SECTION

E

E-1

EFFECT OF LIGHT ON MOVEMENTS OF HERRING IN THE BAY OF FUNDY

By

S. N. Tibbo[1]

ABSTRACT

Crude laboratory experiments indicate that young herring (*Clupea harengus* L.) 10-15 cm long are attracted to the surface by incident light intensities which do not exceed 15-16 m-c and that the speed of attraction varies inversely with the light intensity. Sonic-sounder recordings in depths of 7-22 m show that "sardine" herring lie on or very close to the bottom on sunny, winter afternoons. At twilight they rise from the bottom in dense shoals and after dark become widely dispersed in the upper water layers.

INTRODUCTION

It is well known that herring make vertical migrations which are associated with changes in light intensity. Larval herring are caught within the upper 20 m of water under all light conditions but are taken in greatest numbers in the top metre of water at night (Tibbo and Legaré, 1960). Similarly shoals of adult herring are comparatively rare at the surface during the day but are caught in enormous quantities in the upper water layers at night (Johansen, 1925). Brawn (1960) has shown from echo-sounder records that herring are closer to the surface by night than by day during every month of the year. Because of this diurnal vertical movement drift-nets and purse seines are usually operated at the surface at night, whereas, bottom trawls are used chiefly during the daylight hours.

It is also known that herring near the surface at night are attracted to lights. Torching (*i.e.*, attracting herring with a light and dipping them into a boat) is an effective method of capin some areas (Scattergood and Tibbo, 1959). Weir fishermen in the Passamaquoddy region of the Bay of Fundy are aware of relationships between availability of young herring (sardines) and light intensity. For example, some weirs are most effective in the morning and others in the evening (Johnson, 1940) and catches are better at some phases of the moon than at others (personal communication with fishermen).

In spite of this general awareness of the response of herring to light there has been little effort to measure the light intensities which attract or repel herring or of changes in light intensity which may induce vertical migrations. To obtain some information on these subjeacts crude laboratory experiments were carried out at the St. Andrews Station of the Fisheries Research Board of Canada and a field experiment was carried out in Maces Bay, New Brunswick.

LABORATORY EXPERIMENTS

For the laboratory experiments approximately 100 herring (10 to 15 cm total length) were kept in an outdoor, covered tank (ca. 4 m × 6 m × 1 m deep) for several months and subsequently exposed to artificial light, the intensity of which could be varied within certain limits.

The experiments were carried out at various times of day during the winter of 1948-49. They were done at irregular intervals with a minimum of 1 hr between successive tests to allow the fish time to adjust to darkness. The tank cover (ca. 1.5 m high at the centre) kept the fish in darkness except when artificial lights were turned on. An electrical outlet was attached to the under side of the tank cover. The distance between the lamps and the surface of the water was 142 cm. A reflector directed the light downward to the surface of the water. Light intensities were measured with a Weston incident light meter.

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

TABLE 1. SOURCE OF LIGHT, INCIDENT LIGHT INTENSITY AND RESPONSE OF HERRING TO LIGHT.

Lamp	Filter	Incident light intensity	Phototropism
w		*m-c*	
7 1/2	None	4.3	+
7 1/2	Yellow	3.2	+
7 1/2	Red	1.1	+
7 1/2	Blue	0.3	+
15	None	15.1	-
15	Yellow	8.6	+
15	Red	4.3	+
15	Blue	1.1	+
40	None	26.9	-
40	Yellow	16.1	+
40	Red	7.5	+
40	Blue	2.2	+
60	None	48.4	-
60	Yellow	36.6	-
60	Red	15.1	-
60	Blue	5.4	+

Table 1 shows that herring were attracted to and stayed within the influence of a faint light but were repelled by strong light. Attraction was determined by measuring the time from the turning on of the lamp until 50% of the fish came within the circle of light shed by it.

A 7.5 w, 110 v lamp with a blue glass filter (0.3 m-c) exerted the greatest attraction. It took twice as long to attract the fish with the 7.5 w lamp using red (1.1 m-c) and yellow (3.2 m-c) filters. The herring were attracted but still more slowly by the 7.5 w lamp with no filter (4.3 m-c). Lamps of 15, 40 and 60 w with and without filters were used to produce light intensities varying from 1.1 to 48.4 m-c. From the results it was concluded that herring are attracted to incident light intensities which do not exceed 15 to 16 m-c and that the speed of attraction varies inversely with the light intensity.

FIELD EXPERIMENT

For the field experiment echo-sounder recordings were made from the research vessel *Gulf Explorer* using a Bendix DR1 model echo-sounder. During the daytime on a bright, sunny afternoon recordings were made directly in front of a bottom trawl that was being towed by another vessel, the *Li'l Abner*. At twilight and during the night on the same date (8 February, 1952) recordings were made as close to a fleet of purse seiners as it was possible to go without interfering with their operations.

Figure 1 gives four typical echo-sounder recordings showing the distribution of herring under different light conditions. Figure 1A is typical of the daytime recordings. There was nothing on these recordings to indicate the presence of herring except, possibly, the wide bottom trace at 72 ft (22 m) which is characteristic of soft, muddy bottoms. In Maces Bay much of the bottom is hard packed sand which gives a sharper narrower trace, *e.g.*, Figure 1C. The fishing vessel *Li'l Abner* operated a bottom trawl in this area and made catches from 0.7 to 3.6 metric tons per hour's towing. To obtain the record shown in Fig. 1A the *Gulf Explorer* cruised in all directions ahead of, alongside and over the trawl being towed by the *Li'l Abner*. The trawl and trawl warps were recorded (not included in the Fig.) whenever we passed over them but there was never any more indication of fish than is shown in Fig. 1A which was for areas directly in front of the trawl during one tow. The catch during this tow was 0.9 metric tons.

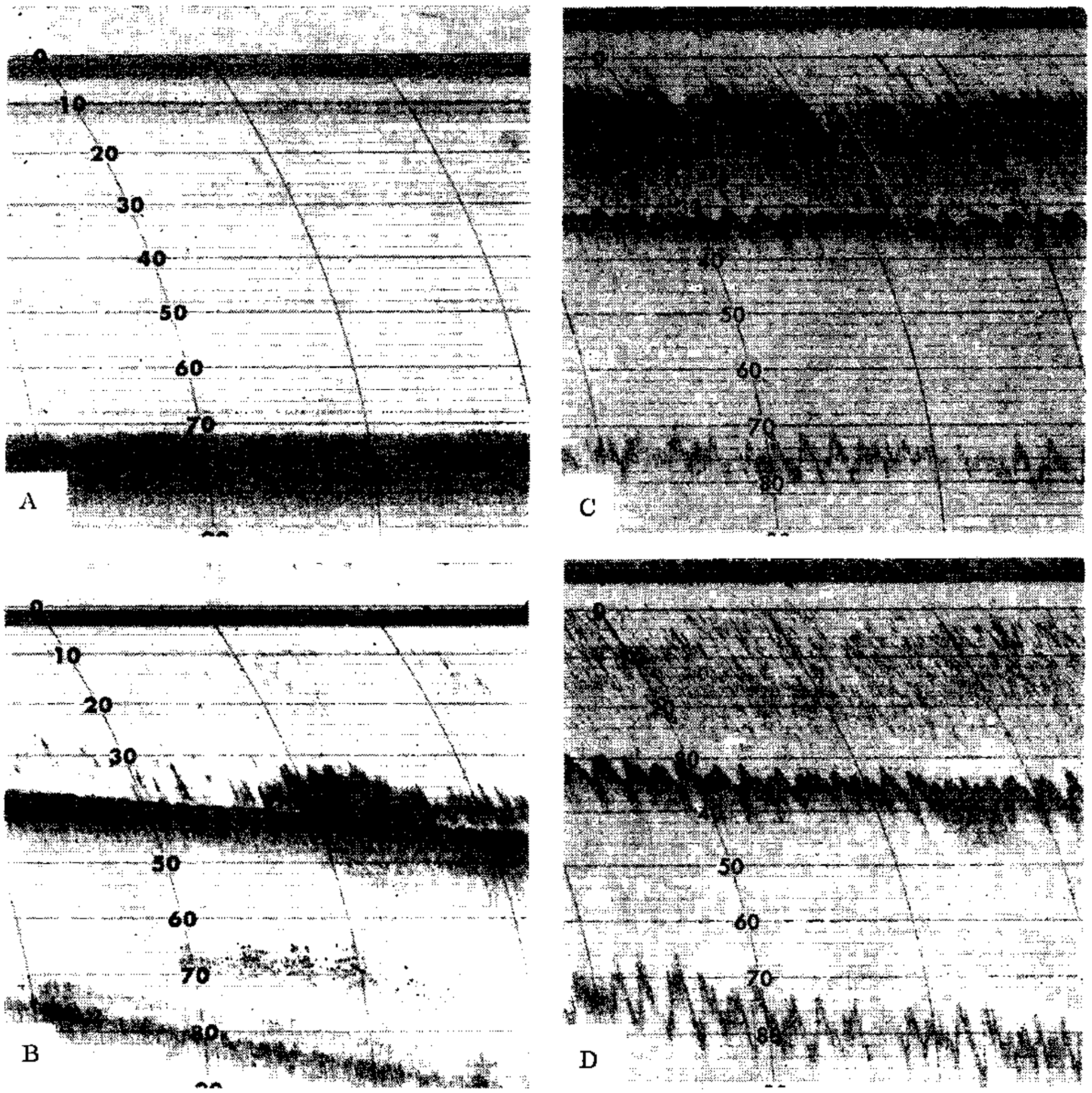


Fig. 1. Echo-sounder recordings from Maces Bay, New Brunswick.
A. Typical daytime recording with herring on or close to bottom.
B. Typical twilight recording showing herring off bottom.
C. Typical dusk recording showing dense shoals of herring in mid-water.
D. Typical night recording showing herring scattered in mid-water.

Figure 1B and 1C illustrate the type of recordings made just after sunset in the same general area of Maces Bay. In these recordings dense shoals of herring can be seen just off bottom and at mid-depths. The movement away from the bottom was quite rapid as evidenced by the fact that the recording shown in Fig. 1C was made less than 15 min after the recording shown in Fig. 1B. It is during the twilight period that the purse seiners are active and catches from 14 to 36 metric tons were made at the same time and in the same area as these recordings were being made.

Figure 1D typifies recordings made at night in showing how the herring have dispersed. Attempts to purse seine these dispersed shoals have yielded small catches (0.9 to 1.3 metric tons) which are not worth the effort.

DISCUSSION

From the pattern of commercial fishing operations it appears that the behaviour of herring illustrated by the echo-sounder recordings from the field experiment is typical of the behaviour of "sardine" herring in the Bay of Fundy. Tentatively this behaviour is explained as a strong, positive attraction to light of low intensity as indicated by our crude laboratory experiment.

Obviously present information is inadequate for an understanding of light-induced movements of herring but from the point of view of the fisheries this understanding may be important. It would be useful to know the depths to which herring will go to avoid light of high intensity.

The recordings shown here indicate that in winter sardine-size herring will descend to the bottom (about 21 m). However, Brawn (1960) showed that some fish of this size were off bottom and that the median depth during the day from May to December varied from 9.1 to 13.4 m. From January to April it varied from 25.3 to 38.4 m. Furthermore, Leim *et al.* (1957) observed that "sardine" herring were distributed at mid-depths after several hours of bright sunlight in areas where the depth of water was about 27 m and concluded that herring do not react to daylight in the same way at all times.

It is obvious that the effect of light on herring is poorly understood and merits serious study.

REFERENCES

BRAWN, VIVIEN M. 1960. Seasonal and diurnal vertical distribution of herring (*Clupea harengus* L.) in Passamaquoddy Bay, N.B. *J. Fish. Res. Bd. Canada,* 17 (5): 699-711.

JOHANSEN, A.C. 1925. On the diurnal vertical movements of young of some fishes in Danish waters. *Medd. Komm. Danm. Fisk. Havundersøg. Bd.* VIII, Nr. 2, 27 p.

JOHNSON, W.H. 1940. Effects of light on movements of herring. *J. Fish. Res. Bd. Canada,* 4 (5): 349-354.

LEIM, A.H., S.N. TIBBO and L.R. DAY. 1957. Explorations for herring in Canadian Atlantic waters, 1945-1950. *Bull. Fish. Res. Bd. Canada,* No. 111, p. 35-83.

SCATTERGOOD, L.W., and S.N. TIBBO. 1959. The herring fishery of the Northwest Atlantic. *Bull. Fish. Res. Bd. Canada,* No. 121, 42 p.

TIBBO, S.N., and J.E. HENRI LEGARE. 1960. Further study of larval herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine. *J. Fish. Res. Bd. Canada,* 15 (6): 1451-1469.

E-2

DISTRIBUTION OF PLANKTON AND SUMMER FEEDING OF HERRING IN THE NORWEGIAN SEA AND ON GEORGES BANK

By

E.A. Pavshtics[1]

ABSTRACT

Comparison of the conditions for the spring-summer feeding of herring in the Norwegian Sea and on Georges Bank (the Gulf of Maine) shows that herring prefer the areas where the biomass of *Calanus finmarchicus* amounts to 200-500 mg/m^3. In search of such concentrations of *Calanus finmarchicus* the Atlanto-Scandian herring of the Norwegian Sea migrate over great distances from the coastal waters into the waters of Atlantic origin and then into the mixed and polar waters where biological spring starts.

On Georges Bank several generations of *Calanus finmarchicus* develop during one season, so herring are provided with food and do not undertake extensive migrations.

An increase in the water temperature in the Norwegian Sea and on Georges Bank results in the change of plankton composition: Medusae and Tunicata occur in great numbers, thus providing the unfavourable conditions for herring.

Soviet plankton investigations were conducted in the Norwegian and Greenland Seas to study the role of plankton in the feeding migrations of herring. The first observations in the Greenland Sea were made in the region of Spitsbergen in June-July, 1947, by an expedition organized by Ju. Ju. Marty and B.P. Manteifel. Subsequently with the extension of the Soviet herring fisheries in the Greenland and Norwegian Seas, the region of plankton investigations also extended over a greater area. As a result of the investigations carried out in the Norwegian Sea, it was established (Marty, 1956; Pavshtics, 1956 and 1960; Rudakova, 1956) that the life cycle of Atlanto-Scandian herring is most closely related to the dynamics of the development of plankton.

The herring developed the habit of feeding migrations during the historical development of the species. The habit allows the fish to take full advantage of the vernal outburst of plankton on which they feed intensely in coastal, Atlantic, mixed and polar waters. Herring adapt easily to considerable changes of environmental conditions. Repeated observations have shown that changes in hydrometeorological conditions in the Norwegian Sea were accompanied by considerable (up to a month) variations in the time of development of plankton and that a corresponding change was also observed in the duration of the herring feeding period.

In the Norwegian Sea in cold years (1958 and 1962) and in years approaching normal conditions (1951, 1953, 1955) (Alekseev and Istoshin, 1960; Istoshin and Alekseev, 1959; Alekseev, Istoshin and Shmarina, 1962) herring usually began to feed in March-April on the spring concentrations of breeding Euphausiacea and *Calanus finmarchicus* near the continental slope of the coast of Norway.

By June the herring migrated from the southern part of the Norwegian Sea to the west (Grusov, 1960 and 1961) and from the coasts of north Norway - to the north-west, to the regions of the Polar Front, where the biological spring (spawning of *Calanus*) begins later (Pavshtics, 1956 and 1960; Pavshtics, 1958). Usually the feeding period of the herring ended in August-September in the mixed waters in the region of the Mohn Ridge and Jan Mayen. In the warm year 1960 and partly in 1959 (Grusov and Pavshtics, 1961) due to a considerable warming of the mixed waters in the south-western region of the Norwegian Sea near the Faroes, the breeding and development of *C. finmarchicus* occurred

[1] Polar Research Institute for Marine Fisheries and Oceanography, Murmansk, USSR.

earlier than in 1951-1958. Accordingly in 1960 the herring reached its highest fat content earlier than in the preceding years - by June-July instead of August-September. In 1960 the feeding period started in an unusual way. The herring, migrating in April 1960 from the coast of Norway to the Faroes, did not encounter the concentrations of breeding *Calanus* which are present at that time of the year. Here the spawning of *Calanus* was already over and the bulk of plankton was composed of small young *Calanus*. Therefore, by the end of May and in early June 1960, in contrast to other years, the herring in the mixed waters, at the Faroes and on the boundaries of the East Iceland current fed on fat red *Calanus* (*Calanus finmarchicus*, III-IV-V stages). The biomass of plankton in the feeding regions was extremely high, two times higher than in previous years (Pavshtics, 1962; Pavshtics and Rudakova, 1962). Due to the early development of red *Calanus* in the western region of the Norwegian Sea in the warm year 1960 not only the young (21-28 cm) but the older herring fed on red *Calanus*.

Earlier detailed field observations on the feeding of young and old herring were made in the Norwegian Sea in the summer 1955 (Pavshtics, 1956). At that time a quite different picture was observed. In June 1955, characterized by a retarded development of plankton, young herring (21-28 cm) were feeding in the central regions of the Norwegian Sea; but red *Calanus* was scarce so that *Oikopleura* sp. and *Themisto abyssorum* were the main items of the diet in June 1955. Older herring stayed in the region of the Polar Front near Jan Mayen, where the biological spring was just beginning, feeding on *Calanus hyperboreus* and *Calanus finmarchicus* in VI copepod stage. In 1955 the red *Calanus* (*Calanus finmarchicus* of the III-IV-V stages) developed in August-September near Jan Mayen and in the region of Mohn Ridge. By that time both old and young herring migrated to this area.

The 1955 observations convinced us that during periods of feeble and slow development of *Calanus*, herring can feed on other plankton organisms, such as *Themisto* juv. and *Oikopleura labradoriensis*, though *Calanus finmarchicus* and various species of Euphausidae still remain their favourite food (Rudakova, 1956; Pavshtics and Rudakova, 1962). In 1960 the highest fat content of herring was already reached in June. In 1955 and 1958, years of retarded development of *Calanus*, the highest fat content was observed only in August-September (Pavshtics, 1962; Pavshtics and Rudakova, 1962). In 1960 and 1959, characterized by an early development of *Calanus*, the feeding period of the herring was short, and at the end of this period the herring was not as fat as in moderate and cold years. The feeding of herring is at times unfavourably affected by an early development of medusa *Aglantha digitale* in the waters of the Norwegian Current.

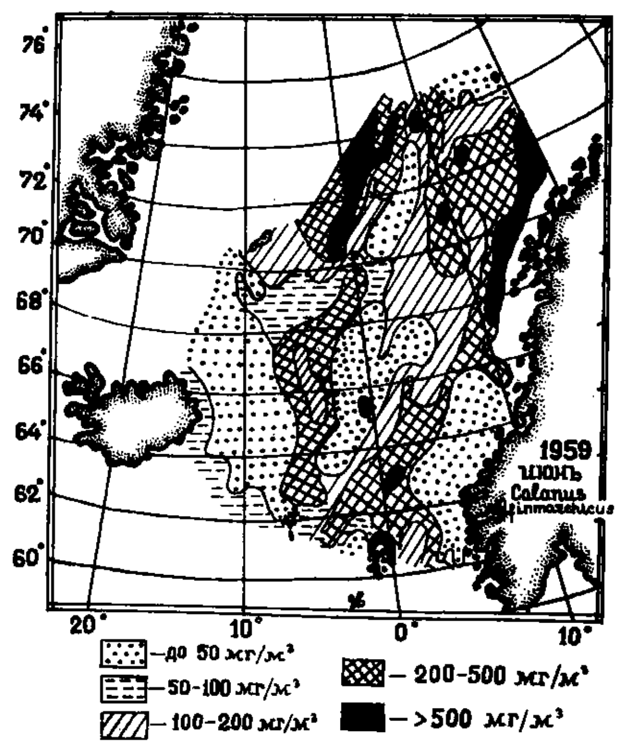


Fig. 1. Quantitative distribution of *Calanus finmarchicus* in June 1959 in the Norwegian Sea (biomass in mg/m^3).

In warm years (1954, 1959, 1960) *Aglantha digitale* appeared in the central and southern regions of the Norwegian Sea as early as June, whereas in colder years a mass development of *Aglantha digitale* was observed in July-August and even in September. The medusae are greatly reducing the quantity of *Calanus* in the upper water layers, thus affecting the feeding of herring. Most often herring moved from the southern and central regions in June-July westwards or northwards, into colder waters, where no medusae are found at that season. At the edge of the East Icelandic Current, where herring feed in June, the biomass of *Calanus* rarely exceeds 200-500 mg/m^3 (Fig. 1). A typical situation was observed in June 1959, when the feeding area of the herring was limited on the west by a zone of *Aglantha digitale*, where the biomass of *Calanus* was less than 50 mg/m^3 (Grusov, 1961). During this period the herring did not move farther west because in June the cold waters of the East Icelandic Current still contain the poor plankton concentrations in winter (Grusov and Pavshtics, 1961). The herring feeding in the mixed waters gradually moved north along the margin of the cold East Icelandic Current.

In 1961 and 1962 material was collected on plankton and feeding of herring in the region of Georges Bank (the Gulf of Maine). A comparison of these materials with observations on the feeding of herring (Benko and

Vilson, 1962) showed that on Georges Bank, like in the Norwegian Sea, the herring feed mainly on *Calanus* (*Calanus finmarchicus* III-IV stages) and *Euphausiacea*. The most intensive feeding on *Calanus* is observed here in May-June. On Georges Bank, like in the Norwegian Sea, herring during the feeding period keep to the mixed waters of the frontal zone and easily tolerate even sharp variations of water temperature.

On the slopes of Georges Bank, Atlantic waters, cold waters of the Nova Scotia Current and moderately warm, low salinity waters of the Gulf of Maine are encountered (Bigelow, 1926). Each water mass carries to the Bank its own plankton. Herring feed mainly on boreal plankton: *C. finmarchicus, Pseudocalanus minutus, Metridia lucens, Thysanoessa inermis, Meganyctiphanes norv., T. compressa f. commpressa* and others. This plankton community inhabits the northern and north-western slopes of the Bank washed by the waters of the Gulf of Maine. Here in the summer months of 1962 were observed the most abundant concentrations of *Calanus finmarchicus* (Table 1). At Station 44 *Calanus finmarchicus* accounted for 94% of the total plankton (by number of specimens). The least amount of food plankton was observed in the central part of the Bank with a rich development of phytoplankton. On the south-eastern slope of the Bank washed by Atlantic waters, the quantity of *Calanus finmarchicus* decreases to 62 specimens per m^3, as compared with 880 specimens per m^3 on the northern slope of the Bank. Here, as in the Norwegian Sea, herring fed mainly where the biomass of *Calanus* reached 200-500 mg/m^3 (Fig. 2).

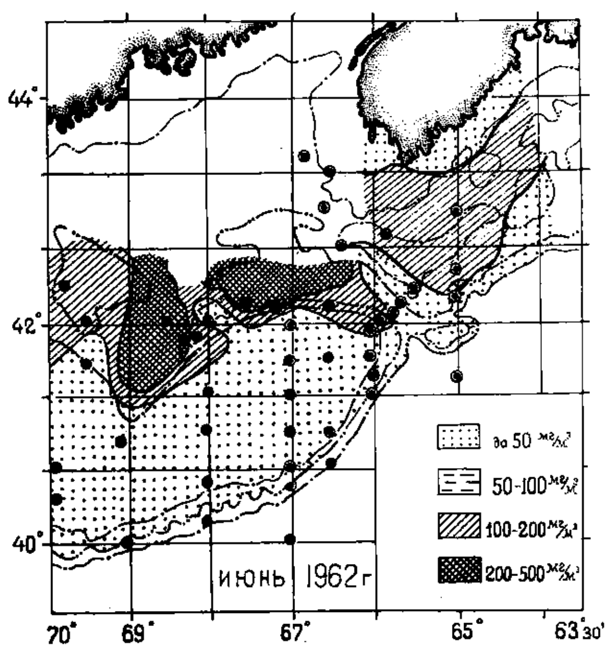


Fig. 2. Quantitative distribution of *Calanus finmarchicus* in June 1962 on Georges Bank (Gulf of Maine) (biomass in mg/m^3).

