hatched bars the landings per unit effort).

Landings per unit effort (Fig. 5) indicate that quantities of haddock were present in the intermediate deep water (146-182 m) in January, but as similar quantities were available in shallow water the fishermen continued to fish there because they preferred the shallower depths. In January the haddock had not penetrated in quantity to the deepest water of 183-220 m. By February both the landings from the shallow water and the landings per unit effort were considerably reduced whereas there was a considerable increase in both of these at the deepest fishing level. When fishing in the shallow water was resumed in May there was only a slight increase in the landings per unit effort beyond those of February. By June the fishery had mainly returned to the shallow water, and the landings per unit effort declined at the deepest level but increased in the intermediate deep water and in the shallow water.

These data indicate that in January and February haddock rapidly migrated downward from the shallow water of St. Pierre Bank to the deep water along the western slope with a gradual return to the shallow water in May-June. Due to lack of fishing in the shallow water in March-April and in the deep water from July to December the record is not complete, but research vessel catches, carried out mostly in June 1951-54 (Fig. 1, 2), showed only small quantities of haddock in the deep water compared with the large amounts in the shallow water on top of the bank.

In the period of sporadic effort in 1946-50, for which data are available for only a few trawlers, most of the fishing for haddock was carried out in deep water (146-220 m) along the western slope of the bank from March to July and a little from June to December on top of the bank in 37-72 m (Fig. 6). Landings at the rate of a ton or more per hour's fishing were made from the deep water in March-June and from the shallow water in June. Catches undoubtedly were considerably larger because at this time almost all haddock below 45 cm and some up to 50 cm in length were discarded.

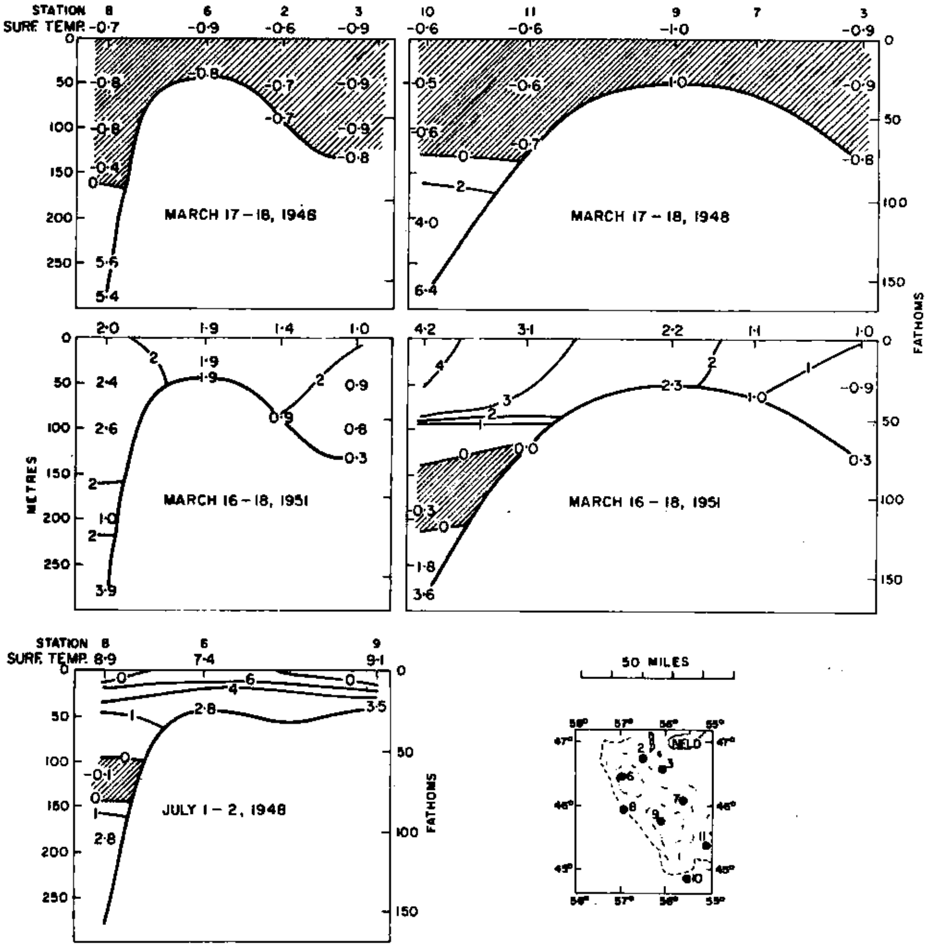

Fig. 7. Temperatures (°C) on St. Pierre Bank in March 1948, 1951 and in July 1948 (from hydrographic cruises of the *Investigator II*.)

. Bottom Water Temperatures in General Relation to the Commercial Fishery

Temperatures were not taken during the commercial cruises but are available from hydrographic ruises of the *Investigator II* for 1948 and 1951 and for 1954-55 (Fig. 7,8). In March (1948) tempratures from the surface to about 150 m were below 0°C and in April (1954 and 1955) bottom tempratures ranged from about 1°C at 40-50 m on the plateaus of the bank to about 0°C at 100 m. In hese months temperatures on the western slope of the bank in 175 m were at 3.0°C or higher and sually 5 to 6°C or higher at 200 m in warmer years such as 1954-55 and at 250 m in 1948, a cold ear.

Even in cold years such as 1948 temperatures in the shallowest water at 40 m on top of the ank were close to 3°C or higher by July. By August these temperatures may be 4 to 5°C or higher. eanwhile in these summer months temperatures in the deep water were usually high as in winter and hroughout the year, but centred in the vicinity of about 100 m there was a cold intermediate layer ith temperatures usually below 1°C. Minimum temperatures in this intermediate layer varied from elow 0°C in cold years (Fig. 7,8) to about 2°C in warm years such as 1951 (Fig. 1).

In March 1951 temperatures were unusually high (1.9 to 2.3°C) in the shallow water on the top f the bank, but cold water extended deeper than usual on the western slope. In exceptional years uch as 1951 (Fig. 1) bottom temperatures on top of the bank may reach as high as 6 to 7°C by late une-early July.

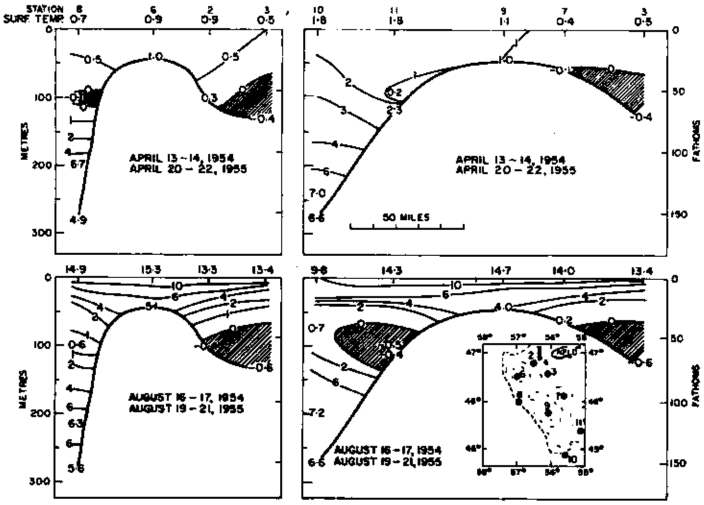

Fig. 8. Temperatures (°C) on St. Pierre Bank in April and August 1954 and 1955 (from hydrographic cruises of the *Investigator II.*)

Both in spring and in summer haddock were restricted in bottom distribution by the presence of water below 0°C in the St. Pierre Channel to the north of the bank. There is some summer migration of St. Pierre Bank haddock, however, to the Burin Peninsula and their shoreward passage to this peninsula is probably pelagic.

DISCUSSION AND CONCLUSIONS

For the Grand Bank, Templeman and Hodder (this symposium) found haddock to occupy the deep water of the southwest slope in late winter and early spring, with the larger concentrations mainly between 120-275 m and temperatures between 2.5 and 9°C. Haddock concentrations were at higher or lower temperatures in this range in different years depending on the prevalence of high or low temperature water on the southwest slope. In movements onto the top of the bank in April-June the 2°C contour was usually restrictive and in the latter part of this movement concentrations were usually at temperatures of 3°C and over. Occasionally a good catch was made at temperatures as low as 0.4°C, but this was unusual. The temperature distribution shown in Fig. 7 and 8 and the related depths and landings per unit effort throughout the year (Fig. 4-6) show that the St. Pierre Bank haddock follow a pattern generally similar to that of Grand Bank haddock in depth and temperature relationships.

The largest catches of haddock from research vessel operations on St. Pierre Bank from late May to early July 1951-54 were in the shallow water. On the average the largest shallow water catches were taken at temperatures between 2.5 and 7.0°C but a few large catches occurred at temperatures from 1.4 to as low as 0.7°C.

The retreat of haddock and the haddock fishery from the shallow water in January-February and the advance into shallow water in May-June are apparently a retreat from low temperatures on the surface of the bank and a return again to the shallower water of the bank as the water on top of the bank warms up.

The relatively greater commercial catches in deep water than in shallow water in June-July 1946-50 (Fig. 6) compared with the same months in 1954-56 (Fig. 5) may be due to several causes: The haddock population at the earlier period consisted, to a much greater degree than in the latter period, of large haddock over 10 yr of age whereas the haddock caught in 1954-56 were chiefly 5-7 yr old. These large fish may have had a greater tendency to remain in deep water during summer as do large cod off the northeast coast of Newfoundland (Templeman and Fleming, 1956). On the whole the earlier period had more cold years. The year 1948 was a cold year in the shallow water of St. Pierre Bank (Fig 7.) whereas 1954 and 1955 were moderately warm years (Fig. 8). The year 1950 was also cold in the early part of the year in the shallow water on St. Pierre Bank with below 0°C temperatures in March approximately the same as in 1948. These low temperatures in the upper water layers may have kept the fish in deep water somewhat longer in the earlier period.

ACKNOWLEDGEMENT

The authors are grateful to Mr A. M. Fleming for the provision of statistics of haddock catches by Newfoundland trawlers fishing on St. Pierre Bank.

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A-10

INFLUENCE OF COLD WATER ON FISH AND PRAWN STOCKS IN WEST GREENLAND[1]

By

Sv. Aa. Horsted[2] and Erik Smidt[2]

ABSTRACT

Redfish is especially sensitive to low temperatures and it is for this species that there are most records of mass mortality after severe winters. Mass mortality because of extraordonarily cold water has also been recorded among other species of fish (cod, lumpfish etc.), but the most catastrophic effect of winter-cooled water in West Greenland was the total destruction of the stocks of deep sea prawns, *Pandalus Borealis*, in the fjords at Holsteinsborg after the very severe winter 1948/49.

In many fjords cod follow the capelin when the latter arrive there in May and June to spawn. In some years, however, when the coastal water is colder than normal, capelin arrive in the fjords without being followed by the cod which cannot go through the cold water barrier.

In certain threshold fjords the bottom water is constantly cold. In these fjords cod and redfish are very rarely found in the trawl catches and *Pandalus borealis* has a very slow growth rate, late sex reversal and negligible reproduction. *Pandalus borealis* is partly replaced by *Spirontocaris machilenta* in these fjords.

MORTALITY DUE TO EXTRAORDINARILY LOW TEMPERATURES

1. Redfish *(Sebastes marinus)*, cod *(Gadus morhua)* and other species.

On several occasions mass death of redfish *(Sebastes marinus)* in West Greenland fjords has been stated as being an effect of heavy winter cooling of the sea. In a paper about *S. marinus* the late Professor Ad. S. Jensen (1922) refers to a letter written on 20 February 1889 by Colonial Manager R. Müller in Sukkertoppen to Professor in Zoology Chr. Lütken, in which it was mentioned that an enormous quantity of dead or dying redfish were covering the surface of the sea off Sukkertoppen. In a letter of 4 April of the same year Müller added that larger or smaller numbers of redfish had been found in different places every day from the middle of February till that date. The Greenlanders told Müller that it was not uncommon at that place for the redfish to rise to the surface in this manner, and that it does not happen to any other fish. Sometimes redfish rise every year in greater or smaller numbers, sometimes after an interval of several years, but always between January and April inclusive and mostly in February and March. About 12 yr before redfish was said to have risen so profusely and so widely that the fjord, seen from the mountain, was red with dead specimens.

Jensen (*loc. cit.*) discussed the phenomenon with the hydrographer, Dr J. N. Nielsen. He was of the opinion that it was caused by the cooling of the water, since the *Tjalfe*-expedition showed that -1°C could be recorded down to 100 m or more off Sukkertoppen towards the end of the winter. Further Nielsen believed that the fish while possibly hunting for food for instance had risen to higher levels than usual and became so weak in the cold water they could not descend again, and so slowly died.

In the warm period which has existed in Greenland waters since about 1920, mass death of redfish does not seem to have been so common. Still we have records after the two severe winters 1937/38 and 1948/49 when many redfish and fish of other species were killed.

After the severe winter of 1937/38 records from Sukkertoppen show that great quantities of dead *S. marinus, Gadus morhua, Reinhardtius hippoglossoides, Cyclopterus lumpus* and *Anarhichas sp.* were found in the spring (Hansen, 1939). In Amerdloq Fjord at Holsteinsborg a great many dead or dying cod were taken by the prawn trawlers at the beginning of the summer. All had a hole in the side through to the body cavity and the intestines had disappeared (Hansen, *loc. cit.*). The most

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probable explanation is that the fishes had been paralysed by the cold water and attacked by a predator, which Dr Paul Hansen, in accordance with Greenlandic fishermen and hunters , thinks is the harp seal (verbal information).

The winter of 1948/49 was more severe than the winter of 1937/38 and winter cooling of the water went down to the bottom of the Amerdloq and Ikertoq Fjords (Holsteinsborg district) and killed the redfish and the prawns (Hansen, 1951, Horsted and Smidt, 1956). In the spring of 1949 great quantities of dead and dying redfish were seen on the surface of the fjords, and once in March the sea off the mouth of Amerdloq was quite red with redfish. As late as the first of July some dead redfish were observed on the surface from the research cutter *Adolf Jensen*.

In the innermost part of Godthåb Fjord, inside the outpost of Kapisigdlit, the fishermen in the middle of March 1959 observed many dead cod. They had never seen this in previous years. This observation corresponds with the fact that unusually cold water, from -1.5 to -1.3°C, was observed from the surface down to 90 m depth.

2. Deep sea prawn *(Pandalus borealis)*

Since 1935 prawns have been trawled in Amerdloq and Ikertoq Fjords at Holsteinsborg, but in 1949 the fishery had to be given up as the prawn stocks were totally destroyed by the cold bottom water. This occurrence, however, must be regarded as abnormal, as the prawns survived the severe winter of 1937/38. After the catastrophe in 1949 it was 4-5 yr before the prawn stocks recovered, which is about the same time it takes a prawn to grow from an egg to fishable size (Horsted and Smidt, *loc. cit.*).

3. Temperature observations showing the effect of the extremely cold winters 1937/38 and 1948/49.

As mentioned the biological effects of the severe winters of 1937/38 and of 1948/49 were very important. No temperature observations, however, were made in winter then, but as can be seen from two series of observations made in summer, one from Fylla Bank (Table 1) and one from Amerdloq Fjord (Table 2), the effect of the winter cooling was still very pronounced in the summers of 1938 and 1949.

TABLE 1. FYLLA BANK (63°58'N. 52°44'W.). BOTTOM TEMPERATURES (°C) AT ABOUT 40 M IN JUNE OF VARIOUS YEARS.

Year:	1925	1926	1928	1934	1936	1937	1938	1947	1948	1949	1950	1953	1954	1956	1957	1959	1960
Temp.:	0.8	2.2	1.8	2.7	2.0	1.3	0.0	3.4	1.3	0.1	1.0	1.4	2.2	0.8	1.3	1.6	2.6

TABLE 2. AMERDLOQ FJORD (66°54'N. 53°35'W.). TEMPERATURES (°C) AT 300 M IN VARIOUS YEARS FROM MAY TO AUGUST INCLUSIVE

Year:	1909	1934	1935	1936	1937	1938	1939	1947	1949	1950	1951	1952	1953	1954	1955	1956	1957	1959	1960
Temp.:	1.0	1.4	1.4	0.9	1.0	-0.9	0.7	2.5	-1.6	0.0	0.9	1.0	1.8	-0.2	1.0	2.7	0.8	1.2	1.4

EFFECT OF UNUSUALLY COLD WATER ON FEEDING MIGRATIONS OF COD

Under normal temperature conditions in Southwest Greenland waters the cod follows the capelin *Mallotus villosus)*, its favourite food, when the latter migrates in the early summer (May and une) to the shore of the fjords in order to spawn. At that time there is an important cod fishry with pound nets in several fjords. In some years, however, when the coastal water is colder han normal the capelin arrives in the fjords without being followed by the cod, which cannot go hrough the cold water barrier. From recent years we have good instances of this phenomenon in 949 and 1954 and possibly in 1963.

After the severe winter of 1948/49, shoals of capelin arrived in Amerdloq and Ikertoq Fjords ear Holsteinsborg in May and June, but they were not followed, as usual, by the cod because of he cold water, so that the cod fishery in the fjords failed at that time.

Ameralik Fjord in Godthåb district is a threshold fjord with constantly cold bottom water. he local cod stock is only small, but when the capelin enters the fjord for spawning it may be ollowed by great quantities of cod from the coastal region. This was the case in 1951, when a ound net fishery was started, but in 1954 the fishery failed completely as the cod kept out of he fjord in spite of a normal invasion of spawning capelin. The coastal water was very cold that ear and must have been the reason the cod could not enter the fjord. The following biological obervations give a clear picture of the conditions in 1954.

From 26 April to 2 June 1954 Ameralik Fjord was visited five times by fisheries biologists, and hroughout that period very few cod could be fished. However, some cod eggs were taken in the 1m tramin net in the surface water at the end of April. On 21 May much roe of capelin was observed on he bottom at the shore, and later, on 2 June good catches of capelin were made with a hand seine. emperature observations were made on 12-13 May showing cold water with negative temperatures from he bottom up to between 30 and 20 m depth inside and outside the threshold. Table 3 and 4 give ome temperature observations made in the coastal region in May since 1954, and clearly show that 954 was a very cold year.

TABLE 3. ENTRANCE TO THE GODTHAB FJORD. TEMPERATURES (°C) AT VARIOUS DEPTHS AND DAYS DURING MAY OF 1954-62.

Depth in m	1954 17th	1955 25th	1956 16th	1957 14th	1958 14th	1959 16th	1960 21st	1961 12th	1962 29th
0	0.8	1.4	1.4	0.9	1.5	3.3	2.3	2.2	2.5
20	0.7	1.2	1.0	0.8	0.9	1.6	1.7	1.7	1.5
50	0.5	1.2	1.0	0.8	0.6	1.3	1.5	1.5	1.3
100	0.4	1.2	1.0	0.8	0.6	1.2	1.6	1.3	1.4
200	0.2	1.2	1.0	0.8	0.3	1.1	1.6	1.3	1.3
300	0.1	1.3	1.0	0.8	0.3	1.0	1.6	1.2	1.3

TABLE 4. COASTAL WATER SOUTH OF GODTHAB (63°53'N.51°28'W). TEMPERATURES (°C) AT VARIOUS DEPTHS AND DAYS DURING MAY OF 1954-58, 1961 AND 1962.

Depth in m	1954 15th	1955 27th	1956 28th	1957 23rd	1958 13th	1961 4th	1962 30th
0	1.2	2.3	1.0	3.8	1.4	1.1	2.8
20	0.0	1.7	1.0	1.0	0.1	0.6	1.8
50	-0.3	1.4	1.0	0.7	0.1	0.6	1.8
100	-0.6	1.2	0.9	0.2	0.2	0.6	0.9
200	-1.0	0.8	0.5	-0.1	0.4	0.3	0.5

TABLE 5. ARFERSIORFIK FJORD: TEMPERATURES (°C) 4-6 SEPTEMBER 1949.

Depth in m	Station A	Station B	Station C
10	2.83	2.58	3.38
50		2.27	1.63
100	2.99	1.80	-1.09
150	2.48	1.66	-1.32
200	2.21	1.04	-1.15
225		0.93	
250	2.15		
300	2.17		

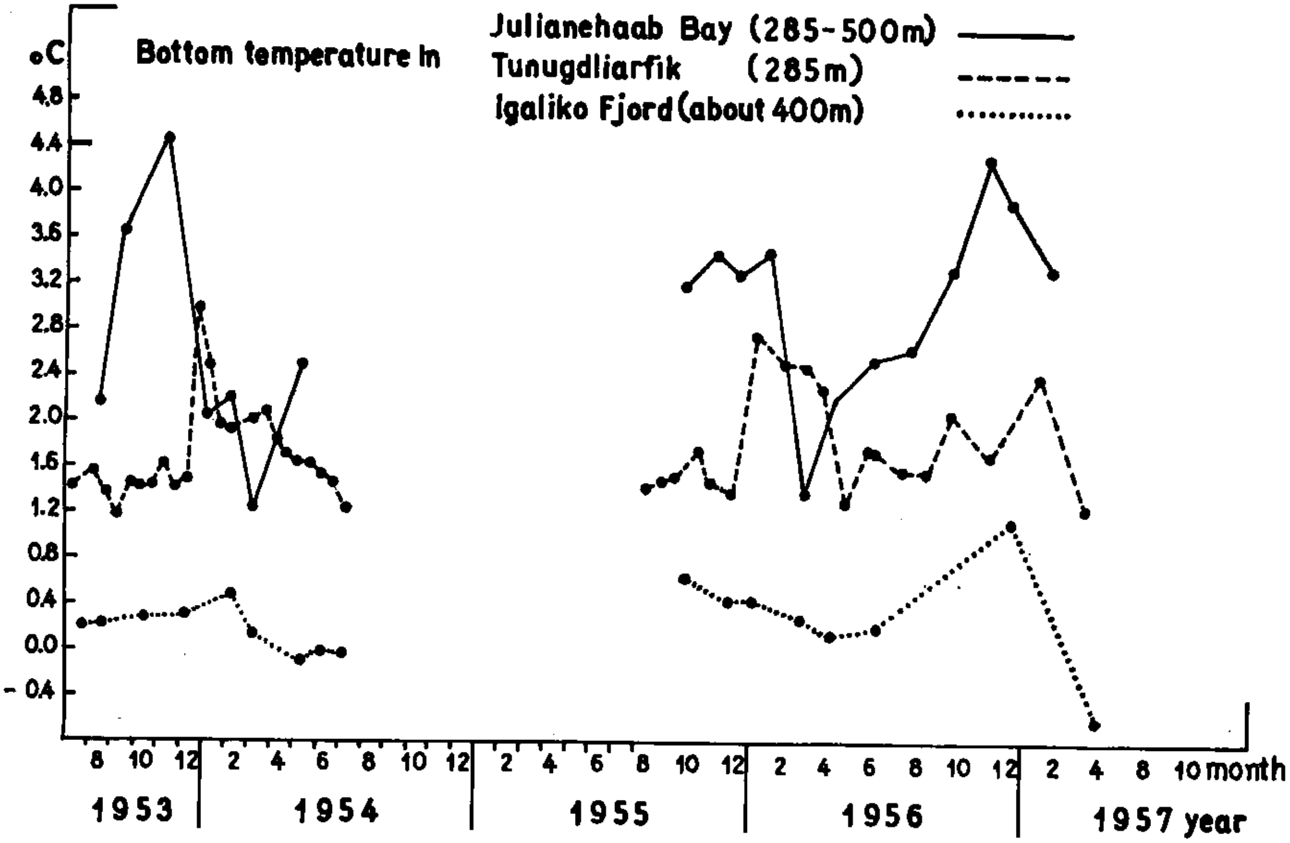

Fig. 1. Bottom temperatures (°C) in Igaliko Fjord (60°46'N.45°40'W.), Tunugdliarfik Fjord (60°56'N.45°47'W.) and Julianehåb Bay. (In Julianehåb Bay the station position has normally been 60°35'N.46°19'W. but in periods with ice other positions near the main station have been used).

EFFECT OF CONSTANTLY COLD WATER ON THE COMPOSITION OF ANIMAL COMMUNITIES AND ON THE BIOLOGY OF PRAWNS ON THE PRAWN GROUND

The depth of the prawn grounds in the West Greenland fjords is normally 250-400 m. The most important of these grounds are found in fjords without a threshold (open fjords) where relatively warm bottom water can enter. The bottom temperature in open fjords is normally above zero throughout the year. Some of the West Greenland fjords, however, are threshold fjords with one or more thresholds in the outer part of the fjord and one or more deeper basins in the inner part of the fjord. The warm deep currents do not enter these threshold fjords. The bottom temperature in the threshold fjords is often below zero and always lower than the bottom temperature in the open fjords. In this section examples of the hydrography of the threshold fjords and of the influence of the constantly cold bottom water on the animal communities are given.

1. Examples of the hydrography of threshold fjords.

1.1. *Arfersiorfik Fjord* (lat 68°10'N.) has several basins divided by thresholds. Threshold depths are 50-100 m while the depth of the trawling grounds in the basins is 220-285 m. Observations were taken in September 1949 (Table 5). Station A is outside the threshold in the mouth

TABLE 6. TEMPERATURES (°C) AT VARIOUS DEPTHS AND DAYS IN IGALIKO FJORD IN 1951, 1953-57.

	1951	1953				1954			
Depth in m	Sept. 14	July 29	Aug. 27	Oct. 19	Dec. 6	Feb. 10	March 9	May 3	June 3
0	5.1	10.1	5.8	2.2	-0.5	-1.0	-1.1	0.6	1.9
10	4.75	4.37	3.90	2.41	0.06	-0.86	-1.09	-0.11	1.17
20		2,52	2.51	2.30	0.80	-0.86	-1.06	-0.47	1.06
25	3.82								
30		1.81	1.92	2.32	0.80	-0.85	-1.10	-0.54	0.74
50	2.24	1.22	1,89	2.51	1.67	-0.56	-1.03	-0.53	-0.23
75		0.87	0.35	1.90	1.91	-0.60	-1.17	-0.57	-0.55
100	0.86	0.45	0.23	1.38	1.83	-0.37	-1.18	-0.72	-0.53
150	0.13	0.32	0.28	0.54		-0.12	-1.01	-0.69	-0.49
200	0.16	0.22	0.21	0.26	0.43	0.40	-0.37	-0.37	-0.23
250	0.17	0.23	0.23	0.35	0.26	0.41	0.18	-0.13	-0.17
300	0.20	0.20	0.18	0.22	0.19	0.36	0.40	-0.07	-0.09
350		0.38	0.24	0.27*	0.21	0.43	0.14	-0.18	-0.06
385-400	0.22+	0.22	0.22		0.33	0.48	0.13	-0.09	-0.01

*) at 325 m +) at 375 m

	1955			1956					1957
Depth in m	July 2	Oct. 6	Dec. 5	Jan. 9	March 9	Apr. 24	June 29	Dec. 21	Apr. 3
0	10.0			-1.1		2.2	6.1	-1.5	0.3
10	3.94	1.84	0.47	-0.60	-0.28	1.19	2.25		
20	2.03	1.69	0.64	-0.55	-0.23	0.70	1.92		-0.35
25									
30	1.19	1.65	0.70	-0.53	-0.27	-0.45	1.46		-0.42
50	0.03	1.21	0.85	-0.39	-0.30	-0.39	1.01		
75	-0.42	0.55	0.84	0.50	-0.29	-0.28	0.32		-0.42
100	-0.22	0.55	0.69	0.66	-0.31	-0.05	0.12	1.04	-0.71
150	-0.53	0.08	0.49	0.91	0.02	-0.01	0.05		
200	-0.27	0.32	0.47	1.17	0.15	0.11	0.11	0.58	-0.74
250	-0.17	0.50	0.49	0.42	0.15	0.10	0.16		-0.77
300	0.02	0.56	0.52	0.43	0.32	0.16	0.20		
350	-0.07	0.65†	0.47	0.43	0.32	0.18	0.22		-0.61
385-400	-0.03			0.43	0.25	0.15	0.22	1.14	-0.63

†) at 330 m

TABLE 7. BOTTOM TEMPERATURES (°C) AND CATCHES OF COD, REDFISH AND *Pandalus borealis* AT 400 M IN IGALIKO FJORD IN 1951, 1953-55.

	Bottom temp.	Cod	Redfish	*Pandalus*	Trawling time
	°C	*no. per hr*	*no. per hr*	*kg per hr*	*hr*
1951					
Sept. 14	0.22	0	0	20	2.25
1953					
July 29	0.20				0
Aug. 27	0.22				0
Oct. 19	0.27				0
Oct. 30		0	0	29	1
Dec. 6	0.33				0
Dec. 15		0	0	57	1
1954					
Feb. 10	0.48	24	4	50	0.50
March 9	0.13	1	0	44	1.25
May 3	-0.09	0	0	15	1
June 3	-0.01	0	0	31	1
July 2	-0.03	0	0	67	0.58
1955					
Oct. 6	0.65	0	0	20	0.75
Dec. 5	0.47	0	0	24	0.58
1956					
Jan. 9	0.43				0
March 9	0.25	0	1	15	0.75
Apr. 24	0.15	0	0	25	0.92
June 29	0.22	0	0	53	1
Dec. 21	1.14	0	1	20	1
1957					
April 3	-0.63	0	1	2	1

of the fjord; Station B inside the first threshold (depth of threshold about 100 m); and Station C in the innermost part of the fjord (threshold depth about 50 m).

1.2. In *Julianehåb district* (southern Greenland) trawling grounds are found in most of the fjords. Of these Tunugdliarfik (60°56'N. 45°47'W.) among others, is an open fjord with depths about 300 m while Igaliko Fjord (60°46'N. 45°40'W.) is a threshold fjord with a trawling ground depth of about 400 m.

The hydrographic conditions in the district are characterized by a mixing of the warm Irminger Current and the cold East Greenland Polar Current. The latter is found mainly nearest the coast and lies above the former.

In the offshore area the warm Irminger Current dominates the deeper water layers in autumn and the beginning of winter, while the cold water dominates in spring and in summer, when Irminger water is found only at great depths (Fig. 1). In the open Tunugdliarfik Fjord these fluctuations appear 1-2 months later. In Igaliko Fjord, however, there is only a very slight inflow of the warm, deep current due to a threshold (Fig. 1, Table 6). The temperature conditions in the threshold fjord depend more upon local warming and cooling of the water as well as upon the extent of he cold surface Polar Current.

. Effect on cod and redfish abundance.

Horsted and Smidt (this symposium p. 435-437) showed that redfish normally occur in the prawn atches in the open fjords throughout the year, and cod occur in the same catches in winter time. n catches from the cold threshold fjords this is not the case.

In Arfersiorfik Fjord trawling was carried out at Stations B and C (Table 5). At Station B, 7 small redfish were caught in one hour. At Station C the fish fauna was poor apart from 233 *ycodes seminudus*. Only one redfish (8 cm) was caught. At both stations cod were absent, but at his time of the year cod is not at all likely to be found at great depths in the fjords (Hansen *oc. cit.*).

In Igaliko Fjord several trawling experiments were undertaken. Catches of cod, redfish and *andalus borealis* per one hour's trawling were recorded together with the bottom temperatures Table 7). Normally cod and redfish are absent in the catches or appear only as single specimens. he exception is February 1954 when 12 small cod and 2 redfish were caught in half an hour's trawing. At this time the bottom temperature was relatively high and the upper water layers down to 50 m had negative temperatures.

Normally, however, no cod and redfish are taken in trawl catches in Igaliko Fjord. The ermilik Fjord (about 60°30'N. 45°00'W.) has a threshold depth of about 50 m. A trawling experient was carried out on 14 August 1953. The depth of the trawling ground was about 350 m and the ottom temperature -0.4°C. Cod and redfish were absent from the catch.

. Influence on prawn stocks (growth rate, sex reversal, reproduction, composition)

The prawn fishery in Greenland is based on *Pandalus borealis*. This prawn has sex reversal protandric hermaphrodity) as shown by various authors. Sex reversal occurs when the prawn has rown to a carapace length of about 25-30 mm. Growth rate, however, is affected by temperature nd consequently the age at which sex reversal occurs is also affected by the temperature (Horsted nd Smidt, 1956, p.43). Thus, in Tunugdliarfik sex reversal takes place at 4 yr of age, but in galiko Fjord one fraction of the prawns have sex reversal at 4 yr of age and another fraction at yr of age. In Sermilik Fjord sex reversal is found only in the 5 yr olds. By comparison, the ame prawn species in the Skagerak has sex reversal at 2 yr of age.

Temperature, however, is not the only factor affecting the growth rate and age at sex reveral. In Disko Bay (about lat 69°N.) sex reversal occurs at 5 yr of age but temperature conditions ere are just as favourable as in Tunugdliarfik where reversal occurs at 4 yr of age. Perhaps in isko Bay the long, unproductive winter season is decisive. There are several deciding factors of hich temperature is the best known, but quantity of food and the length of the period of producivity are certainly just as important (Horsted and Smidt, *loc. cit.*). Reproduction takes place n the prawn stocks in Disko Bay and in the open West Greenland fjords. In some of the threshold jords, however, sex reversal takes place and later on spawning, but many and in some years proably all, females lose their eggs before hatching.

TABLE 8. IGALIKO FJORD. *Pandalus borealis*. DEVELOPMENT OF FEMALES (AND TRANSITIONALS) IN % OF TOTAL FEMALES AND TRANSITIONALS.

Year	1951	1953		1954					
Month	Sept.	July	Oct.	Jan.	Feb.	March	May	June	July
Day	15	3	30	14	10	9	3	3	3
% no roe	54.6	36.5	84.4	100.0	61.4	9.8	10.0	27.9	50.0
% head roe	0.0	4.8	0.0	0.0	29.5	85.3	90.0	19.4	0.0
% ovigerous, embryos eyes not visible	45.5	52.2	15.5	0.0	6.8	0.0	0.0	36.2	44.4
% ovigerous, embryos eyes visible	0.0	0.0	0.0	0.0	0.0	4.9	0.0	0.0	0.0
% no eggs, setae on pleopods	0.0	6.4	0.0	0.0	2.3	0.0	0.0	16.7	5.6
Numbers of transitionals and females	33	63	58	25	44	41	20	36	18

This phenomenon was quite apparent in Igaliko Fjord in 1953-54 (Table 8). Head roe developed during the spring months and spawning is completed by the end of June. Few of the females, however, succeeded in becoming ovigerous. While 90% of the females had head roe in the spring of 1954 only 44% of the females were ovigerous on 3 July 1954. At the same time many females with setae on the pleopods were found but none of them had roe of any kind. Apparently the spawned eggs did not adhere at all or adhered only for a short time to the pleopods. Possibly fertilization was unsuccessful. Even if eggs adhere in some individuals they are gradually cast off so that ovigerous females become fewer and almost none of them carry the eggs at the time when hatching should take place. Only on 9 March 1954 were ovigerous females found, and these comprised only 5% of the females.