The importance of the most common Copepoda in the plankton of Georges Bank, is shown in Table 1 (percentage of the total number of plankton organisms). Comparison of the composition of plankton on Georges Bank and in the Norwegian Sea, shows regular phenomena common to both regions. In the waters of the continental slope, where Atlantic waters mix with coastal waters, *Calanus finmarchicus* predominates (Pavshtics, 1960, p. 166). Regions where Atlantic waters mix with cold waters from the north, are characterized both in the Norwegian Sea and on Georges Bank, by a predominance (in number of specimens) of *Oithona similis*.

In the Norwegian Sea, for instance, in the region of Jan Mayen, where waters of the western branch of the Norwegian Current meet a branch of the cold East Greenlandic Current, *Oithona similis*, in June 1959, made up 69% of the plankton in numbers of specimens (not in the biomass). A similar picture was observed in the region of Georges and Browns Banks where Atlantic waters mix with the Nova Scotia Current. Here *Oithona similis* composed about 37% of the plankton.

There are, however, some differences between the feeding conditions of the Norwegian Sea and those of Georges Bank. According to Fish (1936*a* and *b*) the high water temperature - up to 18-20°C - in the Gulf of Maine favours the development of several generations of *Calanus finmarchicus* and *Pseudocalanus minutus* during a single season. The breeding period of Euphausiacea and of Hyperiidae is prolonged too which ensures a prolonged stay of their young in the mid water layers. As a result, the herring is provided with food almost all year and, in contrast to the herring of the Norwegian Sea, can feed without undertaking any distant migrations. Some data on the feeding of herring in the regions investigated are given in Table 2. When comparing the feeding intensity of herring on Georges Bank with that of herring in the Norwegian Sea, it must be remembered that the herring feeding on Georges Bank are summer spawners, whereas in the Norwegian Sea spring spawners were predominant. The lower average indexes of stomach fullness in herring from Georges Bank in the summer months seem to be determined by a more rapid food digestion owing to higher water temperatures as compared with the Norwegian Sea.

TABLE 1. THE IMPORTANCE OF THE MOST COMMON COPEPODA IN PLANKTON ON THE SLOPES OF GEORGES BANK (IN PERCENT OF TOTAL NUMBER OF PLANKTON ORGANISMS).

Stations, Date, Positions	*Calanus finmarchicus*			*Pseudocalanus minutus (elongatus)*			*Metridia lucens + longa*			*Temora longicornis*		
	Spec/m^3	%	Weight	Spec/m^3	%	Weight	Spec/m^3	%	Weight	Spec/m^3	%	Weight
South-eastern slope 3 June, 1962 Depth 85 m Temp. 7.5°C Layer 80-0 m	62.5	9.3	27.6	17.5	2.6	1.4	1	0.1	1.1	0.5	0.05	0.028
Eastern slope 4 June, 1962 Depth 100 m Temp. 8.6°C Layer 100-0 m	280	16	117.3	234	13.3	13.9	27.7	1.5	25.2	11.6	0.7	0.65
Northern slope 8 June, 1962 Depth 200 m Temp. 10.9°C Layer 50-0 m	728	16	299	180	4	11.3	68	1.5	61.9	-	-	-
Northern slope 7 June, 1962 Depth 210 m Temp. 1.1°C Layer 50-0 m	880	34.2	497	480	18.7	41.3	280	10.9	255	-	-	-
North-western slope 7 June, 1962 Depth 100 m Temp. 11.9°C Layer 60-0 m	690	94	401	23	3.3	1.8	1	0.1	1.67	-	-	-

TABLE 1 (CONT'D).

Stations, Date, Positions	*Centropages hamatus*			*Oithona similis*			*Nauplii calanoida*			Weight of Common Species mg/m³	Total Quantity of Plankton ml/m³
	Spec/m³	%	Weight	Spec/m³	%	Weight	Spec/m³	%	Weight		
South-eastern slope 3 June, 1962 Depth 85 m Temp. 7.5°C Layer 80-0 m	0.5	0.05	0.06	105	15.7	0.53	420	62.8	3.4	34	0.75 "Blooming"
Eastern slope 4 June, 1962 Depth 100 m Temp. 8.6°C Layer 100-0 m	-	-	-	634	36.2	3.2	400	22.8	3.2	163	0.3
Northern slope 8 June, 1962 Depth 200 m Temp. 10.9°C Layer 50-0 m	-	-	-	1016	22.1	5.1	2000	43.6	16	393	0.6
Northern slope 7 June, 1962 Depth 210 m Temp. 1.1°C Layer 50-0 m	-	-	-	440	17.1	2.2	392	15.2	3.1	799	1.8
North-western slope 7 June, 1962 Depth 100 m Temp. 11.9°C Layer 60-0 m	-	-	-	1	0.1	0.0005	17	2.4	0.14	405	1

TABLE 2. SOME DATA ON THE FEEDING OF HERRING ON GEORGES BANK AND IN THE NORWEGIAN SEA IN 1961. BASED ON DATA COLLECTED BY BENKO, VILSON (1962) AND RUDAKOVA'S PERSONAL COMMUNICATION.

	April	May	June	August	October	November	December
Georges Bank Average index of stomach fullness	0.58	1.14	0.54	0.30	0.29	0.37	0.68
Norwegian Sea Average index of stomach fullness	0.87	1.33	1.47	0.95	0.32	0.15	0.09
Georges Bank Average index of fat content	0.84	1.40	1.77	0.76	0.67	0.44	0.83
Norwegian Sea Average index of fat content	0.35	0.58	1.65	1.80	1.16	1.17	1.56

The low index of stomach fullness in herring of the Norwegian Sea during November-December is caused by a sharp decrease in the quantity of plankton during the autumn-winter seasons. In the Gulf of Maine and on Georges Bank the herring is winter fed on Euphausiacea. From November to February no *Calanus finmarchicus* occur on Georges Bank. Their place in the plankton is occupied by small tropical copepods and tunicates. Occasionally Euphausiacea, *Nematoscelis megalops* and *Meganyctiphanes norvegica* appear on the Bank. Due to the earlier development of plankton on the Bank, the herring reach their maximum fat content somewhat earlier than in the Norwegian Sea. In 1961 the fat content of the herring on Georges Bank increased by May-June as compared with June-July in the Norwegian herring. In December, in the Gulf of Maine and on Georges Bank, the feeding of the herring was irregular, though occasionally their stomachs were found to be filled with Euphausiacea (Benko and Vilson, 1962). Perhaps, due to this, the fat content of herring was somewhat higher in December. The increase in the average index of fat content of the Norwegian herring in December 1961 is apparently due to the presence in the catch of young fatter herring of the 1959 year-class (materials from the Herring Laboratory of PINRO).

CONCLUSIONS

1. In the Norwegian Sea and on Georges Bank (Gulf of Maine) the herring feed mainly in frontal zone: The most favourable feeding conditions occur most often in May-June near the continental slope and around islands, where Atlantic waters meet coastal waters. In these regions *Calanus finmarchicus* and Euphausiacea, the favourite food of herring, are often predominant in the plankton.

2. With an increased inflow of Atlantic waters into the Norwegian Sea and on Georges Bank the temperature of the water rises; this is followed by an increase in percentage of jelly fish (*Aglantha digitale* in the Norwegian Sea) and Tunicata (*Salpa fusiformis*, *Doliolum* sp. - in the plankton on Georges Bank). In these cases the quantity of plankton suitable for herring food is reduced sharply.

3. Surveys of summer concentrations of herring should not be conducted in regions rich in jelly fish and tunicates. In the summer herring are found mainly in moderately warm waters (5-8°C), where the biomass of *Calanus* reaches 200-500 mg/m^3 (Fig. 1 and 2). The intensive feeding of herring may greatl reduce the biomass of *Calanus*. By contrast, in northern and eastern regions of the Norwegian Sea whe no herring occur in June, the biomass of plankton is usually very high (more than 500 mg/m^3).

4. Regular observations on seasonal variations in plankton make it possible to predict feeding conditions and to determine with greater accuracy the routes of the migrating herring in different parts of the sea.

REFERENCES

ALEKSEEV, A.P. and B.V. ISTOSHIN. 1960. Some results of oceanographical investigations in the Norwegian and Greenland Seas. *In* Soviet Fisheries Investigations in North European Seas. Moscow.

ALEKSEEV, A.P., B.V. ISTOSHIN and L.R. SHMARINA. 1962. Hydrological conditions in the Norwegian and Greenland Seas in 1961. *Scientific-technical bulletin of PINRO* No. 2-3 (20-21).

BENKO, Ju. K., and A.P. VILSON. 1962. The feeding and physiological condition of herring of the Georges Bank in 1961. *In* "Herring of the North European basin and adjacent seas". *Trudy PINRO,* XIV.

BIGELOW, H.B. 1926. Plankton of the offshore waters of the Gulf of Maine. *Fish. Bull., U.S.* (1924) 40.

FISH, C. 1936*a*. The biology of *Calanus finmarchicus* in the Gulf of Maine and Bay of Fundy. *Biol. Bull.,* LXX, (1).

1936*b*. The biology of *Pseudocalanus minutus* in the Gulf of Maine and Bay of Fundy. *Biol. Bull.,* LXX, (2).

GRUSOV, L.N. 1960. Development of water "blooming" and *Calanus finmarchicus* in the southern regions of the Norwegian Sea in 1958. *Trudy BALTNIRO,* VI.

1961. Influence of plankton on the feeding migrations of herring in the Norwegian Sea in 1959. *Trudy BALTNIRO,* VII.

GRUSOV, L.M. and E.A. PAVSHTICS. 1961. Soviet plankton investigations in the Norwegian Sea. *Ann. biol., Copenhague,* XVI.

ISTOSHIN, B.V. and A.P. ALEKSEEV. 1959. Long termed variations of water temperature in the Norwegian and Greenland Seas during the summer period. *Scientific technical bulletin of PINRO,* No. 2 (10).

MARTY, JU. JU. 1956. Major stages of the life cycle of Atlanto-Scandian herring. *In* "Seldy Severo-Evropeiskogo basseina i smejnykj morey." (Herring of the North-European basin and adjacent seas). *Trudy PINRO,* IX.

PAVSHTICS, E.A. 1956. Seasonal changes in the plankton and the feeding migrations of herring. *Trudy PINRO,* IX.

1958. Plankton survey of the Norwegian Sea in 1956. *Ann. biol., Copenhague,* XIII.

1960. Basic regularities in the development of plankton in the Norwegian and Greenland Seas. *In* Soviet Fisheries Investigations in North European Seas. Moscow.

1962. Soviet plankton investigations in the Norwegian Sea, 1960. *Ann. biol., Copenhague,* XVIII.

PAVSHTICS, E.A. and V.A. RUDAKOVA. 1962. To the problem of long-termed changes in the development of plankton and conditions of the feeding of herring in the Norwegian Sea. *Trudy PINRO,* XIV.

RUDAKOVA, V.A. 1962. Materials on the feeding of Atlanto-Scandian herring. *Trudy PINRO,* IX.

E-3

WATER TEMPERATURE AND THE HERRING FISHERY OF MAGDALEN ISLANDS, QUEBEC

By

L.M.Lauzier[1] and S.N.Tibbo[1]

ABSTRACT

At Magdalen Islands there is a direct relationship between water temperatures during the latter part of April and the "relative" catch of herring during April. The start of the fishery is usually preceded by a rapid warming of the waters to 2.1°C. Air temperatures and ice conditions during the previous winter provide a basis for forecasting the starting date and relative size of the herring fishery in April. A selective and intermittent movement of herring into the spawning area is suggested.

INTRODUCTION

The Magdalen Islands area lends itself to a study of the effects of the physical environment on a fishery. It is located in the centre of the outflow of the Gulf of St. Lawrence and is isolated from other inshore fishing areas (Fig.1). Surrounding waters have a large annual amplitude of temperature. After the disappearance of ice, vernal warming is rapid and during this period there is an intensive herring fishery with landings varying greatly from year to year. This fishery is carried on mainly with trap nets set close to shore. Within the last 30 years, landings have been as low as 4,121 metric tons (1933) and as high as 22,482 metric tons (1955). Generally, the fishery lasts 6 to 8 weeks, beginning in April in some years and in May in others.

Day (1957, *a, b*) described the herring fishery of the Magdalen Islands and showed a relationship between vertebral numbers and water temperatures. Lauzier (1952) drew attention to the unusually high water temperatures of April 1951 which were associated with large landings of herring during that month. This paper presents additional data to show that there is a relationship between herring landings and water temperatures and describes other features of the herring fishery in the Magdalen Islands area.

HERRING LANDINGS AND WATER TEMPERATURES

Figure 2 shows annual herring landings, herring landings in April and surface water temperatures during the latter half of April for the years 1942-63. Landings were obtained from publications of the Bureau des Statistiques, Ministère de L'Industrie et du Commerce, Quebec. Average temperatures (April 16-30 inclusive) were calculated from observations made twice daily at Entry Island. There is some evidence of a direct relationship between herring landings and water temperatures. Total landings, landings in April and water temperatures were all higher in the 1950's than in the 1940's. The decrease in landings after 1955 is probably due to an epidemic disease of herring that caused widespread mortalities in the Gulf of St. Lawrence in 1954-56 (Sinderman, 1958). The increase in landings after 1960 probably reflects recovery from the effects of the disease (Tibbo and Graham, 1963).

From 1942 to 1963, the landings of herring in April varied between 0 and 82% of the total annual landings. These are shown in Figure 3 as "relative" landings in April and plotted against the average water temperature during the second half of April. The correlation coefficient between "relative" landing and the temperature was calculated to be + 0.71 ($P_{0.01}$ = 0.54) and the coefficient between the actual landings and the temperatures for the same years was + 0.61. Within the last 22 years, there are a number of years for which data on landings, date of arrival of herring and temperatures are all available. Representative cold and warm year data are given in Table I and, except for 1949 and 1960, show that the warmer the waters, the earlier fishing starts and the greater the percentage landings in April.

Over this 22-year period from 1942 to 1963, the start of the herring fishery was recorded for 13 years. The earliest first catch was made on April 4 in 1951 and the latest on May 6 in 1943. The average date of the first catch was April 25.

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

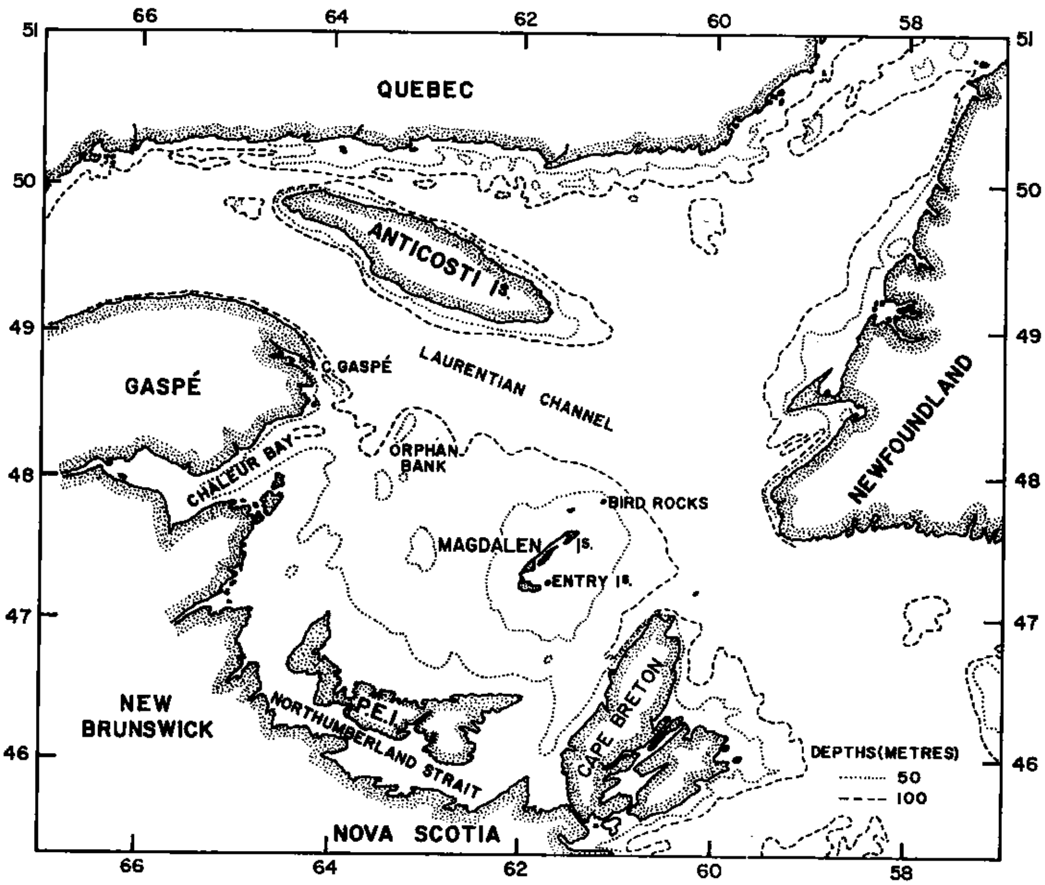


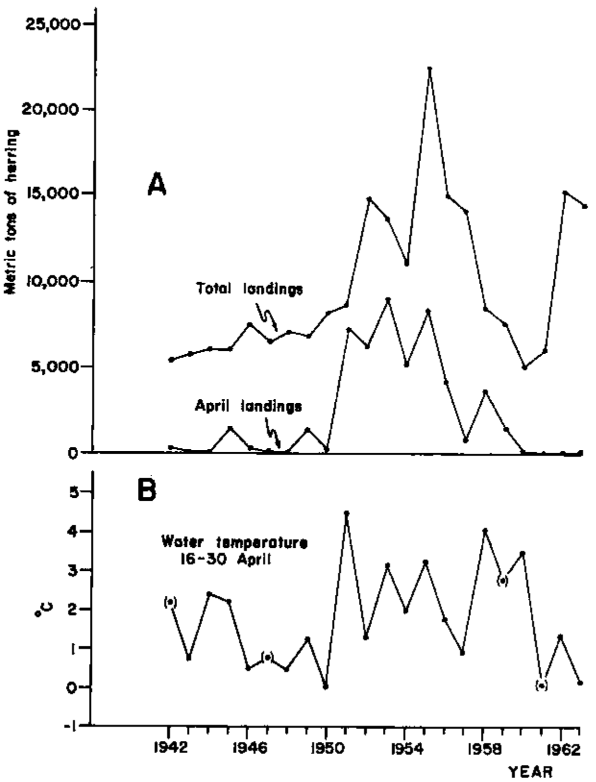
Fig. 1. Chart of the Gulf of St. Lawrence

BEGINNING OF THE FISHERY AND WATER TEMPERATURES

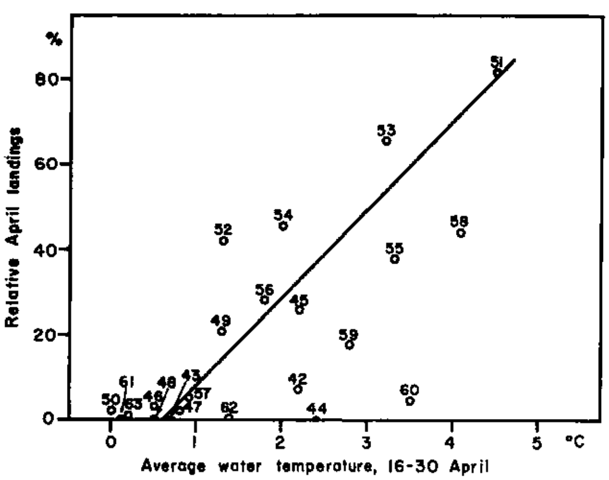
For 13 years, between 1942 and 1963, the date of the first catch of herring and the daily water temperatures before and after that date were compiled to show temperature conditions at the beginning of the fishery. Figure 4 shows that up to 6 days before the first catch of herring the average temperature increased rather slowly and erratically but remained below 1.0°C. This is followed by a more rapid and regular increase in temperature. The first catches were made when water temperatures were increasing rapidly and the average temperature on the day of the first catch of herring was 2.1°C with a standard deviation of 0.9°C.

For each day, before and after the start of the fishery, the temperatures indicated in Fig. 3 are averages based on 5 to 13 observations with a standard deviation varying between 0.9° and 1.6°C. The increase in temperature from one day to the next is not large enough, with such standard deviations, to show the temperature on one day as significantly different from the temperature on the following day. The important feature, however, is the trend in the temperatures, *i.e.*, the average increase with time, and the peculiarities which occur at the beginning of the fishery.

Figure 3 also shows that for the 20-day period after the start of the fishery there is a succession of increases in temperature to about 5.0°C. This rapid increase in temperature is undoubtedly due to advection of warmer waters from another area and not to warming *in situ*. The movement of ice during April on the Magdalen Shallows suggests that warmer waters are located to the northwest of Magdalen Islands. Present surface temperature charts produced three times a week by the Oceanographic Services of the Department of Mines and Technical Surveys support this suggestion. It seems then that the succession of temperature increases is brought about by intermittent drift of warmer waters into the Magdalen Islands area from the northwest. The few wind observations that we have



ig. 2. Herring landings (A) and average water temperature during the second half of April (B) from 1942 to 1963 in the Magdalen Islands area.



ig. 3. Relationship between relative April landings and the average water temperature during the second half of April for twenty years between 1942 and 1963. (42 means 1942)

from the area (these were taken twice a day at the same time the water temperatures were recorded) are inadequate to establish any relationship between wind direction and the succession of temperature increases.

Herring catch statistics are recorded on a monthly basis and hence do not show day to day variations in catch. However, it is a common occurrence and well known especially by fishermen, that within a fishing season several days of good fishing are followed by an equally long period of poor fishing. Biological studies show that the size and age of spawning herring decreases as the season advances. Day (1957*a*) described this phenomenon for spawning runs in Northumberland Strait, on the North Shore of Prince Edward Island and at Magdalen Islands. At Magdalen Islands, for example, the length and age of herring decreases from 30.0 cm and 5.7 years respectively in May to 26.8 cm and 3.8 years in June of the same season. This suggests a selective movement of herring into the spawning area. It is quite possible that this movement is not only selective but intermittent and that such a selective intermittent movement coincides with successive increases in temperature or with successive advection of warmer water. However, this must be considered only as a working hypothesis to explain the prespawning behaviour of herring in the Magdalen Islands.

The location of herring stocks in the Gulf of St. Lawrence during the late winter and early spring is poorly understood. No surveys for herring have been carried out during the January to April period. However, fishing for groundfish species (mainly cod) from the research vessel C.G.S. *A.T. Cameron* was carried on from 1960 to 1962 along the western edge of the Laurentian Channel, near Cape Gaspé at the entrance to Chaleur Bay, between Orphan Bank and Magdalen Islands, near Bird Rocks, and off Cape Breton. Although mesh sizes of the bottom trawls used were unsuitable for catching small fish, some herring were taken in more than half of the sets made. The best catches were made in depths of 48-66 fathoms, at temperatures around -0.7°C. The largest catches were made to the west and northwest of Magdalen Islands at the entrance of Chaleur Bay and this could presumably be the late winter habitat of herring which spawn either in Chaleur Bay area or in the Magdalen Islands in the spring

BEGINNING OF THE FISHERY AND ICE CONDITIONS

Observations made over several years at Entry Island show that, on the average, the first catches of herring are made 10 days after the disappearance of ice, when water temperatures are increasing rapidly. Water

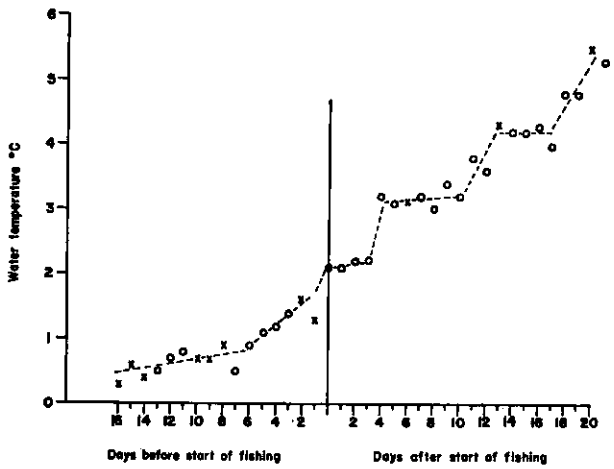


Fig. 4. Average surface temperature before and after the start of herring fishery. (x = temperatures for 5 years or less, o = temperatures for 6 years or more)

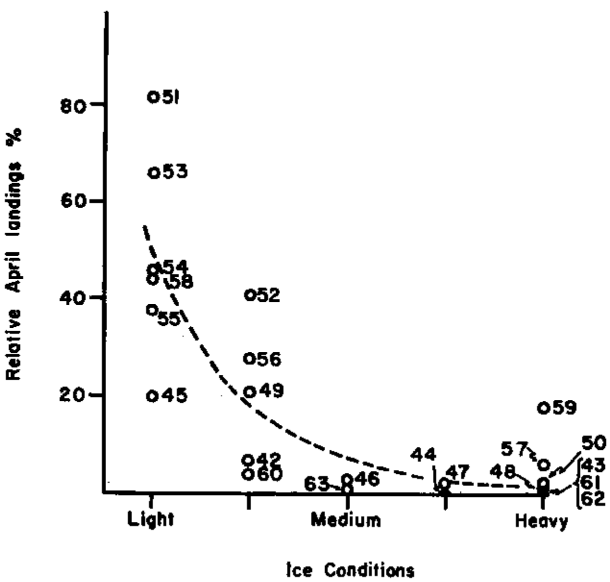


Fig. 5. Relationship of relative April landings of herring and ice conditions during the previous winters (51 means 1951). Ice conditions: "light" indicates that the quantity and extent of ice was smaller than usual with ice concentrated along the coasts and in bays, very little ice in the central Gulf; "heavy" represents a nearly complete coverage of ice in the central Gulf.

temperatures may increase rapidly, as in 1935, after the late disappearance of ice, or they may increase slowly, as in 1955, after the early disappearance of ice. The presence of ice, however, does not seem to prevent herring fishing, since in 1934, 1938 and 1940, the fishery started 1 to 3 days before the disappearance of ice. The average water temperature for those three years on the day of the first catch was 0.3°C as compared to the overall average of 2.0°C. In some years the fast ice disappears from the area but other ice fields drift into the area and prevent warming.