Thus reproduction in Igaliko Fjord is negligible. Larvae hatched on other grounds however, are transported here by surface currents and maintain the stock.

A wide distribution of larvae also explains why *Pandalus borealis* occurs so far to the north in West Greenland as southern Upernavik district. Here, at the island of Skaløen, trawling experiments were carried out in July 1949 and in July 1957. The composition of the prawn stock in 1957 is shown in Fig. 2. The most striking feature of this composition is not the small amount of large prawns (females) but the total absence of prawns with carapace length 24-27 mm. Since prawns of this length are 4 yr old, the 1953 year class is totally absent from the stock. The stock is presumably recruited by drift of larvae from more southerly areas (Disko Bay) and it must be supposed that the conditions for this drift were very bad in 1953. Unfortunately we have not enough observations to say more about this phenomenon.

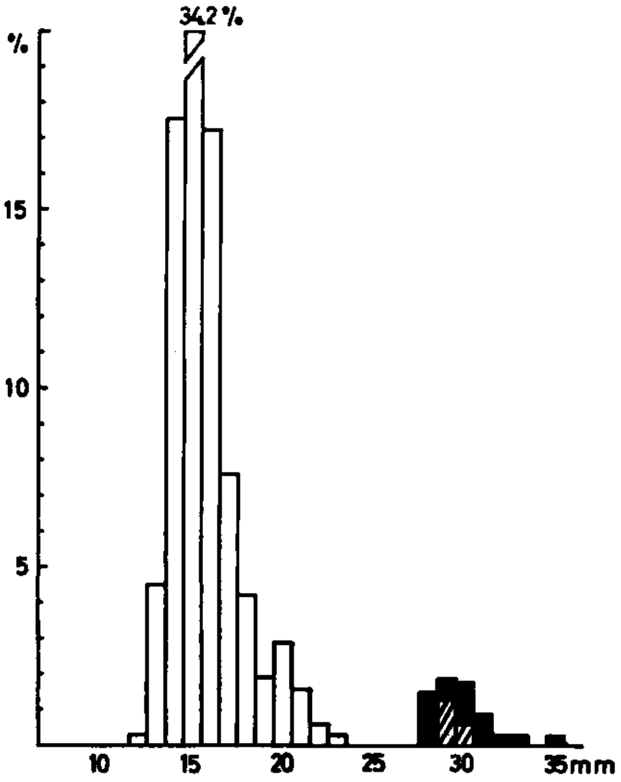

Fig. 2. *Pandalus borealis*. Carapace length of 315 specimens taken 10 July 1957 SE of Skaløen, (71°53'N. 55°26'W.) Symbols: White; juveniles and males. Cross-hatching, transitionals. Black; females. Carapace is measured from eye lobe to posterior lateral edge.

On most of the West Greenland prawn grounds *P. borealis* is by far the predominant species. *Spirontocaris machilenta* is another common species but, because of its small size, is of no commercial value. Experimental trawling was carried out with 18mm mesh size of cod end which retains a great deal of the *Spirontocaris*. In Tunugdliarfik the catch per hour of *Spirontocaris* varied in 1953-54 in the following way. In August-September 1953, 1,000-3,000 individuals per hour were caught, the rest of the year less than 500 per hour and in March 1954, 80 per hour. Looking at the bottom temperatures (Fig. 1) it is evident that *S. machilenta* occurs in the greatest quantities when the bottom temperature is lowest. In this connection *S. machilenta* shows just the opposite to *P. borealis*. Consequently one can expect *S. machilenta* to be particularly dominant in fjords with cold bottom water. In Sermilik Fjord *Spirontocaris* was the predominant species and in Igaliko Fjord it was nearly of the same abundance as *P. borealis*. In Arfersiorfik Fjord (Table 5) *Pandalus* dominated at Station B with *S. machilenta* as a common species. At Station C in the same fjord only a few *Pandalus* were caught but *S. machilenta* was numerous. In Fig. 3 the number of *S. machilenta* in percent of the number of *P. borealis* is given from the various grounds in Julianehåb district and is correlated with the actual bottom temperature. With temperatures less than -0.2°C *S. machilenta* is the dominant prawn species. Between -0.2°C and 2.0°C it must still be, considered as a characteristic animal but *P. borealis* dominates and more so as the temperature rises. Only one out of 46 samples fits poorly into this picture (1.8°C - 70% *S. machilenta* 60°21'N. 45°25'W., 15 September 1953). With temperatures from 2°C to 3°C *S. machilenta* still occurs rather commonly but at temperatures higher than 3°C it is rarely found.

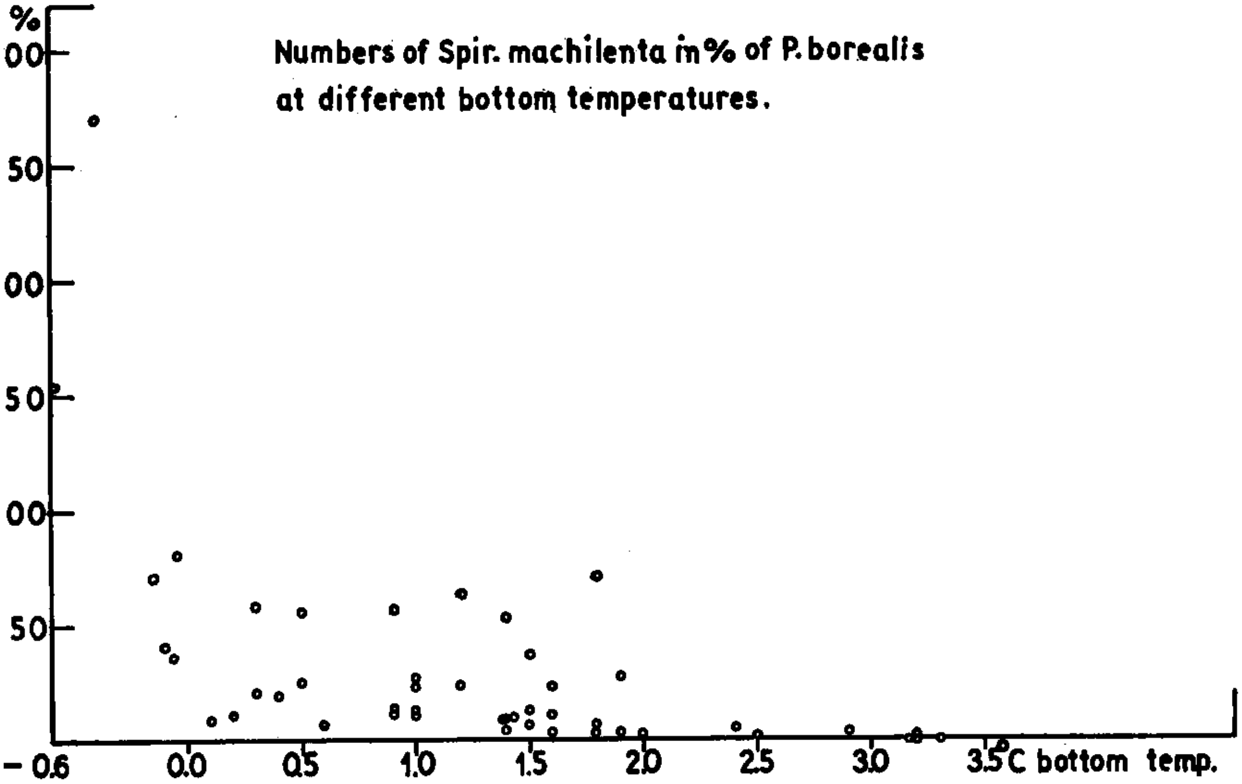

Fig. 3. Numbers of *Spirontocaris machilenta* as a percent of numbers of *Pandalus borealis* at different temperatures from various grounds in Julianehåb district.

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A-11

INFLUENCE OF THE TEMPERATURE REGIME ON THE BEHAVIOR OF REDFISH OFF WEST GREENLAND IN SPRINGS 1959-1961[1]

By

L.N. Pechenic[2] and I.I. Svetlov[2]

ABSTRACT

The authors of this report attempt to show the influence of the temperature conditions on the distribution of redfish (*Sebastes marinus* L.) on the Banana and Lille Hellefiske Banks in spring during the period 1959-61. They state that the location of redfish concentrations during this season is mainly influenced by the intensity of the Canadian Polar Current.

CONDITIONS IN 1959

The results of our investigations (Pechenic, 1960) showed that in April 1959 the redfish concentrations were as usual on the slopes of the Banana Bank and also on the eastern and western slopes of the Lille Hellefiske Bank (Fig. 1B). It is evident that redfish concentrated in the channel between the Banana and Fyllas Banks with the near-bottom temperature between 4.0° and 4.6°C. Scouting vessels caught more than two tons per trawling hour. In 1961 there were no redfish concentrations north west of the Lille Hellefiske Bank (Fig. 3B).

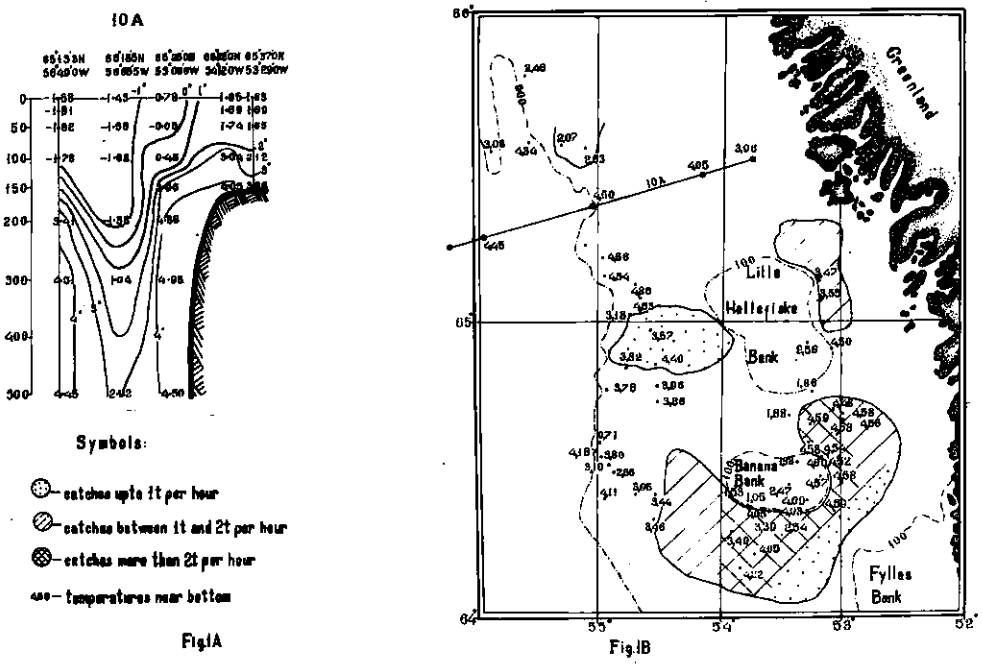

Fig1A Fig1B

Fig. 1. (A) Isotherms on Section 10a on 26 April 1959 north of the Lille Hellefiske Bank.
(B) Distribution of the redfish concentrations and near-bottom temperatures in April 1959.

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We suppose this peculiarity was mainly due to the temperature conditions. Temperatures recorded on Section 10A (Fig.1A) on 26 April 1959 across the Lille Hellefiske Bank north of the areas of redfish concentrations, enable us to conclude that the redfish behaviour was influenced by the extent of the cold Canadian Polar Current. According to Killerich (1943), in early summer this current is often influenced by the north western winds and protrudes far to the east over the western slopes of the Store and Lille Hellefiske Banks to a depth of 150-200 m. On reaching these banks the Canadian Polar Current usually has the temperature of 0° to 1.0°C and salinity of 33.50 to 34.00°/00. However, in April 1959, the waters of the current were much colder than indicated by Killerich and had temperatures of -1.8° to 1.5°C. The cold water penetrated to a depth of 250 m (Fig. 1A) and, on reaching the area northwest of the Lille Hellefiske Bank, evidently hampered the formation of redfish concentrations in that area.

CONDITIONS IN 1960

In the spring (April-the beginning of May) of 1960 the main redfish concentrations were, as previously, found on the Banana Bank, but if we compare 1960 with 1959, the catches were smaller. We ascribe this to some changes in the hydrological conditions north west of the Lille Hellefiske Bank.

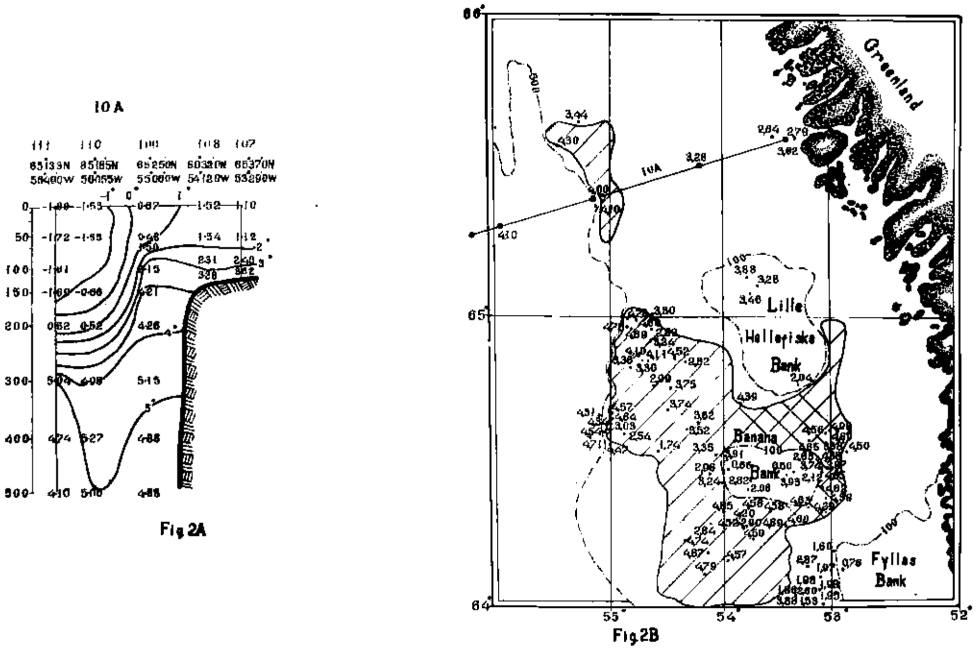

Fig 2A

Fig 2B

Fig. 2 (A) Isotherms of 5 May 1960 on Section 10a.
(B) Distribution of the redfish concentrations and near-bottom temperatures in April 1960.

The temperature distribution on Section 10A (Fig. 2A), carried out in May 1960, shows a decrease from the same period in 1959 in the amount of cold water from the Canadian Polar Current, and it only penetrated down to 150-175 m. In the warm waters of the Irminger Current in 1959 the temperature was 3° to 4°C. at depths of 200-400 m, while in the spring of 1960 the temperature increased by 1°C. All these conditions favoured, to a certain extent, the more extensive distribution of the commercial redfish concentrations, their advance in a north westerly direction and their appearance on the slope. These concentrations were not observed at all in April 1959. During both the above mentioned years the feeding of redfish at the places of concentrations was poor.

CONDITIONS IN 1961

In contrast to 1959 and 1960, the most dense redfish concentrations were met in 1961 on the western slope of the Lille Hellefiske Bank and to the north west. On the Banana Bank concentrations were less dense and catches were poorer.

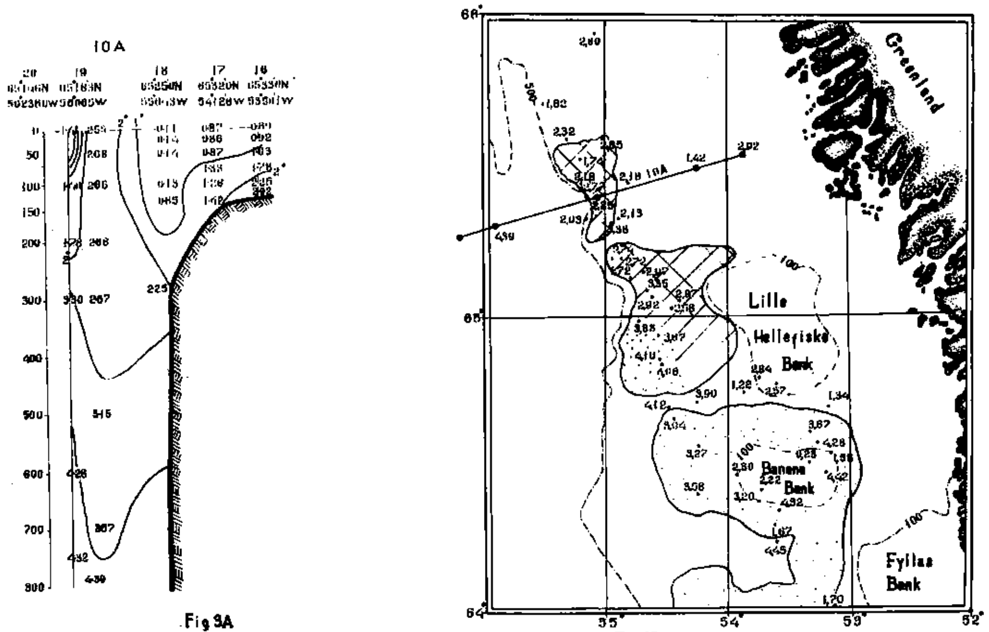

Fig 3A

Fig 3B

ig. 3 (A) Isotherms on 21 April on Section 10a.
(B) Distribution of the redfish concentrations and near-bottom temperatures in April 1961.

Analysing the distribution of waters on 22 April 1961 on the Section 10A (Fig. 3A), we see hat the cold Canadian Polar Current is less developed than in the two previous years. Cold aters with a temperature of -1.5°C. penetrated only to depths of 50-75 m and did not reach the ille Hellefiske Bank. This allowed a more north westerly redfish movement than in the two revious years. There were good food resources for redfish in this area; they fed on krill *Euphausiacea*) and, despite the temperature of 2.5° to 3.5°C. in the near-bottom layer, formed omparatively stable concentrations (Fig. 3B).

DISCUSSION

Figures 1B, 2B and 3B distinctly show that redfish keep to a certain level of temperature (4° to 4.6°C) at which their concentrations are more dense and stable. This is also confirmed by Meyer (1960) who states that the best redfish concentrations were observed in the spring of 1960 on the Lille Hellefiske Bank with water temperatures of 4.7° to 5.0°C and that in the areas, where the waters of the near-bottom layers were warmer, the catches were larger.

SUMMARY

1. The analysis of data obtained in the springs of 1959-61 revealed a certain relationship between the temperature conditions and the distribution of redfish (*Sebastes marinus* L.) in the area of the Banana and Lille Hellefiske Banks off the western coast of Greenland.

2. During some years in spring the cold Canadian Polar Current, depending on its strength, affects the temperature conditions on the Store and Lille Hellefiske Banks and the redfish distribution in these areas. When the inflow of cold waters brought by this current is intensive, redfish have the southern distribution and concentrate on the southern and south-eastern slopes of the Banana Bank and the eastern slope of the Lille Hellefiske Bank (1959). When the inflow of the cold waters is not intensive, redfish have a more northerly distribution and their main and dense concentrations occur on the north-western slope of the Lille Hellefiske Bank and to the north west of it (1960/61).

3. The most favourable temperature conditions for the formation of redfish concentrations are between 4° and 4.6°C in the near-bottom layer.

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A-12

THE RELATION BETWEEN TEMPERATURE CONDITIONS AND FISH DISTRIBUTION IN THE SOUTHEASTERN BARENTS SEA[1]

By

Lars S. Midttun[2]

ABSTRACT

The distribution of cod and haddock in the south eastern Barents Sea, as observed during echo surveys, has been compared with the temperature conditions at 150 m. In the autumn the fish are mainly located in water of temperature above 2°C along the central cold water front and in the warm water tongues bending eastwards. In spring the fish are migrating towards the Finnmark-Murman Coast.

There is an east-west long-term fluctuation in the fish distribution. In 1954 the fish had an easterly distribution. During the following year the fish gradually moved westwards until 1958, when it reached an extreme westerly location. Later, as observed up to 1960, the fish again moved easterly. Similar long-term variations have been observed in the temperature conditions.

OBSERVATIONS AND METHODS

Echo surveys covering the central and south eastern Barents Sea have been undertaken twice a year regularly in order to study the distribution of cod and haddock in this area. Normally, the surveys are made in spring (March-April) and in autumn (September-October). The results of four cruises in the period autumn 1958-spring 1960 are shown in Figs. 1-4. The fish concentrations are illustrated as light, medium and heavy.

Echo-sounding is a suitable method for fish recording, when the fish are pelagic. On the other hand, echo-sounding has proved to be an unreliable method of recording for bottom concentrations. Especially in autumn the cod and haddock show a tendency to be located near the bottom. Even though the echo surveys have been supplemented by a network of trawl stations, one must make some reservations concerning undetected bottom concentrations of fish from the cruises made in the autumn. In spring the fish are more frequently found in pelagic formations, probably because they are heading towards the coast.

THE DISTRIBUTION OF TEMPERATURE

The distribution of cod and haddock in the Barents Sea is to be compared with the temperature conditions. In Figs. 1-4 the temperature conditions are illustrated by means of isotherms at 150 m depth. This depth represents the layer where the major part of the fish normally is located. The temperature conditions in the Barents Sea are characterized by comparatively warm water flowing in from the west and meeting with cold water formed in the eastern areas. The transition area between the warmer western water and the cold eastern water seems at most places to be stationary and is apparently related to the bottom configurations. Thus it is located above the north-south Central Ridge at about 35°E. The warm western water flows into the eastern Barents Sea mainly along two branches, one following the Murman coast, the other passing Skolpen Bank and proceeding eastwards towards Novaya Zemlya. The influence on the temperature conditions caused by these currents is clearly shown by the tonguelike forms of the isotherms.

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Whereas the temperature of the cold water in the north-east shows little change from time to time, there is a considerable variation in that of the warmer inflowing western water. The thin, solid line with the scale to the left in Fig. 5 shows the temperature observed at 150 m on Skolpen Bank (71°00'N, 37°20'E); the broken line with its scale to the right represents the

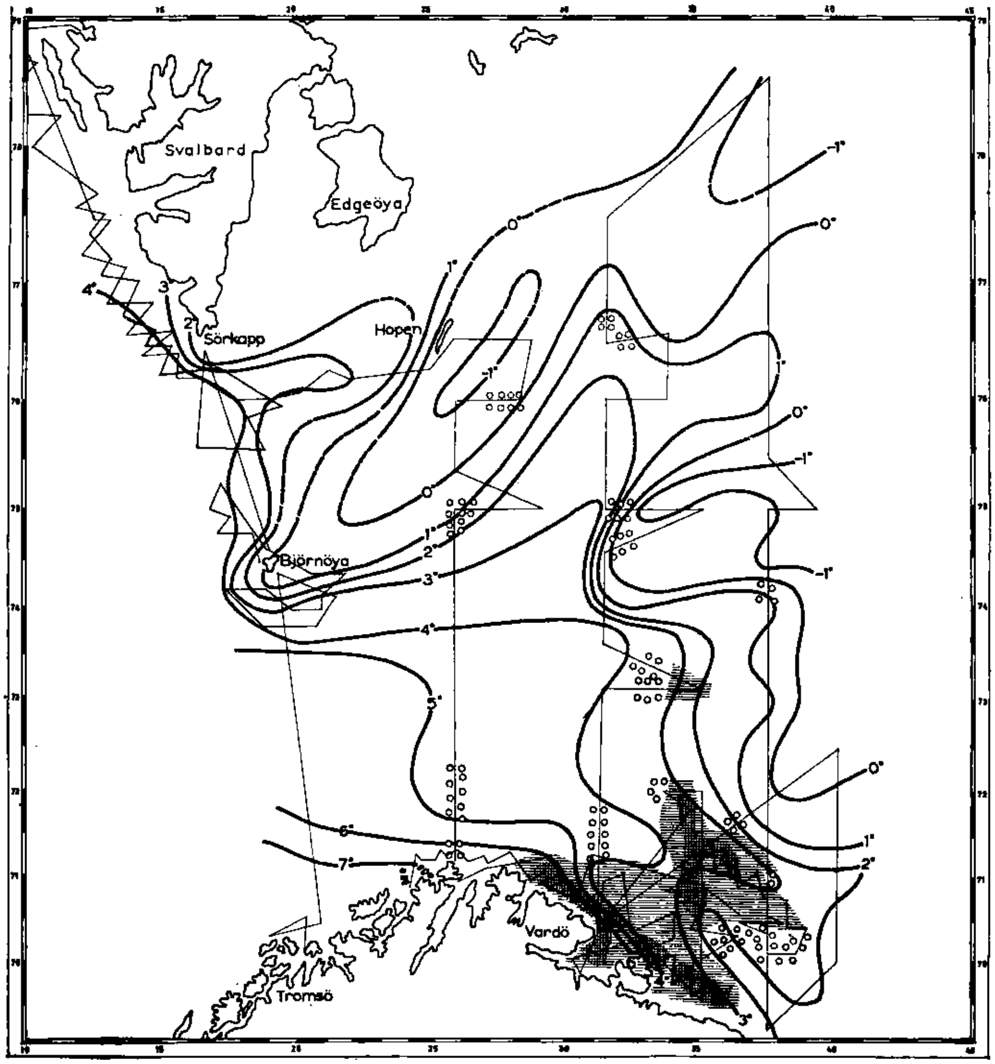

Fig. 1. Fish distribution and temperature (150 m), autumn 1958: *G. O. Sars* 20 September-24 October, 1958. Fish recorded in the Bear Island - Spitsbergen area are not included.
heavy lines = isotherms
thin lines = route of *G. O. Sars*
circles = light concentrations of fish
horizontal lines = medium concentrations of fish
combined horizontal and vertical lines = heavy concentrations of fish.

average temperature at 150 m in a section running northwards from Vardø in 31°13' E between 70° 30' and 73°00' N. Disregarding some irregularities (*i.e.* the spring temperature of 1957), there is a clear trend in the curves, from high values in 1954, decreasing to a minimum in 1958 and then again increasing up to 1960.

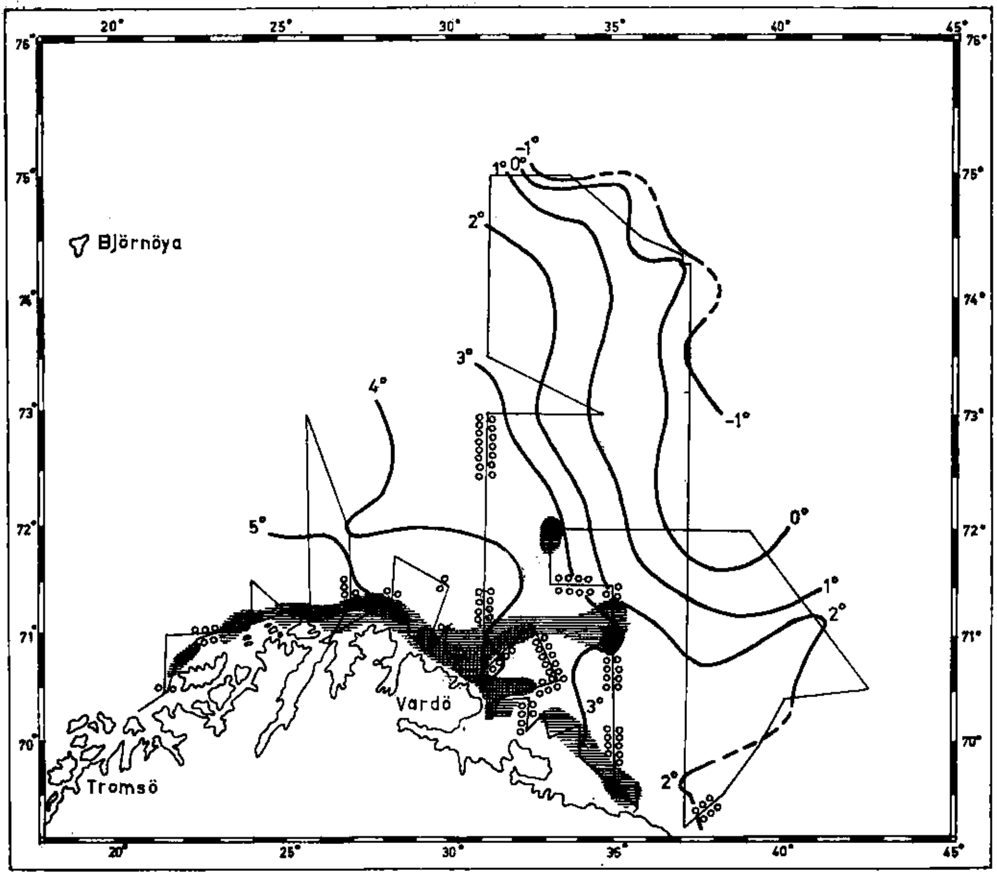

Fig. 2. Fish distribution and temperature (150 m), spring 1959: *G. O. Sars* 23 March - 20 April, 1959. Fish recorded in the Bear Island - Spitsbergen area are not included.
heavy lines = isotherms
thin lines = route of *G. O. Sars*
circles = light concentrations of fish
horizontal lines = medium concentrations of fish
combined horizontal and vertical lines = heavy concentrations of fish

THE DISTRIBUTION OF COD AND HADDOCK IN RELATION TO TEMPERATURE

Let us now consider the distribution of cod and haddock compared with the temperature conditions (Figs. 1-4). The figures show that the fish are located in the warmer western water. In spring the main concentrations are found near the coast of Finnmark and Murman. When surveyed again in the autumn, the fish have moved away from the coast and are now found against the cold water front above the Central Ridge, and in the warm water tongue, extending eastward. This is clearly seen by comparing Fig. 2 and Fig. 3. The fish are reluctant to move into water of temperature below about 2°C.

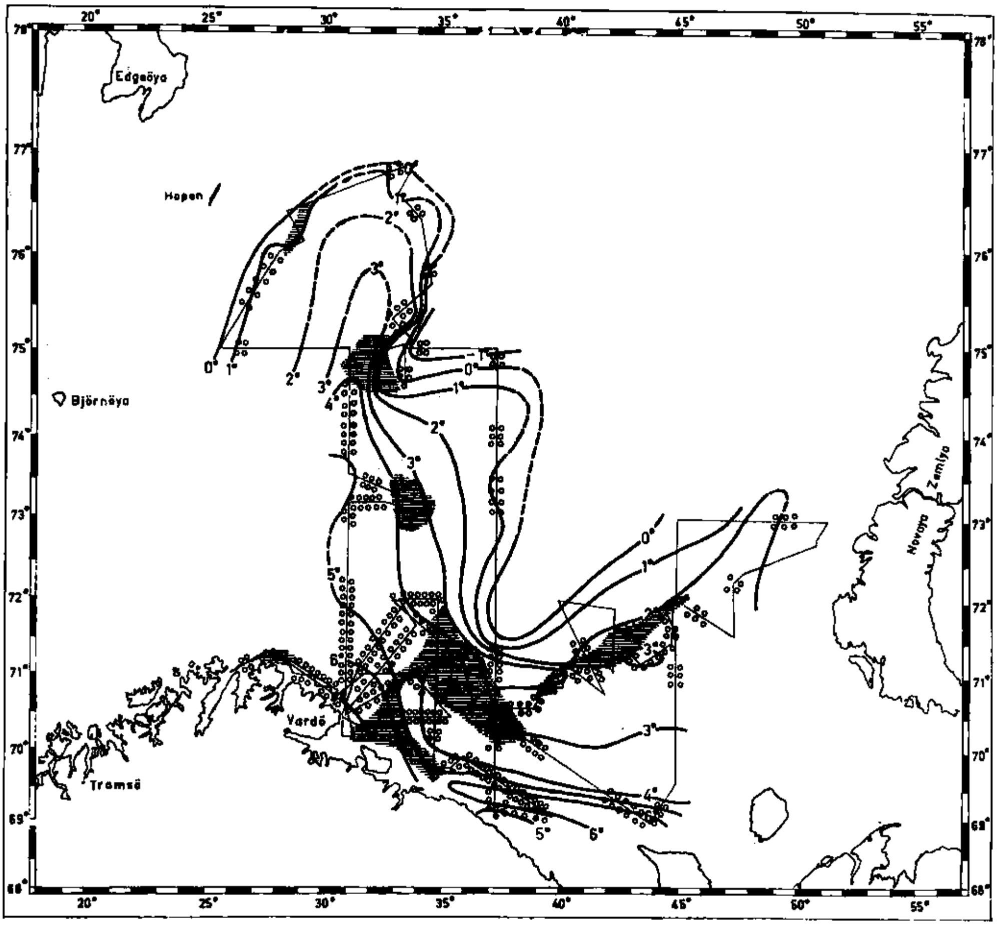

Fig. 3. Fish distribution and temperature (150 m), autumn 1959: *Johan Hjort* 23 September - 20 October, 1959. Fish recorded in the Bear Island - Spitsbergen area are not included.
heavy lines = isotherms
thin lines = route of *Johan Hjort*
circles = light concentrations of fish
horizontal lines = medium concentrations of fish

In addition to this seasonal variation in distribution there is, as well, a year-to-year variation. This variation is obviously connected with long-term temperature variations. The above mentioned trend in the temperature variations (Fig. 5) is reflected also in the fish distribution. Results from fishing and echo-sounding observations have shown that the fish in the warm year, 1954, were found far to the eastward in the sea. Gradually they moved westwards until in the cold year, 1958, they had their extreme westerly distribution. Later, as observed to 1960, the fish again moved towards the east. This can also be seen from Figs. 1-4: for example the fish were located farther to the east in 1960 (Fig. 4) than in 1959 (Fig. 2). A similar displacement can be seen by comparing Fig. 1 with Fig. 3. There is one irregularity in this general picture; the relatively high temperature measured in the spring of 1957 did not bring about a corresponding easterly distribution of the fish concentrations. However, the warmer period of 1957 was very short and there might be a lag or slowness in the displacement of the fish distribution.

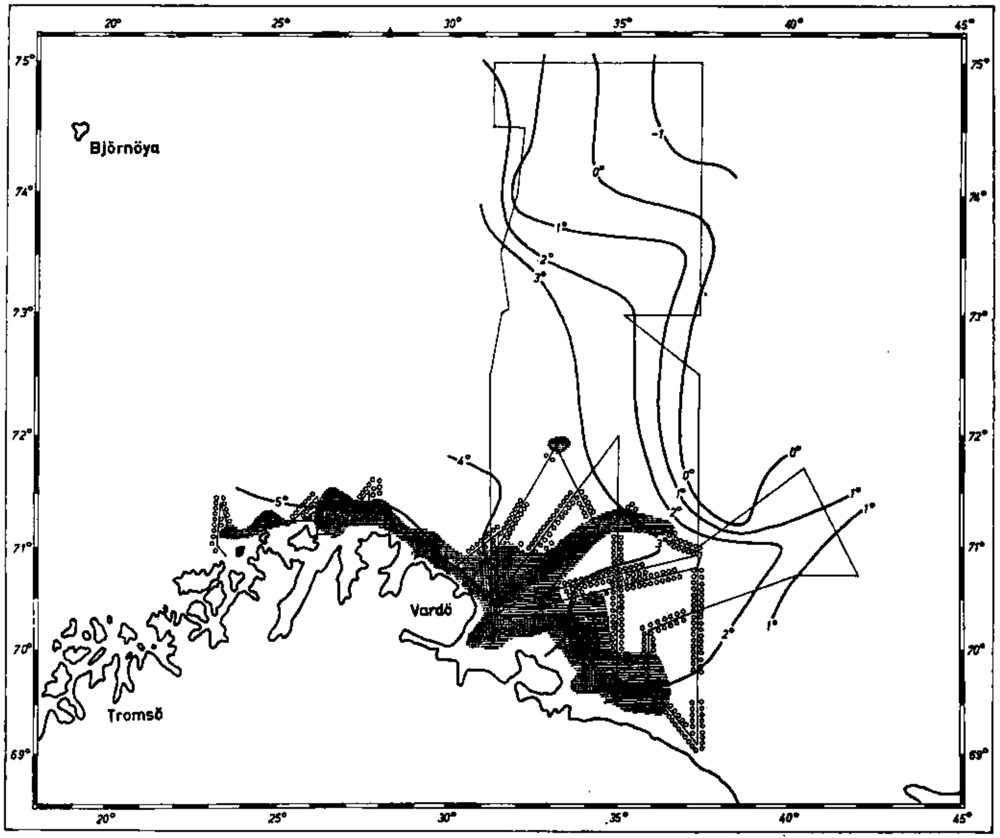

Fig. 4. Fish distribution and temperature (150 m), spring 1960: *Johan Hjort* 22 April-12 May, 1960. Fish recorded in the Bear Island - Spitsbergen area are not included.
heavy lines = isotherms
thin lines = route of *Johan Hjort*
circles = light concentrations of fish
horizontal lines = medium concentrations of fish
combined horizontal and vertical lines = heavy concentrations of fish

Figure 5 shows the total yield of the Norwegian spring cod-fisheries for the years 1954 - 60 (scale to the left). This yield over the seven year period corresponds to the main trend of the long-term temperature variations in such a way that low temperatures give high yields and high

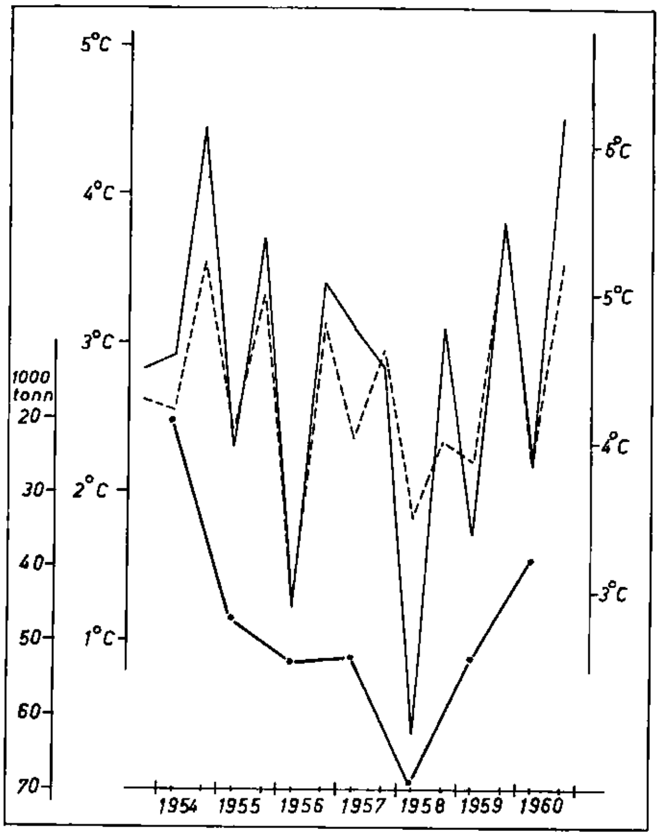

Fig. 5. Yield of the Norwegian spring cod fishery in thousands of tons (heavy solid line) in relation to temperature variations from 1954-60 of

(a) western water at 150 m in a section running northwards from Vardø in 31°13"E and between 70°30" and 73°00" N. Temperature curve in broken line with its scale to right of the figure. And

(b) water on Skolpen Bank (71°00"N, 37°20"E). Temperature curve is thin, solid line with its scale at the left of the figure.

temperatures low yields. When the fish in periods of high temperatures are distributed eastward, they are not so available for the Norwegian fishing fleet as in the colder periods when they are distributed westward.

To obtain a more detailed picture of the distribution of fish near a sharp temperature front, a local concentration of cod, found in October 1956 on the north-eastern Skolpen Bank, was investigated more closely. Figures 6 and 7 show the results of this detailed survey. The cod were located in a layer between 150 and 220 m, with the largest concentrations between 170 and 200 m. The horizontal distribution of fish is illustrated in Fig. 6. Fish concentration is given by numbers referring to an arbitrary scale where high numbers mean high concentration. Isotherms represent the temperature at 200 m depth. Figure 7 shows the temperature and fish distribution in the cross-section indicated by a dotted line in Fig. 6. The figure shows that the main concentration of fish is found between 2 and 3°C, but fish are also found at lower temperatures, even lower than 0°C.

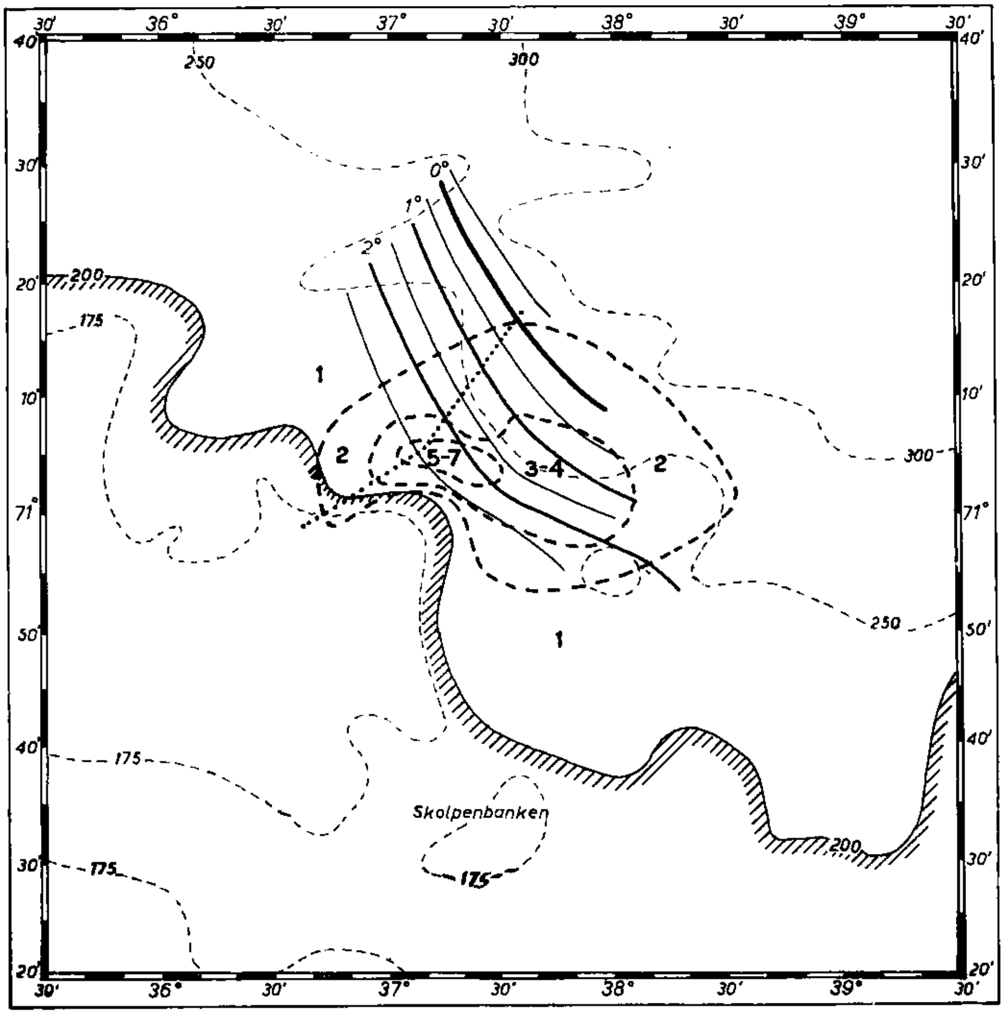

Fig. 6. Local concentration of cod in a temperature transition area on the north-eastern Skolpen Bank, October 1956. Solid lines are isotherms at 200 m. Broken lines circumscribe areas of increasing fish density as indicated by the numbers 1-7. Dotted line shows the location of the cross-section illustrated in the Fig. 7.

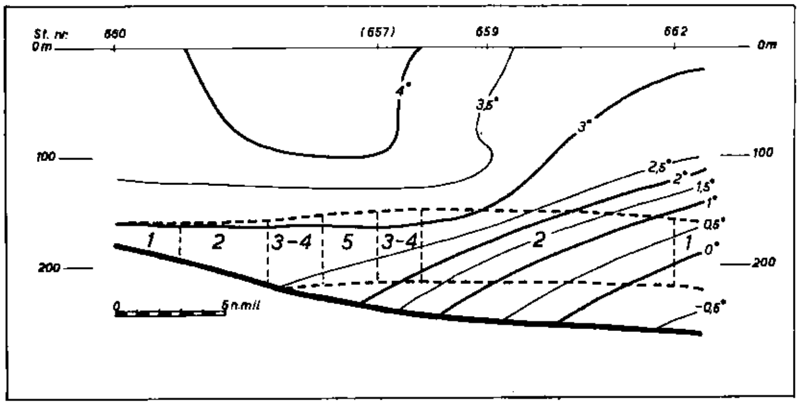

Fig. 7. Temperature and fish density in a cross-section through the same concentration of cod as is shown in Fig. 6. Solid lines are isotherms at 200 m. Broken lines circumscribe areas of increasing fish density as indicated by the numbers 1-7.

A-13

WATER TEMPERATURE AS A FACTOR GUIDING FISHES DURING THEIR MIGRATIONS[1]

By

K. G. Konstantinov[2]

ABSTRACT

When undertaking seasonal migrations, fish are usually guided by the water temperature. There-)re, temperature observations enable us to foresee the paths and time of migrations of commer- :al fishes. Thus, the water temperature in November in the 150-200 m layer on the Kola hydro-)gical section accounts for the area where capelin and capelin cod approach the coasts of the ırents Sea in March-April of the next year. The water temperature in the 50-200 m on the same ection in February-March make it possible to judge upon the mass movements of capelin cod via ıe Murman Shelf in May of the same year.

ABIOTIC CONDITIONS AS ORIENTING FACTORS FOR THE MIGRATORY ANIMALS

Performing complex and lengthy migrations, fish are in need of some guide posts. In the pro- ess of evolution precise responses to the environment were formed. With the help of these res- onses fish can reach points within the area of their distribution where there is more food or ess enemies, or where the conditions are safer for the development of deposited eggs. Neither minosity nor almost inappreciable admixtures of mineral or organic matter themselves (*ipso facto*) e of vital importance for migrants, they only help in searching for migratory ways, thus, serving orienting factors (Konstantinov, 1958). The point of view developed here is particularly well llustrated in the case of white bass (*Roccus chrysops*) which finds its way to the spawning grounds the sun (Hasler, 1960*a*, 1960*b*; Hasler & Henderson, 1963).

In a great number of cases water temperature is a guiding factor for fish. It is generally ıown that some fish occur only within a definite, often very limited temperature range (this ıcilitates detection of fish concentrations). Meanwhile, aquarium observations indicate that sh can safely stand temperatures that are never encountered in nature. Vladykov (1933) showed ıis for haddock, Gerasimov (1961) for herring, Kelly and Barker (1961) for redfish and McCracken 1963) for flatfish. So there are no reasons to suppose that there is a purely physiological ırmfulness in the temperature being avoided by the free-living fishes. The choice of a particular emperature helps a fish to reach the area with the optimum biotic conditions in due time. From ıis point of view it is quite obvious that in nature the range of preferred temperatures changes egularly throughout the year. Thus, the Atlantic cod (*Gadus morhua*) are not found at a temp- ature below +2°C in winter, while in the summer-autumn months they do not avoid the areas even ith 0°C temperature (Woodhead and Woodhead, 1959). Certainly, a more extensive distribution of ish is expedient in the main feeding period than in the period of wintering. An attempt is made elow to consider the afore-mentioned ideas in more detail with special reference to capelin cod.

DEPENDENCE OF THE MIGRATORY PATH OF CAPELIN COD UPON THE WATER TEMPERATURE IN THE BARENTS SEA.

At the beginning of spring, mainly in March-April, the concentrations of capelin (*Mallotus llosus*) and "capelin cod" living on capelin come to the southern coast of the Barents Sea. As rule, specimens of 40-70 cm, immature, with the liver weight not over 5-6% of fish weight, pre- ail in the stock of capelin cod. Stomachs of the cod are packed full with capelin. Concentrating ear shores, capelin cod are subjected to an extensive fishery. In the years of severe hydrologi- al regime both cod and capelin migrate to the coast by more westerly routes than in the warm ears. Favourable fishing conditions may prevail either off the Finmark or Murman coasts.

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Polar Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, USSR.

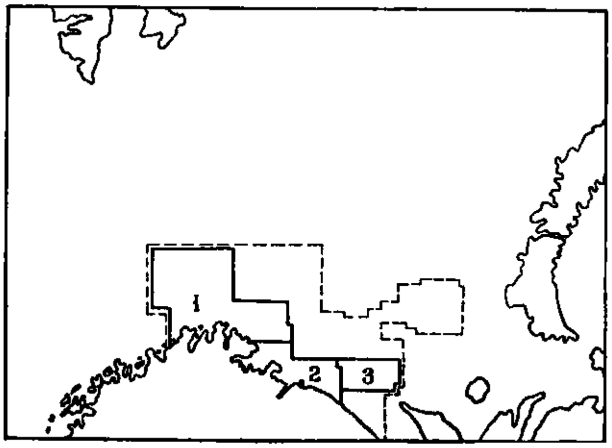

Fig. 1. Areas of the trawl fishery in the Barents Sea: 1 - the Finnmark Coast, 2 - the Murman Coast, 3 - the Murman Shallow. Dotted line - the boundary of the southern part of the Sea within the limits of which the main cod fishery is carried out in March-April.

Therefore, the increase in the Soviet catches of capelin cod and capelin is usually accompanied by the drop in the Norwegian catches and vice versa (Konstantinov, 1961; Prokhorov, 1963*a* and 1963*b*).

Using the hydrological data, one can foresee the route of the spring migration of capelin cod several months before its beginning. The methods proposed are as follows.

The southern coast of the Barents Sea is divided into two zones: western (Finnmark) and eastern (Murman). The importance of each zone for the Soviet trawl fishery in March-April is defined by the percentage of the catch taken in the given zone to the total catch in the whole southern part of the Barents Sea. If compared with ICES, Area I, our boundaries in the southern part of the sea are somewhat smaller (Fig. 1), and some areas where cod are not usually fished in spring are not included.

The whole area treated in the present paper as "the southern part of the Barents Sea" is usually free from ice in spring and is available to fishing trawlers of any type. As a rule each great concentration of cod appearing within the limits of the area described is immediately found and fished by the trawl fleet. Therefore, the commercial importance of some areas in the southern part of the sea the actual distribution of cod shows well. The commercial importance of the coastal zones compared varies considerably: from 0.2 to 87.7% in the western zone and from 4.3 to 37.8% in the eastern zone. From Figs. 2 and 3, it is not difficult to see a rather close relation between the commercial importance of each of the coastal zones in March-April and the water temperature in the 150-200 m layer on the Kola hydrological section in November of the previous year. As a rule, the higher this temperature, the greater the commercial importance of Murman and the lower the commercial importance of Finnmark.

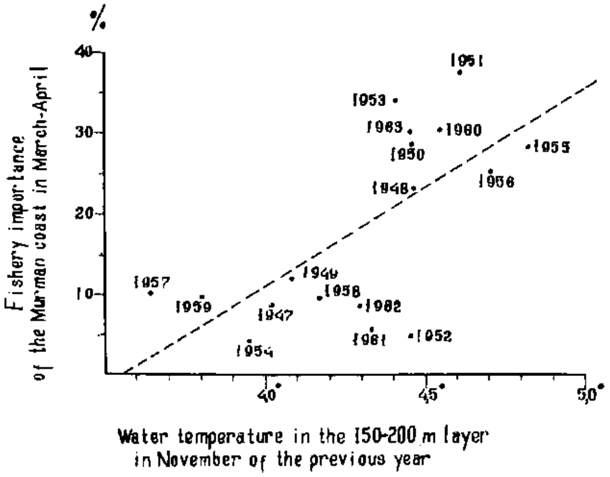

Fig. 2. Commercial importance of the Murman Coast in March-April in relation with the water temperature in November of the previous year.

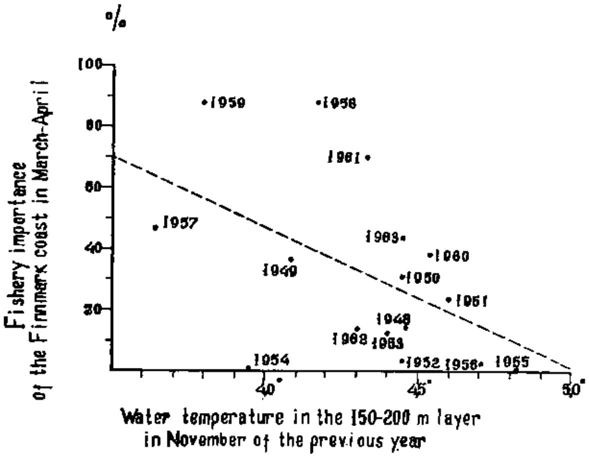

Fig. 3. Commercial importance of the Finnmark Coast in March-April in relation with the water temperature in November of the previous year.

The equations of quantitative relation between the compared indices are given below:

$$y = 24.5x - 86.9 \qquad (1)$$
$$y = 3.8x^2 - 7.6x - 19.5 \qquad (2)$$

In these equations "x" designates the November temperature on the Kola section and "y" the mmercial importance of the Murman Coast in March-April of the following calendar year. The oken line in Fig. 2 corresponds to equation (1): the correlation coefficient (r) = 0.67 ± .13. The parabolic curve corresponding to equation (2) is not represented in the Fig. as it most coincides with the straight line, having only slight curvature. However, forecasting by e equation (2) provides somewhat more exact results than by equation (1).

In equation

$$y = -45.3x + 227.7 \qquad (3)$$

" also presents the November temperature on the Kola section, while "y" shows the commercial imortance of the Finnmark Coast in March-April of the following year. The correlation coefficient) = -0.50 ± 0.19. The straight line in Fig. 3 corresponds to equation (3). Despite the comratively low correlation coefficient, equation (3) is of a certain practical interest as together with the more reliable equations (1) and (2) it helps to forecast the spring migration routes of capelin cod. For instance, the November temperature in the 150-200 m layer was highest in 1954 and 1955. Using equations (1) and (2), it was easy to forecast the outstanding commercial importance of the Murman Coast in March-April 1955 and 1956. At the same time equation (3) enabled us to forecast the very insignificant commercial importance of the Finnmark Coast. As is obvious from Figs. 2 and 3, the actual run of the fishery corresponded to the expected one.

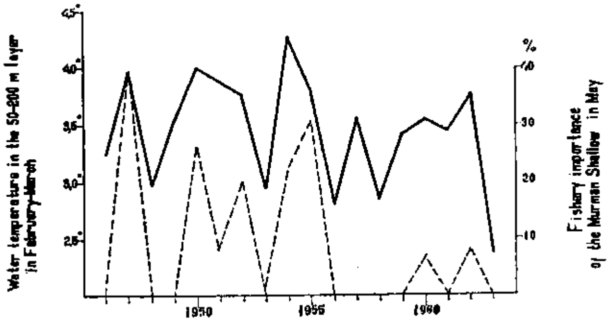

Fig. 4. Commercial importance of the Murman Shallow in May (dotted line) in relation to the water temperature in February-March (solid line).

An even closer relation exists between the thermal regime of the sea and the cod distribution on the Murman Shallow. This area, which is very suitable for the trawl fishery, is shown in Fig. 1. Figure 4 indicates that the higher the temperature is in the 50-200 m layer on the Kola hydrological section in February-March, the greater will be the commercial importance of the Murman Shallow in May. In the cold years cod are distributed west of the Murman Shallow in May, whereas in the warm years they are found within the limits of this area.

In equation

$$y = 18.2x - 53.8$$

x" designates the water temperature in February-March while "y" shows the commercial importance f the Murman Shallow in May: the correlation coefficient (r) = 0.71 ± 0.11.

The measure of reality of the relation between the varying values is usually expressed by he formula $\frac{r}{E}$, where $E = \pm 0.67 \frac{1 - r^2}{\sqrt{N}}$. If $\frac{r}{E} = 6$, the relation is considered to be resent. In our case $\frac{r}{E} = 9.1$; *i.e.* the relation is undoubtedly there.

As the migratory paths of both capelin cod and capelin itself as a rule coincide, the methods proposed can be applied to forecasting the spring arrivals of capelin to the coast of the Barents Sea. The above equations evidently cannot provide an absolutely precise forecast. It is not difficult to see that the dots in the Figs. are considerably scattered. The methods proposed require further development. However, they are successfully used even now to judge whether the commercial importance of Murman (and Finnmark) will increase or drop compared with the previous year. The forecast obtained some months in advance by the methods proposed must be controlled and corrected later, if possible, by means of field observations on the migratory concentrations of cod and capelin.

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A-14

THE INFLUENCE OF HYDROGRAPHIC AND OTHER FACTORS ON THE DISTRIBUTION OF COD ON THE SPITSBERGEN SHELF[1]

By

R. J. H. Beverton[2] and A. J. Lee[2]

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[1] Originally Contribution No. A-12, ICNAF Environmental Symposium, Rome, 27 January-1 February,1964.

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SUMMARY

1. New information is presented on the distribution and movement of cod on the Spitsbergen Shelf in relation to hydrographic and biological factors.

2. Results of a series of cruises covering the edge of the shelf north-east of Bear Island during 1953-55 show the contrasting effects of a cold year (1953) changing to an exceptionally warm one (1954) and back to cold (1955). The observations throughout this period, with only minor exceptions, showed that cod were confined in the relatively warm Atlantic water above 1.5° to 2.0°C. Their distribution varied in accordance with that of the position of the boundary between the warm and cold water, both on a broad scale and locally when a sharply defined temperature structure built up during the warm spring of 1954.

3. Echo-surveys in the late spring and summer of 1956 showed that the short-term movement of cod onto the western edge of the shelf was related to the surge of Atlantic water. At a later stage *in situ* warming on the banks proper appeared to allow a widespread migration of cod from Atlantic to Arctic water.

4. There is evidence that the occurrence of local concentrations of a preferred food (herring and, to a lesser extent, euphausids) within an otherwise tolerable and featureless hydrographic area caused aggregation of cod on them. There was no obvious relation between cod density and intensity of feeding in the absence of a particular preferred food or when the latter was of widespread occurrence (*e.g.* capelin in 1953).

5. The earlier findings of a lack of cod in water below 1.5° to 2.0°C are confirmed by these results. There were no signs of the migration of large concentrations of cod into cold shallow water in the summer that were found in 1949-51 and which constituted the exception to this general rule. The later evidence emphasizes the influence of water movements and lessens the importance of an intrinsic seasonal depth cycle in determining cod distribution in the Spitsbergen Shelf region.

6. Attempts to establish the precise mechanism (*e.g.* response to a temperature gradient or to current shear at the interface) by which cod appear to be restricted mainly to one water mass are largely inconclusive from evidence of this kind. It is suggested that the detailed analysis of fish distribution in relation to a sharply-defined temperature regime (such as is described for the area east of Bear Island in 1954), by modern techniques of fish detection, temperature and current measurement, might provide an answer.

INTRODUCTION

Some of the results of an investigation of the influence of certain environmental factors on the distribution of cod on the Spitsbergen Shelf (Bear Island - Hope Island - Spitsbergen region) carried out from the Research Vessel *Ernest Holt* during the period 1949-59 have been given by Lee (1952), Graham *et al.* (1954), and Trout (1957). The first two of these papers considered the influence of temperature on the cod distribution and the third dealt with the roles of daylight radiance in the sea and of water movement.

The purpose of this contribution is to examine data concerning the distribution of cod in relation to water temperature and other factors for later periods than those covered by the papers referred to above. Two situations are considered. The first relates to the area to the east and north-east of Bear Island, along the eastern edge of the Spitsbergen Shelf, which was covered on a number of cruises during 1953, 1954 and the first half of 1955. A particular study was made of the local distribution of cod in the region of the South-east Gullies (Fig. 1), where a temperature picture of sharp contrasts formed during 1954. The second deals with three cruises made in the summer of 1956 when the distribution and movement of cod along a broad front on the western edge of the Spitsbergen Shelf between Bear Island and Spitsbergen, and later onto the shelf itself, was followed by echo-sounder surveys.

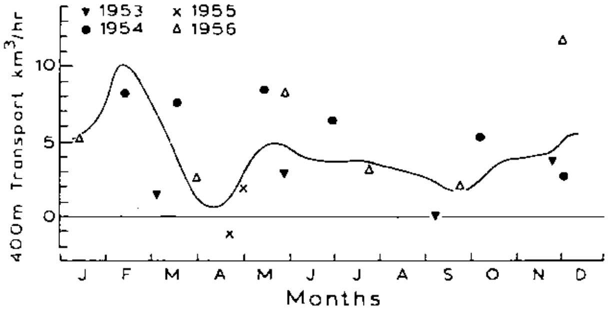
THE GENERAL HYDROGRAPHIC SITUATION IN THE BEAR ISLAND REGION DURING 1953-56.

Figure 1 shows the geography of the Western Barents Sea and the main features of the current system in that area. Warm water is transported northwards along the western edge of the shelf by the West Spitsbergen Current and along the eastern edge by the northernmost arm of the North Cape

ig.1. The western Barents Sea and its current system.

1.Bear Island
2.South-east Gullies
3.Hope Island
4.Spitsbergen
5.Spitsbergen Shelf
6.North-west Gully
7.Storfjordrenna

. West Spitsbergen Current
B. North Cape Current
. Bear Island Current
D. Atlantic Current



ig.2. The annual cycle of volume transport of the West Spitsbergen Current and the values observed in 1953-56.

Current. The bottom temperature in the Bear Island region is determined by two opposing effects - on the one hand by the strengths of these two currents which, since both derive from the Atlantic current, vary together, and on the other by the strength of the Bear Island Current which is cold and of Arctic origin.

The volume transport of the West Spitsbergen Current above 400 m depth along a section running for 93 km due west of Bear Island has been measured on 46 occasions during the period 1949-59 (Lee, 1962), and its magnitude gives a good indication of the general temperature conditions on the edge of the shelf. Figure 2 shows the mean annual cycle of volume transport for these years (Lee, 1961), and the particular values for the years in question (1953-56). This shows that the volume transport was below average during most of 1953 but increased to about average in December. This increase continued to give above average transports until the end of 1954 when it subsided until, by the spring of 1955, the transport was again below average.

Although these 12 observations of volume transport are a guide to the strength of the West Spitsbergen Current during 1953-55, they are not a complete one. They give an index of the geostrophic transport only and are probably correct to no more than ± 2 km hr^{-1}, for the reasons discussed by Lee (1962). Further, they only refer to 12 points in time over a period of 26 months. Hill and Lee (1958) established a positive correlation between the volume transport (v) and the southerly wind component (s) during the 10 days preceding the working of the section. The regression line of v on s was found to be

$$v = 3.85 + 0.29\ s.$$

Since then Lee (1962) has found that the correlation does not hold in the months of July and August, during which there is thermal stratification of the surface layers. In Fig. 3 we have plotted for each month of the period March 1953 - May 1955 the anomaly of the southerly wind component at Bear Island from the 35-year mean based on the years 1920-40, 1946-59. Ignoring the months of July and August in each year, it can be seen that during the spring and summer of 1953 the southerly wind component was below normal in all but one month, but that during the period September 1953 - June 1954 it was above normal for most of the time, particularly in the last months of 1953. From September 1954 through the first half of 1955, but with the exception of the month of November, it was much below normal, particularly in January and April-June. The 12 observations of the volume transport of the West Spitsbergen Current, which we have, agree well with this wind picture and we can reasonably infer from them and the wind picture as a whole, that the influx of warm water into our area was low in spring and summer 1953, high from autumn 1953 to autumn 1954, and low in the first half of 1955. Furthermore, Lee (1961) has shown that the thermal effect of the wind on the ocean in the Bear Island-Spitsbergen region supplements and acts in the same direction as the dynamic effect. Southerly winds not only increase volume transport of the warm current but they also cause increased air temperature and humdity and so reduce the cooling of the sea in winter. Northerly winds reduce volume transport, lower air temperature and humidity, and increase cooling. Bearing this in mind we can use the wind picture as a guide to the sort of hydrographic regime which we can expect in the Bear Island area.

We have some evidence that the actual regime conformed with the expected one. The higher temperatures at the end of 1953 compared with those at the beginning can to some extent be seen in Figs. 4-10 and 12-14, which show the bottom temperature and fish distributions for the period under investigation, but the increase in bottom temperature during 1954 and its decline in 1955, which we would also expect from our consideration of the wind regime and the strength of the West Spitsbergen Current, are much more notable features.

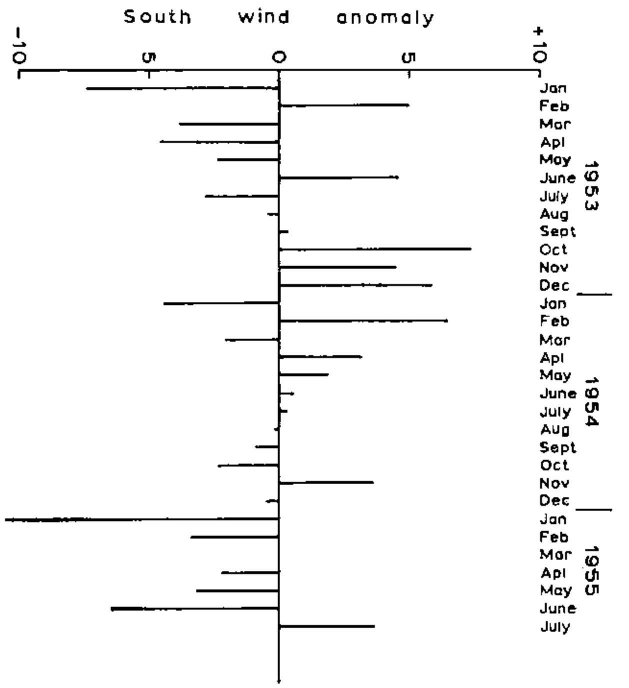


Fig.3. The anomaly of the south component of the wind at Bear Island: 1953-55.

THE SOUTH-EASTERN EDGE OF THE SPITSBERGEN SHELF, 1953-55.

1. Cod and Temperature Distribution to the East of Bear Island, 1954-55.

Figures 4-10 show the research vessel catches of cod and the bottom temperature isotherms from cruises made to the east of Bear Island during 1954 through to the spring of 1955. Catches are given in baskets per hour (40 baskets = 1.5 metric ton); no attempt has been made to contour them and no adjustment has been made for diurnal effects (Woodhead, 1964).

23-29 March 1954; Fig. 4.

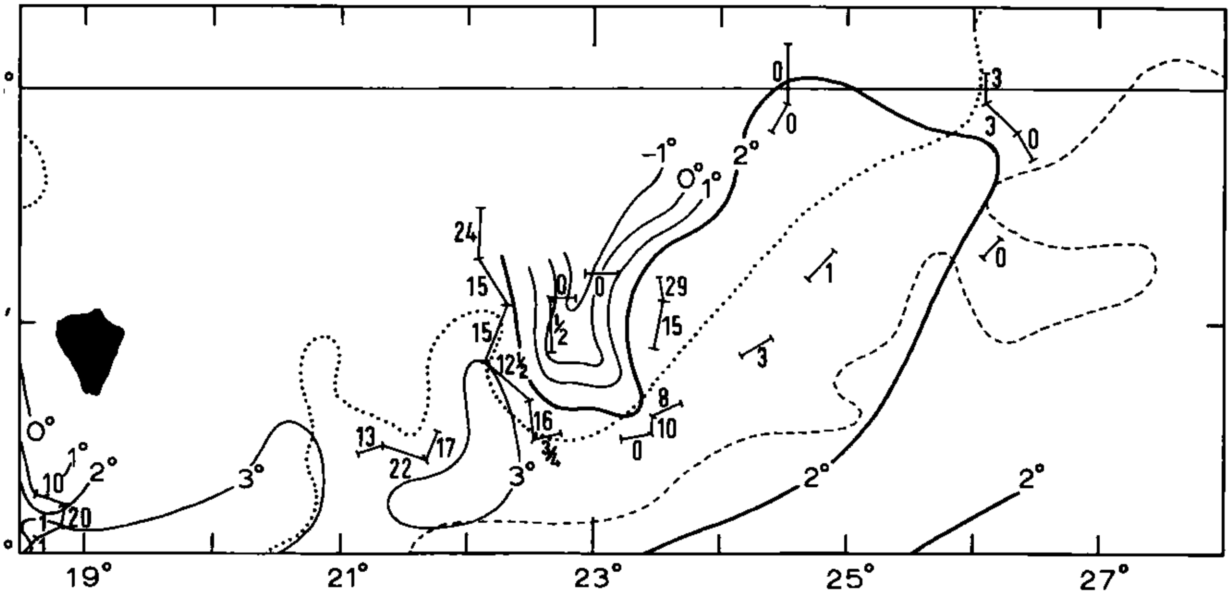
The sharply defined temperature structure in the region of the South-east Gullies is already established in this first cruise with a cold tongue bounded on both sides by water several degrees higher in temperature. Fish were virtually absent in the cold tongue but catches up to 29 baskets per hour were obtained within a few miles on either side in water between 2° and 3°C.