FORECASTING THE FISHERY FROM ICE CONDITIONS

Forward (1954, 1958) made a study of the distribution and movement of ice in the Gulf of St. Lawrence during March, April and May for the period 1940-57. For 1958 to 1962 inclusive the distribution of ice throughout the ice season was reported in Circulars issued by the Meteorological Branch of the Canadian Department of Transport (Anon., 1959; Archibald *et al.*, 1960, 1961 and 1962*a* and *b*). Figure 5 shows that the "relative" landings of herring in April are inversely related to severity of ice conditions during the previous winter. Total landings over the whole fishing season are not related to ice conditions.

During the winter, if air temperatures are below average, there are heavy ice conditions and a late spring break-up. However, the prevailing winds in the spring influence the break-up pattern. The presence of ice until late spring slows the warming of the waters and the herring fishery commences late in April or early in May as it did in 1943, 1944, 1947, 1948, 1950, 1957, 1959, 1961 to 1963. Light ice conditions are the result of above average air temperatures for the winter months. In this case, there is an early disappearance of ice, allowing an early warming of the waters in spring and a consequent early beginning of the herring fishery as in 1945, 1949, 1951, 1952, 1953, 1954, 1955, 1956 and 1958.

It is possible, therefore, by following air temperatures or ice conditions or both during the winter to make a reliable forecast of the starting date and of the "relative" catch of herring in April in the Magdalen Islands area.

SUMMARY

1. Variations in annual herring landings, herring landings in April and surface temperature conditions at Magdalen Islands, Quebec, were examined and showed that "relative" April landings were directly related to water temperatures during the second half of April.

TABLE 1. HERRING FISHERY AND WATER TEMPERATURES AT THE MAGDALEN ISLANDS

	Year	Water temp. 16-30 April	Date of arrival of herring	Landings Metric tons Total	April	Relative landings in April[a]
Cold	1946	0.5°C	29 April	7,648	210	3
	1948	0.5	30 April	7,066	1	0
	1949	1.3	24 April	6,798	1,415	21
	1950	0.0	30 April	8,230	136	2
	1962	1.4	30 April	15,443	13	0
	1963	0.2	29 April	14,590	106	1
Warm	1951	4.5	4 April	8,696	7,104	82
	1955	3.3	18 April	22,482	8,388	37
	1958	4.1	7 April	8,595	3,714	43
	1960	3.5	8 April	5,057	211	4

[a] Relative landings in April = $\frac{\text{April landings}}{\text{Total landings}} \times 100$

2. The arrival of herring or start of the herring fishery is preceded by an increase in water temperature to an average of 2.1°C on the day of arrival.

3. At the beginning of the fishery, the water temperature increases intermittently, suggesting that warmer waters drift into the area in "waves".

4. The intermittent pattern of movement of herring to the spawning area seems to coincide with the intermittent pattern of temperature increases.

5. From air temperatures and ice conditions during the previous winter it is possible to forecast the starting date of the Magdalen Islands herring fishery and the relative size of the landings in April.

REFERENCES

ANON. 1959. Aerial sea ice observing and reconnaissance program in the St. Lawrence River, the Gulf of St. Lawrence and the Strait of Belle Isle, 1958. Meteorological Branch, Department of Transport, Canada, Circular No.3273.

ARCHIBALD, D.C., M.N.MONSINGER and T.B.KILPATRICK. 1960. Aerial ice observing and reconnaissance St. Lawrence River, the Gulf of St. Lawrence and coastal waters of Newfoundland - 1959. Meteorological Branch, Department of Transport, Canada, Circular No.3417.

1961. Aerial sea ice observing and reconnaissance St. Lawrence River, the Gulf of St. Lawrence and coastal waters of Newfoundland, 1960. *Ibid.*, Circular No.3465.

1962*a*. Aerial sea ice observing and reconnaissance, St. Lawrence River, the Gulf of St. Lawrence, and coastal waters of Newfoundland - 1961. *Ibid.*, Circular No.3591.

1962*b*. Aerial ice observing and reconnaissance, Eastern Canadian Seaboard, 1962. *Ibid.*, Circular No.3768.

DAY, L.R. 1957*a*. Populations of herring in the southern Gulf of St. Lawrence. *Bull. Fish. Res. Bd. Canada*, No.111, p.121-137.

1957*b*. Vertebral numbers and first-year growth of herring (*Clupea harengus* L.) in relation to water temperature. *Ibid.*, p.165-176.

FORWARD, C.N. 1954. Ice distribution in the Gulf of St. Lawrence during the break-up season. Geographical Bulletin 6, p.45-84, Ottawa.

1958. Ice conditions in the Gulf of St. Lawrence during the spring seasons 1953-1957. Geographical Branch, Department of Mines and Technical Surveys, Canada, Geographical Paper No.16, 13 p.

LAUZIER, L. 1952. Recent water temperatures along the Canadian Atlantic coast. *Fish. Res. Bd. Canada, Atlantic Prog. Rept.*, No.53, p.5-7.

SINDERMAN, C.J. 1958. An epizootic in Gulf of St. Lawrence fishes. Transactions 23rd North American Wildlife Conference (March 1958), p.349-360.

TIBBO, S.N. and T.R.GRAHAM. 1963. Biological changes in herring stocks following an epizootic. *J. Fish. Res. Bd. Canada,* 20(2): 435-449.

E-4

THE INFLUENCE OF WATER MASSES OF THE NEW ENGLAND AND NOVA SCOTIA SHELF ON THE FORMATION OF COMMERCIAL CONCENTRATIONS OF HERRING

By

V.A. Bryantsev[1]

ABSTRACT

Three water masses govern the distribution and spatial changes of T-S characteristics of the shelf waters. Their peculiarities were ascertained by the analysis of the data collected during the 1960-1962 research cruises organized by ATLANTNIRO.

The most fish-abundant shelf areas of herring fisheries are situated in the regions of the outflow of Labrador waters on the bank slopes, in particular those of Georges and Banquereau Banks. The greatest values of food biomass are observed on the bank slopes in the zone of double border along the 50-100 m isobaths where the borders of Labrador and coastal waters lie in close proximity on the one side and Gulf Stream bottom waters on the other. The reduction of the zone of two borders resulting from the summer transformation consequently effects the reduction of food migration routes of herring in the Georges Bank area. Wind conditions, by shifting the borders of water masses, substantially influence the efficiency of fishing operations. By estimating the value of projection of wind on the SW-NE line it is possible to forecast the relative changes of catches 24 hr in advance.

---

1. The surface layer within the shelf is occupied by the coastal water mass. It is characterized by a relatively low salinity (the extreme value is assumed to be 30.00 °/oo) and rather wide changeability of temperature, from 4°C in winter to 16°C in summer.

2. Outside the shelf the coastal waters border upon the waters of the Gulf Stream. The extreme values of the latter are as follows: salinity (maximum in the shelf area) is 36.00 °/oo; temperature (also maximum in the area) is 15°C in winter and 25°C in summer. Besides, the waters of the Gulf Stream that extend within the shelf along the deep-water valleys at 150-200 m are characterized by the temperature 7 to 8°C and salinity from 33.50 to 35 °/oo. These characteristics result from mixing of Gulf Stream waters with Labrador waters situated immediately above. We call this water mass a bottom modification of the Gulf Stream waters.

3. By "Labrador waters" we refer to an intermediate cold layer of the water mass that extends along the shelf from Newfoundland to Georges Bank and is formed by the Polar waters flown into this area with the branches of the Labrador Current. On the shelf these waters are situated beneath the coastal waters and above the bottom modification of the Gulf Stream waters within the depth range of 50-75 to 150-200 m. The extreme values of this water mass are as follows: temperature, (minimum for the shelf), -1°C, salinity, 33.00 °/oo.

Of the three water masses the Labrador water mass presents the greatest interest. It was defined by the analysis of the results of the hydrological observations carried out by ATLANTNIRO expeditions during December 1960 - February 1961. The data were treated in accordance with a general analysis method suggested by V.T. Timofeev. The following extremes were used:

Coastal water mass	T°C	S °/oo
Coastal water mass	4	30.00
Labrador water mass	-1	33.00
Gulf Stream waters	15	36.00

[1] Atlantic Research Institute of Marine Fisheries and Oceanography (ATLANTNIRO), Kaliningrad, USSR.

These values were used for the construction of T-S nomograms on which the tabulations of all hydrological stations at 0.50, and 100 m layers were plotted. Then, the per cent volume of each water mass was indicated on the map of the area near each station for each of the above layers, and isolines of these values were drawn.

The isolines of 50% volume of Labrador water (the edge of the water mass according to the terms of the method) showed that this water mass was flowing continuously at the 100 m layer, from Newfoundland along the whole shelf area far to the southwest. Judging by the patterns of the 0 and 50 m layers in the Banquereau and Georges Bank areas on the map, there should be an outlet of these waters on the slopes of the above banks. It is in these areas that the Soviet fishing fleet is engaged in an intensive herring fishery.

In summer 1962, more detailed studies of the distribution of water masses were initiated in the Georges Bank fishing area. An attempt was also made to evaluate the degree of changeability in the distribution of waters affected by various factors. The investigations have revealed that the coastal waters occupy the depth ranging from 0 to 50-75 m; the cold Labrador waters occupy the layer from 50-75 m to 150-200 m, and in the Bay of Fundy below 150-200 m the bottom modification of the Gulf Stream waters is observed.

Due to the peculiarities of the bottom relief, the upper edge of the intermediate cold layer over the bottom at the depth of 50-75 m, should wedge out and form a demersal border with the adjacent coastal waters; another demersal border is formed with bottom waters of the Gulf Stream at 150-200 m. The data of observations have supported such delimitation of Labrador waters (Fig. 1). So, in the demersal layer along the slopes of Georges Bank there is something like a narrow inflow of cold waters, bordering upon the coastal waters on the shallower side (50-75 m), and upon the bottom modification on the side of greater depths (150-200 m). However, this cold inflow is not traced at these depths on the southern slopes of the bank. This is explained by the fact that the coastal waters, warm in summer, and the surface warm waters of the Gulf Stream actively transform the cold bottom layer. The degree of such transformation increases with the intensification of the summer heating. Thus, if in May the cold tongue occupies all the slopes, including part of the southern slope, then in late August it is not observed even on the eastern slope.

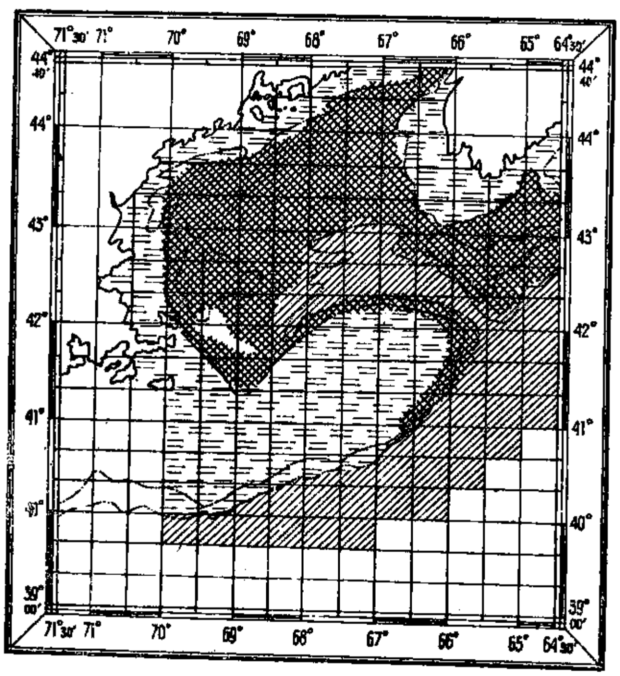


Fig. 1. Near-bottom distribution of water masses. Survey, 5-25 June, 1962.

//// Gulf Stream waters

Labrador waters

== Coastal waters

Such a specific area of two bottom borders is normally characterized by considerable temperature gradients. And it is in this area that, according to the planktonic surveys, the greatest quantities of food plankton gather (Fig. 2). It follows from a comparison of the maps of distribution of water masses and the statistical chart of fishery in 1962 (Fig. 3) that through the whole period of food migrations (March - August) herring form concentrations mainly in the zone of the two bottom borders. Periodically, moving along this zone, herring reduce their route as the cold water flow that forms this zone is getting shorter with the season. In May, herring concentrations may be observed on all the slopes, including part of the southern and the whole southeast slopes, whereas in June-July herring do not move beyond the southeast slope. In

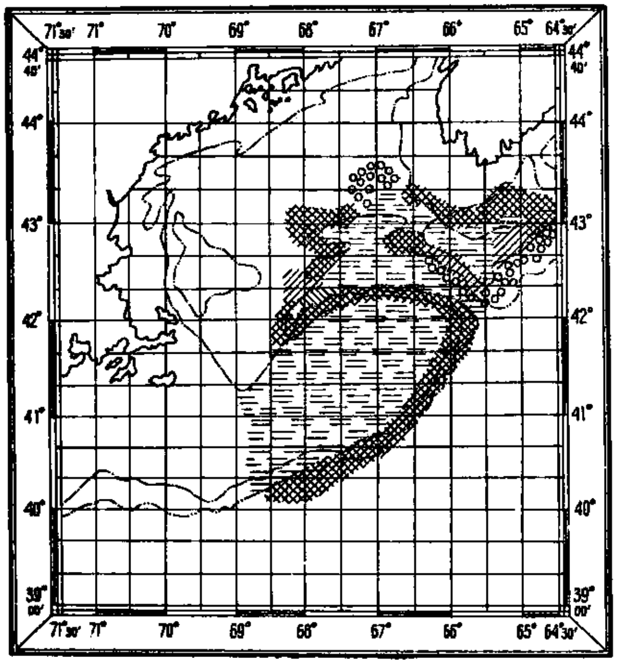


Fig. 2. Distribution of plankton, 29 June - 3 July 1962.

Calanus from 100 to 250 mg/m^3

Calanus to 500 mg/m^3 (phytoplankton in small numbers)

Phytoplankton (*Calanus* in small numbers)

Calanus, Euphausiidae, *Themisto*.

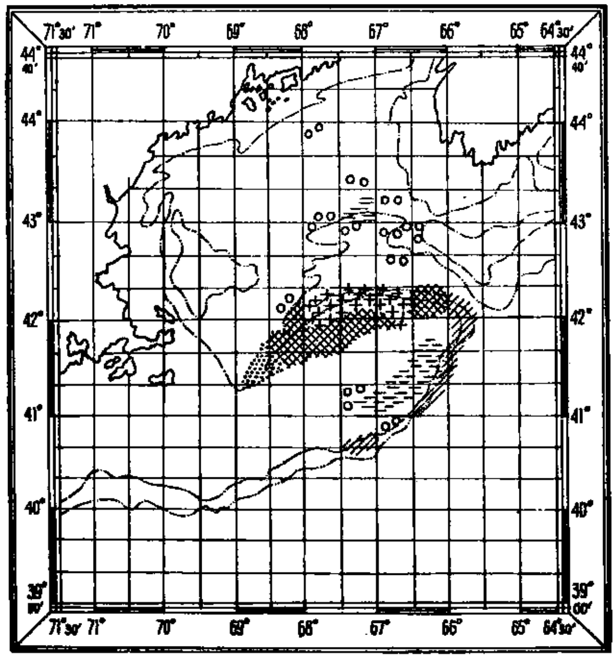


Fig. 3. Operations of fishing fleet in May-August 1962.

Areas of continued fishing operations (92-50% of time)

Areas of periodic fishing operations (50-40% of time)

Areas of seasonal fishing operations. May-June;

June-July; August.

Occasional fishing operations (>5% of time)

August they can, but rarely, be encountered on the eastern slope and continue their migrations along the northern and north-west slopes only. So, the data on the degree of summer transformation of the cold tongue on the eastern and southeast slopes are absolutely indispensible for making forecasts for the fishing fleet.

Apart from the seasonal changeability, the variations of the Labrador water borders were found to be caused by wind. The lack of many days' observations did not permit establishment of the quantitative relationships between the changes of the velocity and direction of wind and the location of the water mass border. Therefore, in order to determine the influence of wind, we had to apply an indirect method of the analysis. The direct changes in a day's catch per net were analysed together with the changes of wind. The former value was taken for March in the Georges Bank area and for April in the Banquereau area. During these months, herring in both areas remained within a limited area, thus making the catch data most indicative.

In order to evaluate wind effects we assumed as a working hypothesis the theory of coastal wind-induced tidal phenomena. In accordance with this theory the water movement in the northern hemisphere is directed to the right of the wind direction. Taking into consideration the fact that the shoreline in the shelf area lies in SW-NE direction, the SW wind will drive waters in the seaward direction and the NE wind will drive them shoreward. This will be accompanied by the changes of the borders of water masses on the slopes of the banks.

It was repeatedly observed during fishing operations that the catches increased in the time of SW winds and decreased in the time of NE winds. This allows us to assume the positive effect of the former and the negative effect of the latter. Taking the SW- NE direction for the 0° to 180° line and by reducing this line, and by means of projecting, the directions of wind of all bearings, we shall obtain the expression of wind effect:

$$P = T \times V \times \text{Cos}\ (\alpha + 135°), \text{ where}$$

P - projection of wind on the line
T - time
V - velocity of wind
α - direction of wind

Then, the total "P" value for a given space would be

$$P = \frac{\Sigma\ T \times V \times \text{Cos}\ (\alpha + 135°)}{n}$$

where n - number of observations at individual points.

To simplify computations the P values were tabulated (in conventional units).

TABLE 1.

Direction of wind: Bearings	Direction of wind: Degrees	Cos (α + 135°)	Value of V × Cos (α + 135°) for units of Beaufort scale: 0	1	2	3	4	5	6	7
N	0	-0.71	0	-0.71	-1.4	-2.1	-2.8	-3.6	-4.3	-5.1
NNE	22.5	-0.92	0	-0.92	-1.8	-2.8	-3.7	-4.6	-5.5	-6.4
NE	45	-1.00	0	-1.00	-2.0	-3.0	-4.0	-5.0	-6.0	-7.0
ENE	67.5	-0.92	0	-0.92	-1.8	-2.8	-3.7	-4.6	-5.5	-6.4
E	90	-0.71	0	-0.71	-1.4	-2.1	-2.8	-3.6	-4.3	-5.0
ESE	112.5	-0.38	0	-0.38	-0.8	-1.1	-1.5	-1.9	-2.3	-2.7
SE	135	0.00	0	0.00	0.0	0.0	0.0	0.0	0.0	0.0
SSE	157.5	0.38	0	0.38	-0.8	1.1	1.5	1.9	2.3	2.7
S	180	0.71	0	0.71	1.4	2.1	2.8	3.6	4.3	5.0
SSW	202.5	0.92	0	0.92	1.8	2.8	3.7	4.6	5.5	6.4
SW	225	1.00	0	1.00	2.0	3.0	4.0	5.0	6.0	7.0
WSW	247.5	0.92	0	0.92	1.8	2.8	3.7	4.6	5.5	6.4
W	270	0.71	0	0.71	1.4	2.1	2.9	3.6	4.3	5.0
WNW	292.5	0.38	0	0.38	0.8	1.1	1.5	1.9	2.3	2.7
NW	315	0.00	0	0.00	0.00	0.0	0.0	0.0	0.0	0.0
NNW	337.5	-0.38	0	-0.38	-0.8	-1.1	-1.5	-1.9	-2.3	-2.7

The values of wind strength in the table range from 0 to 7 (Beaufort scale) because if the wind is stronger the fishing operations are discontinued. The wind values were taken for the given periods (March and April) from the daily weather maps; then the mean wind values were computed for the points Boston, Halifax and Sable Island. The computed P values for each day and average catches in kilograms per net were then tabulated for both areas (Table 2). In this latter table the increased values of P and catches are marked by (+) and the decreased values by (-). A comparison of the trends of both characteristics makes it possible to infer that they coincide (in the table the coincidence is marked by C and the lack of coincidence by N) in 15 cases out of 21 for the Georges Bank area and in 17 cases out of 21 for the Banquereau area. Thus it follows that the percentage of coincidence is 71% in the first case and 81% in the second.

Since the wind values were registered at 3 pm Moscow time, *i.e.* at 20 hr local time of the day before, the P value should be considered as shifted 24 hr ahead.

TABLE 2. Georges Bank (March 1962) | Banquereau Bank (April 1962)

Date	P	Avg. catches in kg per net	P trend	Trend of catches	Comparative trend	Percentage coincidence	Date	P	Avg. catches in kg per net	P trend	Trend of catches	Comparative trend	Percentage of coincidence
1	-2.4	8.0					1	1.8					
2	-1.1	8.0	+	0			2	-1.4		-			
3.	-0.7	-	+				3	1.0		+			
4	-1.6	-	-				4	0.0	62.5	-			
5.	-2.3	14.5	-				5	2.0	100.0	+	+	C	
6	-3.7	10.0	-	-	C		6	1.1	17.6	-	-	C	
7	-2.1	0.0	+	-	N		7	1.4	44.5	+	+	C	
8	-3.4	-	-				8	2.3		+			
9	-1.8	83.5	+				9	1.4		-			
10.	-0.8	86.9	+	+	C		10	2.5	37.5	+			
11	-1.8	29.8	-	-	C	71%	11	1.4	47.2	-	+	N	81%
12	-2.8	17.8	-	-	C		12	0.1	13.3	-	-	C	
13.	1.4	26.1	+	+	C		13	-1.8	25.0	-	+	N	
14	-3.7	42.1	-	+	N		14	-2.1	22.3	-	-	C	
15	-2.1	12.1	+	-	N		15	2.4	-	+			
16	1.9	25.1	+	+	C		16	3.0	148.7	+	+	C	
17	1.8	9.0	-	-	C		17	0.0	-	-			
18	0.0	15.3	-	+	N		18	-0.7	98.4	-	-	C	
19	-0.8	0.7	-	-	C		19	0.9	66.5	+	-	N	
20	1.0	0.7	+	0			20	-1.0	42.2	-	-	C	
21	-0.6	0.0	-	-	C		21	-0.9	49.2	+	+	C	
22	-1.8	0.0	-	0			22	1.8	84.4	+	+	C	
23	-3.0	0.0	-	0			23	1.4	68.5	-	-	C	
24	-2.7	4.2	+	+	C		24	0.0	15.6	-	-	C	
25	-2.3	0.0	+	-	N		25	-0.5	9.1	-	-	C	
26	-1.4	7.4	+	+	C		26	-0.4	18.8	+	+	C	
27	-2.8	1.6	-	-	C		27	0.4	21.8	+	+	C	
28	-2.1	9.9	+	+	C		28	1.4	34.1	+	+	C	
29	0.0	12.8	+	+	C		29	1.3	15.8	-	-	C	
30	1.6	56.0	+	+	C		30	-0.2	17.2	-	+	N	
31	2.0	39.7	+	-	N								

In this way the wind, by changing the borders of water masses, influences the behaviour of herring and, consequently, the efficiency of the herring fishery. By estimating, on the basis of wind data, the values of projection on the SW-NE line, one may forecast the expected relative decrease or increase in catches for the next 24 hr.