5-13 May 1954; Fig. 5.

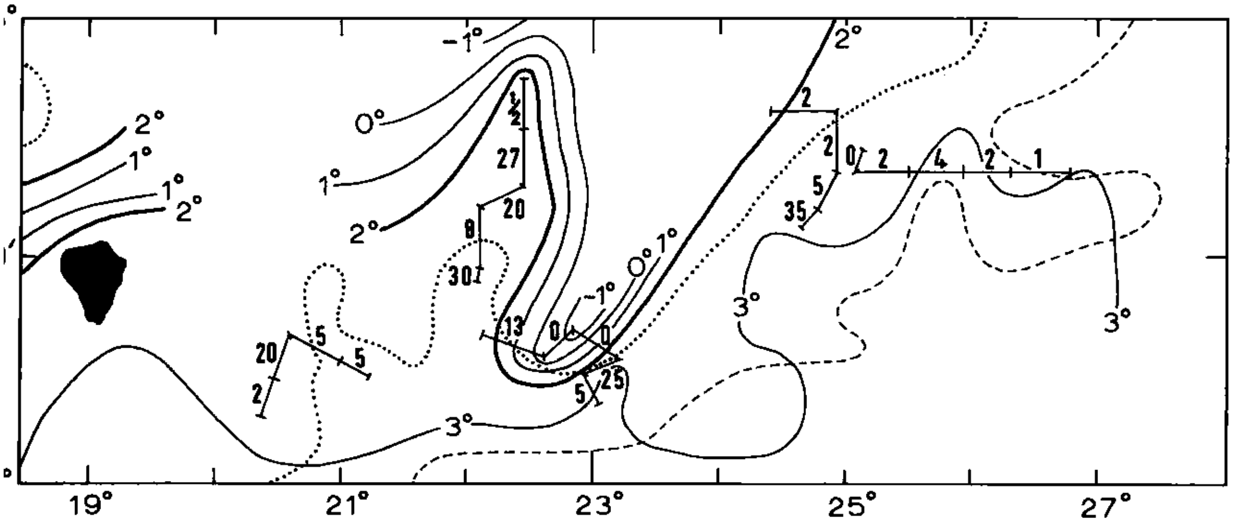
The coincidence of the fish and temperature boundaries is maintained. On this occasion the boundary of the fish distribution at the head of the gullies can be seen, and while not coinciding exactly with the temperature gradient is nevertheless close to it. The absence of fish across the tip of the cold tongue with concentrations on either side is again evident.

18-26 June 1954; Fig. 6.

By now the temperature boundaries have become less sharp, the temperature falling both in the gullies themselves and to the east. There is also a general decline in catches except in one locality where exceptionally heavy catches up to 320 baskets/hr were taken in a depth of 100 fm



ig.4. Catches of cod and the distribution of bottom temperature east of Bear Island 23-29 March 1954. (Catches are in baskets/hr in Figs. 4-10 and 12-14: 1 basket = 0.038 metric tons).



ig.5. Catches of cod and the distribution of bottom temperature east of Bear Island 5-13 May 1954. (Catches are in baskets/hr in Figs. 4-10 and 12-14: 1 basket = 0.038 metric tons).

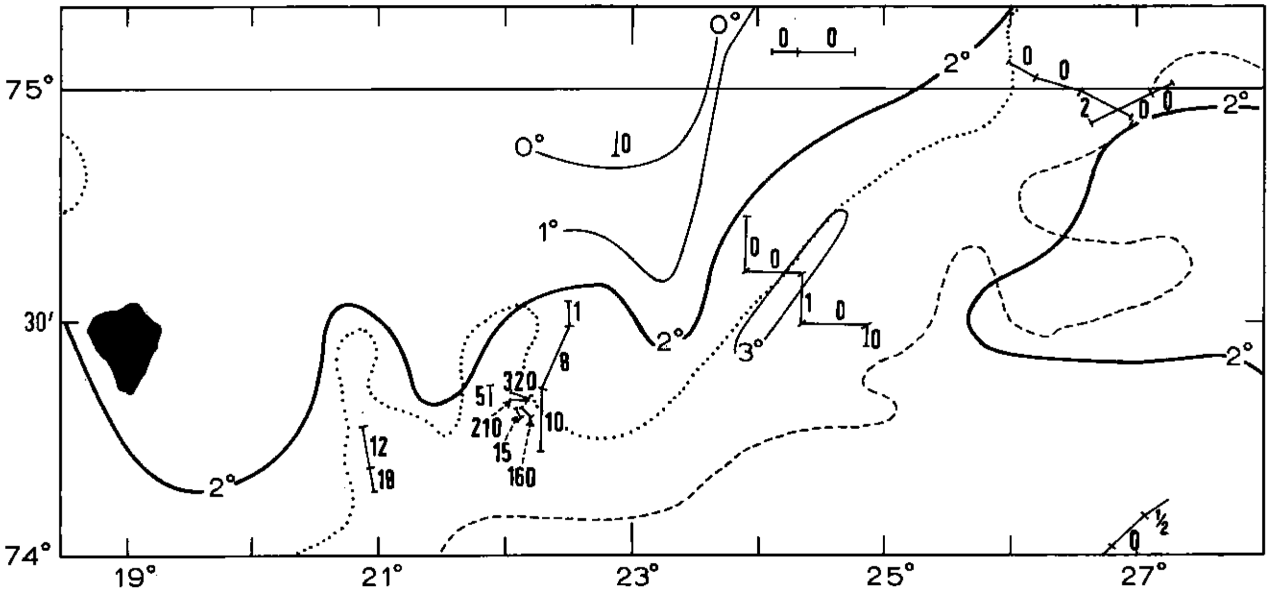


Fig. 6. Catches of cod and the distribution of bottom temperature east of Bear Island 18-26 June 1954. (Catches are in baskets/hr in Figs. 4-10 and 12-14: 1 basket = 0.038 metric tons).

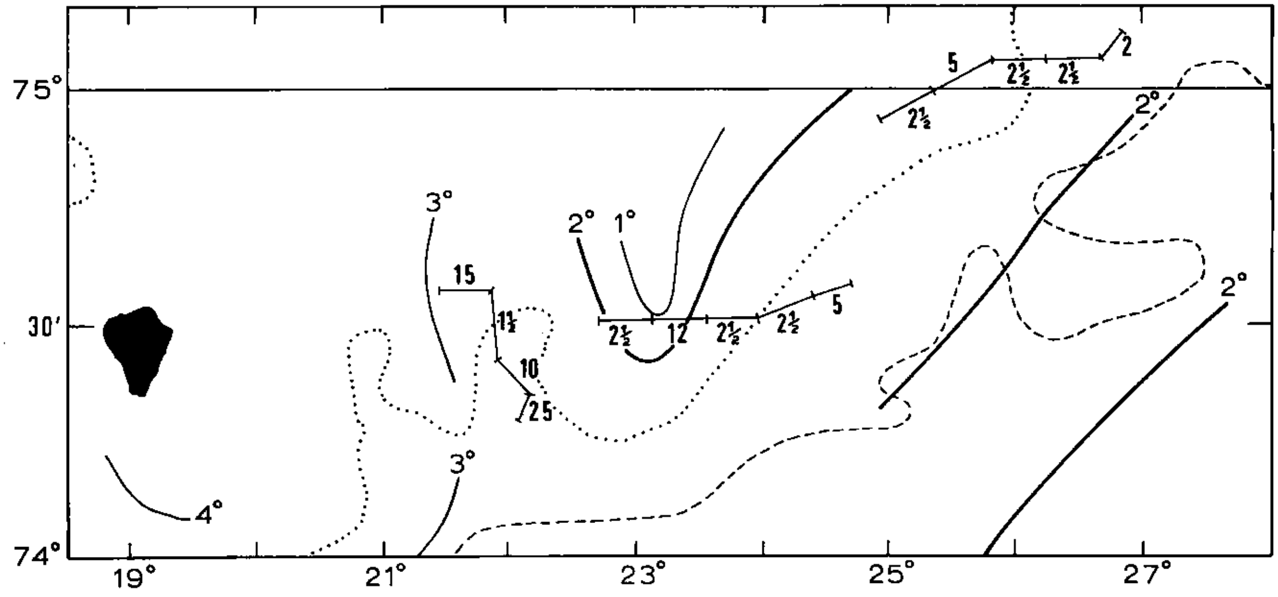


Fig. 7. Catches of cod and the distribution of bottom temperature east of Bear Island 19-21 October 1954. (Catches are in baskets/hr in Figs. 4-10 and 12-14: 1 basket = 0.038 metric tons).

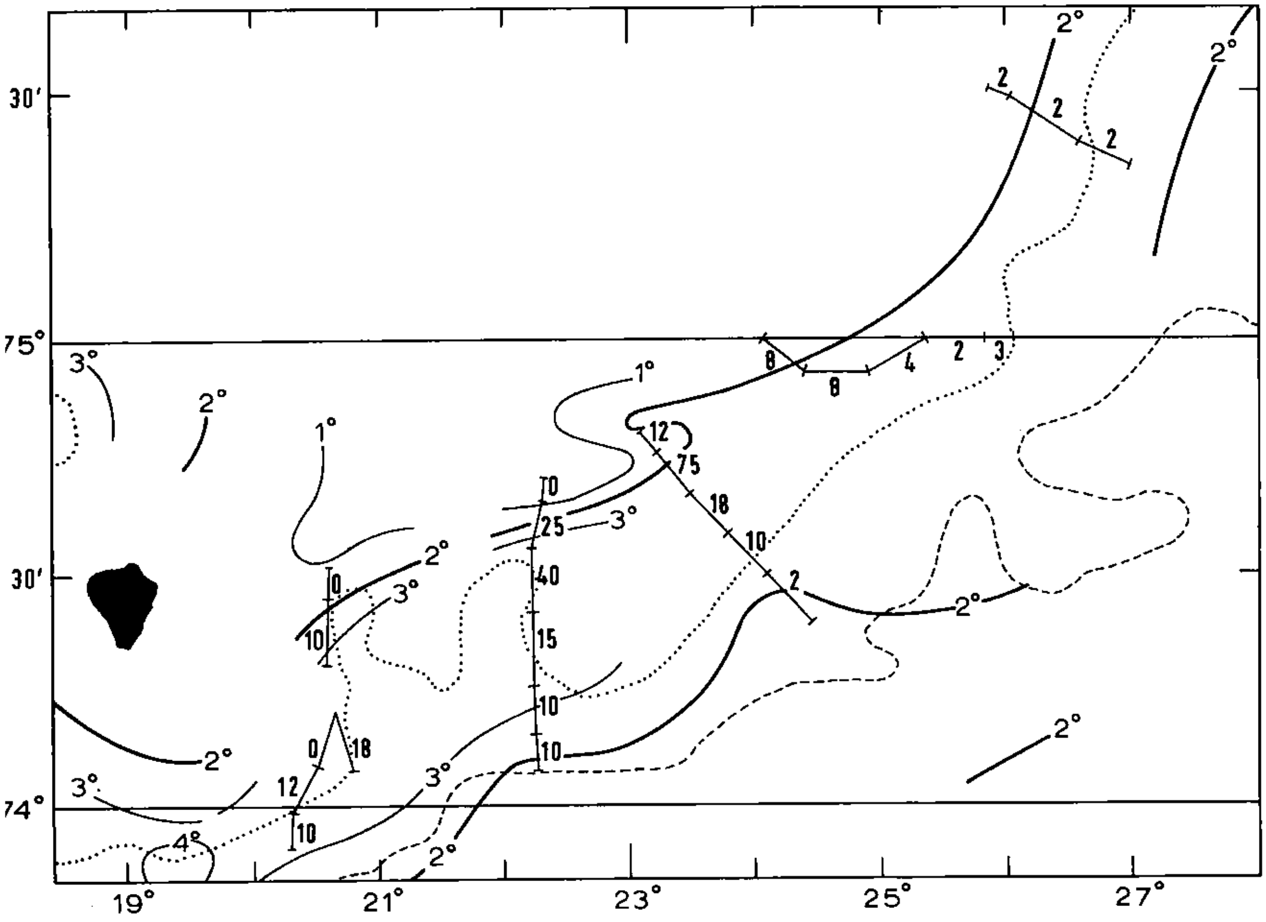


Fig. 8. Catches of cod and the distribution of bottom temperature east of Bear Island 26 November-2 December 1954. (Catches are in baskets/hr in Figs. 4-10 and 12-14: 1 basket = 0.038 metric tons).

(183 m). This was near the end of the cruise, about a week later than the rest of the catches shown in Fig. 6. Whether these fish were there throughout or whether the concentration formed during this short time cannot be established; but in either case there is no correspondingly sharp hydrographic feature to explain it. There seems to have been a movement of fish away from the head of the gully since the previous cruise. This may have been due to the onset of cooler conditions there, but we have no evidence to show conclusively that this has led to the build-up of the concentration in deeper water.

19-21 October 1954; Fig. 7.

There were, unfortunately, no cruises to the area during July-September. By October the temperature structure in the South-east Gullies had begun to return to something similar to that earlier in the year, but the number of stations are too few to establish either the fish or temperature gradients with any precision.

26 November - 2 December 1954; Fig. 8.

The temperature gradients have steepened since the previous cruise, partly through a decrease in temperature on the shallower parts of the bank and partly through an increase in the deeper water. Catches are substantially higher than before and indicate the existence of a band of maximum fish concentration in the region of the 2° and 3°C isotherms and decreasing towards the northeast. Where hauls extended to the 1°C isotherm catches declined sharply.

6 - 14 March 1955; Fig. 9.

The cooling of the shoal water has intensified and most of the deeper parts of the shelf to the south as well as the east of Bear Island are now also covered with water below 2°C. The band of maximum fish concentration also appears to have moved south and is still in the region of the 2° C isotherm. Compared with the corresponding period of 1954 (Fig. 4) the cold water is more extensive and the temperature gradients in the region of the South-east Gullies are consequently less steep. The fish gradients also appear less pronounced and appreciable quantities were caught in cold water, especially to the south of Bear Island. The impression is that the fish distribution has not changed as rapidly since the previous cruise as has the hydrographic regime, and it is interesting to note that over a considerable part of the area the surface water is colder than the bottom. This indicates that some, at least, of the decrease in temperature of the bottom water since December is due to *in situ* cooling as opposed to a southerly transport of Arctic water *en masse*, and this may explain why the fish distribution does not follow the temperature boundaries as sharply as during the period of high transport (in the opposite direction) earlier in the year.

28-30 April 1955; Fig. 10

The progressive cooling of the water on the shelf noticed on both the previous cruises is continued even further, until by now the greater part of the shelf to the south and south-east of Bear Island is covered with water less than 2°C and much of the shoaler parts (*i.e.* the South-east Gullies proper) by water below zero. The two lines of trawl hauls to the east of Bear Island coincide almost exactly with those of the previous cruise (Fig. 9) and show that there has been a dramatic decrease in fish density since then. The only catches of any size (15 and 40 baskets) were again taken near the 2°C isotherm; but now, in contrast to the previous cruise, the fish gradients are sharper and hardly any fish were caught in water colder than this. In contrast to the previous cruise cold bottom water now covers a large area in the bottom of the gullies (Fig. 10), due to the cascading of cold Arctic water downwards from the bank. It is reasonable to suppose that the rapid retreat of fish to the south since the previous cruise is related to this advance of cold water.

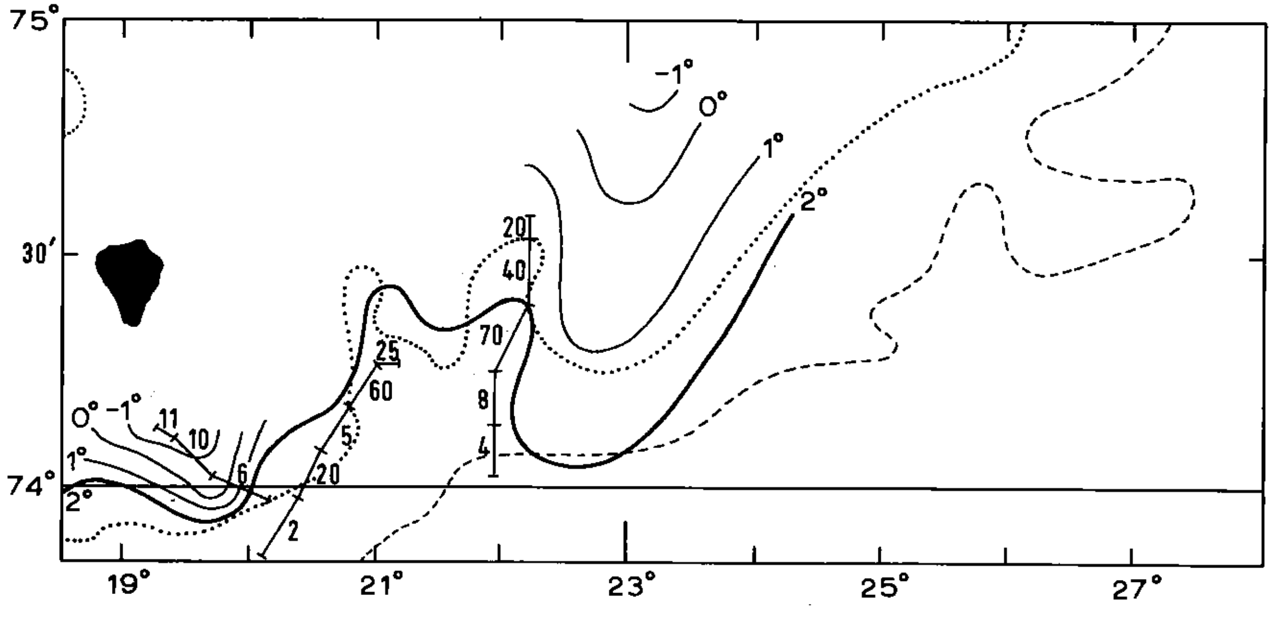
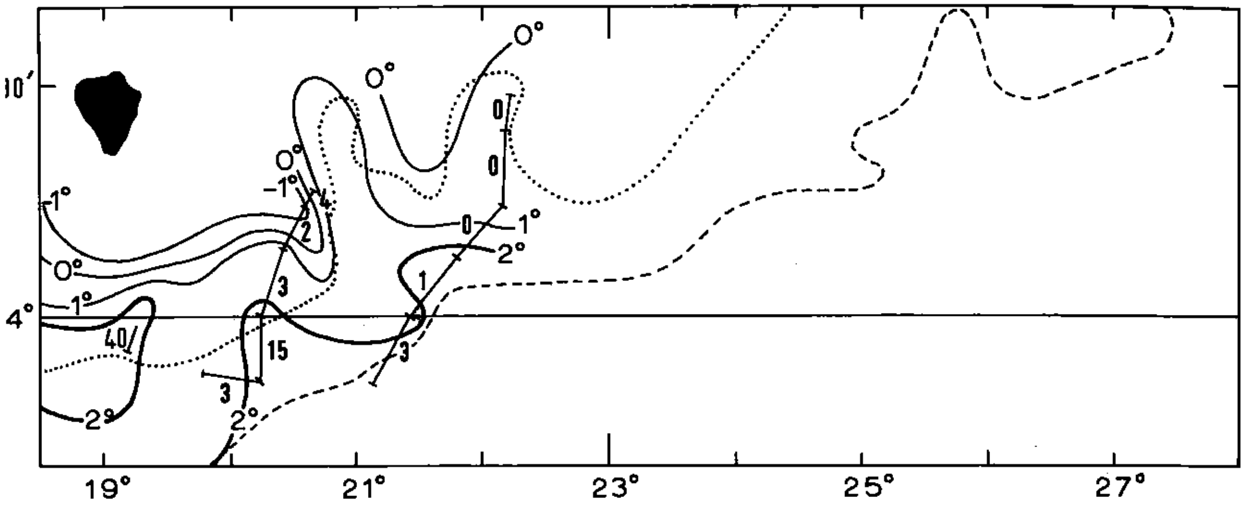


Fig. 9. Catches of cod and the distribution of bottom temperature east of Bear Island 6-14 March 1955. (Catches are in baskets/hr in Figs. 4-10 and 12-14: 1 basket = 0.038 metric tons).



ig. 10. Catches of cod and the distribution of bottom temperature east of Bear Island 28-30 April 1955. (Catches are in baskets/hr in Figs. 4-10 and 12-14: 1 basket = 0.038 metric tons.)

. Temperature or Depth?

The Spitsbergen Bank receives cold Arctic water from its shallow region to the north and east, nd warm Atlantic water from the deeper areas to the south and west. Consequently, there is usually strong association between temperature and depth on the edge of the bank (the shallowest areas eing the coldest), which complicates what might otherwise appear to be a straightforward relation etween fish distribution and temperature. It is therefore necessary to re-examine the evidence resented in Figs. 4-10, to see how far it is possible to distinguish between temperature and depth s the more significant indicator of the limits of cod distribution.

A formal bivariate analysis giving all the data equal weight is of doubtful value if not posiively misleading for this purpose, because sampling was not distributed, temporally or spatially, n either a systematic or a random way with respect to temperature or depth. The evident lack of ish to the north-east, irrespective of temperature and depth, means that many of the data are inonclusive, and it is necessary to examine the rest selectively, although this precludes rigorous tatistical evaluation. To support the hypothesis that cold water rather than shallow depth is he limiting influence (direct or indirect), the crucial evidence is the existence of appreciable oncentrations of fish in shallow but warm water; to refute it, concentrations of fish in cold ater, irrespective of depth, must be demonstrated. Both of these are rare occurrences, but forunately the striking contrast between the "warm" conditions of 1954 and the "cold" of 1955 proides a clue. Since detailed depth contours could not be shown on Figs. 4-10, catches are given n Table 1 by half degree temperature and ten fathom depth intervals. Months are also given in able 1 since the effect of temperature or depth on fish distribution may vary seasonally.

It has been noted above that a feature of interest in the spring of 1954 was the sharply-efined cold tongue of water in the South-east Gullies region, and the absence of fish in it but heir presence in the warm water to each side only a few miles away. The depths in the cold ongue were, however, a little less than where the fish occurred, ranging from 55 to 70 fm. (100-28 m) compared with 65-80 fm. (119-146 m). Whether this depth difference could have been suficient to generate the very sharp boundary of the fish distribution is problematic. Warm water n precisely the same depths as the cold tongue was not found in the South-east Gullies locality, ut immediately to the south of Bear Island a line of trawl hauls extended into even shallower ater (45 - 60 fm: 82-110 m) where the temperature ranged from 1° to 2.5°C (Fig. 4 and Table 1); hese gave catches of 10 and 20 baskets, which are not much different from those in rather deeper ater of similar temperature on each side of the cold tongue. Moreover, this line of hauls did ot close the fish boundary towards the shallow water.

TABLE 1. CATCHES OF COD (BASKETS/HR ; INDIVIDUAL HAULS), SOUTH AND EAST OF BEAR ISLAND DURING THE PERIOD 1954-1955, GROUPED BY HALF DEGREE TEMPERATURE INTERVALS AND 10 FM. (=18.3 M) DEPTH INTERVALS.

Temp. °C	Depth (Fathoms)											
	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	150+
-1.0 to -0.51		11 M/5	0 My/4 10 M/5									
-0.50 to -0.01		0 M/4 0 J/4										
0.00 to 0.49		½ M/4	0 M/4 2 A/5	0 A/5	4 A/5							
0.50 to 0.99		0 D/4		0 My/4	0 A/5							
1.0 to 1.49	10 M/4		0 D/4	20 M/5	0 J/4 5 A/5	13 My/4 0 J/4 12 A/5						
1.50 to 1.99		12½ D/4	2½ 0/4	3 A/5	0 M/4 12 /4 7½ D/4	1 D/4 40 M/5		3 M/4		0 A/5		0 M/4 2 A/5
2.00 to 2.49		20 M/4	25 D/4	½ My/4 75 D/4 5 M/5	0 M/4 2½ My/4 100 A/5 50 A/5	0 J/4 2 D/4 7½ D/4 60 M/5	4 D/4 25 M/5	0 J/4 1½ D/4 70 M/5 7½ A/5	1 M/4 0 J/4 15 A/5	10 M/4 0 M/4	8 M/4 2 J/4 1 A/5 3 A/5	0 M/4 2½ D/4 10 D/4 4 M/5 7½ M/5 3 A/5
2.50 to 2.99		½ J/4	1½ My/4	29 M/4 15 M/4 24 M/4 20 My/4 8 J/4 15 0/4	15 M/4 7½ My/4 27 My/4 20 My/4 10 D/4	12 M/4 15 M/4 16 M/4 30 My/4 10 0/4 17½ D/4 20 M/5	1 M/4 25 My/4 2½ My/4 5 My/4 210 J/4 15 J/4 5 0/4 2½ 0/4 2½ 0/4 25 0/4 1½ 0/4	22 M/4 5 My/4 5 My/4 0 J/4 160 J/4 2½ 0/4 2½ 0/4 2½ 0/4 2½ D/4 12½ M/5	50 M/4 ½ M/4 13 M/4 17 M/4 35 My/4 0 My/4 5 J/4 2 0/4 5 0/4 3 D/4	1 M/4 15 M/4 3 M/4 5 My/4 1½ My/4 ½ J/4 20 M/5 2½ M/5	3½ My/4 0 J/4 15 M/5 11 M/5	2½ My/4 1 My/4 0 J/4 0 J/4 0 J/4 2½ D/4
3.0 to 3.49 +				1 M/4	½ M/4 5 My/4	1 M/4 8 My/4 15 J/4 15 D/4	10 My/4 12½ J/4 10 J/4 320 J/4	6 M/4	1 M/4		10 D/4	
3.50 to 3.99					40 D/4 12½ D/4 0 D/4	17½ D/4 25 D/4				2½ My/4 10 D/4 30 D/4		

Key: M- March, A- April, My- May, J- June, 0- October, D- December. /4 = 1954 , /5 = 1955.

The fact that the maximum catches south-east of Bear Island in the spring surveys of 1954 were taken in depths between 70-90 fm. (128-165 m) but in water between 2° and 3°C is itself significant. This is the time when the average depth of the commercial fishing is greatest (usually in the region of 220 fm.: 402 m) (Trout 1957); it is also the middle of the "hydrographic winter" in average conditions. At this time in 1954, however, the main commercial fishing (to the south and south-west of Bear Island) was at depths between 100-150 fm. (183-274 m). The inference that the unusual occurrence of both fish and warm water in exceptionally shallow depths during the spring of 1954 was not fortuitous is strengthened by comparison with the situation in the spring of 1955 (Fig. 10), by which time the influx of warm water had weakened and cold water extended over much of the bank which at the same period in 1954 had been covered with warm water. Correspondingly, hardly any fish were caught in 1955 in places where good catches had been taken in 1954.

Inspection of Table 1 shows that, throughout the period, only two of the thirteen hauls made in water below 1°C gave any quantity of fish (10 and 11 baskets). Both of these were in March 1955 in shallow water (50-70 fm.: 91-128 m) close to a very steep temperature gradient with warm water only a few miles away. Indeed, the gradient here was so steep and irregular that there is some doubt whether the temperatures at the beginning and end of the two hauls (ranging from -0.5° to -1.0°C) necessarily reflect the actual temperatures where the fish were, which could have been higher than this. Nevertheless, it has been noted above that the general distribution of fish in March 1955 appeared to be lagging behind the rapid spread of cold water down the bank which was occurring then, and it is possible that these fish had been overtaken by a relatively thin sheet of cascading cold water. No hauls were made in exactly this locality on the following cruise (April 1955) because it was close to the ice edge, but heavy catches (50-100 baskets) were obtained at the edge of the warm water (2° to 2.5°C) which by then had retreated further down the bank to depths of 80-90 fm.(146-165 m). Thus it could be that by April fish had become concentrated at the new boundary between the cold and warm water, but detailed information on the gradients of this concentration is lacking.

3. Feeding.

Notes on the main food of cod, and a rough indication of the intensity of feeding, were recorded on most of the 1954-55 cruises. Detailed descriptions of the food of cod in the Bear Island area have been given by Brown and Cheng (1946) and Graham *et al.* (1954); we now examine the information for the period 1954-55 in the area shown in Figs. 4-10, to see whether the kind and intensity of feeding can throw any light on the distribution of cod.

Inspection of these records showed that the broad distinction could be made between

(a) *mixed feeding*	(ctenophores, sagittae, euphausids, *Pandalus borealis*; small gadoid fish; polychaetes, amphipods and other benthic organisms)
(b) *specialised feeding*	(herring and euphausids).

Mixed feeding, usually classified as "light" or occasionally "moderate" in intensity without any obvious seasonal change, was predominant on all cruises except the last (April 1955) when euphausids were the main or exclusive food throughout the area in question. The possibly significant observations concern the first three cruises of 1954 (March-June; Figs. 4-6), when although in the majority of hauls cod were feeding lightly on mixed food organisms, in certain hauls they were feeding heavily on herring or a combination of herring and euphausids. In such instances the catch was markedly greater than the average of the remaining hauls. This was especially pronounced in May (Fig. 5) when the cod taken in the four very heavy catches made at the end of the cruise were feeding heavily on young herring (12-14 cm), although this food species was not recorded on any of the earlier hauls.

The information on this point for the first three cruises is summarised in Table 2 below, which compares the average catch of "specialised feeding" cod with that of "mixed feeding" cod in the same general locality and temperatures.

There was no clear association with catch size when feeding was "mixed" in character, either on the cruises shown in Table 2 or on subsequent ones. In November-December 1954 (Fig. 8) for example, when feeding was exclusively "mixed" in character, the intensity of feeding decreased from "moderate" to "very light" from north-east to south-west of the area shown, which is opposite to the gradient of fish density. Neither was a relation between catch size and feeding intensity observed in April

TABLE 2. COMPARISON OF "SPECIALISED FEEDING" AND "MIXED FEEDING" CATCHES OF COD. NUMBER OF HAULS IN BRACKETS.

Period	Specialised feeding			Mixed feeding	
	Average catch (baskets/hr)	Kind of food	Intensity of feeding	Average catch (baskets/hr)	Intensity of feeding
March 1954 (Fig.4)	18 (5)	Herring	Heavy	11 (19)	Light-moderate
May 1954 (Fig. 5)	21 (5)	Herring and Euphausids	Moderate-heavy	7 (19)	Light
June 1954 (Fig. 6)	175 (4)	Herring	Heavy	9 (6)	Light-moderate

1955, although feeding was again specialised (on euphausids) in character. In contrast to the spring of 1954, however, the specialised feeding in 1955 was general throughout the area.

Taken together, these observations suggest that the presence of young herring and to a lesser extent euphausids, in local concentrations in the spring of 1954 may have played a significant role in causing cod to aggregate for feeding in areas where there were no sharp hydrographic features. This is, in fact, the only apparent explanation of the very high but localised concentration of cod in June of that year. By the same token, if evidently preferred foods such as these are widespread, as were euphausids in April 1955, it is unlikely that they would act as concentrating agents. It may be noted that the occurrence of young herring east of Bear Island is not usual and their presence in 1954 is a further indication of the exceptionally strong influx of Atlantic water in that year. This is in contrast to the situation in the spring of 1955, when no herring were recorded in cod stomachs, and to that throughout 1953 until December of that year, as is mentioned in section 5 below.

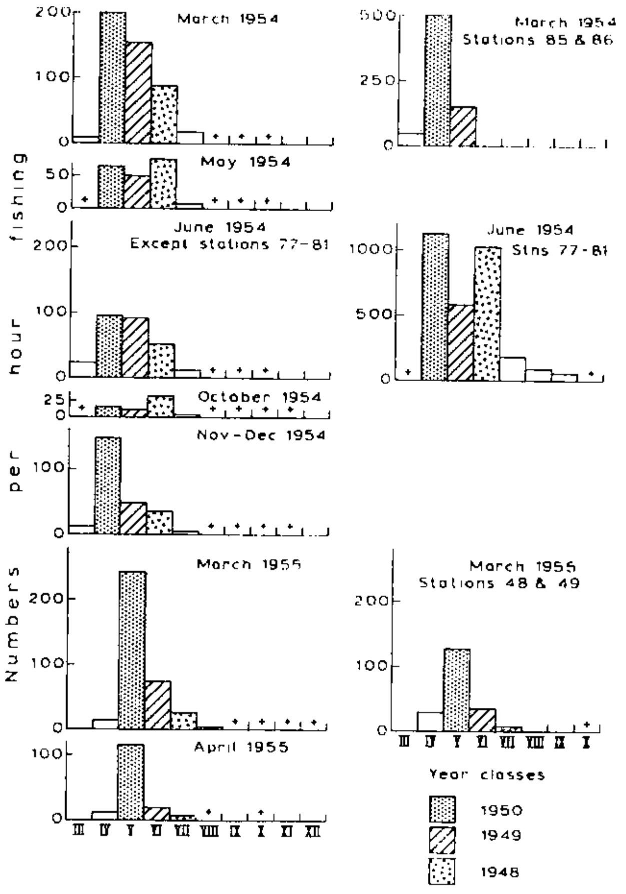


Fig. 11. Age composition of the cod in 1954-55 to the east of Bear Island.

4. Age-Composition.

Since in cod, as in other species, there is a marked tendency for older fish to be found in deeper water and since the physiological effect of temperature may possibly also be age-specific, a brief mention of the age-composition of the cod stock to which this account refers is given here.

The average age-composition of the catches taken on each cruise, expressed as numbers per hour fishing, are shown in the histograms on the left-hand side of Fig. 11. Throughout the period catches consisted almost entirely of three year-classes, those of 1948, 1949 and 1950, which comprised age-groups IV, V and VI in 1954 and V, VI and VII in 1955. Nearly all these fish were immature. The three year-classes ere represented in roughly equal proportions until November-December 1954; thereafter, the 1950 ear-class became dominant as the catches of the two older year-classes declined.

The right-hand histograms show the age-composition of hauls which, for one reason or another, ave been specially mentioned in the preceding account. Thus, stations 84 and 85 in March 1954 ere those in shallow but relatively warm water; the 1950 year-class was about twice as abundant ere as in the area generally, and the 1948 year-class was absent. Stations 77 to 81 in June 1954 ere those where the very high concentration of cod was located; the same three year-classes are ominant but there are more older fish in addition, though these stations were not deeper than the verage for the cruise as a whole. Lastly, stations 48 and 49 in March 1955 were those where fish ere caught in water both shallow and cold; their age-composition was very similar to that for the ruise as a whole, and also to those for the cruises immediately preceding and following.

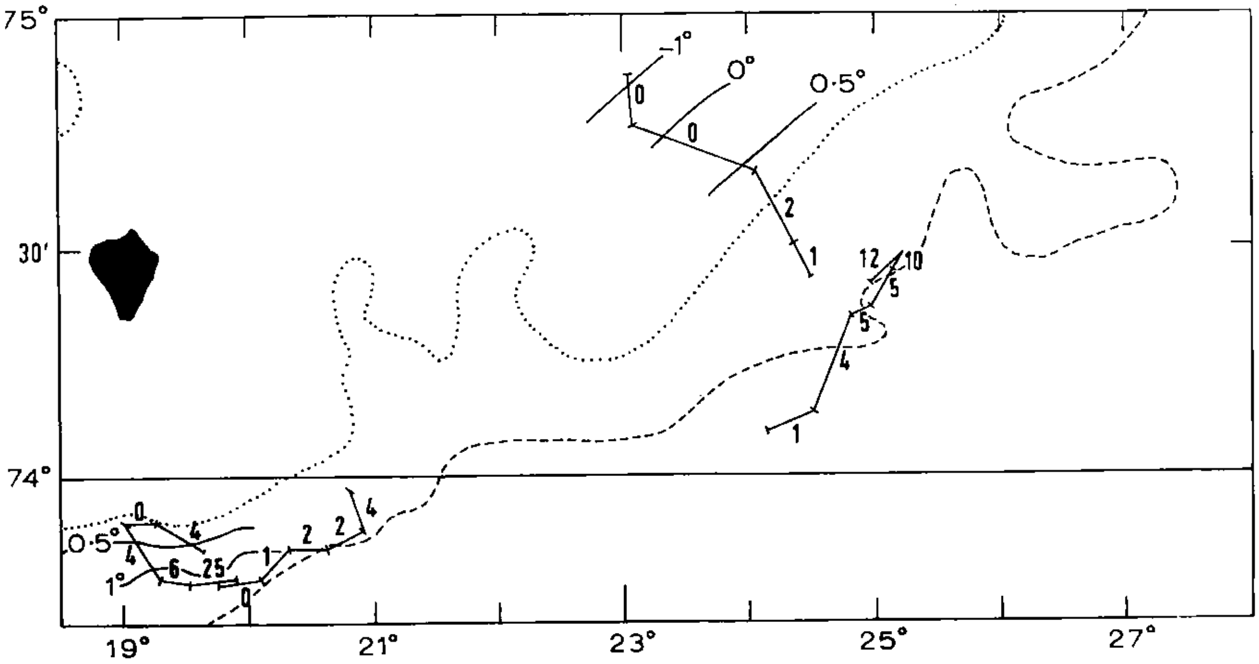
Generally speaking, the age-composition of the stock throughout the period was therefore fairly omogeneous, and the changes observed in its distribution cannot be attributed to any major dif- erences in the constituent year-classes, in time or space.

The Distribution of Cod and Temperature to the East of Bear Island in 1953.

The area in investigation in 1953 extended much further north-east than in 1944, and no detailed nformation for the South-east Gullies region is available. Nevertheless, there is enough to show hat in several respects the two years were sharply contrasted.

Figures 12-14 show the distribution of cod and temperature for three 1953 cruises during which bservations were made in at least part of the area in question; these were in April, July and ctober. Comparing the times of these cruises with those in 1954, the first (Fig. 12) falls between Figs. 4 and 5 and the last (Fig. 14) corresponds with Fig. 7: the second, the July cruise, s of particular interest since no cruises were made to the area in the high summer of 1954.

The most striking feature of all the 1953 cruises is that cold Arctic water covered practically



ig. 12. Catches of cod and the distribution of bottom temperature east of Bear Island, 10-23 April 1953.

all the shelf, all temperatures being below 2°C, even in water as deep as 200 fm. (366 m). In April, pack ice prevented access to the shoaler parts of the bank in the South-east Gullies region which were covered with warm Atlantic water in 1954. The only catches of any size taken in this month were in water of about 150 fm. (274 m) south of Bear Island where the temperature was about 1°C, and in water between 160-180 fm. (293-329 m) further east, where the water was between 0.5° and 1°C (Fig. 12). The situation in May 1953, not shown here, was the same. These depths of maximum catch contrast markedly with the spring of 1954 when the highest catches were taken in warmer water at depths between 75-95 fm. (137-174 m).

By July (Fig. 13) the temperatures on the shelf had dropped even lower. Several lines of trawl hauls covering depths from 80-180 fm. (146-329 m) failed to find fish except in moderate quantity on two hauls on the most northerly line in about 120 fm. (220 m).

On the last cruise, in October (Fig. 14), only a few observations were made, but they are sufficient to show the beginnings of the influx of warm water which led to the unique features of the following year. A cluster of trawl hauls just east of the South-east Gullies at the end of the cruise gave up to 30 baskets/hr, the largest catch recorded throughout the year on the surveys east of Bear Island, including the banks east of Hope Island not shown in the diagrams.

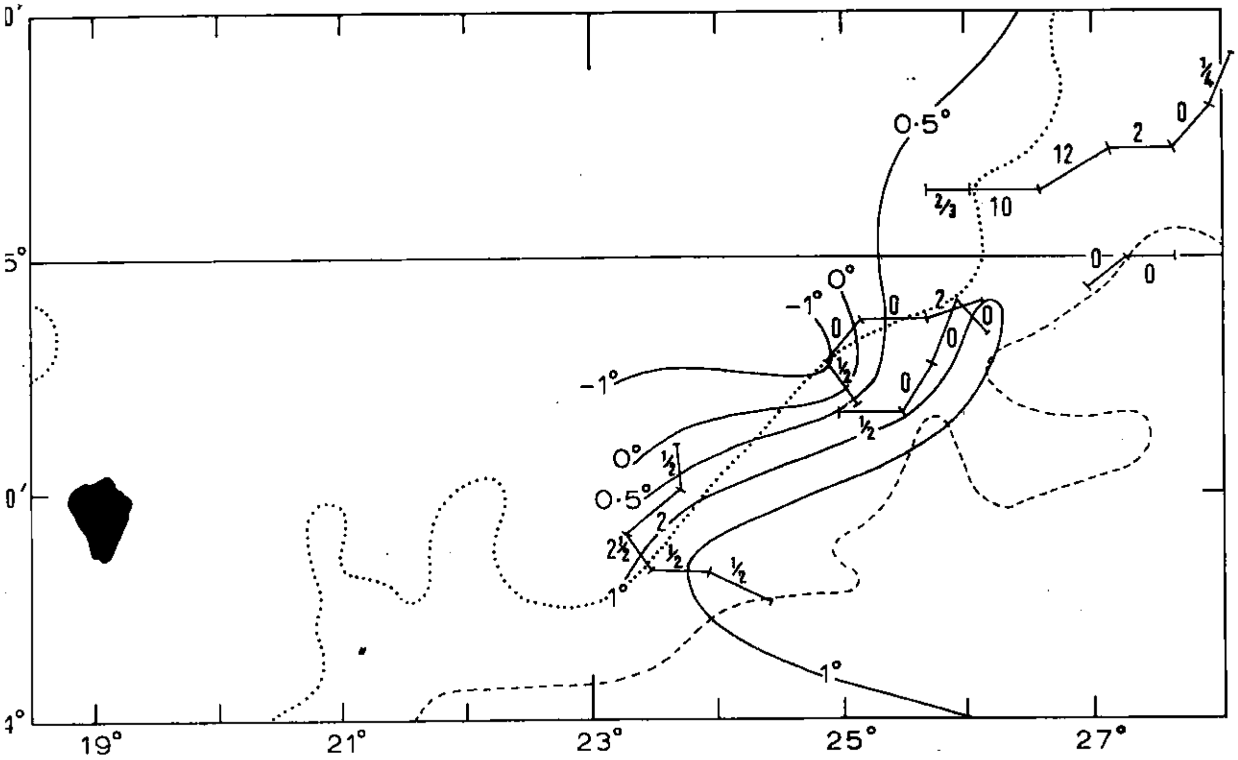
Apart from the unusually cold conditions, 1953 also differed from 1954 in the almost universal occurrence of capelin (*Mallotus villosus*) over all the area from the South-east Gullies eastward. This was by far the dominant food of cod, which were noted as feeding heavily on them in nearly all hauls, irrespective of the quantity caught. Abundant echo traces were also recorded throughout the area and positively identified as capelin on a number of occasions. Here again, therefore, a presumably preferred food of widespread occurrence failed to act as a concentrator of cod. On the last cruise, however, the cod caught just east of the South-east Gullies (Fig. 14) were feeding heavily on herring, so that in this respect also the pattern of 1954 was beginning by the autumn of 1953.

The general temperature conditions in 1953 are similar to those of 1949, in July of which year exceptionally heavy catches of cod were taken at several points on the bank in cold (0.5° to -0.5°C) but shallow water (80-100 fm: 146-183 m) north-eastwards from the South-east Gullies as reported by Graham *et al.* (1954): it was these catches which proved the first clear exception to the general temperature rule for cod distribution. The presence of these fish in cold water at this season became explicable in physiological terms by the later work of Woodhead & Woodhead (1959); yet there were no signs of fish migrating onto the shelf in 1953. In fact, catches comparable in size to those of 1949 were never obtained again east of the South-east Gullies in any subsequent year, cold or warm, except in May 1950 when, as reported by Lee (1952), up to 150 baskets/hr of cod feeding heavily on capelin were taken in the area between 90-110 miles east of Bear Island in bottom temperatures between 2° and 3°C in 160-170 fm. (293-311 m), and again in the summer of 1951 when catches up to 40 baskets/hr were obtained south of Hope Island (just north of the area shown in Figs. 12-14) in cold shallow water. Commercial fishing concentrations also occurred still further to the north-east on the banks east of Hope Island in the late 1940's, but these too appeared largely to have ceased during the early 1950's and did not start again in these areas until 1957.

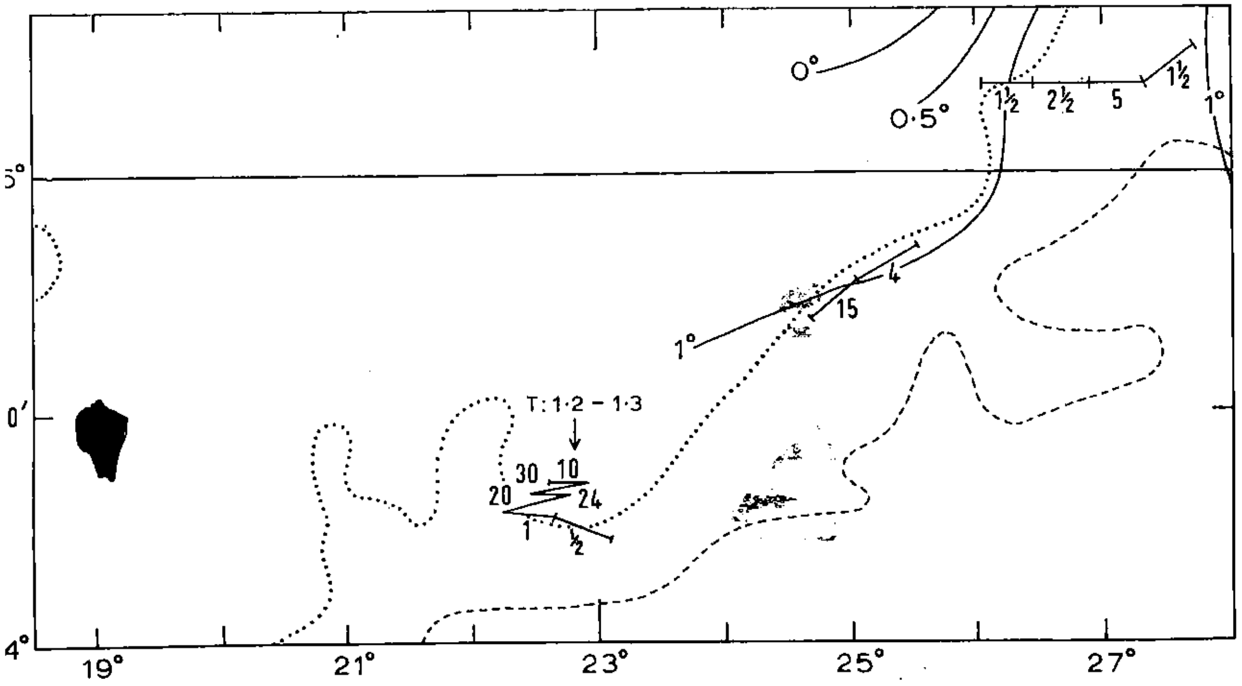
There is no immediate explanation for this change beyond the fact that in these earlier years (*e.g.* 1949) the fish were mainly of age-groups VI-IX and many had spawned at least once, and that the general abundance of these age-groups in the Arcto-Norwegian stock as a whole had certainly declined by the 1950's. Even so, there should still have been sufficient fish to have given at least moderate catches had they shown the same tendency to migrate on to the banks in the summer as in earlier years. The real answer may possibly lie in a change in the main current system near the north Norwegian coast influencing the direction in which fish left the spawning grounds, rather than in the hydrography on the shelf itself.

THE WESTERN EDGE OF THE SPITSBERGEN SHELF, 1956

During the course of two cruises by the *Ernest Holt* in May-August 1956 it was possible to survey the distribution of fish along the western edge of the Bear Island Bank using the echo-survey method described by Cushing in Richardson *et al.* (1959). In this the ship proceeds at her cruising speed along a grid laid out over a wide area, the echoes from fish in the first fathom above the sea-bed are observed on a cathode ray tube, and the total signal from them over a unit distance is measured. By measuring the total signal obtained during trawl hauls and comparing



ig. 13. Catches of cod and the distribution of bottom temperature east of Bear Island, 4-13 July 1953.



ig. 14. Catches of cod and the distribution of bottom temperature east of Bear Island, 17-22 October 1953.

them with the catches expressed in baskets per hour it is possible to obtain a signal/baskets per hour relationship which can be used to estimate the catch over the whole area surveyed.

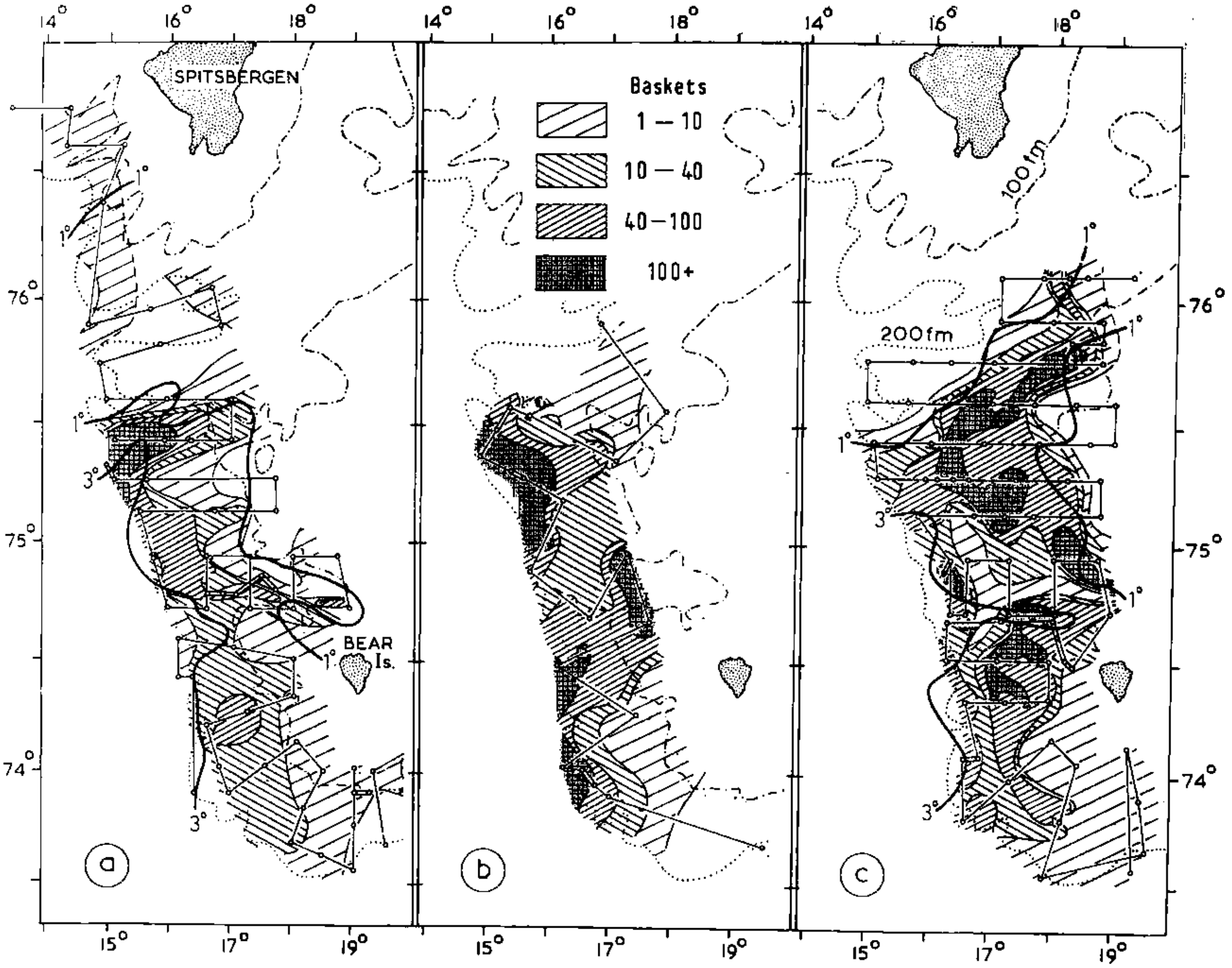


Fig. 15. Distribution of echo survey signals in the fathom above the bottom and the distribution of bottom temperature on the Spitsbergen Shelf.
(a) 29 May-4 June 1956.
(b) 4-6 June 1956.
(c) 11-17 June 1956.

The results obtained by using this technique during Cruise IV/1956 of *Ernest Holt* have already been described by Richardson *et al.* Their charts for the three surveys carried out along the western edge of the Bear Island Bank during the period 29 May-17 June are shown here as Fig. 15. On these charts the catch (baskets/hr) estimated from the total signal recorded during units of 15 min of steaming time (about 2½ miles) has been contoured. Caution is needed in interpreting the finer details of these contours since the fish echoes often occurred in patches separated by periods when few or no signals were recorded, even within a unit distance of ship's track; and with this degree of discontinuity the joining-up of contour levels between adjacent tracks of the grid may not always be fully justified. Nevertheless, the general picture of the fish distribution and, in particular, its changes in time during the period May-August, are shown well by these echo-surveys. Several trawl hauls were made during the surveys which confirmed that for all practical purposes the fish responsible for the echoes were cod.

On the first survey, signals indicating a level of catch of over 10 baskets per hour were observed along the whole of the western edge of the Bear Island Bank from south-west of Bear Island to the southern edge of the Storfjordrenna, but not beyond this trench. The heaviest concentrations, over 40 baskets per hour, were observed at the entrance to the Storfjordrenna, at the entrance to the North-west Gully, and to the west of Bear Island. The bottom temperature distributions on the first and third surveys are shown in Fig. 16 and it can be seen that the fish were not limited by the 2°C isotherms, but that on the whole they were in water warmer than 1°C. Further, the heaviest concentration, at the entrance to the Storfjordrenna, was at a point where warm water was pushing into that gully, and the heavy concentration in the North-west Gully was also in an area where an offshoot of the warm West Spitsbergen Current was pressing eastwards.

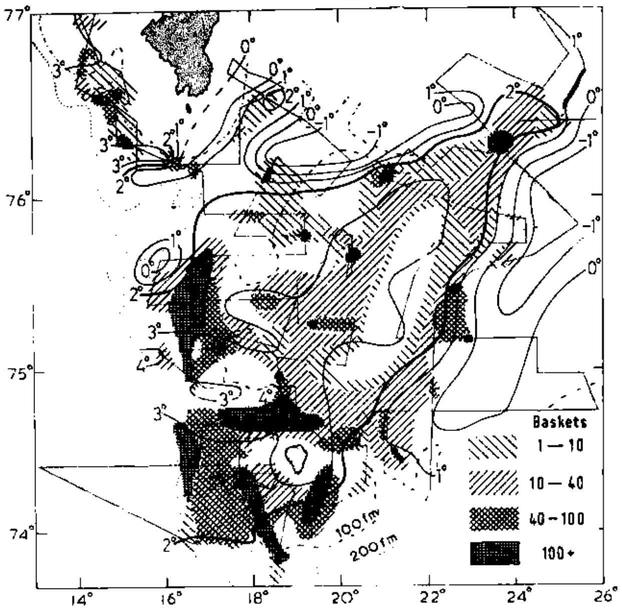


Fig. 16. Distribution of echo survey signals in the fathom above the bottom and the distribution of bottom temperature on the Spitsbergen Shelf.
24 July-15 August 1956.

The second and third surveys showed a rapid movement of the fish concentrations eastwards on to the shelf, particularly in the Storfjordrenna. On the third survey the concentrations were still in water warmer than 1°C, and there had been a marked extension of this water eastwards along the southern edge of the Storfjordrenna and in the region between this trench and the North-west Gully at the same time as the fish concentrations had moved eastwards. Although to some extent this movement of the fish can be interpreted as being a move from deep water into shallow, this could not have been the case in the Storfjordrenna, where the movement was parallel to the isobaths. Furthermore, Fig. 2 shows that between early April and the end of May 1956, there had been a marked increase in the strength of the West Spitsbergen Current: this increase normally occurs at this time of the year, but in 1956, by the end of May, the current had nearly twice its normal volume transport. Although this influx seems to have decreased subsequently and to have reached the normal level by the end of July, it is considered that the remarkable advance of both fish and warm water eastwards in the first half of June was associated with this surge in the current observed at the end of May.

It will be noted that many of the fish on this cruise were in water colder than 2°C. This is not in accord with the findings of Lee (1952): he found that on the comparable dates in 1949 and 1950 the cod to the west of Bear Island were on the whole in water warmer than 2°C, although in 1949 a few paying catches were taken in 1.5°C to 1.0°C. On the comparable dates in 1955, moreover, trawl hauls and an echo-survey in the area between the North-west Gully and the Storfjordrenna showed most of the fish to be in water warmer than 2°C. It would thus appear that along the western edge of the Spitsbergen Shelf the cod are in the warmer water at this season, but that the temperature of this water varies from year to year.

The results of the echo-survey and bottom temperature survey carried out during Cruise V/1956 in July-August are shown in Fig. 16. It can be seen that the advance of the fish and warm water eastwards had continued across the shelf and that the distribution of the fish was now limited remarkably closely by the 2°C isotherm. The heaviest concentrations, however, were still in the same position along the edge of the shelf as on the previous cruise.

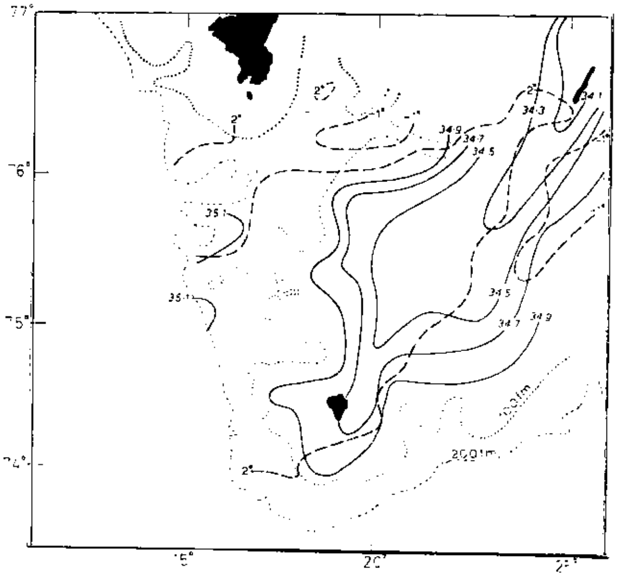


Fig. 17. Distribution of bottom salinity and bottom temperature on the Spitsbergen Shelf. 24 July-15 August, 1956.

It might be thought that the advance of the fish and warm water eastwards was again due to the influx of the West Spitsbergen Current, but Fig. 2 shows that by the end of July this had decreased to its normal level. Further, bottom salinity samples were taken over a wide area on this cruise and the salinity distribution obtained is shown in Fig. 17. It can be seen that the axis of the low salinity water on the shelf, marking the Bear Island Current, lies to the westward of the axis of the low temperature water. If the increase in temperature on this part of the shelf had been due to the advection of Atlantic water one would not have expected this difference in position of the two tongues, and it is considered that summer surface heating is more likely to have been responsible for the rise in bottom temperature. Work carried out by us in 1953 shows that the influence of tidal mixing on the shallowest part of the bank is to prevent the formation of a thermocline and to carry heat right down to the sea-bed. In the deep area further eastward, however, a thermocline is formed and the bottom water remains cold. Thus, although in June the movement of the fish and warm water on to the shelf could be associated with a surge of he West Spitsbergen Current, by July-August some of the fish had advanced on to the shallower art of the bank into an area of water of Arctic origin warmed by summer heating.

DISCUSSION

Earlier publications, covering mainly the southern and western edges of the Spitsbergen Shelf (Lee, 1952; Graham *et al.*, 1954), established that as a general rule concentrations of cod were not ound at bottom temperatures below 1.75°C. Exceptions to this rule were found in July-September n the eastern edge of the shelf between Bear Island and Hope Island (*i.e.*, including the area overed in this paper), when heavy concentrations were located in water as cold as -0.5°C in 1949 nd lesser concentrations in 1950 and 1951. Drawing on additional evidence, including commercial ishing and echo-sounder records, Trout (1957) proposed a mechanism of cod distribution which laced less emphasis on temperature as a determining influence and more on the passive transport f fish in the northerly surge of the West Spitsbergen Current during the first half of the year. e coupled this with the proposition that the fish followed an intrinsic seasonal depth cycle, iving deepest in the late winter and early spring and becoming more pelagic in habit in the summer in response to daylight radiance. The presence of fish in cold Arctic water in summer, he uggested, could have arisen by their movement downwards from warm surface water into cold bottom ater rather than by horizontal migration across the boundary of the two water masses. On the ther hand, the possibility that temperature was having a direct influence on the distribution of od was strengthened by the studies of Woodhead and Woodhead (1959), who showed that except in the onths of July to September certain physiological changes were found in those fish which were in ater below about 2°C; in these three summer months, however, no corresponding changes were observed in fish in temperatures down to -0.5°C. As has been noted above, these are the only three onths when major concentrations of fish have been found in cold water.

The results presented here lend added support to Trout's view of the importance of passive ransport in a definable water mass. The echo-survey results of 1956 show more explicitly than had reviously been possible, by trawling surveys, how the short-term movements of the main cod population on to the western edge of the Spitsbergen Shelf during early summer are closely associated ith the surge of the Atlantic water of the West Spitsbergen Current, but also how later in the ummer the spread of fish on to the shelf is made possible by *in situ* warming rather than by the ovement of Atlantic water. In the opposite direction, the relatively sudden cascading of cold rctic water down the southern slopes of the shelf during the spring of 1955 coincided with an qually sudden retreat of fish to deeper water. More generally, the main features of both the ydrography and fish distribution in the area seem on the whole to follow the seasonal and year-o-year variations in the strength of the West Spitsbergen Current as determined by measurement of ts water transport.

From analysis of otolith structure and tagging results, Trout (1957) concluded that there as appreciable segregation between the fish on the eastern and western sides of the Spitsbergen helf. Those on the eastern side typically possessed a "split ring" otolith structure which Trout ssociated with their entry into cold water to feed in the summer. It is therefore of interest to ind from the 1954 observations on the eastern edge of the shelf that the distribution of these ish, even when feeding, nevertheless coincided in a particularly striking way with sharp temperature gradients while these existed in the early and late periods of the year. Taking the results n both the eastern and western edges of the shelf as a whole, they agree in confirming earlier indings that a temperature a little below 2°C (1.5°C would seem a more precise figure) constiutes an effective limit to the distribution of cod for the greater part of the year.

The observations in the South-east Gullies region show that much of the seasonal depth cycle f cod deduced by Trout, mainly from records of the average depths of commercial fishing, is probbly more a consequence of the seasonal depth change of the boundary between Atlantic and Arctic ater than something intrinsic to the fish. This is evident from a comparison of the fish and emperature distributions in the exceptionally cold spring of 1953, the warm spring of 1954 and he changing spring of 1955. In 1953 the fish were concentrated at even greater depths than would e predicted by Trout's average curve; in 1954 they were very much shoaler; and in 1955 they moved rom shoal to deep water. The boundary of the water masses varied correspondingly. This does not eny, however, Trout's thesis that the pelagic habit of cod in high summer (for which there is now dded evidence from later echo-sounder records) is of significance in enabling fish to complete he final part of their "outward" migration in the warmer upper water layers, from which they may escend here and there into cold bottom water.

The influence of feeding and of the distribution of the food of cod has not hitherto emerged in any clear-cut way, and there is nothing in the evidence presented here to suggest that it is a major factor in determining the general distribution of cod. There are, however, the observations from South-east Gullies region that the presence of a restricted concentration of a preferred food (in this case young herring) may result in significant aggregation of cod on it within a region which is hydrographically tolerable but otherwise featureless; on the other hand, the widespread occurrence of a preferred food has little effect, as was the case with capelin in 1953. It is also clear that the preferred food can change with the hydrographic regime; as the Atlantic influence increased towards the end of 1953 so herring replaced capelin and it remained the preferred food in one locality through 1954 until the Atlantic influence decreased again.

There remains the biological problem of the precise mechanism which causes the cod to be localised - or, more strictly, to appear to be localised - for much of the time in a particular water mass. The three most plausible assumptions, acting separately or together, would seem to be

(a) that the fish are responding directly to the temperature gradient between the water masses by some directional behaviour mechanism

(b) that fish are responding to some difference between the water masses other than temperature, of which differential currents at their boundary seems the only likely feature

(c) that fish are not inhibited from crossing the boundary between the water masses and in fact do so, but die rapidly after entering cold water (except in the high summer), thus giving the impression of a positive behavioural response to the boundary.

Such evidence as there is seems mostly inconclusive in distinguishing between these, except perhaps that the last is unlikely to be a major factor in as much as dead fish have not to our knowledge been reported from cold water in this region, although there is abundant evidence from other areas that low temperatures can and do constitute a major cause of death of cod in certain circumstances (Woodhead and Woodhead, 1959). Disentangling the directional influences of temperature gradients and differential currents is particularly difficult from evidence of the kind presented here, since it follows hydrodynamically that the steeper the temperature gradient the more contrasting the currents are likely to be at the interface. Many of the observed temperature gradients are, in reality, so slight that it is difficult to imagine how fish could respond directionally to them. This may not have been the case at the boundary of the cold tongue in 1954 (Figs. 4-5). Here, the steepest temperature gradient, as judged from the spacing of the isotherms, was about 3°C in a distance of five miles. Accepting the experimental evidence of Bull (1952) that cod can detect a minimum temperature difference of 0.05°C, this means that a fish would have had to swim a distance of at least 150 m before it could detect a change in temperature. The true local temperature gradients may, of course, have been sharper than this, yet for such a structure to have remained localised and evidently stable for a period of several weeks there must have been strong lateral shearing between the water masses in the region of the steep temperature gradient, with the current flowing parallel to the isotherms. Fish in the region of the temperature gradient and in contact with the bottom are likely to have been facing predominantly into the current (whether actually progressing contranatantly or not is immaterial) and to have aligned themselves in a direction parallel to the boundary, and hence they were unlikely to cross it. Again when in the summer of 1956 *in situ* warming on the bank caused the temperature difference between the West Spitsbergen and Bear Island Currents to tend to disappear, fish evidently moved from one water mass to the other; but any current differential that may have previously existed is also likely to have decreased at the same time, and so the respective effects of temperature and current again cannot be disentangled. It would appear that an investigation is called for which analyses conditions around a cold tongue in great detail and which does this by using the echo-survey method together with techniques for measuring currents near the sea-bed and for the continuous recording of temperature against distance over the sea-bed.

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A-15

DATA ON THE DISTRIBUTION OF TUNA CONCENTRATIONS DURING THE FEEDING PERIOD IN THE TROPICAL ATLANTIC OCEAN[1]

By

V. L. Zharov[2]

ABSTRACT

The results of Soviet research fishing expeditions to the Gulf of Guinea and to the region off the northeastern coast of Brazil during 1959-63 are considered.

The distribution of tuna concentrations in both areas is determined first of all by the presence of frontal zones, either between water masses with different characteristics or between the surface waters of these regions and deep waters rising to the surface. Within such frontal zones waters with a high content of biogenic elements and most often characterized by low temperatures are found close to waters carrying a great supply of heat but poor in biogenic elements. Such a combination of high content of biogenic elements and a great supply of heat favours the development of organic life and results in the formation of areas of high biological productivity within the frontal zones. In their search for food, young fishes, many small fishes and large invertebrates (squids) and the tuna which follow them, tend to concentrate within these productive areas or in areas lying close to them. Thus the search for food is the main factor in the concentration of tuna in these areas of the tropical Atlantic Ocean.

Furthermore, in some regions within the frontal zones conditions exist which prevent the movement of some species of tuna in any direction. Factors limiting the movement of tuna include the horizontal and vertical location of the 20°C isotherm and the 35°/oo ishaline. The occurrence of waters with a temperature below 20° and a salinity below 35°/oo in the upper layers of the ocean acts as a barrier to tuna shoals and they concentrate near to the boundaries of these waters.

EDITORIAL NOTE:

As this paper deals with an area not strictly within the terms of reference of the ICNAF Environmental Symposium, Rome, 27 January-1 February 1964, only an abstract is published here. It was, however, presented in extenso at that symposium.

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A-16

INTERPRETATION OF FISH DISTRIBUTIONS IN RESPECT TO CURRENTS IN THE LIGHT OF AVAILABLE LABORATORY AND FIELD OBSERVATIONS[1]

By
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ABSTRACT

The existing knowledge of the response of fish to currents and the orientation and other behaviour of fish in currents is reviewed. The difficulties of observing and relating fish behaviour to currents are pointed out and it is suggested that these aspects be investigated through tests of pre-established hypotheses, several of which are established in this paper. The combined effects of currents and other environmental factors are described through examples from literature. A model of the behaviour of fish in respect to tidal currents is constructed. Some aspects of the seasonal migrations are analyzed in relation to current patterns. The possible effects of current boundaries on the aggregation and migrations of fish are described. These aspects of fish behaviour in currents which promise direct application in fish location and in practical fishery are emphasized.

INTRODUCTION

Several recent investigations tend to show that advection is the greatest component causing local changes of environmental properties in the sea. Fish can be expected to respond directly to those environmental changes caused by currents and, also, to respond directly to and orient in the current. Unfortunately, it is extremely difficult to observe directly the behaviour of fish in currents in the natural environment. Therefore, very few direct publications on the subject are available in literature. If one wants to clarify the interaction between fish behaviour and currents, one has to draw upon the knowledge from pertinent laboratory experiments, knowing that these experiments do not exactly reproduce complicated nature. A useful way to gain more insight on the influence of currents on fish is through testing of pre-established hypothetical models.