CONCLUSIONS

1. The most fish-abundant shelf areas of herring fisheries are situated in the regions of the outflow of Labrador waters on the bank slopes, in particular those of Georges Bank and the Bânquereau area.

2. The greatest values of food biomass are observed on the bank slopes, in the zone of double border along the 50-100 m isobaths, where the borders of Labrador and coastal waters on the one side lie in close proximity to the Gulf Stream bottom waters on the other.

3. The reduction of the zone of two borders resulting from the summer transformation consequently effects the reduction of food migration routes of herring in the Georges Bank area.

4. Wind conditions, by shifting the borders of water masses, substantially influence the efficiency of fishing operations. By estimating the value of projection of wind on the SW-NE line it is possible to forecast the relative changes of catches 24 hr in advance.

REFERENCES

DOBROVOLSKY, A.D. 1961. On the definition of water masses. *Oceanology*, No. 1, Moscow.

KHANAICHENKO, N.K. 1947. On the types of water masses transformation, *Meteorology and Hydrology*, No. 1.

MARTY, JU. JU. 1961. Fishery and some problems of oceanology. *Oceanology*, No. 5, Moscow.

TIMOFEEV, V.T. 1948. The method of isopycnic analysis of mixing and transport of water masses. *Trudy ANII*, vol. 196, Glavsevmorput.

E-5

EFFECTS OF ENVIRONMENT ON SEVERAL DISEASES OF HERRING FROM THE WESTERN NORTH ATLANTIC

By

Carl J. Sindermann[1]

ABSTRACT

Several diseases and parasites of herring (*Clupea harengus harengus*) from the western North Atlantic have been investigated during the past eight years. Two important parasites of immature herring, a myxosporidian (*Kudoa clupeidae*) and a larval trematode (*Cryptocotyle lingua*) were found to be distributed discontinuously in the Gulf of Maine, occurring with greatest abundance in the western coastal area. The occurrence of both parasites seems directly related to summer sea water temperature. Study of a systemic disease of herring caused by the fungus *Ichthyosporidium hoferi* has disclosed apparent periodicity of epizootics and has provided experimental evidence for the importance of high spore concentrations in the environment to abundance and severity of the disease in herring. Since parasites and their abundance are often characteristic of particular age groups of geographic areas, information about herring stocks and their movements has been obtained.

INTRODUCTION

Among the biological features of the environment that affect the abundance of marine species, disease is of great significance. This can be best demonstrated in inshore sedentary species, but applies to pelagic or demersal species as well. Few pelagic species have been adequately examined for diseases, but during the past decade the U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, USA, has carried on a continuing study of diseases and parasites of Atlantic herring, *Clupea harengus harengus*. Attention was first directed to disease in this species because of recurring epizootics of a systemic fungus pathogen (*Ichthyosporidium hoferi*), the most recent of which occurred in the Gulf of Saint Lawrence in 1954-55 and the Gulf of Maine in 1947. The fungus disease has been studied continuously at the Boothbay Harbor Laboratory since 1947 and other diseases and parasites of herring have also been examined.

Many extrinsic and intrinsic factors combine to determine the incidence, distribution, and effect of disease on herring populations. Extrinsic factors include such environmental influences as temperature, salinity, availability of vectors or alternate hosts, and infection pressure (the relative numbers of infective organisms present in the environment at a given time). Intrinsic factors are those which determine susceptibility to disease, including individual and population levels of natural or acquired resistance, and nutritional state of the fish.

The isolation of specific factors in one or the other category is difficult, since many have aspects that fall in both -- for example, immune responses in poikilothermic animals are intrinsic, but are clearly influenced by environmental temperature. Despite some overlap, an attempt has been made to confine this paper to examples of extrinsic or environmental factors that affect certain diseases and parasites of herring in the western North Atlantic. Only three diseases, "pigment spot" caused by metacercariae of the trematode *Cryptocotyle lingua*, myxosporidian disease caused by *Kudoa clupeidae*, and fungus disease caused by *Ichthyosporidium hoferi*, will be considered here, and of these only those aspects pertinent to environmental influences will be included.

PIGMENT SPOT DISEASE

Ecological information is available for the larval trematode *Cryptocotyle lingua*, an important parasite of western North Atlantic herring. The worm occurs as a metacercaria in the skin and flesh. It's life cycle in the Gulf of Maine (Fig. 1) includes the common periwinkle *Littorina littorea* as a first intermediate host and the gull *Larus argentatus* as the definitive host. Herring are

[1] U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, USA.

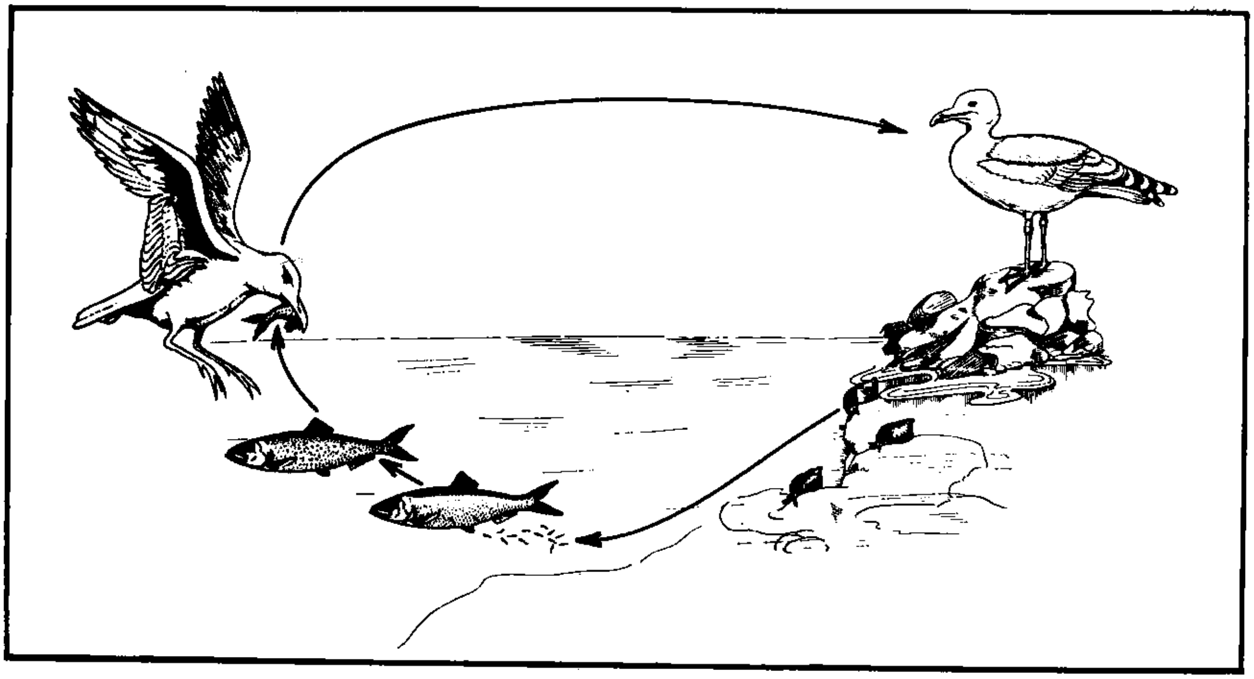


Fig. 1. Life cycle of *Cryptocotyle lingua* in northern New England.

important second intermediate hosts in this region of the western Atlantic. Examination of immature herring from coastal waters of the Gulf of Maine in 1961, 1962 and 1963 disclosed marked geographic variation in intensity of parasitization by *Cryptocotyle* metacercariae. Degree of parasitization was determined according to the following criteria: uninfected; lightly infected (1-5 metacercariae); moderately infected (6-50 metacercariae); heavily infected (over 50 metacercariae). A parasite concentration index (Sindermann 1953) was obtained for each sample by ranking each individual according to the following scale: uninfected (0), lightly infected (1), moderately infected (2), and heavily infected (3). Summation of ranks for each sample of 50 fish provided a concentration index for the sample. Numbers of samples examined were 20 in 1961, 26 in 1962 and 30 in 1963. The northern New England coast was divided into major areas with the following boundaries: (A) Isles of Shoals eastward to Cape Small; (B) Cape Small to Matinicus Island, (C) Matinicus Island to Mount Desert Island; (D) Mount Desert Island to West Quoddy Head; (E) West Quoddy Head to the Saint John estuary. Concentration indices for all samples in each area were averaged in each year to obtain a single index for the area and year (Fig. 2). Parasite concentration indices decreased sharply from west to east in each year.

Since parasitization of herring depends on availability of infective cercariae, a study was made in the summer and early autumn of 1963 of incidences of *Cryptocotyle* larvae in *Littorina*, the first intermediate host. Samples of 50 snails each were collected in the high tide zone from as many locations as possible. Infection was determined by crushing the snail and examining the digestive gland. Results grouped by major coastal areas are presented in Fig. 3. Wide variations in incidences within areas were noted, but no major variations on a coastwide basis were found. This was quite different from the geographic change in abundance of metacercariae in herring just mentioned and suggested that other environmental factors were important for completion of the parasite life cycle. Earlier studies (Sindermann and Rosenfield 1954*b*; Sindermann and Farrin 1962) demonstrated a direct relationship between temperature and cercarial emergence. Emergence declined with lowered sea water temperatures and ceased when temperatures fell below 10°C. Examination of coastal temperatures in July, 1963 (Fig. 4) suggests that the northern New England coast may be a critical zone for the parasite. Easternmost areas, with colder summer sea temperatures, were characterized by much lower parasite indices in herring. Factors other than temperature may be operative, since earlier experimental studies demonstrated that cercarial emergence was also inhibited by salinities below 18 °/oo (Sindermann and Farrin, *op. cit.*). However, no east-west change in salinity was observed in hydrographic data for 1963 that would be great enough to account

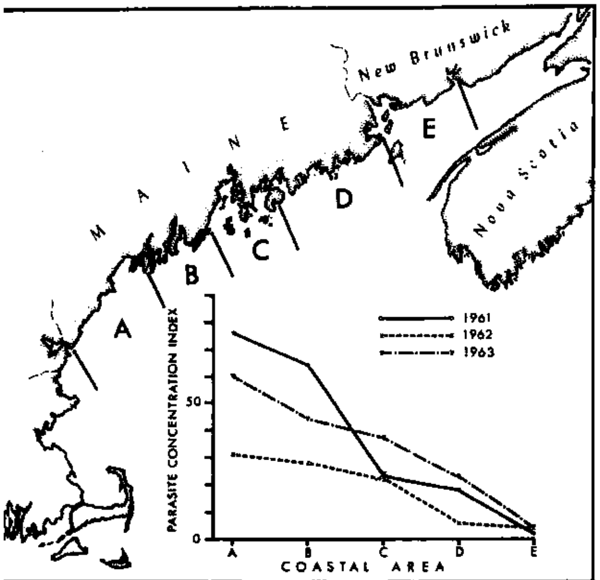
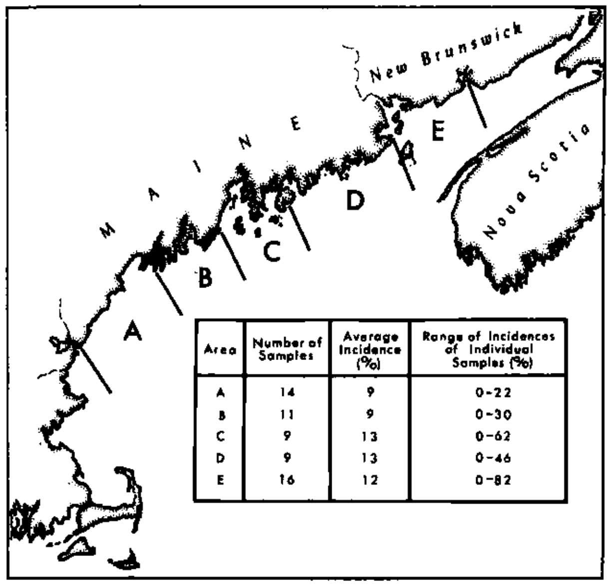


Fig. 2. Coastal sampling areas and concentration indices of *Cryptocotyle lingua* metacercariae in immature herring 1961-63.



Area	Number of Samples	Average Incidence (%)	Range of Incidences of Individual Samples (%)
A	14	9	0-22
B	11	9	0-30
C	9	13	0-62
D	9	13	0-46
E	16	12	0-82

Fig. 3. Incidences of *Cryptocotyle* larvae in *Littorina littorea* from the high tide zone along the northern New England coast, 1963.

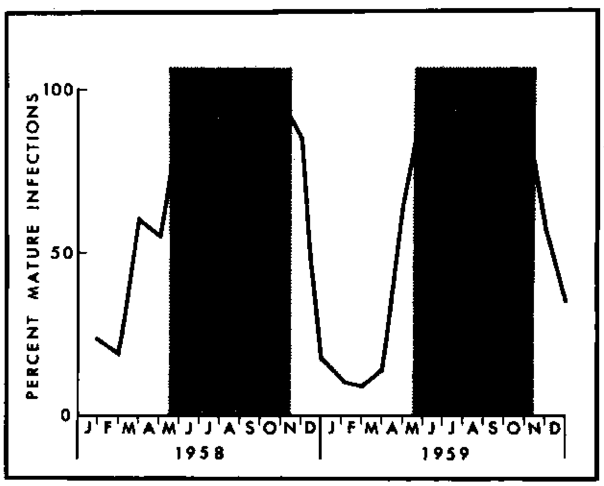


Fig. 4. Periods of the year when immature herring are most abundant in inshore waters (shaded zones) and average monthly maturity of snail infections (line graph). Mature infections are diagnosed by findings of fully-formed active cercariae in crushed snails.

for observed geographic changes in parasite incidences. Based on experimental findings, however, it would be possible for local changes in salinity to enhance or reduce effects of temperature on cercarial emergence.

The evidence suggests a relationship between environmental temperature in summer and degree of parasitization of herring by *Cryptocotyle*. There are of course still many questions to be answered. No information is available on possible geographic variations in degree of parasitization of the definitive host (the gull). Also, local variations in temperatures occur that could produce local anomalies in parasite abundance. For example 1963 hydrographic stations in the upper Penobscot Bay have disclosed July temperatures above 15°C, even though the general coastal area is described as a 10° to 15°C zone.

Comparisons of herring movements and availability of infective cercariae are striking. Immature fish are most abundant in inshore waters from May to November. This is the period when most snail infections are mature and producing cercariae, and maximum opportunity for parasite transfer exists. Results of a two-year study on one island off the central Maine coast are presented in Fig. 5. When cercariae are present in greatest numbers in inshore waters the susceptible second intermediate hosts are also present in abundance.

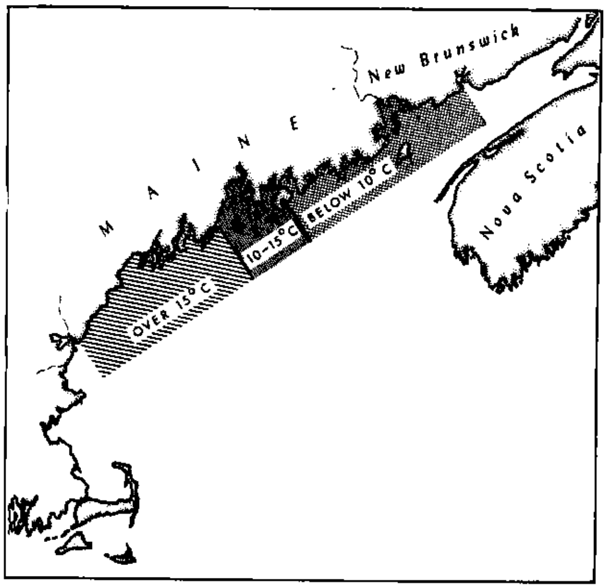


Fig. 5. Average distribution of summer sea water temperatures along the northern New England coast in 1963.

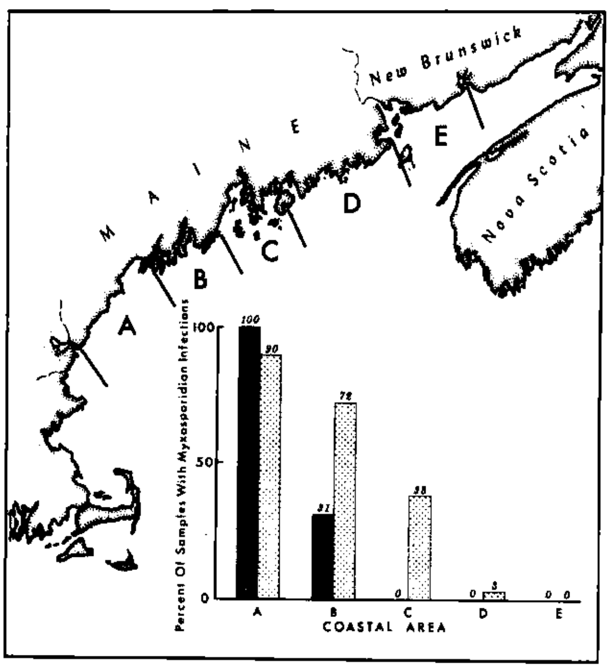


Fig. 6. Percent of samples of one-year-old (horizontal bar) and two-year-old (stippled bar) herring in which myxosporidia (*Kudoa clupeidae*) were present during the period 1955-63. Each sample consisted of 50 fish, and total samples of one-year-old fish were 112, and of two-year-old fish 242. Equal numbers of samples were not obtained in each year or for each area.

MYXOSPORIDIAN DISEASE

Another important parasite of western North Atlantic herring is the myxosporidian *Kudoa clupeidae*. This protozoan occurs in intramuscular cysts in immature herring. Infections are acquired in the early months of life and have been shown to persist in aquarium-held herring for two years, but were rarely found in adult fish (Sindermann and Rosenfield, 1954*a*; Sindermann, 1961). The geographic distribution of the parasite in Gulf of Maine herring has been studied since 1955. Infected fish were common along the western Maine coast, but were almost non-existent on the eastern Maine coast. Average incidences in the major coastal areas already described are presented in Fig. 6. Infections have not been found in one-year-old fish east of Matinicus Island. Infected two-year-old fish, with a single exception (one fish in a sample from Grand Manan Island in 1963) have not been found east of Mount Desert Island. The fect that infections were carried annually as far east as Mount Desert Island by eastward movement of infected two-year-old fish, while the disease organism did not occur east of Matinicus Island in one-year-old fish, indicates that some limiting influence on the diseast is operative. While other environmental factors may be important in determining the discontinuous distribution of *Kudoa*, temperature may exert a critical influence. Decreasing summer sea water temperatures from west to east along the coast (Fig. 4) correlate positively with parasite incidences, with Matinicus Island the general eastern limit of temperatures in excess of 15°C and the eastern boundary of infections in one-year-old fish.

Another indication of possible influence of temperature on the distribution of *Kudoa* is seen in the larger picture of its occurrence in herring of the western North Atlantic. Herring occur from Virginia northward to Labrador, with centers of abundance in the Gulf of Maine and the Gulf of Saint Lawrence. Although sampling has been concentrated in the Gulf of Maine, herring from the Rhode Island and New Jersey coasts, the Nova Scotia coast and the Gulf of Saint Lawrence have been examined since 1955. Infections were common in herring from Rhode Island and New Jersey, were absent on the Nova Scotia coast, but reappeared in the southern Gulf of Saint Lawrence where, because of shallow water, summer temperatures often reach 20°C. The parasite occurred in waters that characteristically exceed 15°C in summer and did not occur in waters with lower summer maximum temperatures (Fig. 7).

It is possible, of course, that factors other than environmental temperature may be important in determining the geographic distribution of *Kudoa clupeidae* in herring, or that temperature may act indirectly by influencing the distribution

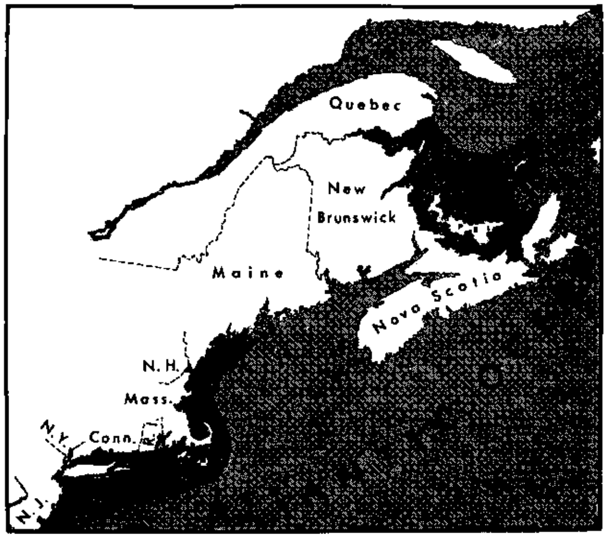


Fig. 7. Coastal areas of the western North Atlantic (heavy shading) where summer sea water temperatures usually exceed 15°C and where *Kudoa clupeidae* occurs in immature herring.

of transfer or other hosts. The Myxosporidia are usually considered one-host parasites, but the possibility of an invertebrate intermediate host needs further exploration. If another marine species plays a role in determining abundance or distribution of *Kudoa* in herring, temperature may operate indirectly.

FUNGUS DISEASE

Another disease of Atlantic herring with interesting environmental relationships is that caused by a systemic fungus pathogen *Ichthyosporidium hoferi*. At least six epizootics of this disease have occurred in herring during the past 70 years, resulting in widespread mortalities and affecting abundance of the species in the western North Atlantic (Sindermann, 1963). Individual variations in susceptibility to the pathogen have been demonstrated (Sindermann, 1958) and an explanation of changes in disease abundance based on intrinsic factors such as changes in population susceptibility and extrinsic factors such as infection pressure has been proposed.

Infection pressure appears to be an ecological factor of significance in determining outbreaks of *Ichthyosporidium*. Transmission from fish to fish is effected by heavy-walled spores which have been found to survive in sea water cultures for over six months with no loss of viability. Spores have been demonstrated in inshore bottom sediments during an epizootic. Since during an outbreak peak an average of one-fourth of the population is infected, and since most infected fish die either from acute or chronic infections, the spore load in mortality areas can be very high.

Knowledge about the effects of increasing infection pressure on occurrence of the fungus disease in susceptible hosts has been obtained by experimental exposures and experimental epizootics created in aquarium populations of immature herring. Massive and repeated exposures were necessary to achieve infection in two-year-old fish (Table 1). Beyond a critical dosage level, acute as well as subacute or chronic infections resulted. With experimental demonstration of the effect of increasing spore dosage or infection pressure on prevalence and severity of the disease, a large scale experimental epizootic was created in a laboratory population of 2,000 one-year-old herring. Spore dosage of 2×10^5 spores on each of four consecutive days resulted in infection of 23% of the population--8% acute and 15% subacute. The disease was terminal in all acute cases within 30 days. Chronic or subacute infections resulted in death of all but very light cases within six months. As with most aquarium studies of this kind, occasional deaths due to causes other than fungus disease occurred in experimental and control groups during the 18 month observation period, but these were infrequent enough so that they would not materially alter the findings. At the termination of the experiment (18 months after initial exposure) all surviving individuals were examined; only three lightly infected fish were found.