It could be expected that currents will affect the following aspects of fish behaviour:

1) Transport of fish eggs and larvae from spawning areas to nursery grounds and from nursery grounds to feeding grounds. Thus, any abnormality in this transport would affect the survival of a given year brood;

2) Currents might serve as the orienting means for the migration of adult fish;

3) Currents might affect the diurnal behaviour, especially in relation to tidal currents;

4) Currents, especially current boundaries might affect the distribution of adult fish, either directly or indirectly, through the aggregation of fish food or by determining other environmental boundaries;

5) Currents might affect the properties of the natural environment, thus determining the abundance and occurrence near the limits of the normal geographic distribution of given species.

The following summary deals with adult fish in relation to currents. It attempts to summarize the essentials of past investigations on the subject and to establish some hypothetical models of behaviour which need careful testing in nature before they can be accepted as valid.

The influence of currents on fish stocks is greatest in the egg and larval stages. Excellent investigations on this subject have been conducted by Walford (1938), Carruthers *et al.* (1951) (who also suggest the future approach for prediction of year-class strength from the wind current data), Rae (1957), Bishai (1960), Hela and Laevastu (1962). These aspects will not be discussed in this paper.

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RESPONSE OF FISH TO CURRENTS

Bull (1952) found in his numerous, carefully designed laboratory experiments on the behaviour of fish in relation to hydrographic factors, no response of fish to the rate or direction of current flow and was unable to condition the fish to the current. Several other laboratory and field observations have shown that fish respond and react to currents and their changes in various ways. Elson (1939) found that a sudden increase in current strength and the amount of turbulence resulted in increased activity of speckled trout. In still water, the activity took the form of random wandering. The increased activity while in the current was manifested by movement upstream. Brawn (1960) observed that herring responded to real and apparent currents greater than 3 - 9 cm sec^{-1} by swimming upstream at a rate in excess of the current speed until the maximum swimming speed had nearly been reached. It is possible that there is a lower threshold value of current speed to which fish react and this threshold value may vary from species to species.

Aleev (1958) analyzed the adaption to movement and manoeuverability of fish. He has classified 25 species according to horizontal and vertical manoeuverability and the coefficient of resistance for rectilineal movement. It is obvious from his work that different species must react differently to currents, and it is not possible to generalize results obtained with a given species to all fish.

Most field and laboratory observations show that fish usually head to the current. It has been observed that a fish also heads to the current when it lets itself be carried along with the current. However, if the fish turns downstream in the current, it usually swims faster than the current. In weak currents, other directions and orientations can be observed.

It has been observed that fish are inactive in cold water and allow themselves to be carried along with the current (*e.g.*, herring during winter in the Norwegian Sea). It has also been found that when pelagic fish are feeding, they usually drift with the current (Bullen, 1912).

It can be noticed that the orientation of fish within the school and the movements of the schools of herring might be regulated by currents because in the net fishery for herring, the fish go into the net usually only from one side in a given night and only on rare occasion from both sides.

It has been further observed with fresh water fish that light plays a role in the orientation of fish to the current. Fish are observed to swim against the current in the light but drift with it in the dark. The behaviour of adult fish in respect to currents (as well as in respect to other environmental conditions) depends also on the physiological stage (*e.g.*, maturity stage) of the fish.

Some data on the observed and measured swimming and cruising speeds of fish have been summarized in Table 1. Swimming and cruising speeds obviously vary with the size of fish and also from species to species. Some observations also show that the swimming speed is greatly affected by the prevailing temperature. Brett *et al.* (1958) found that the optimum cruising speed of sockeye salmon was at 15°C and that of coho at 20°C. However, Blaxter and Dickson (1959) found no obvious correlation between the average maximum swimming speed and temperature. Blaxter and Dickson (1959) estimated that small fish (smaller than 30 cm in length) can swim about 10 body lengths per second, and the speed increases less above this body length than in the proportion mentioned.

It has been observed that fish cannot maintain the maximum speed for a long time and the cruising speeds are usually much lower than the maximum swimming speeds observed in the experiment. Some idea of the cruising speeds of fish can also be obtained from the pelagic trawling experiments. Schärfe (1959) found that the minimum speed required for the catching of sprat with a pelagic trawl was 2.5 knots, and for the catching of herring in the North Sea 3.5 knots. It can be tentatively concluded from various data that for small and medium size pelagic fish, the cruising speed is ca. 2.5 knots during the daytime and the day and night average is ca. 1.5 knots.

TABLE 1. SWIMMING AND CRUISING SPEEDS OF FISH

Species	Speed *cm sec*$^{-1}$	Remarks	Author
Young sockeye and coho salmon	30-40	Maximum sustained speed	Brett, Hollands and Alderdice (1958)
Herring larvae	0.58-1.03	Critical velocity	Bishai (1960)
Herring	91	Maximum speed for 15.2 cm fish	Brawn (1960)
Herring	143	Maximum speed for 26.7 cm fish	Brawn (1960)
Cod (12 - 56 cm)	75-210	Maximum speed	Blaxter and Dickson (1959)
Herring (1 - 25 cm)	3-170	Maximum speed	
Mackerel (33 - 38 cm)	189-300	Maximum speed	
Plaice (6 - 25 cm)	6-129	Maximum speed	
Horse mackerel	5-55	Observed speeds; most frequent 25	Kawada, Tawara, and Yoshimuta (1958)

COMBINED EFFECTS OF CURRENTS AND OTHER ENVIRONMENTAL FACTORS ON FISH BEHAVIOUR

The behaviour of fish in relation to the environment might be, in most cases, a result of a combination of the influence of several environmental factors together. It is obvious to connect the diurnal behaviour with the diurnal change in light conditions which, when combined with currents (*e.g.*, tidal) can considerably affect the distribution of fish. Davidson (1949) reported experimental results which indicate that salmon swim during the day and rest on the bottom at night, whereas, eels burrow in the gravel in bright daylight, come out in the evening and translocate rapidly even at night when the salmon are resting. As already mentioned, it has been observed in fresh water fish that they swim actively against the current during the day, whereas, they drift with it during the night.

The temperature of the water can be expected to greatly affect the migrations and transport of fish by currents. It has been observed that in colder, near 0°C waters, fish are inactive and are carried with the current. This fact is assumed to affect the Norwegian herring migrations: Those herring aggregate in the cold water pocket east of Iceland during the early winter, and are assumed to be carried into this convergence area by a branch of the East Greenland Current. When these cold water pockets are cut off into the warmer Norwegian Current waters and sink, the fish come into the warm Norwegian Current waters and start their active migrations to the spawning grounds in the Norwegian coastal areas.

Trout (1957) described the migrations and movements of the Bear Island cod. This description illustrates the seasonal interactions between currents, light and seasonal migrations. The conclusions were as follows:

"Water movement is responsible for the changes in distribution of the Arcto-Norwegian cod.

Yet, this is only a secondary effect of their changing behaviour in respect to changing light conditions which results in their primary annual vertical migration and their annual depth range.

Winter, rheotactic, contranatant migration takes place on the bottom in the absence of light during the period of annual water transport maximum.

Summer, passive, or denatant migration takes place during the lower summer peak of water transport at which time the cod shoals are largely pelagic in response to light. They are, thus, capable of being displaced horizontally, relative to the bottom, by movement of the water mass containing them. Maximum horizontal displacement is not achieved because a portion of the shoal spends a part of each 24 hr on the bottom. All known geographical limits of fishing are well within this maximum distance. Variations in summer transport values will affect the limits reached by shoals from year to year. Therefore, distribution is the resultant of interaction of changing behaviour with the cycle of movement of the water masses in which the cod are found.

Normally, fish would tend to remain in their particular water mass, but transference from one water mass to another may take place as a result of changes in behaviour. In the absence of water movement, horizontal movement will be of limited extent, but the annual depth range would be expected to persist."

Fraser (1958) assumed that the diurnal migrations of fish and plankton also play their part in the transport of fish by currents, as for example, when the organisms are at the surface at night and are drifted in one direction, and in the daytime are returned by deeper currents running in the opposite direction.

The behaviour of fish in relation to light and currents might be valid also for other areas and species and merit testing with available distributional data. An analogous hypothetical behaviour pattern in relation to tidal currents is given in the section on these below.

LARGE SCALE TRANSPORT AS A FACTOR DETERMINING FISH DISTRIBUTION

It could be assumed that one of the main factors affecting the year to year variations of availability of fish in any given ground might be the prevailing currents, as affected by the year-to-year anomalies of winds; and that the same methods as suggested for the prediction of the brood-strength fluctuations (Carruthers, *et al.*, 1951) could also be used for the prediction of the availability of adult fish. Craig (1958) has shown that the availability of herring four years old and older in the Buchan pre-spawning fishery is related to the wind and temperature during the catching season. Obviously, the temperature can be greatly affected by the advection, and thus, the whole fishery might be directly related to currents which in turn are related to winds.

Based on the advection and temperature ranges, Craig (1958) devised a formula to predict the catches of herring in the Buchan fishing grounds. The main basis for such a prediction is the analysis of the anomalies of winds.

Fraser (1958) analyzed the influence of current transport of egg and larvae in the North Atlantic and the significance of this transport on the recruitment of given fish stocks, and found that some stocks are entirely dependent on broods from "downstream" spawning grounds.

The seasonal behaviour and migrations of fish might also be related to current patterns. The eggs and larvae are transported with the current from the spawning ground. At a certain stage of life, the fish have to begin swimming actively against the current to reach the spawning grounds again. This migration cycle may even be an annual one. Spawned fish, being weak after this process might be carried with the currents to the feeding grounds and must swim back later to the spawning grounds against the current, thus completing one cycle per year. This can be illustrated with the example of the Arcto-Norwegian cod which cover the whole of the Barents Sea and West Spitsbergen waters in their summer feeding migrations and come together to spawn in the early spring off the Lofoten Islands (Corlett, 1956). The current charts show that fish as well as larvae can be carried in the West Spitsbergen and North Cape Current as far as the Bear Island area. Thus, the products of the spawning in the West Fjord in spring are distributed over the feeding grounds of the western Barents Sea by autumn. This recurrent system and the spawning grounds in relation to it has been described by Lee (1952) and by Corlett (1959). A similar situation might exist in the Northwest Atlantic as well.

Lee (1961) has further analyzed the variation of the volume transport of the West Spitsbergen urrent and showed the dependence of this current on the development of the polar high pressure ystem. He has also suggested the possible process of cooling and anomalous advection in the area.

Rodewald (1960 *a,b,c,d*) has analyzed the fluctuations of the landings and availability of ifferent commercially important fish stocks in the Barents Sea, Labrador area, and Icelandic aters in relation to the anomalies of winds. All his results indicate that anomalous water transort caused by large scale variations of atmospheric pressure and winds determine the availability f a number of commercially important fish species, especially in northern waters where they are istributed close to the boundary of their normal range. By predicting the wind and pressure anomlies and the resulting anomalous currents, one would be able to predict the availability of fish n those fishing grounds. One of the biggest year to year fluctuations of the availability of elagic fish is that of the California sardine. This fluctuation has been described as being due o changes in the current system (Cal.Coop. Oc. Fish. Invest., 1953). It is assumed that a strong ountercurrent in the spring and early summer would affect the northward migration and physical ransport of sardines. If the countercurrent remains strong throughout the year, the southward eturn against the current would impede the fish, and therefore, the sardines would reach the pawning grounds later in the year. The heavy countercurrent along the coast also causes the emperatures in the inshore areas to be higher than average. Thus, if it is the cooling of the ater due to the onset of winter that causes the sardines to migrate southward, the beginning of he migration would be delayed. Further, the abundance of California sardines may be influenced y the transport of egg and larvae.

A preliminary study of the boundaries of ichthyofaunal regions of the world in relation to urrents indicates that sharp changes of fauna occur where the permanent currents along the coasts re strong, exceeding one knot. The species inhabiting the downcurrent waters have especially harp distributional boundaries in the Agulhas, Kuroshio, and Florida currents. Currents weaker han the above mentioned might well establish distributional boundaries of less mobile species uch as flatfish.

FISH IN RELATION TO TIDAL CURRENTS

One of the first to describe the possible relation between herring catches and tides was ester (1938) who discovered an inverse relation between the tidal difference and herring catches n the British Columbia waters. His explanation was:

> "At present, therefore, it would seem that the most plausible explanation of why herring are ore available in the Swanson Channel fishery during the first and third quarters of the moon and ess available during the new and full moon lies in the effect of tides on the movements of hering."

Tester further assumed that strong tidal currents affect the transport of herring to and from arious areas. The interaction between diurnal behaviour and strong tidal currents might affect he transport of any fish. Assume that a fish species spends the day on or close to the bottom and ises into the water mass during the evening. Assume also that strong diurnal tides prevail in a iven locality. In these conditions, the fish are expected to keep a given position on the bottom uring the day, but are most probably carried along with the tidal currents during the night. In he case of diurnal tides, the ebbing current dominates during the night for about two weeks. The ish may be transported in one direction during this period and carried back again during the next wo week period.

Jones (1957) studied the movements of herring shoals in relation to tidal currents in the North ea. His conclusions were:

> "Echo surveys carried out in the Calais region in December 1955 show that herring shoals move n the same direction as the tidal currents. It is most likely that these observations were made n herring which had not yet spawned.
>
> It was not possible to come to any definite conclusion as to whether the fish were stemming he current, swimming with it, or being carried along passively.
>
> One set of results suggested that the herring were stemming the current at a swimming speed f 1 to 2 knots although they were being carried along the ground."

There are several fishing methods which rely on tidal currents. One, most peculiar, is the so-called bag net fishery off Bombay where the fish are carried by strong tidal currents into big, anchored bag nets. It seems that the fish stem the current but are transported with it, being relatively sluggish in the low oxygen content water on the Bombay continental shelf.

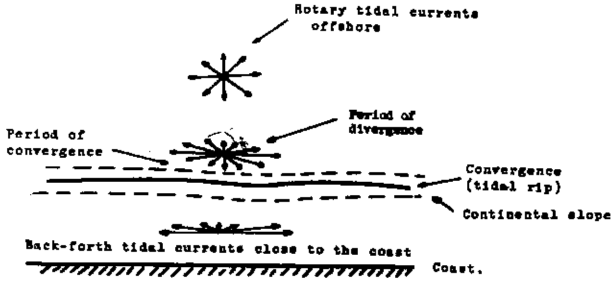

Fig. 1. Scheme of coupling of coastal back-forth and offshore rotary tides.

The present author has observed the aggregation of fish (nehus, dolphins, sharks, and other species) along the island slopes of the Sandwich Islands where a convergence is caused by the prevailing tidal currents. The scheme of this convergence is shown in Fig. 1. It is possible that smaller fish and other fish food are aggregated on this current boundary by the tidal currents and bigger fish aggregate there actively for feeding purposes. Some of these problems are examined in the next section.

EFFECTS OF CURRENT BOUNDARIES ON THE DISTRIBUTION OF FISH

Zusser (1958) described the theory that commercial aggregation of fish usually occurs in the centers of the eddies of currents where fish rest. His explanation points to the fact that the fish usually stem the current and need occasional rest.

Orton (1937), Redfield (1939, 1941) and Laevastu (1962) have shown, at least partly, that the retention and accumulation of plankton, fish egg, and larvae occur in the centers of anticyclonic eddies on the northern hemisphere. This aggregation might also be connected with (*e.g.*, through feeding) the aggregation of adult fish in the current eddies. Local eddies are caused by the morphology of the coast and configuration of the bottom. Therefore, local knowledge of the details of the currents would play an important role in the locating of fishable concentrations of fish, if the fish distribution is affected by eddies.

The current convergences cause a "mechanical" aggregation of forage organisms and also small fish. This hypothetical mechanism of concentration has been described by the present author (Laevastu, 1962). For a long time, Japanese tuna fishermen have made practical use of this knowledge to locate concentrations of pelagic tunas. The convergence between cold and warm currents are found to be especially rich. Here, in addition to the transport, high basic organic production may play an additional role. The convergences usually change positions during the year in medium and high latitudes. The Japanese salmon fishery in the Bering Sea follows the movement of the eastern convergence of Oyashio towards the northwest during the salmon fishing season. The bulk of the largest catches of pelagic salmon are obtained at the convergence.

Uda (1936) stated that the 'saury' *(Cololabris saira)* stays in the areas between the boundaries of the Kuroshio and Oyashio Currents, and always migrated toward the maximum gradient of surface temperature. According to Uda (1952) the best areas for pelagic fishery in general are the convergences of currents.

The relation between convergences and fish aggregation might not be a simple statistical one. Three hypothetical conditions must be recognized in this relation.

1) The converging currents might be weak, below the threshold value for orientation of fish. Zooplankton is slowly accumulated at the convergence and the aggregation of fish might still occur on prey. Because of this the convergence might act as an environmental boundary.

2) The converging currents might be of medium strength. Fish orient to the current and aggregate at the "upcurrent" end of the convergence. Slight accumulation of zooplankton occurs.

3) The converging currents might be strong. Fish head the current and are carried along with t. Fish aggregation at the "downcurrent" end of the convergence is possible. Because of the trong current no aggregation of zooplankton occurs.

Several hypotheses on the effects of currents need testing with observational data, the obaining of which requires at times the help of experienced fishermen.

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A-17

FISH MIGRATION AND WATER CURRENTS

By

F.R. Harden Jones[1]

ABSTRACT

The relations between fish migration and water currents are presented with reference to a heoretical framework linking gyrals, production and fish movement. The terms denatant and contra-atant are discussed and suggestions are made as to the biological significance of migration and oming. The conditions under which fish react to water currents and the nature of the response rovide the basis of making a distinction between migration on the open sea and migration on the ontinental shelf. In the open sea oceanic currents are important in the surface waters and fish hould be carried passively with them. Seasonal or diurnal vertical movements would allow fish to ove into a counter-current or into faster or slower water. A comparison is made between fish and ocusts. Passive drift could enable the fish to be carried into areas of high production (upwellng zones, polar fronts) and the problem then becomes that of the control of the timing mechanism hich ensures that the fish leaves and joins the gyral, or the counter-current, at the appropriate oment. On the continental shelf tidal currents are often more important than oceanic currents. n shallow water complications arise as the combination of changing tidal current and diurnal verical migration allows a complex interaction between passive drift and orientated movement by isual or tactile contact with the bottom. A model is presented to study the horizontal displaceents resulting from such an interaction in the case of Downs herring migrating down the Southern ight of the North Sea in the autumn. The model, based on tidal data and what is known of the ehaviour of the herring, shows that the fish are carried to the south towards their spawning rounds. Reversing this line of approach predictions are made of currents based on knowledge of he movements of fish. Counter-currents should be present to carry the European eel to the Sargasso, he Arcto-Norwegian cod to Lofoten, and the south-west Greenland cod to Iceland. Reference is made o Sund's reports of a deep south-going current off the Norwegian coast carrying cod from Andenes o Lofoten.

INTRODUCTION

Fish migrations are thought to conform to the pattern shown diagramatically in Fig. 1. The arvae drift from the spawning ground to the nursery ground. From the nursery ground the juveniles ecruit to the adult stock. The adults migrate to the spawning ground and return later as spent ish to the feeding ground. These movements are, in general terms, related to the water currents. he drift of the larvae is downstream and with the current. The adult spawning migration is against he current, and that of the spent fish with the current. From the association between the moveent of the spawning fish and that of the water current it is often inferred that the latter proides a directional clue during migration. As this hypothesis appears to be widely accepted, the elation between fish migration and water currents will be considered more closely.

A THEORETICAL FRAMEWORK

A pelagic fish, with pelagic eggs and larvae, living within a region covered by an oceanic ddy or gyral, and carried passively within the system, is essentially a planktonic organism, hower strong a swimmer it may be. In marine tropical waters it is not unreasonable to suppose that he environmental conditions would be favourable for the development and survival of eggs and larae at all seasons of the year and throughout the whole region covered by the eddy. Production in ropical waters is probably continuous, and perhaps even a steady state process (Cushing, 1959), nd food, if available at all, should always be present in sufficient quantities for the larvae. gg production could be continuous as Quasim (1955) suggests. Eggs, larvae, young and adult fish ould be found together, but possibly at different depths, and the species would have a continuous istribution throughout the region of the eddy, as shown diagramatically in Fig. 2A. This pattern ay be characteristic of tropical oceanic species, and under these conditions the pelagic fish has o biological need for a definite spawning area or season. Young fish that are carried out of, or

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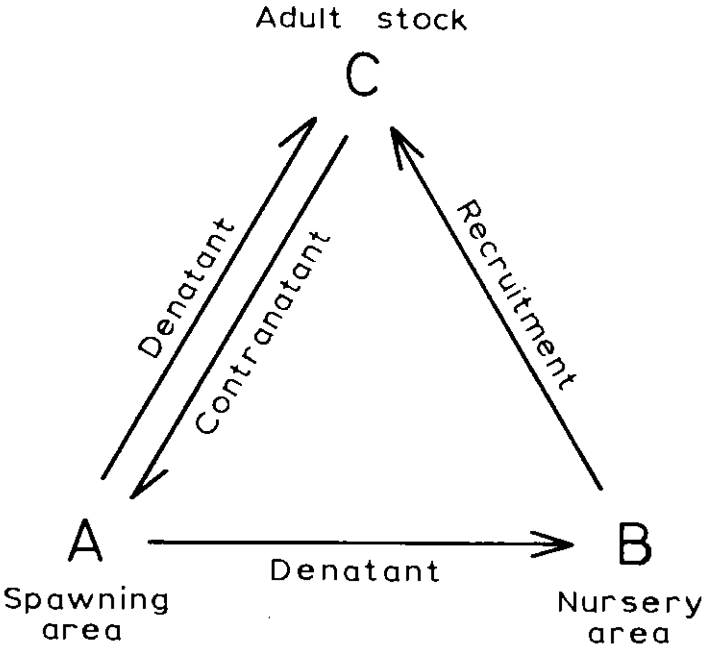

Fig. 1. A simple diagram to illustrate the general pattern of fish migrations.

escape from, the system would, so far as reproduction is concerned, be waste material. But if the eddy system extends from the tropics into temperate or arctic water there would be environmental differences within the region covered by the gyral. The water may change its character as regards temperature and salinity, so that while the older fish may be able to live anywhere within the system, the younger stages could not do so and spawning would only be successful within a limited area. In temperate and arctic waters the production cycle differs from that found in tropical waters. Food is unlikely to be available in more or less equal quantities throughout the year. If the young are to survive the adults must spawn, not only at the right place, but also at the right time. There must be an annual cycle of activity in the gonads and, as shown in Fig. 2B, egg production will be limited to a particular season. The distribution of the species becomes discontinuous and it can only survive as a passive, planktonic organism if the processes of growth and maturation are geared to the circulation time of the eddy so that sufficient numbers of mature and ripe adults are brought into the spawning area at the right time. If the adults take to the bottom, or leave the gyral for a time (Fig. 2C), they could still reach the spawning area by rejoining the system later. But there may be an environmental barrier, such as temperature, which prevents the mature fish completing the circuit, or the gyral itself may be broken by some geographical barrier (Fig. 2D). Under these conditions the adults must return to the spawning ground in the opposite direction to the current in which the eggs and larvae were carried.

DENATANT AND CONTRANATANT MOVEMENTS

Meek (1915) introduced these terms. Denatant means swimming, or drifting, with the current; contranatant means swimming against the current. Thus one would speak of the denatant migration of the pelagic eggs and larvae, and the contranatant migration of the adults towards the spawning area. Now it is important to be clear as to what water current the adults are supposed to migrate against. The biological significance of the migration of the ripening fish is that it is in the opposite direction to the current which carries the eggs and larvae away from the spawning area.

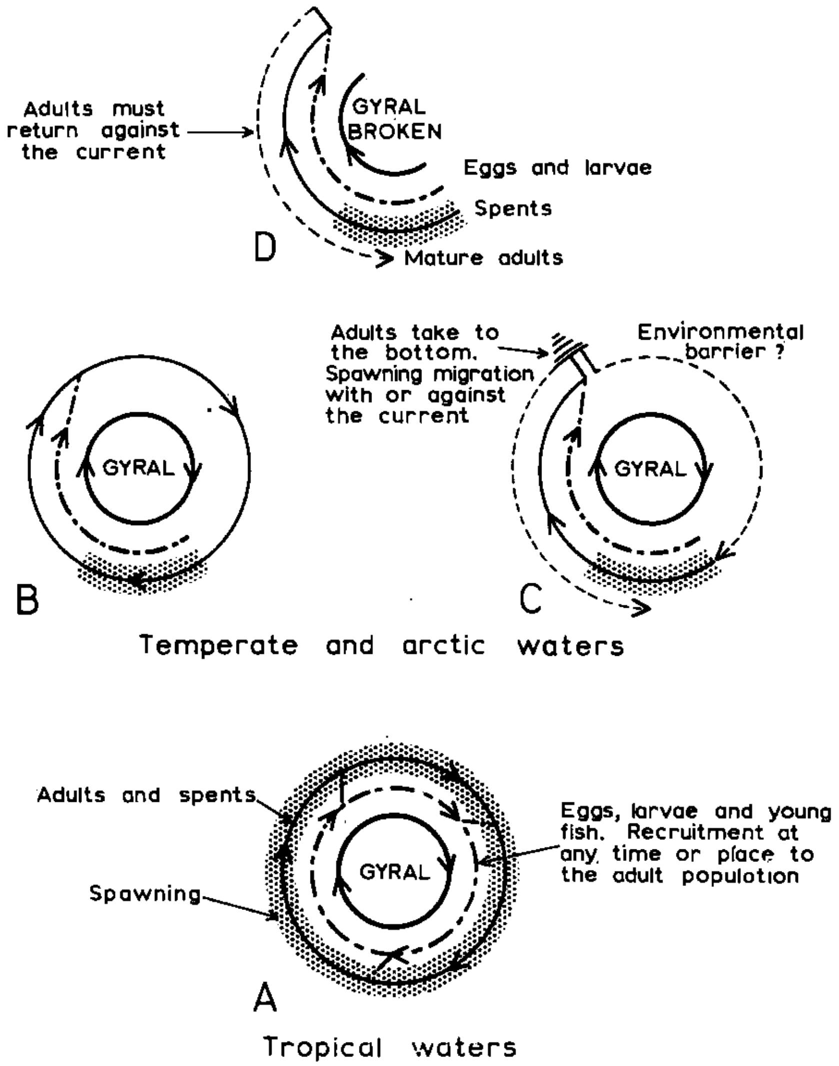

Fig. 2. The relation between oceanic gyrals, production, spawning and fish migration in different water masses. A. Gyral restricted to tropical waters; production and spawning continuous. Gyral extends into temperate and arctic waters. B. Production and spawning restricted, gyral complete. C. Production and spawning restricted, gyral complete, but adults may become demersal or there may be an environmental barrier which prevents them completing the circuit. D. Production and spawning restricted, gyral broken.

t this does not mean that the adults always have to swim against a current, that is, upstream, spawn. In the sea, and even in fjords or lakes, there may be the possibility that the adults, iving in deeper water than the younger stages, are moving with the stream in a counter-current ing below that in which the eggs and larvae are carried in the opposite direction. I think that ch a migration should be thought of as contranatant even if the adults are swimming, or even rifting passively, in a counter-current towards the spawning area: one of the points of Meek's rminology is that it recognises the biological relationship between the migration of eggs and larvae on the one hand, and that of the adults on the other. It does not follow that there is a causal relationship between the direction of the water currents and the movements of the fish. "Contranatant" is a useful description. There is a danger in that a description of a phenomenon can so easily become accepted as its explanation and there may be confusion if a migration which is obviously contranatant in the biological sense (cod migrating south to Lofoten; herring migrating down the Southern Bight of the North Sea) turns out to depend on some other environmental factor, or on another behaviour pattern.

BIOLOGICAL SIGNIFICANCE OF MIGRATION AND HOMING

The biological significance of migration and of homing follows from the theoretical relationships between migration patterns and water currents. In the temperate latitudes, or in a restricted environment, there may not be enough food on the spawning or nursery grounds to maintain the immature and mature members of a large population. So it may be an advantage to an expanding stock to have separate spawning, nursery and feeding areas. Migration could then be regarded as an adaptation towards abundance. Taking Gerking's (1959) definition of homing as the return to "a place formerly occupied instead of going to other equally probable places", there is something to be gained by a species whose adults return to spawn in the area where they themselves survived. A fish might spawn along the length of a coastline, or in half a dozen tributaries of one river system. At any one part of the coast, or in any one tributary, conditions might be particularly favourable for the survival of eggs and larvae. A return of the survivors to the parent spawning area, or ground, provides a means by which the good conditions may be exploited. It is worth remembering that good survival from a particular area, or ground, could be a consequence of local environmental conditions, or because the site stands upstream to a favourable nursery ground onto which the larvae drift. Homing could be a disadvantage if fish persisted in returning to spawn to an area or ground where the conditions had become unfavourable to the survival of eggs but not to the act of spawning. Frost (1963) cites the disappearance of charr (*Salvelinus willughbii*) from Ullswater (English Lake District) as a case where this might have happened. The only biological insurance against this is a satisfactory level of "straying" and a multiplicity of spawning grounds, whose contribution to the population would change as environmental conditions varied. Fish would do well to follow the proverb and not put all their eggs in one basket.

THE REACTION OF FISH TO WATER CURRENTS

Experimental work in the laboratory has shown that fish will react to a water current only when they can detect their displacement through visual or tactile clues. In the dark, or when blinded, fish that are in midwater drift passively with the current. Observations made at sea tend to confirm those from the laboratory. Midwater shoals drift with the tide; only shoals close to or on the bottom have been found to stem the current (Jones, 1962).

The normal response to a water current is to head upstream and swim against the flow. Thresholds for an orientated response are low, 5-10 cm/sec for a displacement of the background simulating the optical stimuli produced by a water current (Jones, 1963). The thresholds for a water current detected by tactile stimuli are probably 2-3 times higher. I have found that fish react kinetically to the optical stimuli equivalent to a water current, swimming faster as the background speed increases. But the relation between the speed of the fish and the moving background shows that they would gain ground at water currents equivalent to speeds less than 1 fish length/second, but lose ground when swimming against faster currents. The herring was an exception to this rule, and always gained ground up to background speeds equivalent to currents of 3-4 fish lengths/second, its maximum cruising speed.

MIGRATION IN THE OPEN SEA

In the upper waters of the open sea, down to about 400 m, water movement will be predominantly under the influence of the wind-driven surface currents. As laboratory results show that fish out of sight or out of touch of the bottom drift with the current, I think we should face these facts and admit the possibility that fish in the open sea may behave in the same way. Changes in horizontal distribution could be achieved through seasonal or diurnal vertical movements, the fish being carried in water layers moving at different speeds or in different directions. Hardy (1953) has discussed these possibilities. Under such circumstances the fish could be thought of as being carri on what has been called a hydrographic escalator (Jones, 1961). I would suggest that the migration patterns of at least three species (sockeye salmon in the Alaska Gyral; Atlantic herring in the Norwegian Sea, northern and central North Sea; and the European eel, returning to the Sargasso in a eep counter-current, or the Canary current) are more consistent with the hypothesis of an overall ovement with the current than against it. Only detailed investigations comprising simultaneous bservations of the movements of the fish, and water current measurements at the depth at which hey are swimming, will give us the speed of one relative to the other. Sophisticated sonar techiques, such as sector scanning (Jones and McCartney, 1962), would be the research tools to use for his job.

It is of interest to note that the movements of desert locust swarms are essentially downwind nd Rainey (1951) has pointed out that the winds lead to zones of convergent surface wind-flow, here there is a net ascent of air and heavy precipitation. These are the areas where conditions f moisture and vegetation are suitable for breeding. There is, perhaps, a parallel here with ishes which could ride the oceanic currents to areas of upwelling or to the polar fronts, and eturn to the spawning grounds on the counter-current, or the other limb of the gyral. The problem ere is the control system which ensures that the fish leaves and joins the gyral at the appropriate ime. It is possible that an innate releasing mechanism is involved, triggered by a simple sign timulus (Creutzberg's (1961) work with elvers), the stimulus level to which the fish responds being nder hormonal control.

MIGRATION ON THE CONTINENTAL SHELF

On the shelf tidal currents become important and in certain shallow water areas must be the redominant source of water movement. The situation is further complicated by diurnal vertical igrations which may bring the fish on to or close enough to the bottom during the day to obtain he tactile or visual clue essential for orientation to the current. So the combination of chaning tidal current, and diurnal vertical migration would permit a complex interaction between pasive drift and orientated movement. It is of some interest to consider, by means of a model, the orizontal displacements which could follow from such an interaction. An analysis has been made or the Downs herring on their migration down the Southern Bight of the North Sea to the Channel pawning ground (Jones, 1961), but as the details have not been published, they will be given here.

THE MIGRATION MODEL

The Downs Herring

The overall migration pattern for this stock is fairly well known. The larvae drift with the esidual current from the Channel spawning grounds to the nursery grounds which lie along the oastal regions of the Southern Bight south of 52°N to the west, but extending beyond Texel and nto the German Bight to the east. From these coastal grounds the young fish move offshore so hat the centre of the distribution of the I-group usually lies south-east of the Dogger, near the lay Deep. From this area II-group fish move west and north to recruit to the feeding fisheries ff the north-east coast of England, and then, as maturing fish, migrate south to enter the East nglian fishery in October, and spawn on the Channel grounds in December. The spent fish move orth, and some reach the northern North Sea the following summer. Cushing (1955, Fig. 5) figures he migration route of this stock.

Parameters of the Model

The model only deals with a small part of one leg of the migration and the following assumtions are made and procedures followed:

A 25 cm herring starts at a position 53°N 27.5'N, 2°46.0'E (Admiralty Tidal Station B12) to he east of the Indefatigable Banks at sunset on 1 October 1961 (Fig. 3).

The times of sunset and sunrise are those given in a nautical almanac for the appropriate day.

Between sunset and sunrise it is assumed that the herring loses tactile and visual contact with he bottom and drifts passively with the tidal stream.