Experimental results agree with findings during the last outbreak in Gulf of Saint Lawrence herring (Sindermann, 1958). Twenty-seven percent of all fish sampled in that Gulf during the epizootic peak were infected, the ratio of acute to subacute being approximately one to two. Disease incidence was very low when spawning fish first appeared on the coast in late April, but mortalities due to acute infections began about one month after inshore migration. Deaths continued at a low level throughout the summer, due to subacute infections. A related observation of the effect of infection pressure concerned the alewife, *Alosa pseudoharengus*. This species has been reported, principally on the basis of histological evidence, to be less susceptible to *Ichthyosporidium*, by Sindermann and Scattergood (1954). During the recent epizootic in herring, alewives present in inshore waters also became infected, in sufficient numbers so that mortalities were observed and reported.

TABLE 1. SPORE DOSAGE AND EXPERIMENTAL INFECTION RATE IN TWO-YEAR-OLD HERRING. (Experimental groups of 50 fish each, from a laboratory population previously found to be free of fungus disease, were maintained in 250 gallon sea water tanks. Spores were obtained from naturally infected fish and tested for viability by culturing in Sabouraud-serum agar. Spore suspensions were added to food just before the fish were fed. The experiment was terminated at 90 days, and surviving fish examined for gross or histological evidence of disease).

Exposure and Dosage Schedule	Observations
2×10^5 spores in single exposure	No gross or histological evidence of disease after 90 days.
2×10^5 spores on each of 3 consecutive days	After 90 days, 4 of 50 fish had subacute or chronic infections; spores few and encapsulated; other fish uninfected.
2×10^5 spores on each of 5 consecutive days	After 20 days, 1 fish dead with massive acute infection; extensive tissue necrosis; little host response. After 90 days, 10 of remaining 49 fish exhibited subacute or chronic infections of varying severity; 39 fish uninfected.
2×10^5 spores on each of 7 consecutive days	After 15 to 30 days, 5 fish dead with massive acute infections. After 90 days, 12 with subacute infections of varying severity; 33 fish uninfected.
Control (no spore exposure)	No gross or histological evidence of disease.

DISCUSSION AND SUMMARY

The distribution and abundance of many parasites of herring vary geographically to such an extent that several have been used as "natural tags" in migration and population studies. Incidences of encysted larval cestodes (Trypanorhyncha) and nematodes (Anisakinae) have been examined over much of the range of herring in the western North Atlantic (Sindermann, 1961), and have been found during eight years of sampling to occur with characteristic frequencies in different geographic areas. Undoubtedly the presence and abundance of infected first intermediate and definitive hosts for these worms plays a role in determining parasitization of herring, although environmental variables might also be of importance.

Age of the herring is related to the kinds and numbers of parasites found. Certain parasites are characteristic of only very young fish, others only of older fish, while still others occur in herring of all ages. Adult cestodes (Pseudophyllidea) and a sporozoan (*Plistophora* sp.) occur only in herring younger than six months; the myxosporidian *Kudoa clupeidae* occurs only in immature fish; larval cestodes (*Trypanorhyncha*) occur only in fish older than one year; while the fungus *Ichthyosporidium hoferi* may occur in fish of any age. Diet, proximity to other hosts in the life cycle, segregation by size in schooling, and increasing immunity with age may all be of importance to the changing spectrum of disease with age. Research in the USSR that can best be described as ecological parasitology of fishes has been admirably summarized by Dogiel *et al.* (1958). Changes in parasite fauna of marine fishes with age and geography have been documented for a number of European species, including White Sea and Baltic herring.

Other diseases of herring, particularly those of bacterial etiology, deserve intensive ecological and laboratory study. Systemic bacterial infections are not uncommon in immature herring, and have been responsible for mass mortalities in experimental tanks. Artificially high temperatures, near the upper limit of tolerance of herring, were accompanied by extensive mortalities of experimental fish exhibiting characteristic symptoms of bacterial disease described by Sindermann and Rosenfield (1954*a*) as "bacterial tail rot". Snieszko (1962) has demonstrated that furunculosis and other bacterial diseases of fresh-water fishes can be influenced to a marked degree by temperature, and that even slight increases in temperature can increase mortality rates significantly.

Diseases in marine species result from a complex and constantly changing relationship between factors extrinsic and intrinsic to the individual and the population. Extrinsic or environmental influences on occurrence and effects of diseases may in some instances be marked, but have been inadequately studied, particularly in pelagic species. A continuing investigation of disease in Atlantic herring, *Clupea harengus, harengus*, has provided some information about environmental effects on three diseases: "pigment spot" disease caused by a larval trematode (*Cryptocotyle lingua*); myxosporidian disease caused by *Kudoa clupeidae*, and fungus disease caused by *Ichthyosporidium hoferi*.

Larval trematode abundance was found to decrease markedly from west to east along the northern New England coast. Fewer parasites occurred in herring from eastern Maine and New Brunswick than in herring from western Maine. Incidences of the larval trematode in *Littorina littorea*, the snail first intermediate host, did not have a corresponding geographic distribution. Experimental studies demonstrated a critical role of temperature in determining emergence of infective cercariae from the snail, and a relationship of abundance of the parasite in herring and environmental temperatures has been proposed.

Myxosporidian distribution and abundance followed a trend much like that of the larval trematode, with fewer infections in eastern regions of the Gulf of Maine than in western. The parasite did not occur in one-year-old fish taken on the eastern coast during eight years of sampling, but was abundant in fish of the same age taken on the western coast. The larger picture of occurrence of this parasite in the western North Atlantic provides further indication of a direct relationship of parasitism with environmental temperature, although other factors may be involved.

Epizootics of the fungus disease have occurred repeatedly in western North Atlantic herring. While knowledge about the possible influence of environmental conditions on prevalence of the disease is incomplete, it has been demonstrated experimentally that increasing infection pressure (increased dosage of spores) results in increased abundance and severity of the disease in herring. Intrinsic factors such as individual and population resistance are undoubtedly important also, and individual variations in susceptibility have been demonstrated.

Other instances of changes in occurrence of disease with locality and age of the fish have been observed during the course of this research. Surveys of disease incidence, life cycle studies, experimental studies of the role of environmental variables; all should prove to be fruitful areas for future investigations. Concurrent studies of immune responses and variability in resistance should provide a broad basis for understanding the role of disease in herring populations.

REFERENCES

CHRISTENSEN, N. and H. ROTH. 1949. Investigations on internal parasites of dogs. *K. Vet Højsk. Aarsskr.* (Copenhagen) 1949: 1-73.

DOGIEL, V.A., G.K. PETRUSHEVSKI and Y.I. POLYANSKI. 1958. Parasitology of fishes. Leningrad Univ. Press (Translation by Z. Kabata, English edition published by Oliver and Boyd Ltd. Edinburgh.)

DOLLFUS, R. 1956. Liste des parasites animaux du hareng de l'Atlantique Nord et de la Baltique. *J. Cons.* 22: 58-65.

SHULMAN, S.S. 1956. (Parasite fauna of *Clupea harengus*, *Osmerus eperlanus*, and *Eleginus navaga* in the White Sea.) Tr. Karelo-Finsk. fil. AN SSSR. 4 (cited by Dogiel *et al.* 1958 -- original not seen).

SINDERMANN, C. 1953. Parasites of fishes of North Central Massachusetts. Mass. Div. Fish and Game, Fishery Rept. for North Central Massachusetts, 1950: 4-28.

1958. An epizootic in Gulf of St. Lawrence fishes. *Trans. N. Amer. Wildl. Conf.* 23: 349-360.

1961. Parasite tags for marine fish. *J. Wildlife Mgmt*, 25: 41-47.

1963. Disease in marine populations. *Trans. N. Amer. Wildl. Conf.* 28: 221-245.

SINDERMANN, C. and A.E. FARRIN. 1962. Ecological studies of *Cryptocotyle lingua* (Trematoda: Heterophyidae) whose larvae cause "pigment spots" of marine fish. *Ecology* 43: 69-75.

SINDERMANN, C. and A. ROSENFIELD. 1954*a*. Diseases of fishes of the western North Atlantic. I. Diseases of the sea herring (*Clupea harengus*). *Maine Dept. Sea and Shore Fish., Res. Bull.* No. 18: 1-23.

1954*b*. Diseases of fishes of the western North Atlantic. III. Mortalities of sea herring (*Clupea harengus*) caused by larval trematode invasion. *Maine Dept. Sea and Shore Fish., Res. Bull.* No. 21: 1-16.

SINDERMANN, C. and L.W. SCATTERGOOD. 1954. Diseases of fishes of the western North Atlantic. II. *Ichthyosporidium* disease of the sea herring (*Clupea harengus*). *Maine Dept. Sea and Shore Fish., Res. Bull.* No. 19: 1-40.

SNIESZKO, S.F. 1962. Predisposing factors in the occurrence of diseases in fish. *Proc. First Internat. Conf. on Wildl. Dis.* 1962: 56-58.

STUNKARD, H.W. 1940. The life history of *Cryptocotyle lingua* (Creplin) with notes on the physiology of the metacercariae. *J. Morph.* 50: 143-191.

E-6

SEASONAL AND AREAL DISTRIBUTION OF GULF OF MAINE COASTAL ZOOPLANKTON, 1963

By

Kenneth Sherman[1]

ABSTRACT

Gulf of Maine coastal waters were sampled for zooplankton on single cruises during the winter, spring, summer and fall, 1963. Areal and seasonal variations were found in zooplankton volumes, major group occurrences and species composition. Three areas - the western, central and eastern Gulf - showed differing patterns of relative zooplankton abundance, with highest volumes occurring in the western sector, moderate volumes in the central area and lowest volumes in the eastern area.

Major zooplankton groups were more numerous in the western Gulf during winter, spring and fall. In summer, zooplankton groups were found in a variable pattern throughout each of the sampling areas. Larval forms were most numerous during spring and summer, indicating widespread breeding during these periods.

Copepods were the most numerous group of zooplankters encountered. Twenty-two species were present of which eight - *Calanus finmarchicus, Centropages typicus, Metridia lucens, Pseudocalanus minutus, Acartia longiremis, Oithona similis, Temora longicornis,* and *Tortanus discaudatus* - were most numerous. Six species were more abundant in the western area then in the eastern sector during all seasons. *Calanus finmarchicus* was more abundant in the east than the west in spring and *P. minutus* reached maximum numbers in the central area during summer. The fluctuations in seasonal and areal distribution of zooplankton volumes, major groups, and species are discussed in relation to previous studies and possible causes of variation.

INTRODUCTION

As part of a research program on the relation between environmental factors and availability of immature herring, *Clupea harengus* L., the Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, initiated a study of the Gulf of Maine coastal zooplankton. Research has provided information regarding seasonal and annual changes in zooplankton distribution and abundance.

In his classic work, Bigelow (1926) was first to describe the Gulf of Maine zooplankton. He characterized the dominant forms as the "Calanus Community" and showed that this endemic assemblage of zooplankters underwent seasonal pulsations in standing crop, progressing from a winter minimum to a spring-summer maximum, and was augmented annually by intrusions of northern and southern immigrant forms. Subsequent studies of Fish and Johnson (1937) and Redfield (1941) acknowledged the permanence of Bigelow's calanoid community, and the occurrence of immigrant species. Reports on endemic copepod species have been published by Fish (1936*a*, *Calanus finmarchicus;* 1936*b* *Pseudocalanus minutus;* 1936*c* *Oithona similis;* 1955 *Microstella norvegica*) and Redfield (1941, Calanoid species). Information regarding immigrant zooplankters was presented by Redfield (1939) for populations of the pteropod *Limacina retroversa* and by Redfield and Beale (1940) for several chaetognath species. Recently, Colton, *et al.* (1962) reported on the periodic intrusions of oceanic copepods into the inner reaches of the Gulf.

In the earlier works of Bigelow (1926) and Fish and Johnson (1937), lower mean-annual-volumes of zooplankton were reported east of the centrally located Penobscot Bay area than to the west of this region. Recent information, provided by staff members of the Boothbay Harbor Laboratory, suggests that this difference in areal distribution along the Maine coast is not limited to zooplankton. During 1962, it was observed that mean length of two-year-old herring was greater in the area west of Penobscot Bay than to the eastward (Watson, J.E., unpublished data). Erythrocyte antigen frequencies

[1] U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbour, Maine.

of young herring were found to differ east and west of Penobscot Bay (Sindermann, 1962). A discontinuity of the myxosporidian parasite, *Kudoa clupeidae*, was observed in small herring with infestations occurring west of Penobscot Bay but not to the eastward (Sindermann, 1961). Also, differences in spawning time of herring occur east and west of Penobscot Bay, as evidenced by the occurrence of larvae (≤ 9 mm standard length) east of Penobscot Bay two to three weeks earlier than larvae of the same size found to the westward (Graham, J.J., personal communication). In view of these findings, sampling was undertaken to determine whether differences in the composition and relative abundance of zooplankters occurred along the Maine coast.

METHODS

This report is based on the examination of 71 zooplankton samples collected from Gulf of Maine coastal waters during four seasonal cruises of the research vessel, *Rorqual*. Station locations and periods of collection are given in Table 1. Zooplankton samples were collected with a Gulf III sampler

TABLE 1. STATION LOCATIONS AND PERIODS OF COASTAL ZOOPLANKTON COLLECTIONS, *Rorqual* CRUISES 1, 4, 5 AND 7, 1963.

Station number	Position		Sampling periods, 1963			
	Lat.	Long.	*Rorqual* 1 5-16 Jan.	*Rorqual* 4 25 May- 2 June	*Rorqual* 5 10-22 July	*Rorqual* 7 11-20 Oct.
1.	42°43'	70°30'	X	X	X	X
2.	42°51'	70°43'	X	X	X	X
3.	42°56'	70°41'		X	X	X
4.	43°08'	70°23'		X	X	X
5.	43°17'	70°30'	X	X	X	X
6.	43°24'	70°12'		X	X	X
7.	43°39'	70°09'		X	X	X
8.	43°35'	69°52'	X	X	X	X
9.	43°42'	69°42'			X	X
10.	43°48'	69°29'	X	X	X	X
11.	43°51'	69°26'		X	X	X
12.	43°46'	69°06'	X	X	X	X
13.	43°48'	68°47'		X	X	X
14.	43°57'	68°93'	X	X	X	X
15.	44°02'	68°14'	X	X	X	X
16.	44°17'	68°07'	X	X	X	X
17.	44°10'	67°53'	X	X	X	X
18.	44°27'	67°50'		X	X	X
19.	44°27'	67°18'	X	X	X	X
21.	44°34'	67°19'	X	X	X	X
Number of stations sampled			12	19	20	20

Gehringer, 1962), fitted with an eight-inch nose cone and monel netting (aperture width 0.37 mm). All tows were of 30-min duration, taken during daylight hours, from 20 m to the surface in an oblique manner, with 10 min of towing at the surface and at depths of 10 and 20 m. A calibrated flow meter, affixed to the tail section of the Gulf III, was used to determine the amount of water strained. In addition, a U.S. Navy Electromagnetic Underwater Log, mounted on the keel of the *Rorqual*, measured the distance traversed during each tow. Analyses of the variation in the amount of water strained as determined by meter readings and Electromagnetic Log values indicated no significant differences in amount of water strained (Graham, J.J., unpublished data). For cruises 1 and 7, meter readings were used to calculate the amount of water strained, and for cruises 4 and 5, Electromagnetic Log readings were used. The average 30-min tow covered a distance of three nautical miles and filtered approximately 200 m^3 of water. Towing speed was maintained at approximately 6 knots.

In the laboratory, displacement volumes of all samples were taken. Ctenophores, large coelentrate remains (>2 cm long), and all fish larvae were removed from the samples and not included in the final volume determinations. Samples containing large quantities of ctenophores and medusae were not included in the analyses, due to the filtration error introduced by mesh clogging. Zooplankton samples were split into aliquots ranging from a half to a sixty-fourth, depending on the mass of the sample, and sorted into major taxonomic groups. Copepods were identified to species and the numbers of copepods and other zooplankters, per 100 m^3 of water strained were calculated.

RESULTS

Zooplankton Volumes

Seasonal and areal distributions of zooplankton volumes were compared. Abundance estimates are considered to be minimal, as use of a 0.37 mm mesh aperture limited sampling to the larger zooplankters. Also, tows were limited to the upper 20 m, and were taken only during daylight hours. To examine differences in areal distribution, the coastal region was divided into three areas, a central area located in the vicinity of Penobscot Bay, an eastern area extending from Mt. Desert Island to Grand Manan Island, and a western area from Casco Bay to Cape Ann. The areas, station locations, and sampling periods are shown in Fig. 1.

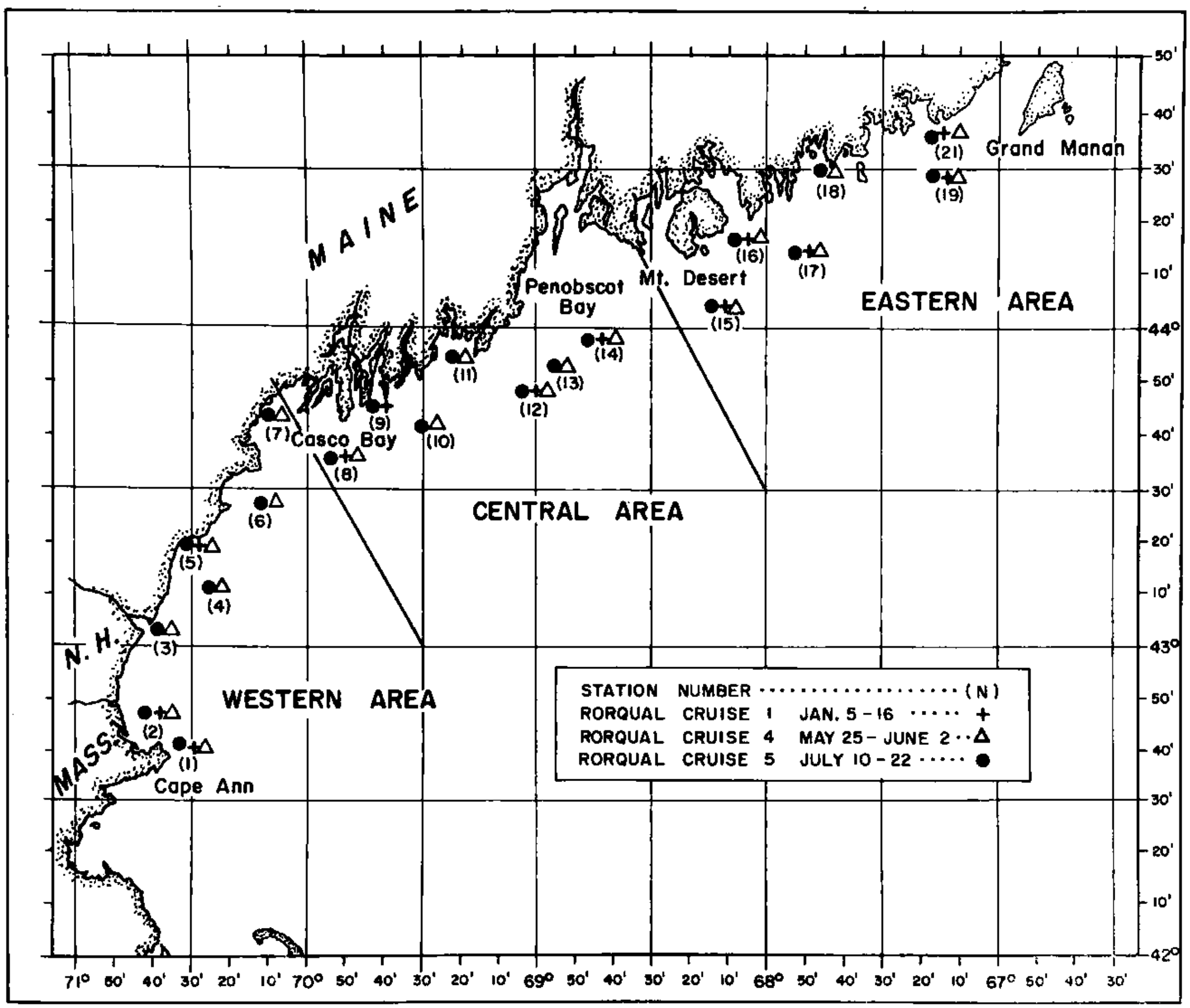


Fig. 1. Zooplankton sampling areas, station locations and periods of collections.

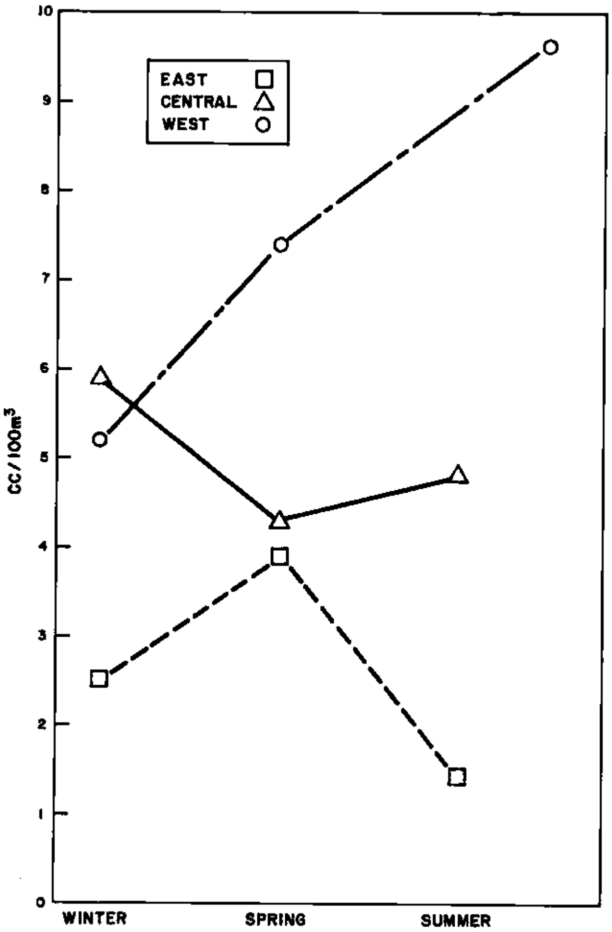


Fig. 2. A comparison of average zooplankton volumes per 100 m^3 of water strained among seasons for each of the three areas.

A comparison of average zooplankton volumes among areas for each of the four seasons is given in Fig. 2. Significant differences among areas (H=19.159, P <.01) were found using the Kruskal-Wallis analysis of variance (Siegel, 1956). In the eastern area the displacement volumes were the lowest encountered, ranging from a spring high of 3.9 cc/100 m^3 to a summer low of 1.4 cc/100 m^3. An intermediate range of values was found in the central area, ranging from a winter high of 5.9 cc/100 m^3, to a fall low of 3.2 cc/100 m^3. The greatest seasonal change in mean volumes occurred in the western area with values progressing from a winter low of 5.2 cc/100 m^3 to a summer high of 9.6 cc/100 m^3.

Zooplankton Groups

The percentage composition of the zooplankton groups encountered on each of the seasonal cruises is presented in Fig. 3. Copepods were the dominant zooplankters during each of the seasons, reaching a fall and winter high of 91% of the total zooplankton and declining to 45% in summer. Of the other planktonic forms found, nine-pteropods, chaetognaths, decapod larvae, cladocerans, brachyuran larvae, tunicates (appendicularians), cirripeds, and fish and crustacean eggs--constituted greater than 1% of the total zooplankton. The spring and summer decline in percentage composition of copepods was associated with the increase of other abundant (> 1% of the total zooplankton) groups; from two in winter to five in spring and seven in summer (Fig. 3). The breeding period of many species during warmer months was evidenced by the abrupt rise in decapod larvae in spring, and fish eggs and crustacean eggs during summer. Cirripeds occurred in swarms during spring, but diminished in summer with the onset of substrate attachment. Brachyuran and pelecypod larvae occurred during the summer and fall periods only. The fall decrease in the number of abundant zooplankton groups present indicated that the zooplankton population was approaching the winter minimum.

To examine the areal distribution of the dominant zooplankton groups, the mean number of zooplankters per 100 m^3 of water was determined for each of the three areas and for each of the seasonal cruises. Differences in areal distribution were plotted for major groups only (>100/100 m^3). During the winter period, copepods were the dominant zooplankters in all areas (Fig. 4A), but were more numerous in the western than in the eastern area.

In spring as in winter, copepods were the dominant zooplankters, increasing in numbers from a group mean of 645/100 m^3 in winter to 5,575/100 m^3 in spring (Fig. 4B). The spring rise in copepods was accompanied by increases in numbers of other major groups - decapod larvae, cladocerans, pteropods, cirriped larvae and tunicates. All major groups, with the exception of cirriped larvae, decreased in numbers from west to east (Fig. 4B).

An increase in the number of major groups was evident during the summer period (Fig. 4C). As in the preceding two seasons, copepods were the dominant zooplankters, with the grestest number (9,853/100 m^3) present in the western sector. Decapod and brachyuran larvae were also more numerous in the western area than in the east. The central area was characterized by a number of dominant

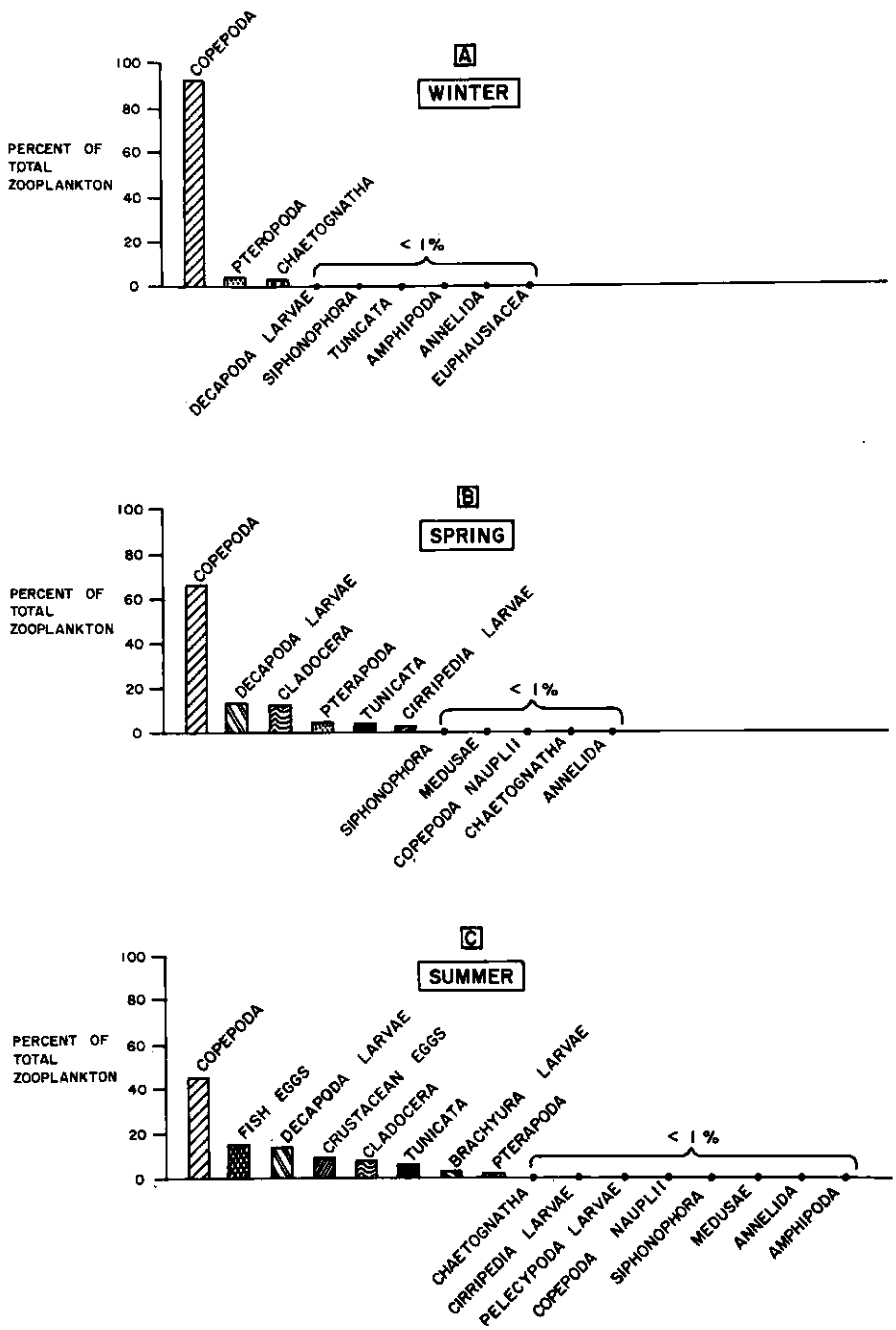


Fig. 3. Percentage composition of the zooplankton groups encountered on each of the seasonal cruises.

forms; cladocerans, pteropods, chaetognaths and fish eggs. Tunicates and crustacean eggs were more numerous in the eastern area.

During fall, fewer major groups of zooplankters were found than in summer, with a reduction from nine to four (Fig. 4D). Fish and crustacean eggs were also markedly reduced in numbers, from a summer high of 4,625/100 m^3 and 2,721/100 m^3, respectively, to less than 100/100 m^3. As in the preceding seasons, copepods were the dominant zooplankters in all areas, with the greatest number

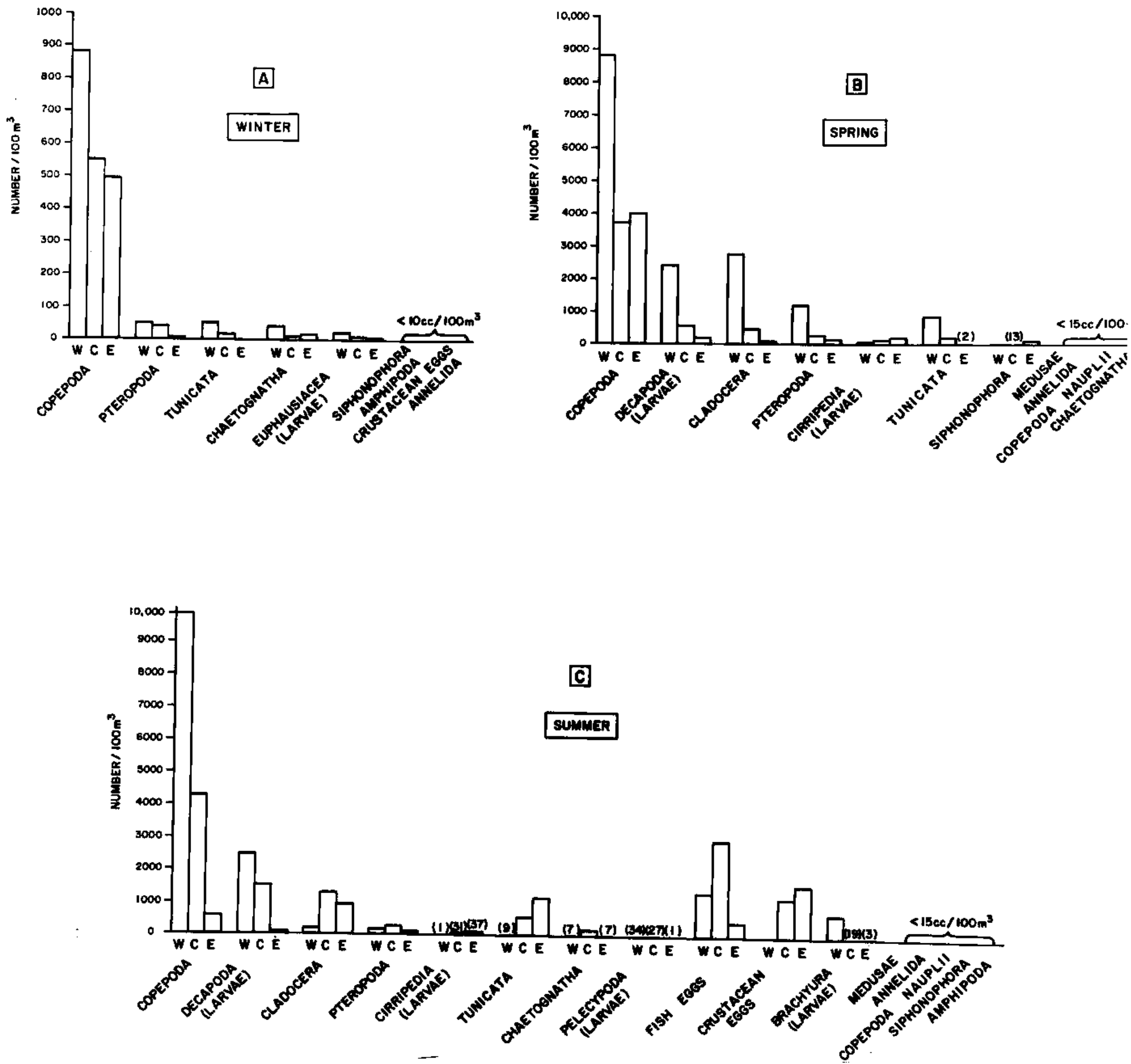


Fig. 4. Bar graph represents the mean number per 100 m^3 of water strained of the dominant zooplankton groups present in each of the three areas-west, central and east-during winter, spring, summer and fall.

(12,744/100 m^3) occurring in the western sector. Other groups more numerous in the western than in the eastern area were cladocera and pteropods. Of the four major groups, only one, brachyuran larvae, was more numerous in the central area. The low abundance of fish eggs, crustacean eggs, and larvae of other groups, indicated that the widespread breeding, characteristic of the summer period, was over and that the zooplankton population was approaching the winter minimum.

Copepod Species Occurrence

Copepods were the dominant zooplankters during all seasons. Species encountered are listed in Table 2. They have been arranged into two groupings; the common forms, those species exceeding

TABLE 2. COPEPOD SPECIES ENCOUNTERED DURING THE 1963 ZOOPLANKTON SAMPLING.

	Mean number/100 m^3	
	Common species >50/100 m^3	Less numerous species <50/100 m^3
Acartia longiremis (Lilljeborg)	204	
Calanus finmarchicus (Gunnerus)	1446	
Centropages typicus Kroyer	2308	
Metridia lucens Boeck	411	
Oithona similis Claus	141	
Pseudocalanus minutus (Kroyer)	398	
Temora longicornis (Muller)	160	
Tortanus discaudatus (Thomson and Scott)	76	
Acartia clausi Giesbrecht		3.17
Aetidius armatus Boeck		0.197
Calanus hyperboreas Kroyer		0.70
Candacia armata (Boeck)		3.21
Centropages hamatus (Lilljeborg)		0.704
Euchaeta norvegica Boeck		0.845
Eurytemora sp.		2.51
Oithona plumifera Baird		0.113
Oithona spinirostris Claus		23.00
Pleuromamma robusta (Dahl)		0.028
Pleuromamma xiphias Giesbrecht		0.028
Rhincalanus nasutus Giesbrecht		0.098
Scolecithricella minor Brady		0.042

a mean value of 50/100 m^3 for all cruises, and the less numerous species, with a mean value of <50/100 m^3 for all cruises. Of the eight common species, *Centropages typicus* was the dominant copopod, followed by *Calanus finmarchicus*, *Metridia lucens*, *Pseudocalanus minutus*, *Acartia longiremis*, *Temora longicornis*, *Oithona similis* and *Tortanus discaudatus* (Fig. 5).

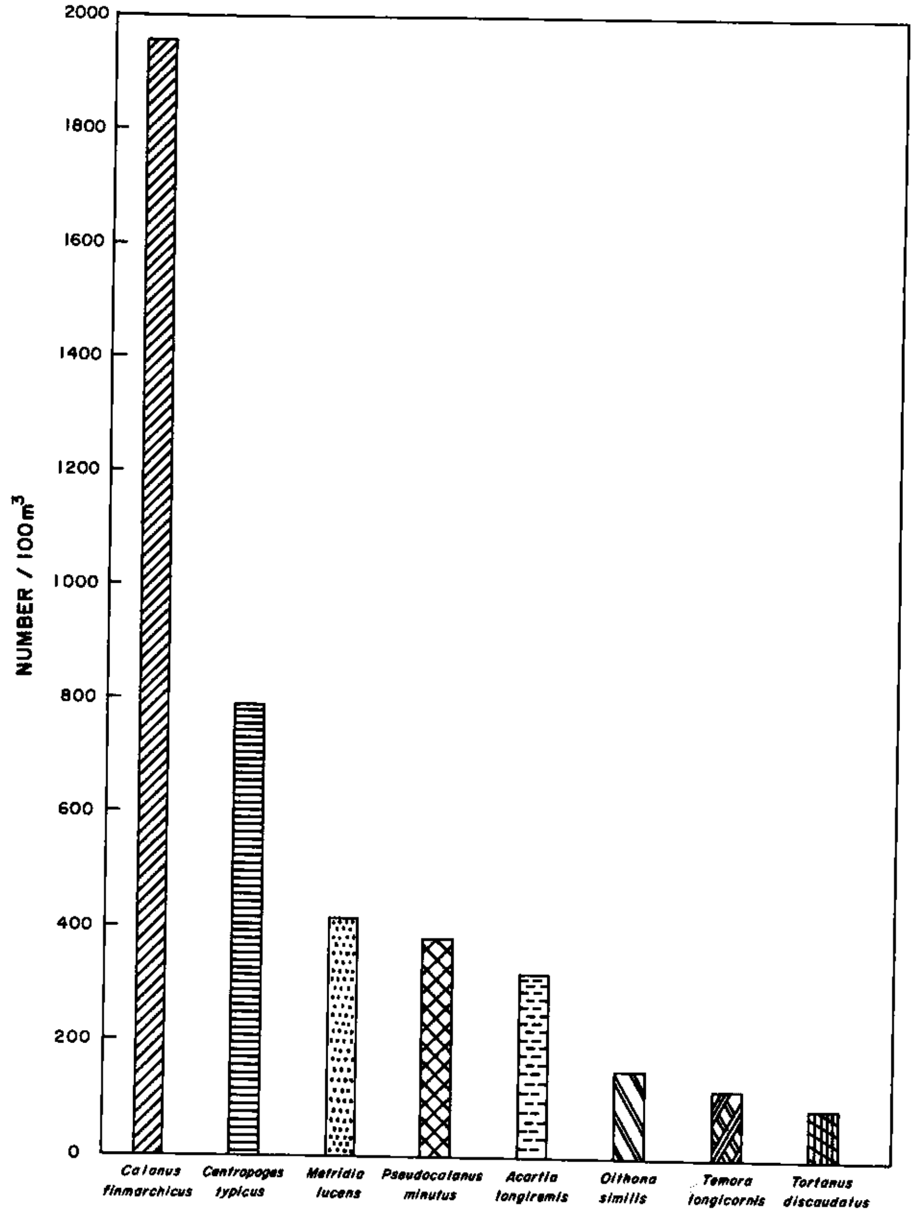


Fig. 5. Bar graph represents the mean number per 100 m^3 of water strained of eight commonly occurring copepod species during 1963.

Six of the eight commonly occurring species declined in abundance from west to east during all seasons (Fig. 6A to F). Differing patterns of occurrence were shown by two species, *C. finmarchicus*, and *P. minutus*, with the former species more abundant in the eastern area than in the western sector during spring and the latter reaching maximum numbers in the central area during summer (Fig. 6G and H).

Seasonal variability in species occurrence was observed among the eight common species. Five reached peak numbers in summer; *C. finmarchicus, M. lucens, O. similis, P. minutus* and *T. discaudatus*. Of the remaining three, *A. longiremis* was most numerous during spring, and *C. typicus* and *T. longicornis* reached peak numbers in the fall (Table 3).

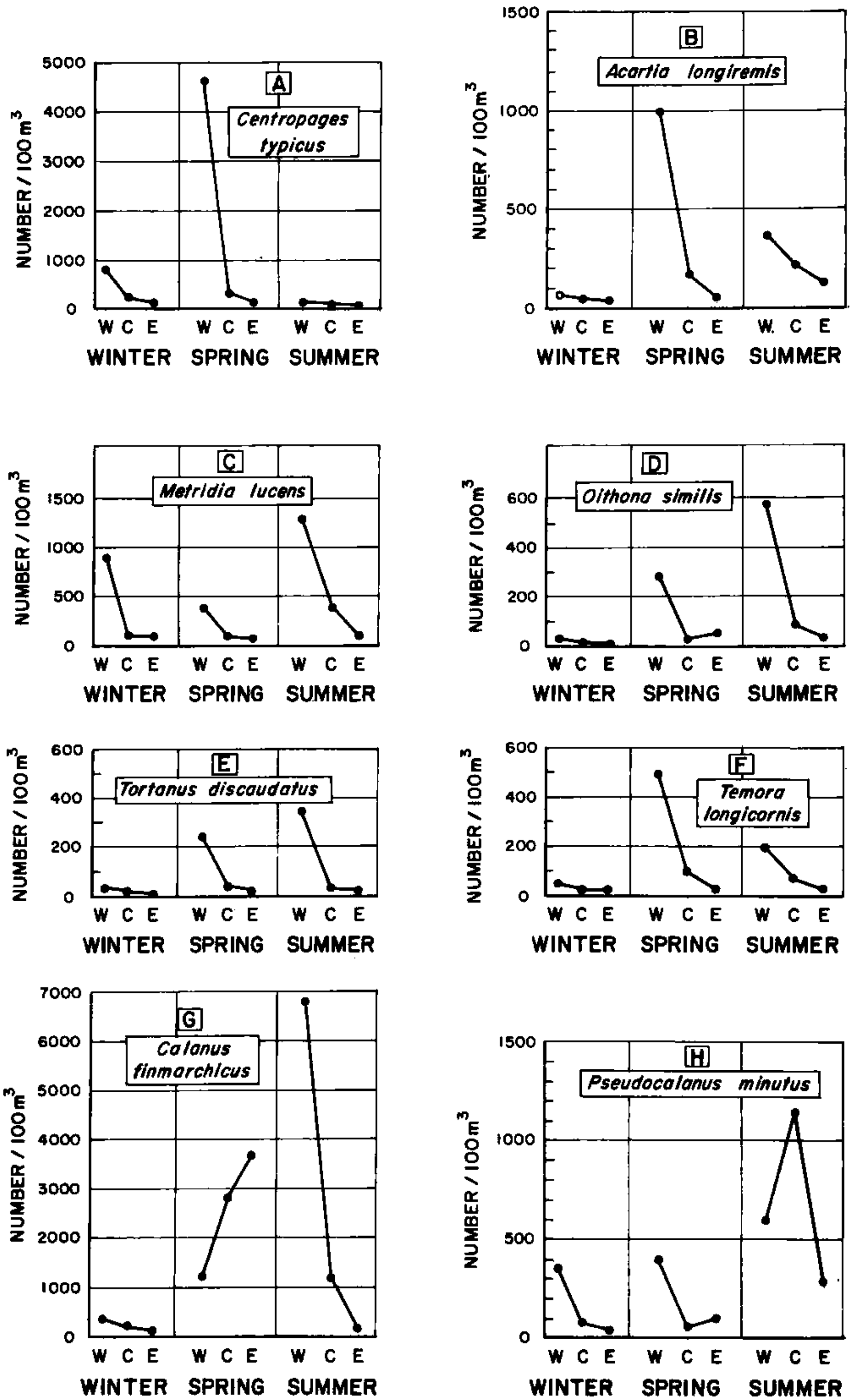


Fig. 6. The areal and seasonal variation in numbers per 100 m^3 of water strained of the eight commonly occurring copepod species.

TABLE 3. SEASONAL PERIODS OF MAXIMUM ABUNDANCE OF THE COMMONLY OCCURRING COPEPOD SPECIES.

Species	Winter 5-16 Jan.	Spring 25 May-2 June	Summer 10-22 July	Fall 11-20 Oct.
Acartia longiremis		0		
Calanus finmarchicus			0	
Centropages typicus				0
Metridia lucens			0	
Oithona similis			0	
Pseudocalanus minutus			0	
Temora longicornis				0
Tortanus discaudatus			0	

TABLE 4. SEASONAL AND AREAL OCCURRENCE OF THE LESS NUMEROUS COPEPOD SPECIES.

Species	Winter (+)			Spring (0)			Summer (X)			Fall (Ø)		
	west	central	east	west	central	east	west	central	east	west	central	east
Aetidius armatus	+											
Acartia clausi				0		0				Ø		
Calanus hyperboreas			+									
Candacia armata	+	+	+						X	Ø		
Centropages hamatus				0						Ø		
Euchaeta norvegica		+								Ø		
Eurytemora sp.				0			X	X	X	Ø		
Metridia longa											Ø	Ø
Oithona plumifera					0							
Oithona spinirostris	+	+			0	0			X	Ø		
Pleuromamma robusta						0						
Pleuromamma xiphias			+									
Rhincalanus nasutus			+									
Scolecithricella minor								X				

The less common species presented interesting patterns of occurrence (Table 4). Of the 14 species found, 8 occurred only during a single season. In winter 4 species, considered to be oceanic in origin, were found - *Aetidius armatus, Calanus hyperboreas, Pleuromamma xiphias*, and *Rhincalanus masutus*. All but *A. armatus* occurred only in the eastern area. Other seasonally occurring species were: *Oithona plumifera*, and *Pleuromamma robusta*, present only during the spring, *Scolecithricella minor*, found in summer and *Metridia longa* present only in fall. Species occurring in more than a single season were: *Acartia clausi, Candacia armata, Centropages hamatus, Euchaeta norvegica, Eurytemora* sp. and *Oithona spinirostris*.

DISCUSSION

A comparison of mean displacement volumes for each of the areas and seasons revealed different patterns of abundance. The highest values for all seasons were found in the western area. The lowest values occurred in the eastern sector, and intermediate volumes in the central area. Based on data collected during the warmer months (April-October), Bigelow (1926), Fish and Johnson (1937) also found that the region west of Penobscot Bay was consistently higher in zooplankton volumes than the relatively "barren" area to the eastward, from Mt. Desert to the Bay of Fundy. The progression from a winter low to a summer high in the western area is also in agreement with Bigelow (1926); Fish and Johnson (1937) and Redfield (1941). In addition these authors have indicated a late summer reduction in volumes, followed by a short-lived fall increase. During 1963, this fall increase was not apparent in the western or central areas. However, a slight increase in zooplankton volumes occurred in the eastern area.

The seasonal variations of volumes in the central and eastern areas are not compatible with the findings of Bigelow (1926) or Fish and Johnson (1937). However, Redfield (1941) showed that the "Seguin" sector of the Gulf, an area comparable to the central area, had only moderate plankton volumes in summer which declined in fall, increased in winter, declined in spring and increased in summer. The present pattern of seasonal variability in volumes in the central area is in agreement with the description given by Redfield for 1933 data. The increase in volumes, however, from summer to fall of 1934, reported by Redfield (1941), indicated that annual variations can be expected in the central area. In the eastern area, the winter-spring increase in volumes although of a lesser magnitude than the western sector, is in agreement with previous reports. However, the summer decline observed in this region has not previously been reported. Future sampling is planned for this region to examine these results more closely.

Major zooplankton groups showed a seasonal variation both in numbers and areal distribution. Most of the groups were more numerous in the western sector than in the eastern. The most notable exceptions occurred during the summer period when six groups - cladocerans, pteropods, tunicates, chaetognaths, fish eggs and crustacean eggs - were more numerous in the central and eastern areas. The significance of this shift in areal distribution is not known. However, it was found that considerable breeding during the warmer months occurs in the northeastern sector of the Gulf of Maine eddy, as evidenced by the presence of large numbers of fish and crustacean eggs occurring in the central and eastern areas. The general southwesterly movement of surface waters in this eddy (Bigelow, 1926; Bumpus, 1960) may be one of the factors contributing to the concentration of zooplankton in the western area in the period succeeding the peak summer breeding.

Bigelow (1926): Fish and Johnson (1937) indicated that copepods were the most numerous and comprised the greatest volume of zooplankters occurring in Gulf of Maine waters. These investigators also found that volumes of zooplankton were consistently higher west of Penobscot Bay than east of this region. It would follow then, that most of the endemic copepod population would also decrease in abundance from west to east. Fish (1936 *a, c*) reported this decrease for the copepods *Calanus finmarchicus* and *Oithona similis* and noted two breeding stocks for each species - one located east of Penobscot Bay and the other, the principal breeding grounds, to the west.