Between sunrise and sunset the herring regains visual contact with the bottom, orientates to ace upstream and swims against the tide at a speed 1.4 times that of the current. The multiplier .4 is based on laboratory experiments relating the swimming speed of small herring to that of a oving background simulating the optical stimuli produced by a water current. The average tidal urrent in the surface waters at Station B12 is about 1.5 knots (75 cm/sec). Profiles in the

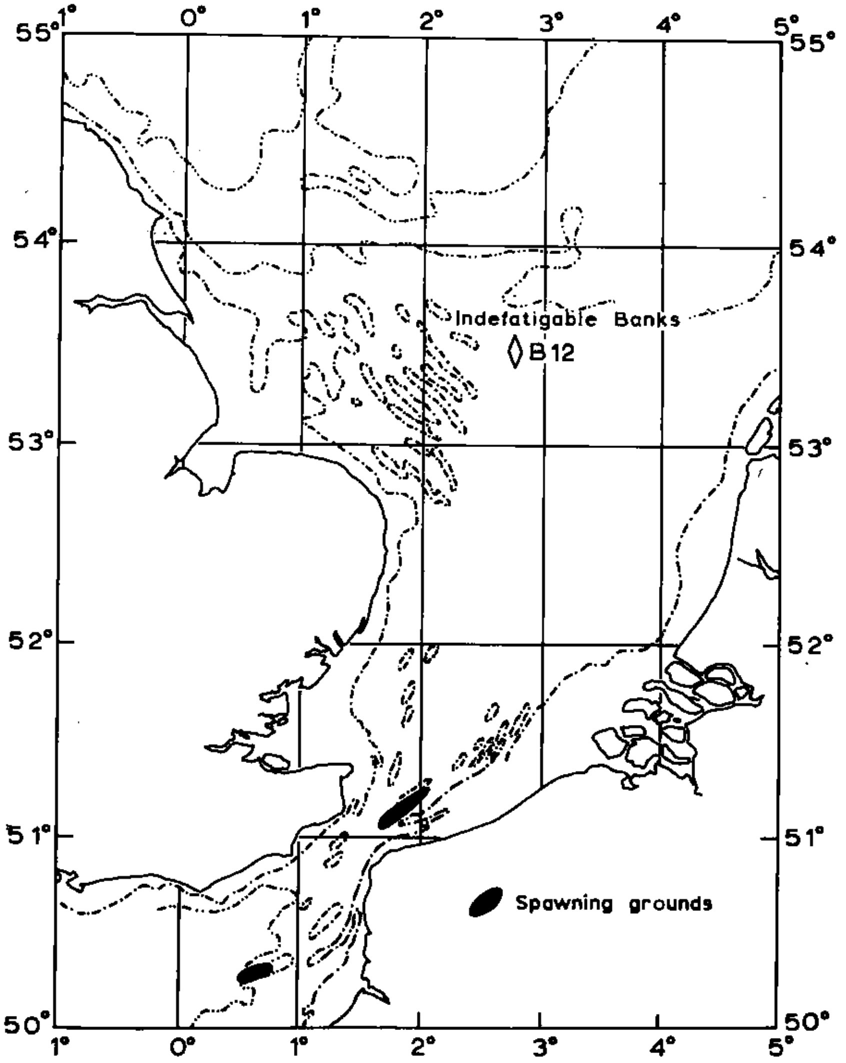

Fig. 3. The position of Admiralty Tidal Station B12. Spawning grounds of the Downs herring are shown.

Southern Bight have shown that the water current 5m from the bottom is approximately two thirds of the surface speed giving, at B12, a speed of 1 knot (50 cm/sec), equivalent to 2 fish lengths per second for the 25 cm fish in the model. The laboratory experiments showed that herring gained ground by a factor of 1.4 at background speeds equivalent to a water current of 2 fish lengths/second.

The Results of the Model

The results of the model are shown in Fig. 4, where the noon positions of the fish are shown from 2 October to 1 November 1961. The course made good during the night (passive drift) is shown by the thick lines, that made good during the day (1.4 against the tide) by the thin lines. Inspection of this figure shows that there are two periods when the fish makes ground to the south, between 4-10 October and 19-24 October, the periods of new and full moons and the spring tides. It may be significant that these are the times when the catch per effort in the East Anglian drift net fishery is highest (Bolster, 1962).

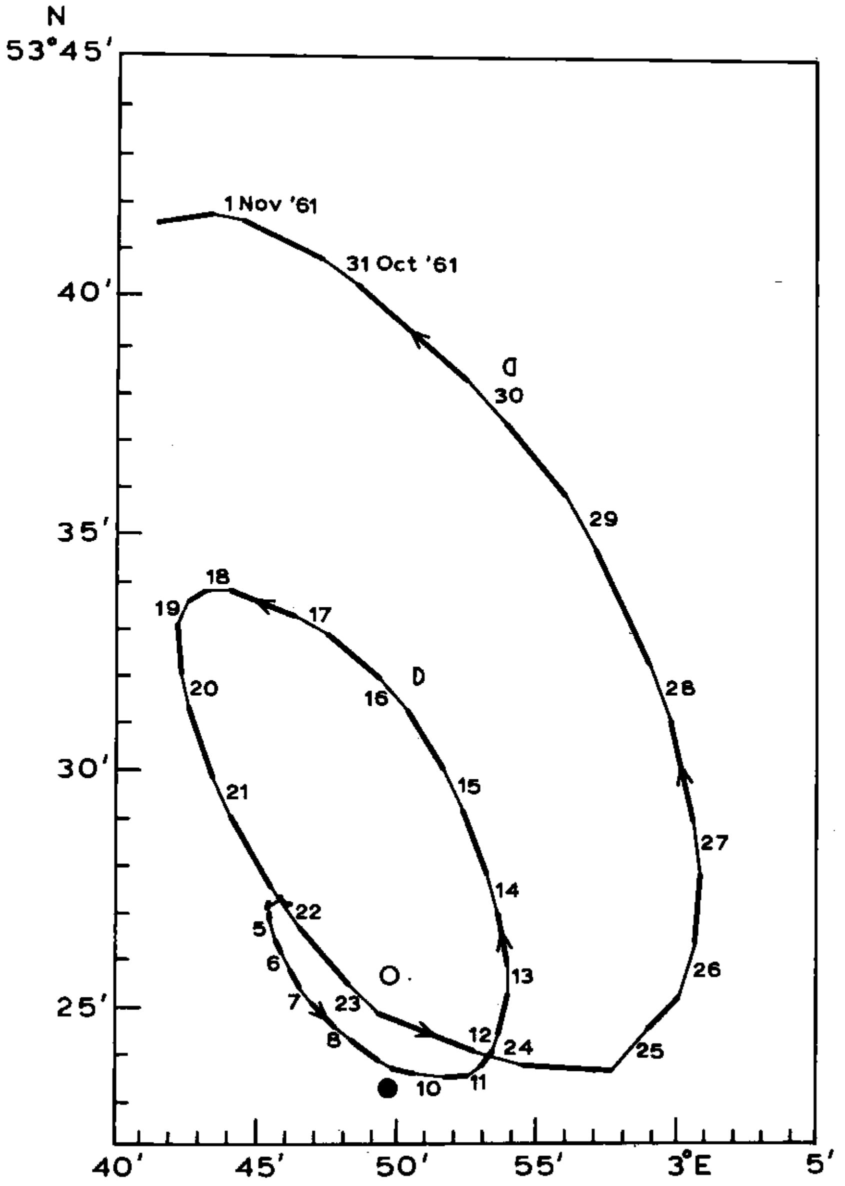

Fig. 4. The migration model: noon positions of the herring which left Station B12 at sunset on 1 October 1961, drifting with the tide during the night (thick line), swimming against the tide during the day (thin line). For further explanation see text.

The semi-lunar periodicity in the south-going movement suggests that if a fish arrives at
tation B12 on certain days it might get into a "tidal-fishway" and make rapid progress southwards.
igure 5 shows the noon position on 25 October of fish that arrived at Station B12 at sunset each
ay from 2-24 October inclusive. This figure was derived from Fig. 4 in the following way. The
ourse and distance made good between any day from 2-24 October and 25 October was given by the line
oining the sunset position on the first day to the noon position on the 25 October. The course
nd distance run were then transferred to B12. It is clear that fish that arrive at B12 between

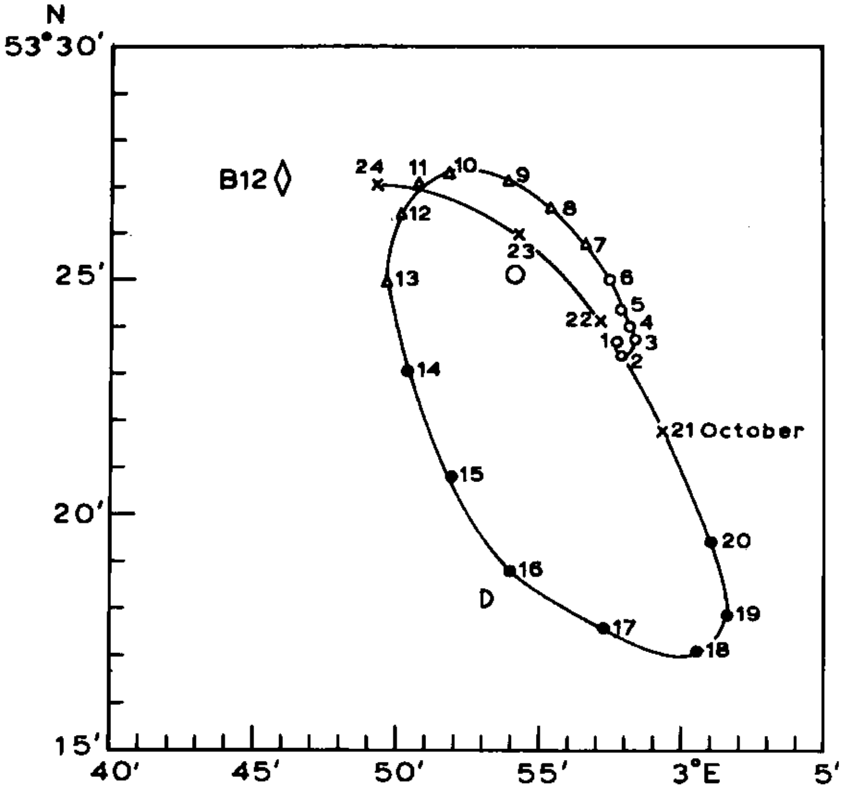

Fig. 5. The migration model: positions at noon on 25 October 1961 of fish leaving Station B12 at sunset, 1-24 October inclusive. For further explanation see text.

15-21 October move rapidly southwards if they drift passively with the tide by night and swim against it by day. The model does provide a mechanism for a south-going migration based on assumptions that are consistent with our knowledge of the behaviour of the fish.

The Residual Current

No allowance has been made for the residual current at B12, which flows eastwards across the axis of the tidal stream at a velocity of about 1.5 miles/day. The residual is unlikely to have any significant effect on the southward movement of the fish, even if it were flowing along the line of the tidal stream. During the night the fish would be carried north, but it would gain ground south during the day. If day and night were of equal length there would be a net gain south of (1.5 x 1.4) - 1.5 = 0.6 miles/day to add to the noon positions plotted in Fig. 4. But during October and at a latitude of 52°N, the ratio of day/night hours is close to 1:1.3 so the ground gained during the day is almost entirely lost by the extra drift at night. The effect of the residual has therefore been ignored.

Further Study of the Model

The apparent success of the model should not be pressed too far. While the calculations do offer a basis for a prediction of the distribution of the recovery of tagged fish, or movements of the fishery, they only relate to one tidal station and the extrapolation of the data relating to this single point has probably been carried too far. When the fish has moved a few miles from Station B12 its movements should be calculated using tidal data relating to its new position, and so on down the Southern Bight. These calculations require the services of a computer and this is eing considered. Other models of migration (drift by day and by night, drift by night and holding round by day, swimming south day and night with and against the tide etc.) should also be examined.

It would be very interesting if there was a "tidal-fishway" which could carry the herring rom the feeding area to the spawning ground. To get them back again does not present the same roblem. A change in behaviour to light, so that they stayed in midwater and never made visual ontact with the bottom, would allow the spent fish to drift north-east with the residual current.

CURRENT PREDICTIONS FROM FISH MIGRATIONS

Let us reverse this line of thought and try to predict the presence of currents from what is own of the migration of fish. The European eel is an abvious example. European eels leave fresh ater in November-December and spawn in February-March, but it is not known whether they take a ew months or one of two years over the migration. There should be a deep counter current which ould take the mature fish back from the continental shelf to the Sargasso Sea in 3, 15 or even 27 onths. There is some evidence to show that deep counter-currents are present in the eastern tlantic (Stommel, 1958; Lappo, 1963).

Migrations of the Arcto-Norwegian and south-west Greenland cod should also be considered. I uggest that there may be a deep counter-current carrying the mature fish from the Bear Island area o Lofoten, and from West Greenland to Iceland. This is not a new hypothesis so far as the Arcto-orwegian cod are concerned, and I want to draw attention to Sund's (1932; 1938; 1939) much earlier uggestion. Sund was clearly of the opinion that the cod were carried to Lofoten, at least from denes, on a south-going current at a depth of 300-700 m on the edge of the shelf, at a velocity about 7 km a day. We have not heard very much about Sund's hypothesis or about this current. s there a counter-current running along the Norwegian coast? And if there is, where does it come rom, and where does it go? Could it carry the cod as Sund said?

ACKNOWLEDGEMENT

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A-18

EFFECTS OF LIGHT UPON BEHAVIOUR AND DISTRIBUTION OF DEMERSAL FISHES OF THE NORTH ATLANTIC[1]

By

P.M.J. Woodhead[2]

CONTENTS

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[1] Originally Contribution No. A-15, ICNAF Environmental Symposium, Rome 27 January-1 February 1964.

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SUMMARY

1. Data concerning the structure, function and performance of the fish eye are considered in relation to the problems of vision in the demersal environment.

2. Some laboratory observations on the reactions of demersal fish to light changes are reviewed and particular attention is drawn to diurnal patterns of behaviour changes by day and night. It is concluded that these patterns are frequently endogenous cycles which are environmentally timed, although they may be suppressed or modified under experimental conditions. The diurnal patterns of behaviour are frequently complex.

3. Diurnal changes in behaviour in demersal fish frequently result in changes in their rates of capture by trawls. In some cases this seems to be due to vertical migration of the fish.

4. It is suggested that many "demersal" species may spend considerable periods in midwater, and some evidence of this for flatfishes, haddock, redfish, whiting, hake, coalfish and cod is reviewed.

5. Changes in vertical distribution may be associated with feeding in some species but not in others, and it is suggested that vertical movements away from the sea-bed may be part of the specific behaviour patterns of different fish. The patterns may vary with the size or condition of the fish.

6. Changes in vertical distribution in relation to light may expose fish to differences in the action of currents, or even to different current systems. These changes must have fundamental effects upon the horizontal distribution of the fish. Some examples are considered and it is suggested that diurnal vertical migration may form an integral part of the distribution mechanism of many demersal fish.

INTRODUCTION

Against the relative physical and chemical uniformity of the seas over considerable areas, submarine light shows almost continuous cyclical changes in quality and intensity, both diurnally and seasonally; light also changes rapidly with increasing depth. It is therefore not surprising that light has a fundamental role in determining fish behaviour. The modes by which light may affect the fish are complex; its intensity, angular distribution, polarization and spectral composition may all exert direct effects upon behaviour and physiology. These properties of submarine light all vary with depth and with the time of day, and in some cases their rate of change may also be important. The diurnal changes of day and night (including the duration of daylight and the quantity of light energy received per day), monthly lunar changes, and the annual light cycles may all be of considerable physiological importance to fish.

I do not intend to discuss all of these many diverse effects of light upon fish, but will consider only those aspects which appear to be of significance in influencing the distribution of demersal fishes of the North Atlantic. Even in this more restricted field, the relationships of light to the behaviour and physiology of the demersal fish are by no means simple. (Certain effects of light upon seasonal changes in the physiology of cod are discussed elsewhere (Woodhead and Woodhead, this symposium)).

LIGHT IN THE SEA

Absorption and scattering in seawater both rapidly reduce the light from the surface. In coastal waters light is reduced to 1% of its surface value in 15-30 m, whereas for continental slope waters this reduction is achieved in 40-60 m, and at about 100 m in clear oceanic water (Clarke, 1954). Within a single area there may be considerable seasonal variations in transparency which may have greater effects upon subsurface illumination than the seasonal changes in surface radiation; thus Clarke (1938) showed that although the total solar radiation at the surface per day off the Massachusetts coast was about four times greater in summer than in winter, at a depth of 30 m the total radiation was 10,000 times greater in May, with high incident light and high transparency, than in December when both incident light and transparency were low.

In coastal waters maximum transparency is in the yellow-greens (500-600 mμ) whereas in clear oceanic waters maximum transparency is in the blue part of the spectrum (400-500 mμ). With increasing depth the composition of the light changes as the spectrum narrows to the most penetrating wavelengths. Towards both ends of the spectrum extinction is more rapid than in the middle, and at depths of more than 100 m blue light predominates (Jerlov, 1951).

In the sea directionality of light is maintained to considerable depths, light flux from above being about a hundred times greater than light scattered from below (Clarke and Denton, 1962). However, in clear weather the direction of maximum light intensity will be at an angle of obliquity to the vertical, related to the altitude and azimuth of the sun. In the relatively clear waters of the English Channel Atkins and Poole (1959) found that the average angle of obliquity remained about the same down to 70 m; Tyler and Preisendorfer (1962) have given extensive tables for the estimation of radiance distribution in lake water under different weather conditions. In the sea, light is also linearly polarised, and Ivanoff and Waterman (1958) have shown that, in clear water, although the polarization decreases rapidly in the surface layers, after that the rate of decrease is slow and submarine polarization extends towards the limit of the photic zone. The pattern of polarization is dependent upon the sun's position in the sky and changes during the day. Waterman (1958) has suggested that these changes may still be appreciable at 200 m and could provide a form of compass for orientating horizontal migrations. The possibilities of orientated movements by fish well below the surface, in relation to the sun, guided either by the direction of maximum light radiance or by submarine polarization patterns, cannot therefore be dismissed. It is possible that the claims of some North Sea fishermen that in the early mornings in spring the best trawl catches of plaice are to be made by towing towards the sun may have their basis in such orientated movements by the fish. However, too little is known of such behaviour in demersal fish for this fascinating subject to be pursued further here.

The qualities of light in the sea are discussed in greater detail by Blaxter (this Symposium p.647).

THE EYE

In discussing the reactions of fish to light it is necessary to consider the properties of the receptor organs. The principal light receptors in demersal fishes are the eyes. Although the pineal organ and the mid-brain have also been shown to be light-sensitive in some freshwater fishes (Scharrer, 1928; Breder and Rasquin, 1947, 1950), it seems unlikely that they play an important part in the behaviour of the adult fish considered here, principally because their sensitivity is low, and because the top of the head is frequently too thick or opaque to allow the penetration of the weak light present at the depths in which the fish live. Dermal photoreceptors have also been shown in a few fishes, but none were found in the marine fishes examined by Parker (1909).

All fish do not have the same sensitivity to light, nor is their vision equally good. It could not therefore be expected that the eye would be the same, even for all fish living within the same demersal environment. In fact the eyes show many diverse modifications and adaptations to the mode of life of particular species. Aspects of vision and photoreception in fishes have recently been reviewed by Nicol (1963) from the viewpoint of physiological function and by Rochon-Duvigneaud (1958) for general aspects of the fish eye.

1: Visual pigments and retinal structure

The scotopic visual pigments of marine fish have generally been shown to be adapted to the type of light occurring in the region in which they live. The eyes of the coastal and surface-living fishes have rhodopsin pigments absorbing maximally in the yellow-greens at about 500 mμ, whereas conger eels (*Conger conger*) and deep-sea fishes have chrysopsins in which the maximum absorption occurs in the blues, about 485 mμ, greatest sensitivity corresponding to the wavelengths of greatest penetration (Munz, 1958 *a* and *b*: Denton and Warren, 1957). The visual pigments from the coalfish (*Pollachius virens*), plaice (*Pleuronectes platessa*), gurnards (*Trigla lucerna*) and spurdogs (*Squalus acanthias*) have absorption peaks at 500 mμ (Nicol, 1960).

Coastal teleosts usually have duplex retinae in which the cones are frequently large and well spread; double cones and occasionally triple cones also occur in many species; there is usually a well developed pigment epithelium. Pure rod retinae are found in deep-sea teleosts and in the majority of elasmobranchs (though the retinae of *Mustelus* and *Myliobatis* are duplex). High-cone retinae are generally found in fish feeding in light and possessing good vision, whereas numerous large rods are associated with life at low illumination. Visual acuity might be expected to increase with the numbers of cones per unit area of retina, but in the eyes of nocturnal and deep-sea fish acuity is actually sacrificed for high light sensitivity, many rods communicating through secondary neurones with single nerve fibres. Wunder (1925, 1926, 1936) has described these relationships in detail for freshwater fish, and it might be expected that they would also apply to marine fish. High rod densities occur in the retinae of some elasmobranchs; in *Chimaera* there are 100,000 per sq mm of retinal surface, and 30,000 per sq mm in *Acanthias*. However, in the specialised eyes of deep-sea fishes extremely high densities of up to 25 million rods per sq mm have been reported (Brett, 1957).

Engström (1961) has described the arrangement and structure of cones in gadoid fishes, and Ali and Hanyu (1963) have reported on the retinal structure for several species caught in moderately deep Atlantic waters. Cod (*G. morhua*), sea poachers (*Aspidophorodes menopterygius*) and a sculpin (*Triglops ommatistuus*) had a well developed pigment epithelium and many cones and conducting elements, suggesting good vision; *Lycodes* sp. and redfish (*Sebastes marinus*) had a less well developed pigment epithelium, numerous rods and fewer conducting elements, presumably no longer adapted to vision at high intensities. Pure rod retinae for low light vision occurred in the silver smelt (*Argentina silus*) and rat-fish (*Macrourus bairdi*), in which form perception is probably of little importance. Comparing specimens of *Sebastes marinus marinus* and the sub-species *S. m. mentella*, caught at the same depth in *S.m. mentella* the retina had larger rods and smaller cones than in *S. m. marinus*, and in this respect it is interesting that *S.m. mentella* has a relatively larger eye, both differences suggesting intraspecific visual adaptations to the deeper habitat of this form (Templeman, 1959). It is of interest that within the sub-species *S.m. mentella*, a specimen from 549 m had shorter cones and larger rods than a specimen from 275 m, differences which would better fit the deeper-living fish for life at lower light intensities (Hanyu and Ali, 1962). Obviously further investigations would be required to confirm these results, but they raise the interesting possibility that there may be a number of different physiological forms, or ecotypes, within the species, each specialised to fit a particular depth-range, perhaps with little vertical interchange.

2: Light sensitivity

Although the absolute light threshold of the fish eye has not been measured, Nicol (1963) concludes that many fish are equally as sensitive as man. The eyes of marine fish frequently have a number of properties tending to increase their sensitivity; there is usually a relatively large pupil, the rods in the retina are long, and the retinal pigment density is high, so that up to 75% of the incident blue-green light may be absorbed compared with 30% absorption in the human eye. (Denton (1959) has calculated that in the specialized eyes of deep-sea fishes absorption may exceed 90%). It is therefore likely that the absolute light threshold in many demersal fish will be lower than in man; Denton and Warren (1957) have suggested that for some deep-sea fishes this gain in sensitivity may be as high as 100 times that of man (indeed the eyes of deep-sea fishes are believed to be the most sensitive in existence).

On this basis, light from the surface could probably be detected by demersal fish at an intensity of 10^{-8} μ W/cm^2, which is similar to Harden Jones' (1958) estimate of 10^{-7} m.c. Clarke and Denton (1962) have calculated figures for the depths of penetration of sunlight and moonlight into seas with different rates of light absorption, in relation to the visual thresholds of fish and man (calculated for light from a broad field of illumination). Their results for the limits of detectable light, together with those estimated from absorption data given by other authors, are summarised in Table 1.

TABLE 1. CALCULATED APPROXIMATE DEPTHS OF PENETRATION OF SUNLIGHT AND MOONLIGHT INTO VARIOUS SEAS IN RELATION TO MINIMUM INTENSITY FOR VISION IN FISH.

Sea	Sunlight	Moonlight	Author
Turbid harbours or estuaries	20 m	–	Clarke and Denton, 1962
Southern North Sea (53°N 2°E)	120 m	65 m	P.O.Johnson (unpublished observations)
Baltic Sea) English Channel)	200 m	100 m	Clarke, 1954
Barents Sea	500 m	250 m	Trout, 1957
Clearest oceanic water	900 m	500 m	Clarke and Denton, 1962

3: Underwater vision and visual acuity

The problems of underwater vision are complex (Duntley, 1962), but, in general, visibility in water is restricted by light scattering (much as fog reduces visibility on land), and by heavy absorption, which is much greater than in air; both properties profoundly affect visual range. The visibility of objects thus depends not only upon the intensity of the residual image-forming light reaching the eye but also upon the degree of diffusion of the image, and upon the radiance from the scattering of ambient light in the sea along the line of vision. The relationship of the amount of image-forming light reaching the eye, to the ambient radiance, is dependent upon the scattering properties of the water and independent of light intensity, so that above a critical visual threshold underwater visibility would be expected to be constant over a wide range of intensities; this has been confirmed by direct measurements made from a submarine (Sokolov, 1961).

In the fish eye the spherical lens is almost completely free of spherical and chromatic aberration (Pumphrey, 1961), so that good retinal images could be formed. The cornea is of the same refractive index as the sea water and plays no part in forming the image.

Acuity is governed partly by the concentration of cones in the retina and the number of ganglia supporting them, but in demersal fishes with duplex retinae the cones tend to be large and well spread and there is rarely a fovea in fish. For these reasons, and because scattering of light in water will also limit precise vision, the image perceived is probably poor compared with that in many terrestrial vertebrates. However, the retinal elements are not evenly distributed and in particular areas of the retina there may be differentiation; thus cones predominate in the upper half of the eye of the bottom-feeding dragonet (*Callionymus lyra*), which is appropriate to downward vision. Similarly, although the cones in the genus *Gadus* radiate outwards from the centre of the eye in a regular pattern, there may be differences in visual cell density, concentration frequently occurring in the temporal plane of the retina, as in the pollock (*P. pollachius*) (Engström, 1961).

As the light intensity rises above the absolute visual threshold, visual acuity increases very quickly, and fish can probably begin to discriminate surrounding objects at intensities only a few times greater than the threshold (Clarke and Denton, 1962); that is at depths which would be only short distances above the depths given in Table 1 as the limits for detection of sunlight and moonlight. Nicol (1963) states that, due to the high sensitivity of the eye, a fish at 100 m could perceive objects from sunrise to sunset on the darkest winter day (latitude 50°N) in coastal waters with an absorption coefficient of about 0.13 (*i.e.* English Channel or Baltic Sea).

DIURNAL CYCLES OF ACTIVITY

Diurnal cycles of activity have been described for a large number of species of fish, generally based on observation of fish living in aquarium tanks. Observations on a large number of marine and freshwater fish living in the aquarium of the Zoological Society of London were reported by Boulenger (1929) who found that elasmobranchs and most marine teleosts, including the flatfishes, were more active at night than by day, or at least were equally active at both times. However, the gurnards (*Trigla hirundo* and *T. gurnardus*) rested on the bottom at night, and four species of wrasse were observed to be lying on their sides at the bottom at night. Other species including the grey mullet (*Mugil cephalus*) and the sea breams (*Pagella centrodontus* and *Pagrus pagrus*) floated quiescent at night just above the bottom, while others including the sea bass (*Morone labrax*) were found resting just beneath the surface at night. Breder (1959) also gives a number of examples of differential diurnal behaviour patterns. Obviously there may be considerable diversity in the type of activity cycles exhibited by different species.

A few attempts at more quantitative analysis of the activity patterns of fish have been made. Harder and Hempel (1954) studied the activity of flatfish in an experimental tank containing only seawater; plaice and soles exhibited considerable nocturnal activity and were quiescent by day, although flounders were active in the apparatus at all times of day and night. Kruuk (1963) and Woodhead (1963*a*) have also described sole as being nocturnally active in aquaria, but lying wholly or partly buried in sand at the bottom of the aquarium during the day; deGroot (1963) and Woodhead (1960) have made somewhat similar observations on the behaviour of the plaice, which frequently swam freely off the bottom at night. Both Kruuk and deGroot drew attention to the close resemblances between the behaviour of the flatfish in the laboratory and their postulated behaviour in the sea, as reflected in the catches of trawlers.

The author has made observations on the activity of 30 cm to 80 cm cod in a large concrete tank (4 m x 6 m x 1 cm). Twenty to thirty cod kept in the tank showed slow swimming activity under diffuse daylight illumination of about 500-1000 m.c. at the water surface. They tended to swim together in loose groups of four or five fish, often stopping or milling very slowly. At night activity increased by several times, the cod swimming constantly back and forth across the bottom of the tank, each fish moving independently. It was remarkable that diffuse illumination by a fluorescent light giving about 1 m.c. at the water surface did not appear to interfere with this pattern of nocturnal swimming activity if it was switched on.

Laboratory studies are of considerable interest and importance in demonstrating the contrasting activity patterns which may occur in different species, but some caution should be exercised in the interpretation of such behaviour as "normal", since its relationship to the behaviour of the fish in the sea may be less direct than would at first appear. Thus Bregnballe (1961) showed that flounders (*P. flesus*) swam actively both by night and by day in an aquarium containing only seawater, as had also been observed by Harder and Hempel (1954), but when sand was placed on the bottom of the tank the flounders were active only at night and lay buried during the day. Perhaps the clearest demonstrations of effects of experimental design on diurnal activity were the experiments of Harden Jones (1956) with minnows (*Phoxinus laevis*); in an open glass aquarium the minnows were very active by day and inactive at night, but when a very simple shelter was provided for the fish their pattern of activity was completely reversed - they sheltered, inactive, during the day, and were nocturnally active. Similarly minnows swimming in a tank covered by a light gradient showed marked changes in their behaviour patterns above and below an intensity of about 0.2 m.c. (Woodhead, 1956). If ecological parallels are to be drawn from laboratory studies of marine fish, the animals should not be submitted to higher daylight intensities than they might normally encounter in their lives in the sea; thus deGroot (1963) was able to show that the degree of activity of plaice during daytime was to some extent dependent upon the lighting of the experimental tanks.

It seems likely that most of these diurnal changes in locomotory behaviour are timed by the light-dark cycle. They might be regarded as forms of photo-kinesis (Fraenkel and Gunn, 1940); such kineses have been demonstrated in a number of freshwater fish (Shaw, Escobar and Baldwin, 1938; Schlagel and Breder, 1947; Harden Jones, 1955; Woodhead, 1957) and in the marine larvae of the herring (*Clupea harengus*), *Blennius ocellaris* and *Lepadogaster microcephalus* (Woodhead and Woodhead, 1955, 1962). This suggestion gains some support from experiments in which continuous light has inhibited movement or continuous darkness has allowed persistent activity. However, there is frequently an endogenous component to such rhythmic activities (Brown, 1958; Harker, 1958); thus Kruuk (1963) was able to suppress the diurnal activity cycle of soles by keeping them in continuous light, but when they were kept in darkness for two days the normal periodicity of activity was maintained - although a fairly high level of activity occurred throughout the day it was still at a lower level than at night, when peak activity was recorded. In similar experiments, in which plaice were kept in artificial light during the night, Harder and Hempel (1954) were able to reduce nocturnal activity but did not achieve complete suppression; similarly deGroot (1963) observed little reduction of nocturnal activity in plaice kept at a low level of artificial light. It has also been reported that a 24-hr rhythm of activity persisted in goldfish (*Carassius auratus*) kept in continuous light (Spencer, 1939).

Strong evidence of a precise internal rhythm or "biological clock" was provided by freshwater fishes which were trained to use the sun as a directional reference. They were able to compensate for the daily movement of the sun, remaining orientated in the trained direction during the course of the day (Hasler and Schwassmann, 1960; Braemer and Schwassmann, 1963).

Behaviour in relation to light has been shown to change diurnally in a few species. Breder (1959) gave some evidence for *Gambusia* sp; and Kawamoto and Konishi (1955) showed a definite diurnal rhythm in the "light-seeking" responses of *Girella punctata* and *Rudarius ercodes* to an artificial light in a dark-room. Bluegills (*Lepomis macrochirus*) which have been kept in darkness have a well defined light-shock reaction when exposed to a bright light, and Davis (1962) has clearly shown a regular daily rhythm in the intensity, or duration, of this reaction to a constant stimulus. Such behavioural changes could imply central variations in the responsiveness of the fish, but could also be due to changes in the sensitivity of the eye itself. In fact there is some evidence that the eye is not a consistent receptor organ throughout the day; thus rhythmic movements of the cones and pigment epithelium of the retina have been shown to persist in catfish kept in constant darkness (Welsh and Osborne, 1937; Arey and Mundt, 1941). Similar experiments made on goldfish kept in constant darkness also showed that the condition of retinal dark adaptation, with cones and pigment expanded, was more extreme at night than during the hours of daylight (Wigger, 1941). Tamura (1957) found that even when illuminated at low light intensities the retinae of the sea bass (*Lateolabrax japonicus*) and the carp (*Cyprinnus carpio*) tended to a condition of stronger dark adaptation before midnight than after midnight, suggesting retinal responses to cyclical changes occurring within the fish.

It is concluded that there are probably endogenous 24-hr cycles of physiological and locomotor activity in many fish, more strongly expressed in some species than in others; thus Gompel (1937) found evidence for the presence of a persistent rhythm of oxygen consumption in plaice (*Pleuronectes platessa*) and turbot (*Rhombus maximus*). Normally these endogenous cycles will tend to "anticipate" the start of the daylight or night periods, but will be environmentally timed and reinforced by the changes in light intensity at dusk and dawn. Laboratory experiments with continuous light or darkness, which may partially or completely inhibit the normal expression of such rhythms, or cause the phase to drift, in no way refute their presence.

In considering such cyclical changes in diurnal behaviour it is important to make the distinction that although light may exert important orientating and kinetic influences directly upon the fish, as would appear to occur in herring shoals whose migration to the upper waters at dusk has been related to an optimum light intensity (Postuma, 1957; Chestnoy, 1961), light changes at dusk or dawn may also be important in simply releasing a pattern of behaviour which is then largely "self-steering" and independent of further changes in illumination. The diurnal cycles of behaviour in fish are usually complex, and swimming activity may be associated with feeding, vertical migration, changes in aggressiveness, dispersion or aggregation of shoals, etc. The duration and level of activity are by no means constant in any phase, and the periods of swimming have frequently been found to achieve maxima both at dusk, when light intensities are falling, and at dawn, when they are increasing again.