The decrease in numbers from west to east of all but two species of the commonly occurring copepods found during the present study confirms the conclusions reached by earlier investigators. The apparent exceptions were the species, *Calanus finmarchicus* and *Pseudocalanus minutus*. In this regard, Fish (1936*a*) has shown that successive broods of *C. finmarchicus* produced in the western Gulf were transported initially to the outer Gulf and then to the inner reaches of the eastern and central areas by the upper waters of the Gulf of Maine eddy. These circulation features were thought to be the mechanism for transporting large numbers of *C. finmarchicus* to other areas of the Gulf from the principal western breeding area during spring and summer (Fish, 1936*a*). The large numbers of *C. finmarchicus* found in the eastern area during spring may have resulted from this type of current transport.

The large numbers of *Pseudocalanus minutus* found in the central area during summer is not entirely unexpected. Fish (1936*b*) reported the presence of three stocks of *P. minutus* for: 1) the outer Gulf, 2) the western coastal area, 3) the region east of Mt. Desert to the Bay of Fundy. He indicated that in early spring, the western brood became widely dispersed, and that in late summer, the larger part of the *P. minutus* population originated in waters of the outer Gulf. The presence of large numbers of *P. minutus* in the central area during late summer could have been related to the inshore movement of the Gulf of Maine eddy in this area during the late summer period. Copepod length frequency data could provide additional information regarding the origin of copepod populations and future effort will be directed toward providing this information.

Although occurring in relatively small numbers, immigrant zooplankton species have provided an insight into the origin and along-shore movements of the mixed waters of the Gulf of Maine eddy system (Bigelow, 1926; Fish and Johnson, 1937; Redfield, 1939, 1941; Colton, *et al.*, 1962). The presence of *Calanus hyperboreas*, *Pleuromamma xiphias*, and *Rhincalanus nasutus*, in the eastern area only during winter is in agreement with Redfield (1939, 1941), who reported the indraft of oceanic water from the Nova Scotian banks into the Gulf of Maine during Winter.

In a discussion of the environmental characteristics of the Gulf of Maine, Bigelow (1927) concluded that the wide seasonal variations in temperatures of the Gulf are due to... "its geographic location to the leeward of the continent and to the vigorous land climate. Only in a much smaller degree is it influenced by warm or cold currents flowing into it". He further indicated that the wide seasonal variation in salinity characteristic of the Gulf is due to local conditions,..."the water freshening at the season of the spring freshet and then gradually salting again as this inrush of river water is incorporated by the mixings and churnings caused by the tides, winds, and waves". In this regard, it would appear that a great salinity influence on coastal waters would be exerted by the Penobscot Bay area.

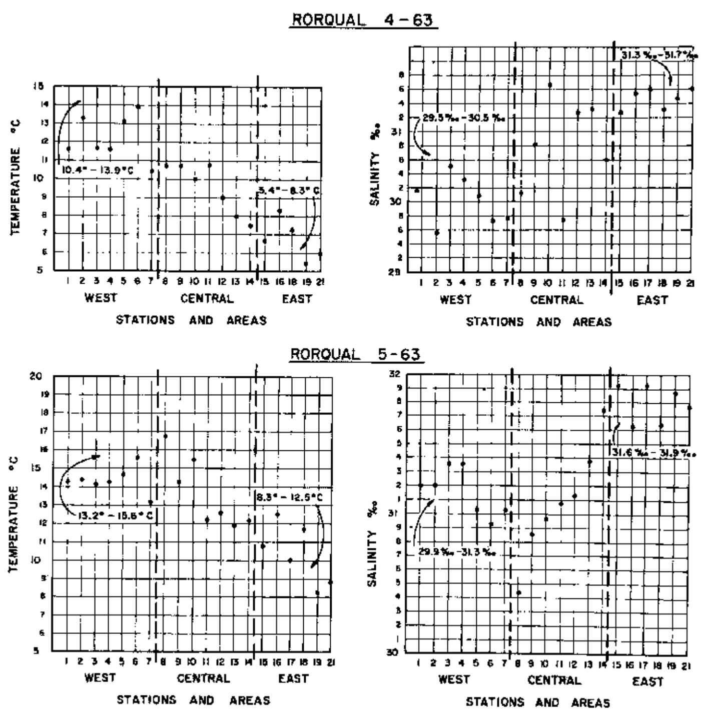


Fig. 7. Areal distribution of surface salinities and temperatures, *Rorqual* cruises 4, 5

Surface temperatures and salinities plotted for spring, summer, and fall by areas (Fig. 7) suggest that the Penobscot Bay region represents a transition zone between surface waters of lower salinity and higher temperature ranges located in the western sector and higher salinity, cooler waters of the eastern area. Whether these environmental differences are the result of local conditions or advection cannot presently be determined, but will be subject to future investigation. In addition to hydrographic differences, faunal changes east and west of Penobscot Bay occur for: 1) mean length at age of immature herring, 2) erythrocyte antigen frequencies of two-year-old herring, 3) myxosporidian parasite infestation of young herring, 4) differential herring spawning as evidenced by length frequencies of larvae. The high zooplankton volumes, greater numbers of groups, and copepod species found in the western Gulf, when considered with the surface temperature and salinity differences, suggest that the Penobscot Bay region represents a faunistic boundary between eastern and western coastal biota.

REFERENCES

BIGELOW, H.B. 1926. Plankton of the offshore waters of the Gulf of Maine. *Bull. U.S. Bur. Fish.*, 40 (2): 1-509.

1927. Physical oceanography of the Gulf of Maine. *Bull. U.S. Bur. Fish.*, 40 (2): 511-1027.

BUMPUS, D.F. 1960. Sources of water contributed to the Bay of Fundy by surface circulation. *J. Fish. Res. Bd. Canada*, 17 (2): 181-197.

COLTON, J.B., R.F. TEMPLE and K.A. HONEY. 1962. The occurrence of oceanic copepods in the Gulf of Maine-Georges Bank area. *Ecology* 43 (1): 166-171.

FISH, C.J. 1936*a*. The biology of *Calanus finmarchicus* in the Gulf of Maine and Bay of Fundy. *Biol. Bull., Woods Hole*, 70 (1): 118-141.

1936*b*. The biology of *Pseudocalanus minutus* in the Gulf of Maine and Bay of Fundy. *Biol. Bull., Woods Hole*, 70 (2): 193-216.

1936*c*. The biology of *Oithona similis* in the Gulf of Maine and Bay of Fundy. *Biol. Bull., Woods Hole*, 71 (1): 168-187.

1955. Observations on the biology of *Microstella norvegica*. *Deep-Sea Res. Suppl.* 3: 242-249.

FISH, C.J., and M.W. JOHNSON. 1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. *J. Biol. Bd. Canada*, 3 (3): 189-322.

GEHRINGER, J.W. 1962. The Gulf III and other modern high-speed plankton samplers. *Contrib. Symposium on Zoopl. Prod., Rapp. Cons. Explor. Mer*, 153: 19-22.

REDFIELD, A.C. 1939. The history of a population of *Limacina retroversa* during its drift across the Gulf of Maine. *Biol. Bull., Woods Hole*, 86 (1): 26-47.

1941. The effect of the circulation of water on the distribution of the calanoid community in the Gulf of Maine. *Biol. Bull., Woods Hole*, 80 (1): 86-110.

REDFIELD, A.C., and A. BEALE. 1940. Factors determining the distribution of populations of chaetognaths in the Gulf of Maine. *Biol. Bull., Woods Hole*, 79 (3): 459-487.

SIEGEL, S. 1956. *Nonparametric Statistics*. New York. McGraw-Hill Co., 312 p.

SINDERMANN, C.J. 1961. Parasite tags for marine fish. *J. Wildlife Mgmt.*, 25 (1): 41-47.

1962. Serology of Atlantic clupeoid fishes. *Amer. Nat.* 96 (889): 225-231.

E-7

ECOLOGY OF HERRING LARVAE IN THE COASTAL WATERS OF MAINE

By

Joseph J. Graham and Harold C. Boyar[1]

ABSTRACT

The ecology of larval and juvenile herring, *Clupea harengus* (Linnaeus) in the coastal waters of the Gulf of Maine is being studied at the U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine. This report is the first of a series and covers a period of a year beginning June, 1961. Hydrographic and biological observations were made in three embayments located along the central Maine coast; the Sheepscot, Boothbay and Damariscotta. Major seasonal environmental events were similar in the three areas. Average conditions for the year were somewhat different; eastward from the Sheepscot to the Boothbay and Damariscotta areas, average seasonal salinities, surface temperatures and surface standing crops of zooplankton increased. Meter-net catches showed marked differences in the seasonal and areal distribution of herring larvae. The seasonal distribution of herring larvae was inverse to other fish larvae. The source of the herring larvae, the influence of avoidance and migration by larval herring on meter net catches and the utilization of the estuarine environment during their larval stages are discussed.

INTRODUCTION

The U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, is studying the ecology of larval and juvenile herring, *Clupea harengus* (Linnaeus), in the coastal waters of the Gulf of Maine. The study is designed to determine trends in the distribution and abundance of the early life history stages of herring and their relation to variations in the environment. This is the first of a series of reports and covers the period from June 1961 to June 1962. The region investigated, an inshore habitat, is part of the rocky coast of Maine which is deeply embayed and dissected by drowned river valleys (Fig. 1). The sides of the lower estuaries and bays are usually steep and their basins relatively deep, the water is well mixed, and dilution evident only during periods of peak river discharge. Within the bays and lower estuaries, water exchange is influenced by the presence of islands and ledges in the areas of deep water, and by narrow guts (or passages).

The general ecology of the lower Sheepscot River estuary has been described by Stickney (1959) and a specific study of the bottom fauna has been made by Robert W. Hanks, whose paper, "A benthic community in a New England estuary", is in press in the Fishery Bulletin series of the U.S. Fish and Wildlife Service. The Sheepscot River has a drainage area of approximately 148 sq. mi. and an average daily discharge of 239 c.f.s. (U.S. Geological Survey, 1962, 1962*a*). During the study period, 83,840 c.f.s. was discharged by the river, with the highest monthly discharge (36% of the total) in April and the lowest(2%) in September. A secondary high (14%) and a low (3%) occurred during December and February, respectively. Similar data were not available for the Damariscotta River basin which is smaller than the Sheepscot. The Boothbay area does not receive discharge from any major stream.

METHODS AND MATERIALS

Each of the 18 stations shown in Fig. 1 was sampled biweekly, alternating hydrographic and fishing cruises. Weather conditions occasionally hampered sampling but of 26 cruises, only 5 were not completed and no more than 5 stations were abandoned on any one cruise. There were considerable variations in the sequence, stage of tide, and time of day that stations were sampled. These variations are not considered to detract from the average seasonal and areal data obtained. The sampling procedure is considered analagous to that of Hopkins (1963). He concluded that several tows spaced

[1] U.S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, USA.

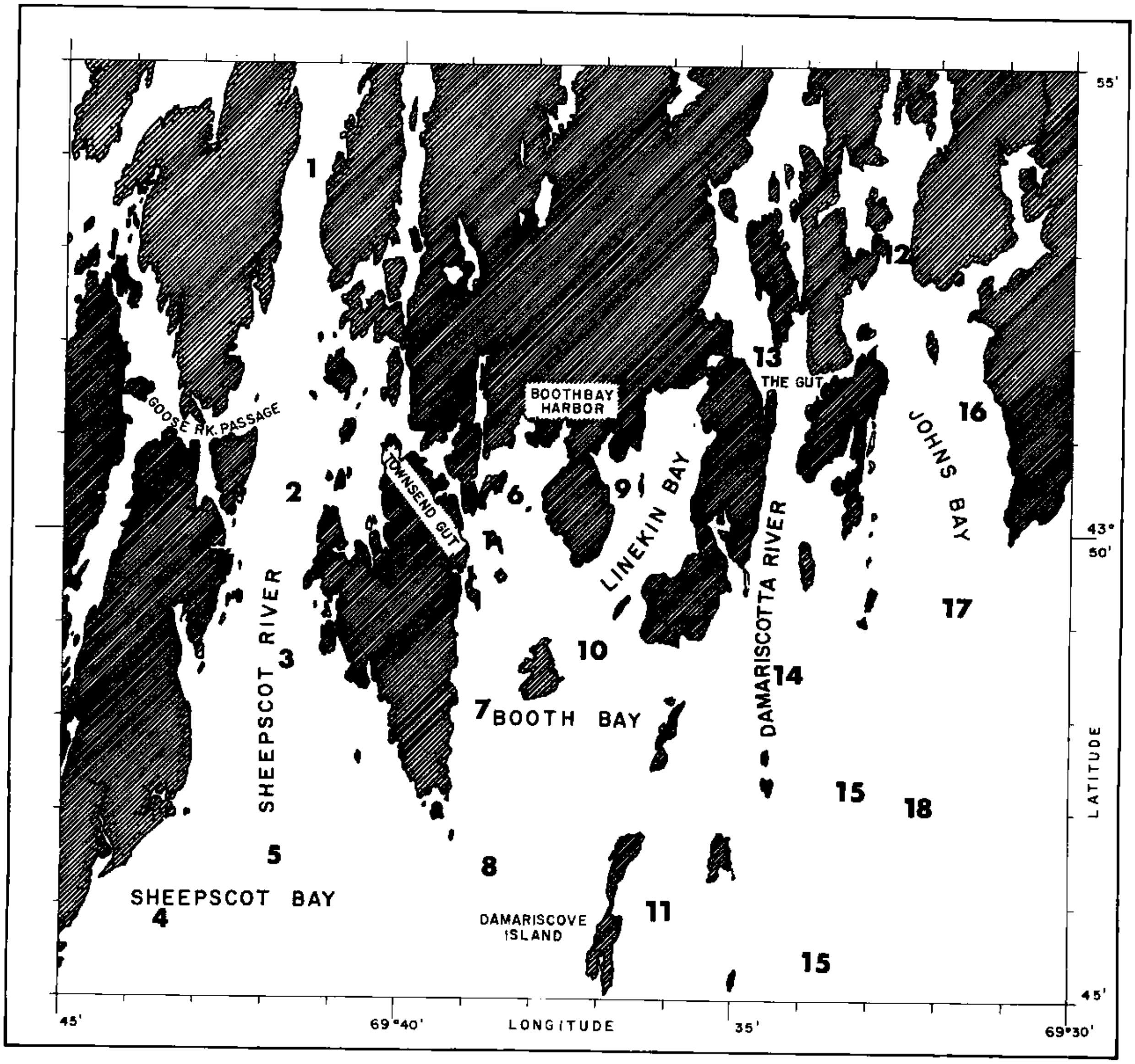


Fig. 1. Sampling stations in the Sheepscot-Boothbay-Damariscotta region of Maine. Two positions are shown for station 15. Because of obstructions in the water the original station position was shifted midway during the year of sampling.

over a single tidal cycle were more effective in estimating average biological characteristics at a station than one that filtered a large amount of water in a single tow.

Bathythermograph casts, surface temperatures and appropriate meterological observations were made during all cruises. On hydrographic cruises, Nansen bottle casts were made at 0, 10 and 20 m and just above the bottom. Plankton tows were made at the surface and vertically from the bottom. On fishing cruises an otter trawl with a 25-ft mouth opening and cod end liner (fine mesh) was towed along the bottom. The mesh at the mouth had a stretched measure of 4.4 cm; and the cod end, 3.2 cm. Sampling of salinity and plankton was confined to the surface. The 1-m plankton net used to capture

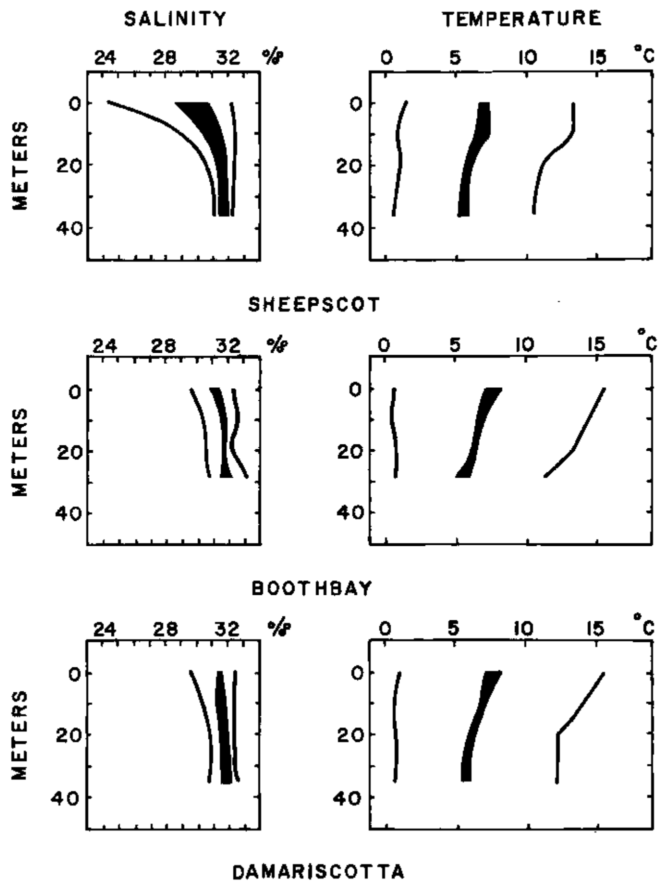


Fig. 2. Annual means and extremes of temperature and salinity. The mean range for each area at various depths is shaded.

larvae and plankton had a 0.51 mm mesh opening with 13 meshes per linear centimeter; no flowmeter was used during tows on station. The column of water strained on a vertical tow depended upon the depth of water. The amount strained during surface tows was determined by a calibrated Atlas flowmeter. The flowmeter was suspended in a meter net ring and towed over a known distance both with and without a net. This calibration, revolutions of the flowmeter per cubic meter of water strained, was applied with a net factor to metered tows. The average volume of water strained during the standard 10-min tow at 3 knots was 1,550 m^3.

In the laboratory, fish larvae were separated from plankton samples, identified and counted. Displacement volumes were calculated for the remaining plankton after removing foreign materials and organisms larger than 5 cm. Salinity samples were titrated by the Knudsen method.

RESULTS

Environmental conditions

Figure 2 summarizes, as profiles, the hydrographic data obtained during the year. The highest salinity values in each area were similar, reflecting a seasonal maximum in evaporation and a minimum of runoff common to the three areas. In the upper 20 m, Boothbay and Damariscotta were comparable, mean salinities were higher and their range less than in the Sheepscot, which receives a greater inflow of freshwater. Below 20 m mean salinities were similar in the three areas. The narrow range of mean salinities at the surface in the Damariscotta area was related to turbulence and mixing in the narrows above station 13. The Damariscotta estuary was not affected by the shallow gut leading to John's Bay, but water from the Sheepscot estuary flowed through the deeper Townsend Gut (6-15 m) reducing the mean salinity at station 7.

Average temperatures in the Sheepscot area indicated a relatively homogeneous distribution in the upper 10 m. A similar situation existed for highest temperatures. In the Boothbay area, mean and highest temperatures increased generally from the bottom upward because some of the shallow stations (6 and 9) were completely stratified throughout in the summer. The deeper stations of the Damariscotta area showed a relatively homogeneous layer from 20 m to the bottom. Lower temperatures reflected the lower winter air temperatures common to all of the areas.

At station 1 the seasonal progression of temperature and salinity was pronounced and was not obscured by advection of other water types or excessive turbulence, but represented seasonal events at other stations (Fig. 3). These were summer stratification, fall overturn, winter homogeneity and spring dilution. The estuary was coldest throughout its water column in late winter and coldest near the bottom during early spring. Salinity was highest in the winter, interrupted briefly by an increase in river discharge. With vernal warming and increased runoff salinity was lowered and the water column was stratified. By late spring to early summer this diluted water was mixed by the tides and removed from the estuary.

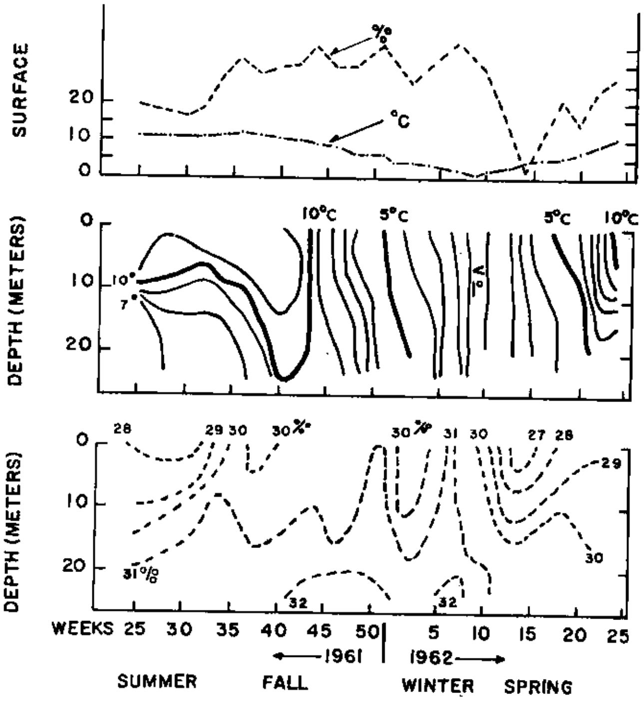


Fig. 3. Seasonal progressions of temperature and salinity at station 1 in the Sheepscot estuary. Original temperature measurements in degrees Fahrenheit and depths in feet.

During the year, either temperature or salinity controlled the density distribution. This is illustrated with selected shallow- and deep-water stations in Fig. 4. In April, the discharge of freshwater preceded thermal stratification and the steep density gradient at station 1 was more closely related to a change in salinity than temperature, although the gradient was accentuated by the colder bottom water. A steep gradient was not present during April at station 5 because the freshwater was well mixed through tidal action when it departed the estuary. Temperature was the dominant variable during the summer and fall, when the density of the entire water column was lowest. In the winter, the water column approached homogeneity except at stations in the Sheepscot area.

Displacement volumes of zooplankton obtained in meter net tows were not normally distributed and a median-quartile description (Snedecor, 1948) was used to summarize data from each of the 18 stations (Table 1).

TABLE 1. MEDIAN-QUARTILE DESCRIPTION OF PLANKTON VOLUMES

	Range in ml		
	Sheepscot	Boothbay	Damariscotta
Quartile 1	2.0 - 3.5	2.0 - 6.0	2.0 - 5.0
Median	4.0 - 6.5	4.0 - 8.0	4.0 - 9.5
Quartile 3	5.75 - 12.0	11.75 - 18.75	11.00 - 27.0
Extremes	< 1 - 70	< 1 - 197	< 1 - 341

The volumes in the first quartiles and medians overlap considerably between the three areas. This overlap is related, in part, to measuring small displacement volumes less than 5 ml. Very small volumes are present for all areas, but the third quartile, large volumes, showed a progressive increase from the Sheepscot to the Damariscotta. The three areas differed, as suggested above, in their average temperature and salinity distributions and in their resultant sigma-t values at the surface. In this regard, a positive correlation (r = 0.562, N-2 = 16, P < .05) was obtained between the third quartile of surface plankton volumes and sigma-t values at each station. Stations in the lower estuary of the Sheepscot River had the lower sigma-t values and lower plankton volumes while the Damariscotta area, particularly stations 17 and 18, more exposed to coastal waters, had the highest. The seasonal progression of zooplankton volumes from station 1 in the Sheepscot estuary was similar to those of the other stations and is shown in Fig. 5. The standing crop was high during late summer and early fall, low in the late fall and winter, high again in late winter and early spring, and low again during the late spring and early summer.

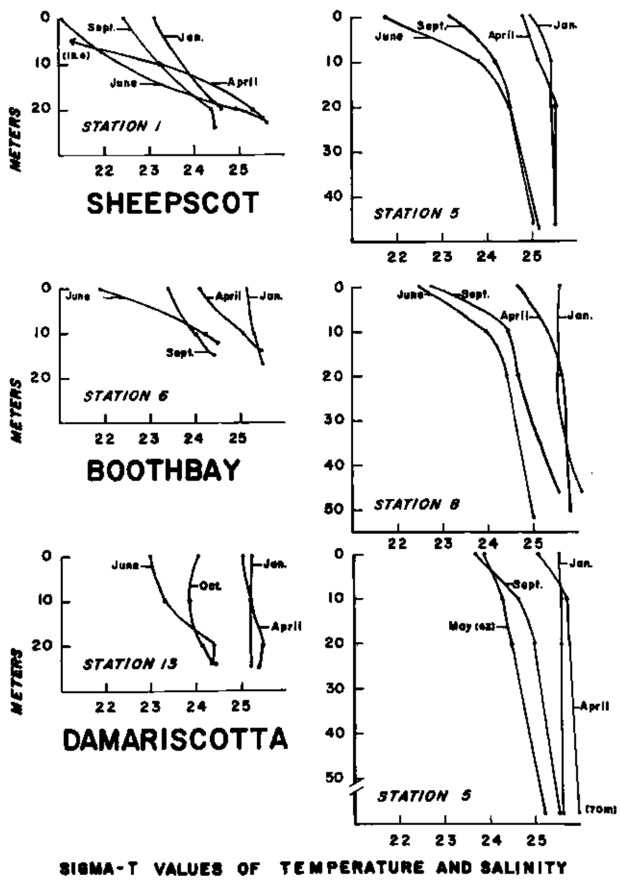


Fig. 4. Vertical distributions of density at selected shallow and deep water stations. See Fig. 1 for the location of numbered stations.