DIURNAL BEHAVIOURAL CHANGES IN THE SEA AND CHANGES IN CATCHES BY FISHING GEAR

In the sea the diurnal rhythms of swimming activity are frequently associated with feeding. Thus Kruuk (1963) showed that soles fed during their period of nocturnal activity. Plaice and flounders are largely visual feeders on benthic animals, and some feeding may go on generally during the day, but the main feeding periods occur at twilight and also coincide with the activity peaks at dusk and dawn (Franz, 1910; Jones, N., 1952; Hempel, 1956; Bregnballe, 1961; deGroot, 1963). In the sea, plaice and flounders do not appear to feed much during the middle of the night, and in aquaria they have frequently been found to swim freely well off the bottom at night (Harder and Hempel, 1954; Woodhead, 1960; Bregnballe, 1961; deGroot, 1963).

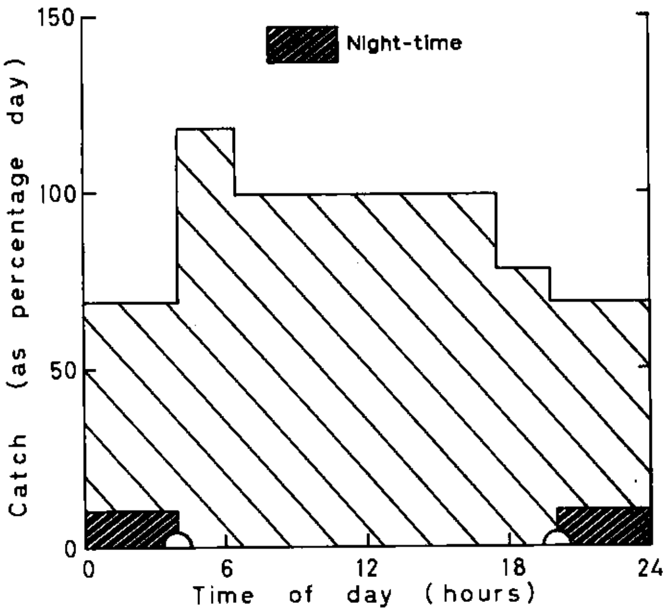


Fig. 1. Diurnal pattern of trawl capture of plaice in the southern North Sea, Haddock Bank (from Woodhead, 1960).

Such marked changes in the behaviour of demersal fish would be expected to be reflected in their catches by fishing gear; thus soles are caught in sea-bed gill-nets during their periods of nocturnal activity (Møller Christensen, 1960), and the marked diurnal changes typical of trawl catches of soles have been well established (Boerema and Stam, 1962; Boerema, 1963; Woodhead, 1963*b*). It has been suggested that soles are largely able to avoid trawl capture during the day when lying inactive, buried in sand, but become more vulnerable when moving over the sea-bed searching for food during their nocturnal period of activity (Kruuk, 1963; Woodhead, 1963*b*). Diurnal variations in trawl catches of plaice have also been described in offshore regions; the catch of large plaice frequently falls at night (Woodhead, 1960; deGroot, 1963) (Fig.1), and Woodhead has suggested that this fall may be partly due to a decrease in availability as fish leave the sea-bed to swim in midwater, behaviour which has been observed in large aquarium tanks. Paradoxically the trawl catches of plaice, and of flounders, in very shallow inshore areas are greatest at night. Bregnballe (1961) has pointed out that this may be partly explained by the inshore migration of fish from deeper water at night. However, in such shallow waters as Kysing Fjord (1 m) the vertical range of the fish could not be much greater than the headline height of the trawl and there would be little change in availability. Furthermore, in shallow waters flatfish would probably be more vulnerable to trawling when swimming freely within the depth of operation of the trawl than when buried in the sea-bed, and under these conditions higher catches could be expected at night.

Although such attempts to account for diurnal changes in catches of fish in terms of cyclical changes in their locomotory and feeding activities, particularly in relation to vertical migrations, may meet with limited success, in fact it is seldom possible to differentiate completely between the innate behaviour patterns of the fish and the changes in their reactions to the fishing gear by day and night. Detailed analyses of diurnal changes in the composition of trawl catches of fish show that they may be complex, showing many variations during a 24-hr cycle (Woodhead, 1963*b*). Diurnal changes in innate behaviour patterns may reduce the numbers of fish available for capture by the gear, particularly when associated with vertical migration, but they may also increase the vulnerability of those fish remaining within the effective zone of operation of the trawl. The catching efficiency of the fishing gear would also be expected to change by day and night. Thus the direct avoidance of trawls by those fish within their zone of operation is probably decreased at night, but the herding effect, believed to be produced by the trawl-doors and bridles, may also be reduced or made ineffective when these parts of the gear cannot be seen by the fish (Blaxter, Parrish and Dickson, 1963).

Although it is not possible to provide direct evidence for the vertical migration of fishes on the basis of the diurnal changes occurring in the catches of bottom trawls, nevertheless such catch changes are not to be completely disregarded and may provide supplementary evidence if they have occurred at the same time as other indications of fish departing from or returning to the sea-bed.

VERTICAL DISTRIBUTION

There is considerable evidence that many fish considered as demersal species, largely because they are normally caught in trawls on the sea-bed, in fact regularly assume a pelagic habit, swimming freely in midwater and frequently feeding there. Cases where fisheries have been developed to catch demersal species in midwater provide strong evidence of their pelagic habit. But in other instances it may be argued that the capture of small numbers of particular species well above the sea-bed, or at the surface, may be based upon chance encounters not typical of the population as a whole; for example, whiting are very frequently caught at night in herring drift-nets, but large numbers are seldom caught on any occasion. However, here it can equally be asserted that the herring drift-net may be unsuited to the efficient capture of whiting, just as salmon are not usually taken at sea in surface-floating longshore herring nets, although they certainly swim at the surface at night and can be caught there with the appropriate trammel gear.

Perhaps the best example of an apparently completely demersal fish periodically assuming the pelagic habit on an unsuspected scale is provided by the sole. Although soles have occasionally been reported swimming at the surface (Verwey, 1960; Møller Christensen, 1962), the recent report of de Veen (1963) has shown this behaviour to be a widespread and regular phenomenon amongst North Sea soles prior to spawning; indeed, at that time, the soles may leave the sea-bed in sufficient numbers at night that the normally marked diurnal pattern of trawl capture is reversed, the night catches being less than during the day.

Some evidence for commoner demersal fish leaving the sea-bed is now considered, although a comprehensive review is not attempted.

1: Cod (*Gadus morhua*)

There are many reports of cod in midwater or near the surface of the sea. Bigelow and Schroeder (1953) described cod being caught by gaff at the surface in the Gulf of Maine, and in Holsteinborg Deep, Greenland, a commercial fishery was established using pelagic longlines (Rasmussen, 1953, 1954). Cod have been caught near the surface in gill nets over depths of more than 1000 m (Hjort, 1914; Konstantinov, 1958), and Jensen and Hansen (1931) have reported Greenland cod pursuing capelin (*Mallotus villosus*) close to the surface; similar reports have been made for the Barents Sea (Zatsepin and Petrova, 1939). In the North Sea, cod have frequently been caught in mid-water trawls used from research vessels of this laboratory (unpublished observations) and by commercial pair-trawlers (Harden Jones, 1962).

One of the first successful uses of the echo-sounder to locate fish (Sund, 1935) showed large shoals of cod above the bottom in the Norwegian Vestfjord, and echo-sounders have since frequently

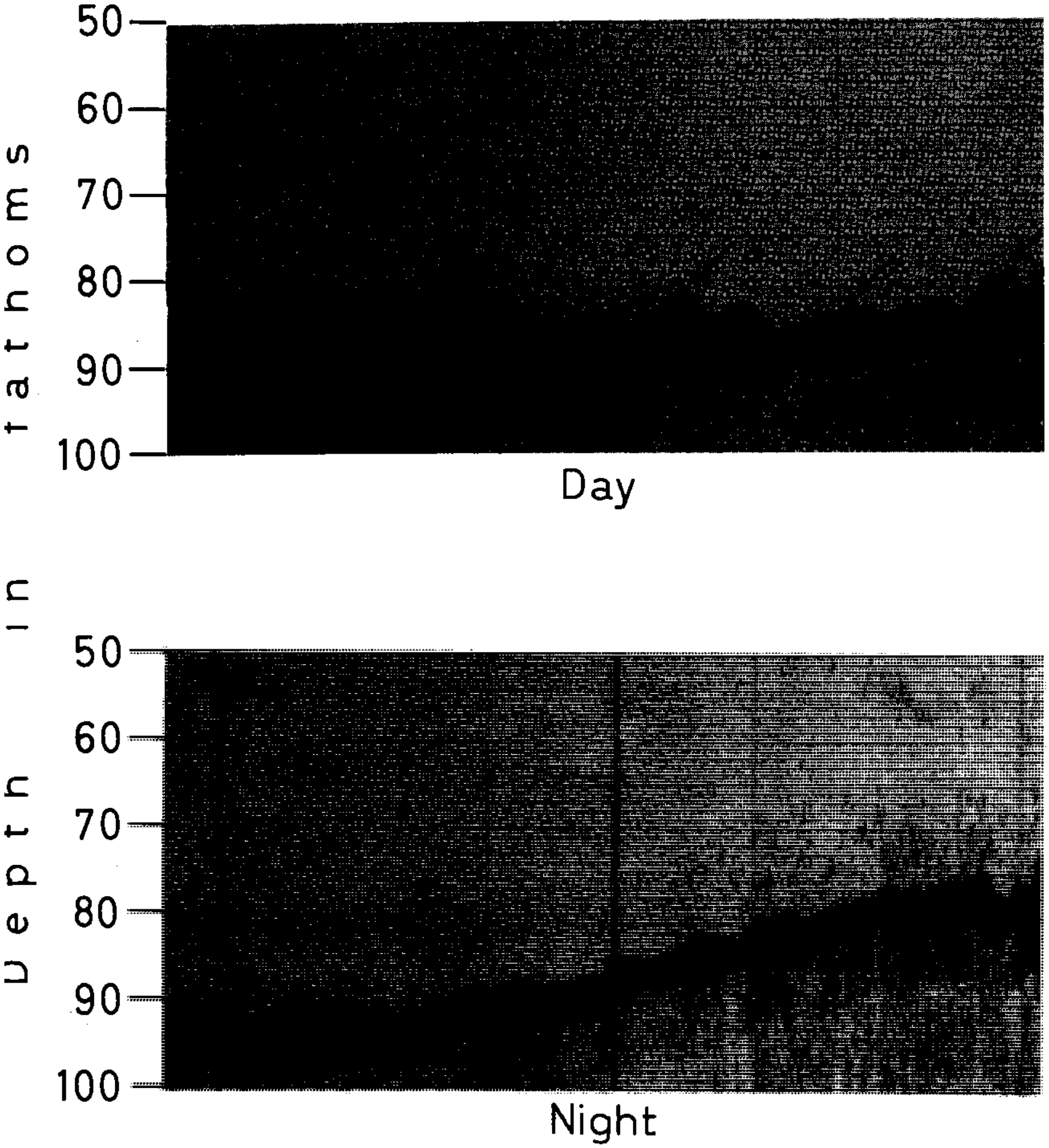


Fig. 2. Echo-recordings of cod on the Norwegian coastal banks, outside the Lofoten Islands, showing dispersion into midwater at night (ship steaming at 10 knots).

shown cod well above the sea-bed, particularly in the Barents Sea (Saetersdal, 1955; Midttun and Saetersdal, 1956; Trout, 1957; Konstantinov, 1958; Richardson *et al.*, 1959). The fish have sometimes been restricted to a relatively narrow range of depth (Ellis, 1956) and at other times have been spread over a range of perhaps 100 m - 200 m.

Possibly because cod have been observed over such a wide depth range, there have been few accounts of diurnal changes in vertical distribution in relation to day and night. The most complete series of echo-sounder records over a period of day and night was collected by Ellis (1956) in September in the Barents Sea on board a Hull trawler fishing around two dahn buoys; although the cod showed marked changes in shoaling behaviour, there was no obvious variation in the catch; however, this observation may not have been significant since it was apparent from the echo-records that the bulk of the cod were off the bottom throughout the period. Compact shoals at 100 fathoms in daylight dispersed at sunset and reformed at sunrise; during the night there was some evidence of vertical migration although its extent was not greater than 30 fathoms.

Echo-grams of cod inside the Vestfjord spawning grounds also showed dispersion of shoals at night and aggregation by day, some of these shoals staying in midwater by day but others returning to the sea-bed (Saetersdal and Hylen, 1959). During trawling on the north Norwegian coastal banks in winter with the research vessel *Ernest Holt* the author has frequently observed the vertical movement of cod shoals from the sea-bed at the onset of night, and this has been accompanied by a fall in the average catch of cod to about 50% of the daytime average; echo-recordings of the formation of cod shoals in this area by day and night are shown in Fig. 2. From this figure it can be seen that at night the cod dispersed into midwater over a range of 70 m or more. Konstantinov (1958) also reported diurnal changes in the catches of cod made by Russian trawlers during the spring and autumn in the Barents Sea; he associated these changes with cod leaving the sea-bed at night and presented echo-recordings of the cod shoals breaking up to disperse into midwater at night. In Scottish waters cod catches have also been found to decrease at night as cod were seen to leave the bottom, and some cod were also sighted at the surface at night (Parrish, Blaxter and Hall, 1963). Brunel (this symposium p. 439) described some interesting fishing experiments for cod with a split trawl, and with gill nets fished simultaneously on the bottom and just above it.

It would seem that, at least in distant northern waters, cod may spend considerable periods swimming pelagically both by day and night. As light intensities fall at dusk there is a dispersion of the cod shoals; if fish are on the sea-bed by day many of them rise into midwater at dusk and this diurnal dispersion is accompanied by a decrease in the catches of bottom trawls.

2: Coalfish (*Pollachius virens*)

Coalfish may have a pelagic distribution over deep waters and have frequently been caught near the surface in purse seines off Iceland and in the Norwegian fjords.

Clearly defined vertical migrations at night of more than 100 m have been shown by Schmidt (1955) in a remarkable series of echo-recordings. The coalfish left the sea-bed as a number of large shoals at dusk and there appeared to be some tendency to disperse into smaller shoals; however, in the middle of the night the fish had formed an almost continuous layer of midwater shoals some 10 m - 20 m deep. At dawn they returned to the neighbourhood of the sea-bed, once again forming numerous compact shoals. At Svinøy Bank, off the western coast of Norway, the present author has also made observations on the behaviour of large mature coalfish which were about to spawn; at dusk similar migrations were made of up to 100 m from the sea-bed, but at Svinøy Bank there was a greater tendency to disperse during the night and a midwater layer, as had been found by Schmidt at Iceland, was not recorded; the fish returned to the sea-bed at dawn.

Trawl catches of coalfish frequently show marked diurnal variations; on the northern Norwegian coastal banks the average night catch is about half the day catch (Woodhead, 1963*a*); but the situation may not be simple. Wagner (1959) has observed diurnal variations in the size of the fish caught, and Schmidt states that, both off Iceland and at Norway, although the greatest numbers of large fish were caught during the daytime, most small fish were caught at night.

3: Hake (*Merluccius merluccius*)

Although the hake is believed to make extensive vertical migration in pursuit of its prey, there seems to be surprisingly little published evidence of such behaviour. Hickling (1935) reported that at night Breton fishermen set pelagic long lines for hake about 30 m from the surface;

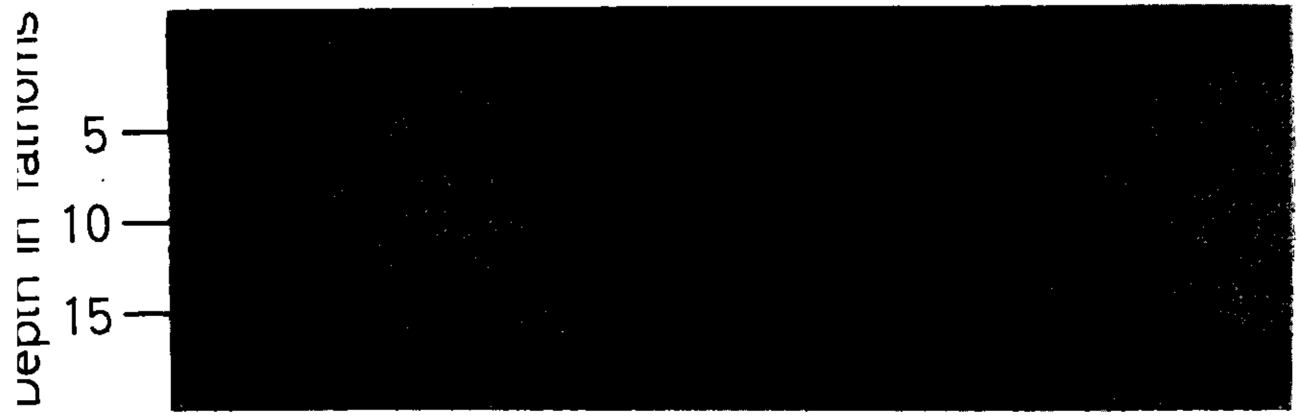
ake were also reported to be caught in large numbers in trammel nets set at the surface for salmon, nd mackerel drifters also catch small hake in their nets near the sea-surface. They have been aught at night within a few metres of the surface in midwater Engels trawls fished by research essels (H.A. Cole, *personal communication*).

There are marked diurnal changes in otter trawl catches of hake, the night catches frequently eing so small that commercial trawlers may stop fishing (Hickling, 1927, 1933). Hickling considred that the fall in catch was certainly due to the hake leaving the sea-bed and pointed out that he diurnal effect extended over a wide range of depths, the diminished catches being as notable n deep waters of 600 m as in shallower water, so that it was unlikely that the behaviour was dirctly related to the depth of an optimum light intensity; it would seem more likely that the change n light initiated an innate cycle of nocturnal migration. He suggested that when the hake were eeding at night they probably dispersed over all the water levels. There is some evidence of diferential vertical migration with size in hake, the day to night catch ratio being higher for smaler fish (Hickling, 1933).

: Whiting (*Gadus merlangus*)

It has already been mentioned that whiting are frequently caught in small numbers at night in erring drift nets fishing in the surface waters; longshore herring nets, which fish right up to he sea surface, frequently catch whiting in the top metre. It seems that the whiting are dispered at night since they are normally caught singly in drift nets, not in patches as might be exected if they were in shoals.

Blaxter and Parrish (1958) reported that in Loch Striven, Scotland, whiting moved down from he surface waters at dawn to a daytime depth of about 50 m, and they calculated that the light inensity at that depth was 0.17 lux. At night, by using electric artificial lights of different trengths, Blaxter and Parrish were able to alter the depth of whiting aggregations, over a range of rom 5 m to 18 m. They showed that the depth of the aggregations was related to the intensity of he lights, the fish remaining at a general "optimum" intensity range of 0.06 to 0.22 lux; that was t about the same intensity as at their normal daytime depth, suggesting that the whiting had inleed an optimum light intensity.



ig. 3. Echo-recordings of numerous single whiting in midwater at night, Southern Bight of North Sea (ship at anchor with slow tide running past).

In the Southern Bight of the North Sea, the author has observed the diurnal behaviour of hiting shoals in a depth of 18 fathom (unpublished observations); the shoals rose in the water at lusk and then the fish dispersed to spread singly throughout the water column at night (Fig. 3). t dawn the fish sank down and reformed small shoals which went down to, or on to, the sea-bed. he fish were maturing adults; examination of their guts showed them to be empty, so that the verical migrations were not obviously related to feeding movements.

In view of these observations it might be expected that the trawl catches of whiting would decrease at night but, rather surprisingly, Parrish, Blaxter and Hall (1963) reported, fairly consistently, better catches of whiting during darkness in Scottish waters. In the southern North Sea it is common to catch large numbers of whiting well above the sea-bed at night with midwater trawls, used both by research vessels and by commercial pair-trawlers (Harden Jones, 1962).

5: Haddock (*Gadus aeglefinus*)

Haddock are generally considered to be more closely associated with the sea-bed than many of the other gadoids of commercial interest, but there are a few records of haddock being caught in midwater. Zatsepin (reported by Konstantinov, 1958) observed that, in the Barents Sea, haddock (like cod) may follow the capelin close to the surface. Trout (1962) caught large haddock in a midwater trawl about 120 m above the sea-bed, and Saetersdal has caught haddock on pelagic line in the Barents Sea (reported by Trout, 1962); Hjort (1914) also took a few haddock in surface nets over water of more than 1,000 m depth. Blacker (unpublished, reported by Trout, 1962) has obtained photographs of juvenile haddock in the surface waters of the Barents Sea.

Trawl catches of haddock in the Barents Sea have been reported as being greater by day than at night and this has been interpreted as an effect of the fish rising into midwater (Bückmann, 1931: Konstantinov, 1958). Similar results were obtained when fishing with the *Ernest Holt* on Skolpen Bank in late November, and analysis of the catches also led the author (Woodhead, 1961, 1963*a*) to conclude that the low night catches (28% of mean day catch) were probably due to a change in availability as large numbers of smaller haddock left the sea-bed. Fish echo traces were seen leaving the sea-bed at dusk, but since cod were also present in the area no conclusions could be drawn about the identity of the traces, although the cod catches showed no significant variation. On this bank the greatest diurnal changes occurred in the smaller fish, little change being recorded in the diurnal catches of the largest haddock. The changes were not associated with feeding, since the smallest fish were feeding almost exclusively on benthic animals (echinoderms polychaetes and anemones) whilst the food of the larger haddock was increasingly of planktonic origin (*Beroe*, amphipods, *Tomopteris*) (Table 2)*; only 2% of fish were recorded as having a mixture of planktonic and benthic food in their stomachs.

TABLE 2. DIURNAL CHANGES IN CATCH OF HADDOCK, AND FEEDING CHANGES IN RELATION TO THE SIZE OF FISH.

Length (cm)	$\frac{\text{Mean night catch}}{\text{Mean day catch}} \times 100$	Planktonic food %	Benthic food %
20-29	17	0	100
30-39	11	12	88
40-49	26	27	73
50-59	44	46	54
60-69	60	54	46
70+	75	65	35

Since the apparent changes in vertical distribution were unrelated to feeding, it was thought that they might be characteristic behaviour patterns of the species which tended to change with size. This may be taking too simple a view, since although daytime catches of haddock are also greatest on the Norwegian coastal banks (Woodhead, 1963*b*), at the Faeroes Islands the greatest catches of haddock are made at night (Jones, R., 1956), and in Scottish waters Parrish *et al.*(1963) obtained very variable results at different times or localities.

6: Redfish (*Sebastes marinus*)

Like the hake the redfish is a pelagic feeder and there are very marked diurnal changes in their catches in trawls. The daytime catches are almost invariably greatest and in some fisheries these changes may be so great that trawling becomes unprofitable at night (Steele, 1957; Konstantinov and Scherbino, 1958; Templeman, 1959; von Seydlitz, 1962). It seems that these

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* In the paper of Woodhead (1961) the changes in feeding were described in the text, but in a tabulation of the analysis the captions were unfortunately transposed. The correct results are given in Table 2.

arked diurnal changes in catch are due to vertical migration by the redfish, since the fall in rawl catches has been linked with echo-records of the movement of redfish shoals from the bottom t dusk (Konstantinov and Scherbino, 1958; Templeman, 1959); Templeman reported that the shoals ad been observed to disperse during the night, though the migrations of 300 m described by onstantinov and Scherbino did not result in the dispersion of shoals of large redfish observed t Flemish Cap.

The vertical movements of redfish have also been approached from a physiological standpoint; n the basis of nitrogen analyses from the gas bladder of redfish caught at 200 m, Scholander *et al.* 1951) suggested that the fish had made migrations of up to at least 80 m during the night; howver, later work (Scholander and Van Dam, 1953) on some apparently bottom-living species gave ather similar results, and the earlier results were considered inconclusive.

: Flatfishes

There are generally few reports of flatfish swimming near the surface, at least in deep waters. he sole seems to be rather exceptional in that periodically numbers of soles may be reported as wimming along in the surface layer in the North Sea (deVeen, 1963); this behaviour seems to be ssociated with the spawning migration and occurs on dark moonless nights.

Most of the data concerning the vertical movements of flatfish have come from midwater trawing. In the southern North Sea plaice and dabs are very frequently caught in midwater at night Woodhead, 1960; Harden Jones, 1962; unpublished observations on research vessels). Soles are selom caught well off the bottom, despite their surface-swimming on particular occasions. Hartley 1940) mentions flounders being sometimes taken in surface drift nets in the Tamar estuary and hey have also been taken at night with midwater trawls in the southern North Sea.

It is difficult to assess laboratory observations of flatfish swimming in midwater at night, ince the aquaria normally apply severe restrictions to both the vertical and horizontal movements f the fish; however, swimming activity may persist for considerable periods. Using a circular rough for experiments, Bregnballe (1961) recorded average speeds of about 900 m per hour in 26 cm lounders, and one flounder swam 5 km during the course of a night.

In offshore regions of the southern North Sea trawl catches of plaice tend to decrease at night, nd it has been suggested that this may be due to a change in availability as plaice leave the sea-ed (Woodhead, 1960; de Groot, 1963; as discussed above). However, Parrish, Blaxter and Hall (1963) ound that in the northern North Sea plaice catches were generally greater at night; as yet these ifferences cannot be explained.

ADAPTIVE SIGNIFICANCE OF VERTICAL MIGRATION

In many pelagic fish, such as the herring and anchovy, feeding generally occurs at twilight ear the surface, and Zusser (1958) has suggested that daily vertical migration is of advantage o the fish in changing their environment and choice of food by "scanning" a range of depths twice aily. This might also apply to hake and coalfish which feed on other fish and on plankton in midater. Yet many other demersal species which feed mainly at the sea-bed, such as plaice, flounders nd possibly haddock, show evidence of adopting basically similar diurnal behaviour patterns, freuently involving movement of the fish away from the sea-bed. Examination of the stomach contents f such fish has frequently shown that they feed little, if at all, when swimming clear of the botom at night. In these species the adaptive value of leaving the sea-bed is not immediately so bvious, since it imposes a restriction on the feeding period; nevertheless this behaviour appears o be widespread, although it may show some variations seasonally or with the size and condition of he fish. The possible role of vertical migrations as part of distribution mechanisms of particular pecies is now considered.

Diurnal changes in the behaviour patterns of demersal fish, which take the fish away from senory contact with the sea-bed, must expose the fish to changes in the actions of water currents, and ay well lead to their passive displacement; in some cases the extent of their vertical migrations ay take the fish into different current systems from those at the sea-bed. Very little is known of he reactions of fish to steady linear currents once they have lost tactile and visual contact with he sea-bed, or some external reference point (for discussion see Harden Jones, 1958). However, obervations on the behaviour of blind fish well clear of the bottom in a steady stream of water have hown that their swimming is unorientated by the current, the fish being carried passibely along in

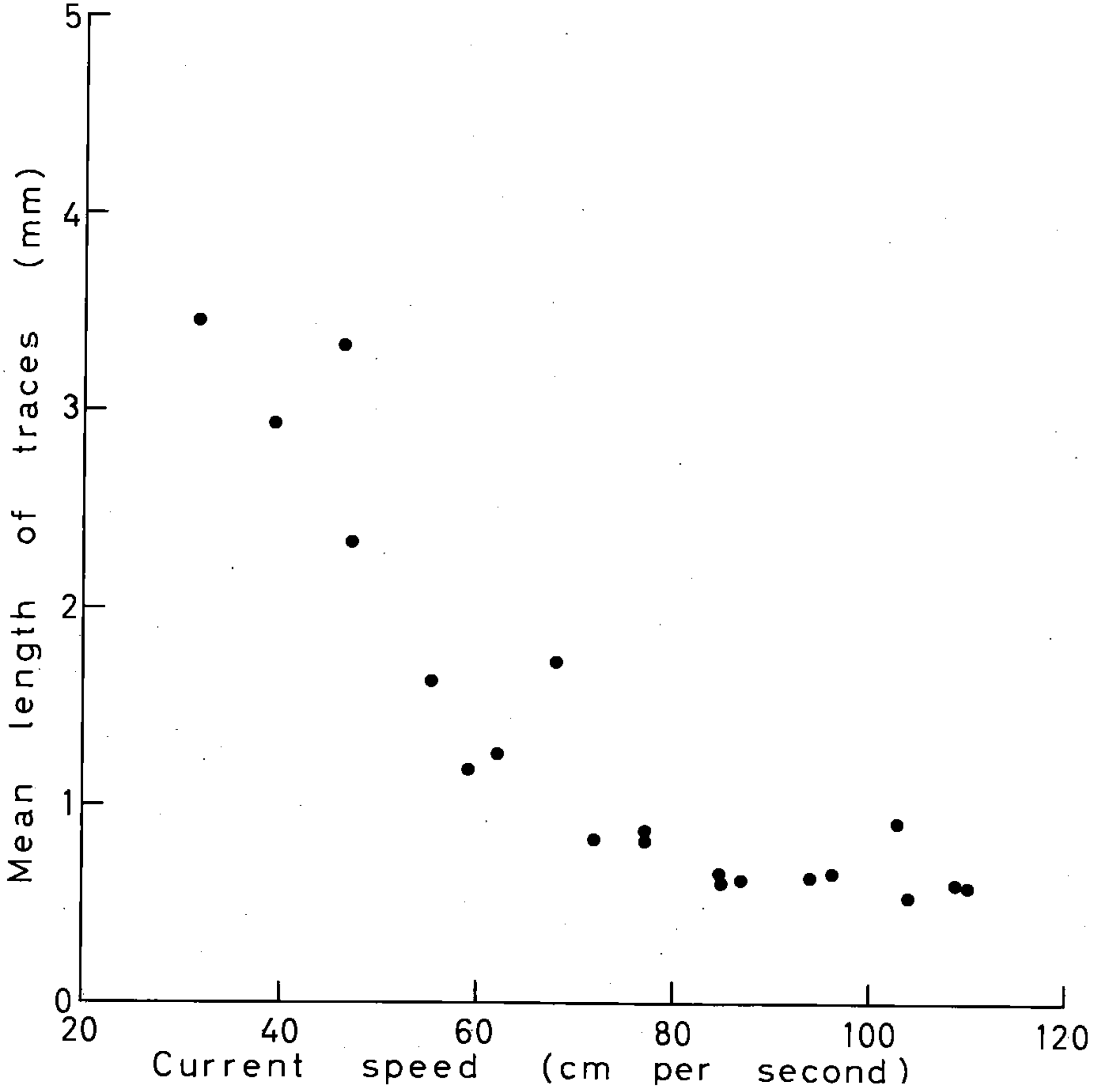

Fig. 4. Mean length of echo-recordings from whiting, in relation to the speed of the tidal current, for one quarter of a tidal cycle. The size of the traces has been corrected for the depth at which the fish occurred.

the water (Lyon, 1904, 1909; Dijkgraaf, 1933). If this also happened with marine fish, once they had lost contact with the bottom, their duurnal vertical migrations could exert considerable effects upon their horizontal displacment.

An example of this form of passive displacement at night was provided by observations on the behaviour of whiting made during a recent cruise of the research vessel *Clione* in the Southern Bight of the North Sea. The ship lay at anchor in a tidal stream in an area in which the echo-sounders recorded numerous small fleck or comet echo-traces, typical of single fish (Richardson *et al.*, 1959), in midwater. The tidal speed was measured with two Kelvin Hughes Direct Reading Current Meters, suspended at 8 m and 20 m. It was observed that, as the current speed decreased, the echo-traces recorded from the fish become progressively longer as they passed more slowly beneath the ship. It was concluded that the fish were being carried along passively in the current, but this was checked by measuring the size of the echo-traces recorded within the depth range 8 m - 26 m, and comparing their mean sizes with the simultaneously measured mean current speed. The results are shown graphically in Fig. 4, in which it can be seen that the relationship wss curvilinear. From the results it would appear that the fish were being carried rapidly past the ship at fast current speeds. If this had also been the case at low speeds the relationship should have been hyperbolic, but the considerable increase in mean trace size at low speeds suggested that the fish were then partly stemming the tide. Although the fish may have been using the ship as an external reference point for orientation against the tidal current at low speeds (though the seawater was very turbid and the ship's lights were obliterated, except for the minimum required for navigational purposes, so that visual clues were small), it was apparent from the form of the relationship in Fig. 4 that for most of the observation time the speed at which fish were passing the ship was directly related to the tidal speed, and it seems probable that they were largely being carried passively in the tidal current. The fish were identified by fishing with an Engels midwater trawl immediately after the tidal observations had been made; the catch was mainly whiting 29-49 cm long (215 fish), with 17 pilchards and 1 herring, 5 codling of 40-60 cm, and 6 flatfish. After daybreak the fish were observed to form small shoals which later returned to the sea-bed.

Transport of fish by water currents after they have left the bottom has been suggested by a number of authors as a mechanism for carrying out directional migration (*e.g.* Trout, 1957; Fraser, 1956; Harden Jones, 1961; Stieve, 1961), although little direct evidence has been obtained until recently. Harden Jones (1957 and 1962) showed that at night in the Southern Bight of the North Sea midwater herring shoals moved in the direction of the tidal current, though it was not possible to say whether the movements were due to passive drift; herring shoals in contact with the sea-bed were able to maintain their position by stemming the tides. Vertical migrations from the sea-bed may coincide with a particular phase of the tide, and Verway (1958 and 1960) has suggested that the migration of elvers, shrimps, and possibly soles may be achieved by passive transport during special phases of the tidal cycle. This suggestion has been amply confirmed for elvers by the experiments of Creuztberg (1959, 1961), and the recent report of deVeen (1963) on the surface swimming of soles suggests that passive transport during particular parts of the tidal period may indeed help these fish to achieve directional migrations. If such methods of migration exist in some fish of limited swimming ability, there seems to be no reason *a priori* why similar behaviour should not apply, at least in part, to better-swimming species; indeed, Harden Jones (1961) suggests that by making judicious use of systems of currents and counter-currents, fish may be able to achieve most of their migratory movements by passive transport mechanisms.

It is concluded that diurnal changes in behaviour patterns in relation to light are widespread in fish; frequently these cyclic patterns involve changes in the vertical distribution of the fish. In some species vertical migrations are obviously related to feeding activities, but in other species there appears to be little direct relationship. Changes in the vertical distribution of demersal fish may expose them to differences in the action of currents, and in some cases may take them into current systems other than those at the sea-bed. Essentially, the transport of the fish in such currents must have considerable effects upon their horizontal distribution. Diurnal vertical migration may therefore be considered as an integral part of the distribution mechanism of demersal fish. It may be that future research will show that some fish are able to make orientated movements with or against the currents, or at compass bearings to them, even when swimming well away from the sea-bed; nevertheless the direct effects of water transport will still be important, since the overall movements of the fish with respect to the sea-bed will be the resultant of the swimming movements of the fish and the movement of the water.

At present there is surprisingly little published information on the vertical movements of demersal fish, mainly due to problems of sampling the fish in midwater. Quantitative information on the vertical distribution of demersal species is now required, and valuable results are likely to come from the development of effective and easily applied midwater trawling techniques.

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