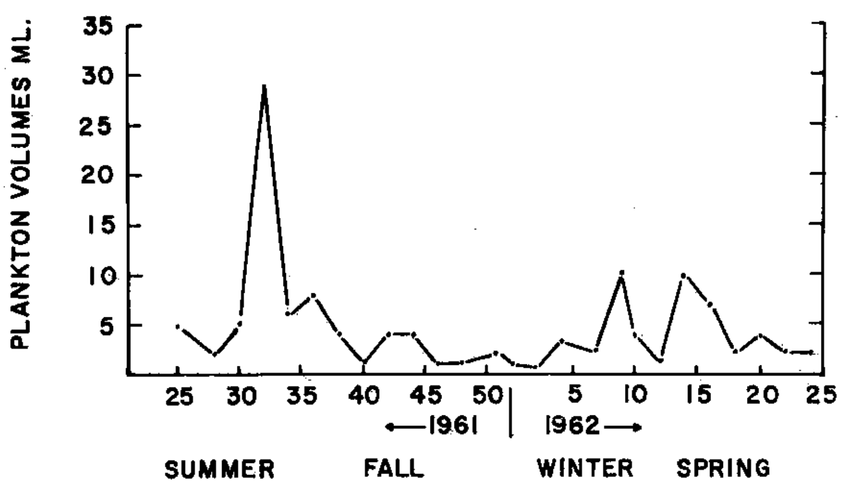


Fig. 5. Zooplankton volumes at station 1 in the lower Sheepscot estuary.

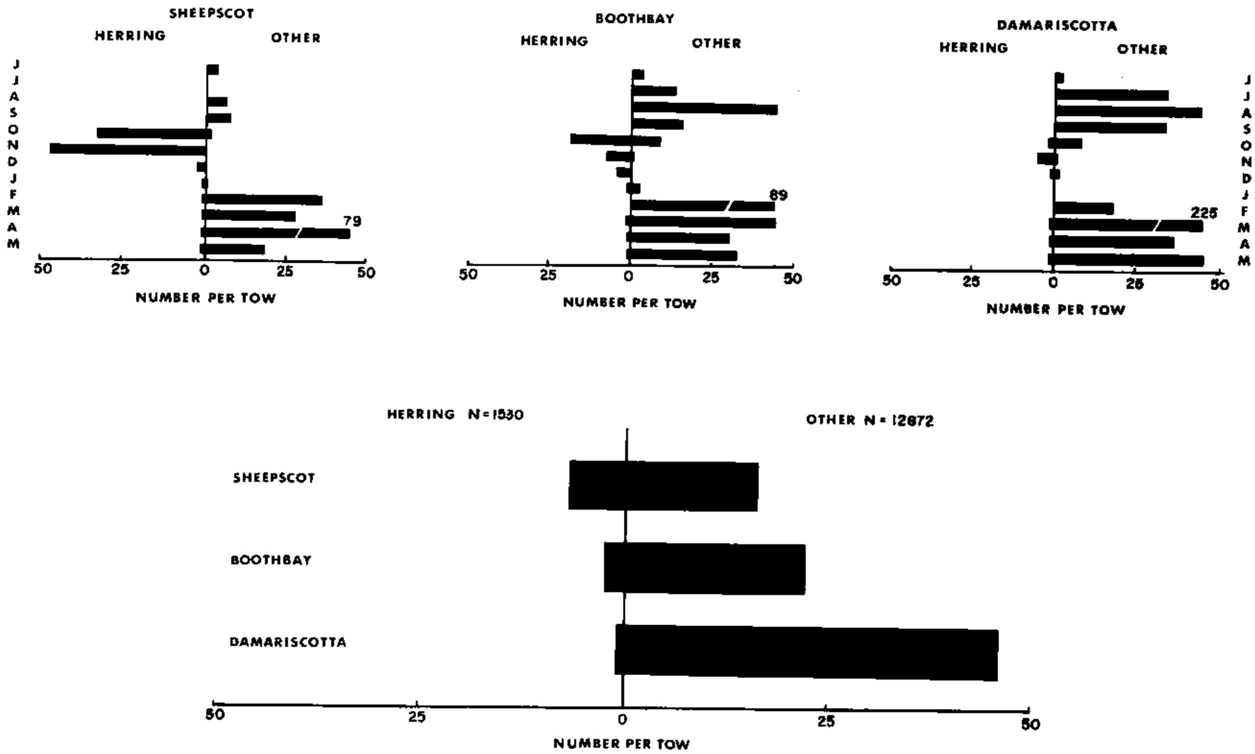


Fig. 6. Average number of herring and other fish larvae caught in surface tow

Larval distribution

Monthly meter-net catches of larval herring and other larval fishes had three notable features: 1) there were marked differences in the seasonal distributions of larvae, 2) the differences in areal distribution were equally marked, 3) the seasonal and areal distribution of herring larvae was inverse to that of other larvae (Fig. 6).

Herring larvae were first captured in October and were relatively abundant. Catches were largest in the Sheepscot and smallest in the Damariscotta area. Their numbers increased in the Sheepscot and Damariscotta areas during November but decreased in the Boothbay area. By December, there was a sharp drop in all areas and catches remained at a low level. During February, herring larvae were not captured in the Boothbay area, nor in January and February in the Damariscotta area. The average number per tow decreased from the Sheepscot to the Damariscotta area.

The number of larvae captured in vertical meter-net tows was small, 50 during October and November, a period of relative abundance at the surface. No particular pattern of areal distribution or relation to surface catches was discernible. Possibly the distances towed, 14-67 m, were too short and the amounts of water strained, 12-52 m^3, too little to register any distinct pattern of distribution. Surface samples strained 1,550 m^3 and were towed for 830 m. Otter trawling was largely unsuccessful in capturing the larger larval herring in the spring and summer. When larvae were captured, they were entangled in the leading meshes of the trawl with only a few reaching the cod end liner.

Very small herring larvae (< 9 mm standard length) were present in October and November. (Fig. 7). Recruitment of these small larvae ended in December when both the range and mean length increased considerably. From October through May there was a consistent increase in length. In the fall to early winter months, smaller larvae were captured in the Sheepscot than in the other areas. Most of the larvae (1,530) were captured in the fall with a surface meter-net tow; the remainder (188) were captured during the spring when otter trawling.

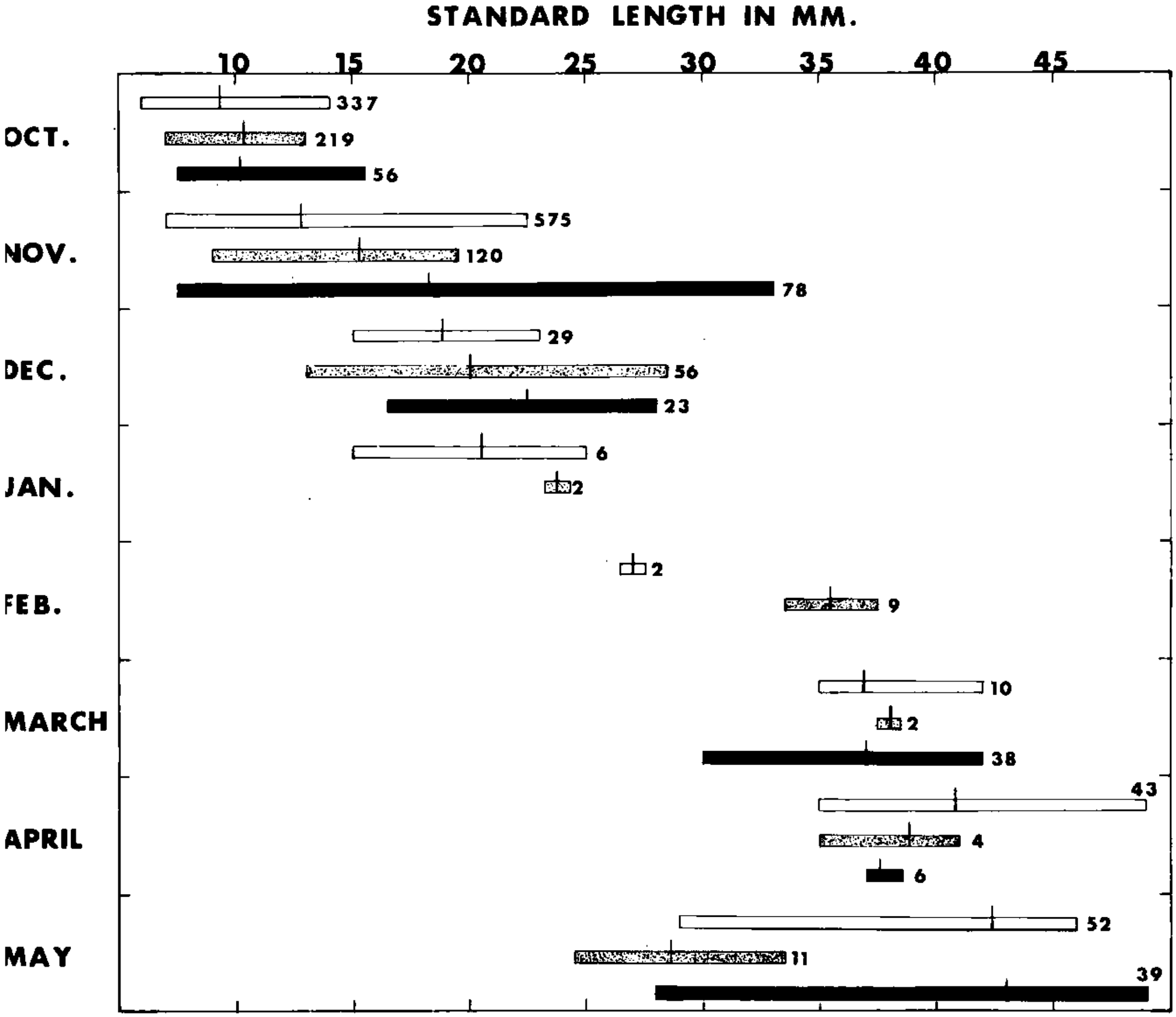


Fig. 7. Monthly average length (vertical line) and range (bars) of larval herring captured in meter net and otter trawl tows. The light, stipled, and dark bars represent the Sheepscot, Boothbay, and Damariscotta areas, respectively. The number of fish measured is given to the reader's right for each bar.

In contrast to the fall distribution of herring, larvae of other fishes were caught in largest numbers during the spring and summer. Monthly catches of other larvae were generally highest in the Damariscotta area and lowest in the Sheepscot; an extensive period of low catches occurred between October and February. The more abundant species during the spring months were: *Ammodytes americanus*, *Myxocephalus scorpius*, and *Pholis gunnellus;* and during the summer months: *Ulvaria subbifurcata*, *Enchelyopus cimbrius*, and *Cyclopterus lumpus*. The numbers, and mean standard lengths of larvae other than herring are given in Table 2. Unlike herring larvae, some species showed no consistent increase in mean length.

The seasonal occurrence of other juvenile and adult fishes in the otter trawl catches is shown in Fig. 8. Although there is some variation from month to month, peaks in relative abundance appeared in the fall and spring, with lows in the summer and winter.

TABLE 2. NUMBER AND MEAN LENGTH OF FISH LARVAE, OTHER THAN HERRING, CAPTURED IN THE SHEEPSCOT-BOOTHBAY-DAMARISCOTTA REGION OF MAINE, 1961-62. (EELS, *ANGUILLA ROSTRATA*, WERE IN THE ELVER DEVELOPMENTAL STAGE.)

	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY
Cyclopterus lumpus	16/6.7	24/4.7	47/5.3	48/6.3	12/10.2	3/9.0		1/5.9	62/6.3	179/7.2	151/11.6	75/7.5
Ulvaria subbifurcata	18/7.9	826/7.3	861/8.7	378/8.8	36/7.9	4/11.8					6/7.0	1183/7.1
Gadus morhua	4/28.3											
Urophycis chuss	1/5.0	1/68.5	8/3.2	16/6.2	19/3.5	2/9.4						
Gasterosteus aculeatus	2/19.3	1/18.5	1/34.0			1/27.0						1/32.0
Enchelyopus cimbrius		1/42.5	53/4.4	143/4.2	208/3.5	1/23.5						
Syngnathus fuscus			9/16.7	1/18.5								
Scophthalmus aquosus			9/3.1	5/3.9	2/3.5							
Merluccius bilinearis			29/3.2	3/3.2								
Glyptocephalus cynoglossus			4/3.2	1/3.5	5/6.7							
Sebastes marinus				5/38.0								
Tautogolabrus adspersus			52/4.4	38/4.6	9/3.3							
Scomber species			5/3.3									
Pollachius virens							1/143.5					
Pholis gunnellus								19/11.9	426/10.2	4150/13.4	775/12.6	62/13.1
Gadus or Pollachius species									9/24.9	17/22.8	39/25.7	95/25.1
Lumpenus lumpretaeformis								6/17.8	16/18.2	16/18.6	6/18.8	15/18.4
Myoxocephalus scorpius								30/7.5	299/7.6	942/9.9	334/12.2	92/15.1
Cryptacanthodes maculatus									23/18.9	151/18.7	99/20.1	6/30.0
Anarhichas lupus									1/5.0	1/8.5		
Ammodytes americanus								1/6.5	2/5.4	115/5.4	200/18.3	196/21.2
Anguilla rostrata									1/55.0	3/56.8	9/57.6	3/59.3
Aspidophoroides monopterygius											5/9.6	30/12.2
Myoxocephalus octodecemspinosus											51/6.4	32/6.8
Melanogrammus aeglefinus											6/5.9	
Limanda ferruginea												7/5.2

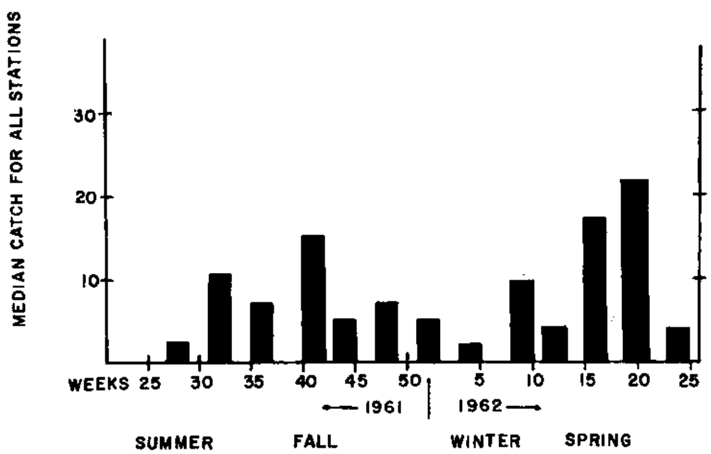


Fig. 8. Seasonal variation in the number (median) of fishes other than herring captured by 20-min otter trawl tows.

DISCUSSION

Distribution of larval herring

In the Gulf of Maine, the largest spawning grounds are found on the northern edge of Georges Bank and off the Nova Scotia coast (Tibbo *et al.*, 1958). Non-tidal drift suggested that some newly hatched larvae, determined by size (< 9 mm), were carried northward from Georges Bank to the Nova Scotia coast, but the majority were carried southward. Few inshore spawnings have been reported and confirmed and there is no evidence of large spawning grounds along the Maine coast.

The presence of very small herring larvae in the Sheepscot-Boothbay-Damariscotta region suggested that their source was local. Recent catches of herring with gonads in a running state and catches of yolk-sac larvae were recorded from the vicinity of station 11 during the fall of 1963. Regardless of their source, larvae in their early planktonic stage would have obtained some assistance from currents to introduce or maintain themselves in the bays and estuaries. This assistance could be in the form of both non-tidal and tidal currents. The presence of the greatest numbers of larvae in the Sheepscot area suggested that transport by non-tidal currents was important. The Sheepscot estuary is influenced by freshwater discharge while the Boothbay area has no major streams entering it. The Damariscotta area has a smaller stream entering it and its effects are masked by considerable turbulence. In the Sheepscot estuary the discharge of river water was lowest in the fall and vertical sigma-t gradients were largely a function of thermal stratification rather than changes in salinity. Vertical density gradients in the Sheepscot were not steep and a two layered estuary would be poorly developed for conveying larvae inward along the bottom. In contrast, a lateral flow would be accentuated by water of lower salinity entering from the Kennebec River. This water enters the Sheepscot from Goose Rock Passage and flows southward along the western side of the estuary. Tidal currents could transport larvae in water eddying behind promontories (Stommel, 1953) and other rugged features common to the region. Stranding of larvae in an eddy would make it possible for advancement upstream on the next flood tide.

The distribution of other larvae complements that of herring. Many of these larvae were obtained in a planktonic stage and presumably were susceptible to transport by currents, particularly in the spring when river discharge was at its height. Their distribution could be associated with their behavioral attributes or to the location of spawning grounds; little is known locally of either aspect of their biology.

Avoidance of net and migration

Catches of herring larvae decreased with an increase in larval size. Bridger (1956) found that more clupeid larvae were taken with a 1-m silk tow net and other nets at night. He suggested that the lower catches of larvae by daylight were related to avoidance of the net by larger larvae and discounted the possible effects of shoaling, dispersal, and congregation near the bottom by day. Colton (1961) found that escapement and diurnal migrations influenced the catches of larval herring in the Gulf of Maine. His tows were limited to 10 m and were made with a 1-m plankton net. The seasonal abundance of herring larvae in this study was similar to that obtained in the Gulf of Maine and the Bay of Fundy (Tibbo *et al.*, 1958; Colton *et al.*, 1961). That is, 1) larvae were captured in greatest numbers in the fall, 2) catches were subsequently small during the winter months, 3) recruitment of newly hatched larvae was completed by the winter months. While the sharp drop in larval catches was probably related to escapement as indicated by Colton *et al.* (1961) the movement of fish from the vicinity of the sampling stations was also suspect. Recently, explorations were made upstream of station 1 in the Sheepscot, during the winter and early spring, and a concentration of larvae was found. Their size (30 - 35 mm) agreed with the growth expected since the fall. Apparently, herring larvae overwinter in the Sheepscot. To test this hypothesis this upstream area is being sampled routinely with high speed sampling gear and samples are taken from the surface to the bottom.

CONCLUSIONS

This study provided the first evidence that herring larvae utilize the estuarine environment along the Maine coast. The distribution of herring larvae differed in the three adjacent embayments studied. More herring were captured in the Sheepscot area than the Boothbay and Damariscotta areas. Differences in the seasonal distribution of herring larvae were marked, with the greatest abundance occurring in the fall. The seasonal and areal distribution of other fish larvae was inverse to that of herring larvae. Eastward from the Sheepscot to the Boothbay and Damariscotta areas average salinities, surface temperatures, and surface standing crops of zooplankton increased.

REFERENCES

BHATTACHARYYA, R.N. 1957. The food and feeding habits of larval and post larval herring in the Northern Sea. *Mar. Res.*, no. 3, 16 p.

BRIDGER, J.P. 1956. On day and night variation in catches of fish larvae. *J. Cons.*, 22 (1): 42-51.

COLTON, J.B., Jr., K.A. HONEY and R.F. TEMPLE. 1961. The effectiveness of sampling methods to study the distribution of larval herring in the Gulf of Maine. *J. Cons.*, 26 (2): 180-190.

HOPKINS, THOMAS L. 1963. The variation in the catch of plankton nets in a system of estuaries. *J. Mar. Res.*, 21 (1): 39-47.

SMAYDA, THEODORE J. 1957. Phytoplankton studies in lower Narragansett Bay. *J. Limnol., Oceanogr.*, 11 (4): 342-359.

SNEDECOR, GEORGE W. 1948. *Statistical Methods*. Fourth Edition, Ames, Iowa, Iowa State College Press, 485 p.

STICKNEY, ALDEN P. 1959. Ecology of the Sheepscot River estuary. *Spec. sci. Rep. U.S. Fish Wildl. Serv. - Fish.*, No. 309, p. 1-21.

STOMMEL, HENRY. 1953. The role of density currents in estuaries. *Proceedings Minnesota International Hydraulics Convention*, 1-5 September, 1953. (Contribution no. 655, Woods Hole Oceanographic Institution, p. 305-312).

TIBBO, S.N., J.E. HENRI LEGARE, LESLIE W. SCATTERGOOD and R.F. TEMPLE. 1958. On the occurrence and distribution of larval herring (*Clupea harengus* L.) in the Bay of Fundy and the Gulf of Maine. *J. Fish. Res. Bd. Canada*, 15 (6): 1451-1469.

U.S. GEOLOGICAL SURVEY. 1962. Surface water records of Maine 1961. District Engineer, Surface Water Branch, *U.S. Geological Survey*, Augusta, Maine, 70 p.

1962*a*. Sheepscot River discharge, October 1961 to September 1962 (Provisional). District Engineer, Surface Water Branch, *U.S. Geological Survey*, Augusta, Maine, Mimeographed, 1 p.

E-8

DISTRIBUTION OF WINTERING HERRING IN THE SOUTHERN PART OF THE NORWEGIAN SEA ACCORDING TO TEMPERATURE CONDITIONS

By

L.R. Shmarina[1]

ABSTRACT

This contribution deals with the influence of the temperature conditions of the southern part of the Norwegian Sea on the distribution of herring concentrations in the wintering and spawning periods.

The main features of mature herring distribution in the Norwegian Sea while wintering are of a regular character. Due to the hydrological conditions, however, both the distribution of herring and the time and migration routes display certain divergences. In the present paper an attempt is made to demonstrate the influence of winter temperature conditions according to the data obtained in 1958-63.

In November - January great concentrations of pre-spawning herring form in the southern part of the Norwegian Sea, north of the Faroes. From January, herring move then to the spawning grounds located along the western coast of Norway.

The changes in the hydrological conditions in this above-mentioned region are defined by interaction of the cold East-Icelandic and the warm Atlantic waters and have a great influence on the movements of herring.

To show the temperature conditions of the wintering area, charts of surface temperature are compiled for the second half of November and December for the years 1958-62. Also schemes of vertical temperature distribution in the western part of the section along 65°46'N are drawn, with the locations of herring concentrations indicated. For estimation of temperature conditions in the areas of pre-spawning migrations and on spawning grounds, charts of surface temperatures for January, February and March, 1959-63, are constructed where the boundaries of herring distribution are traced (Fig. 1-6). Mean temperatures on standard sections in the southern part of Norwegian Sea are also calculated for these same years.

The month of November is the beginning of the wintering period for herring. In December commercial concentrations of herring are distributed over the small area along the western edge of the East-Icelandic Current. In January pre-spawning herring concentrations start moving eastward to the west coast of Norway. February is characterized by the ending of the wintering period for the pre-spawning herring concentrations and they leave the cold waters for the upper layers of the warm Norwegian Current and move to the spawning grounds.

WINTER SEASON OF 1958-59

In November-December 1958 at the section along 65°45'N "the dome" of the cold East-Icelandic Current with temperature 2° to 3°C was well developed and reached to the 50 m layer (Fig. 1a,b). Warm waters of the Norwegian Current, however, penetrated on the surface far out to the north-west. Herring concentrations kept at the western edge of the East-Icelandic Current in the 0-50 m layer at the temperature of 3° to 5°C. In the period from November to January considerable displacement of the wedge of the East-Icelandic Current to the south-east took place. In January at the section along 63°00'N, mean temperature in the 0-50 and 0-200 m layers of this Current was about 6.1° to

---

[1] Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, USSR.

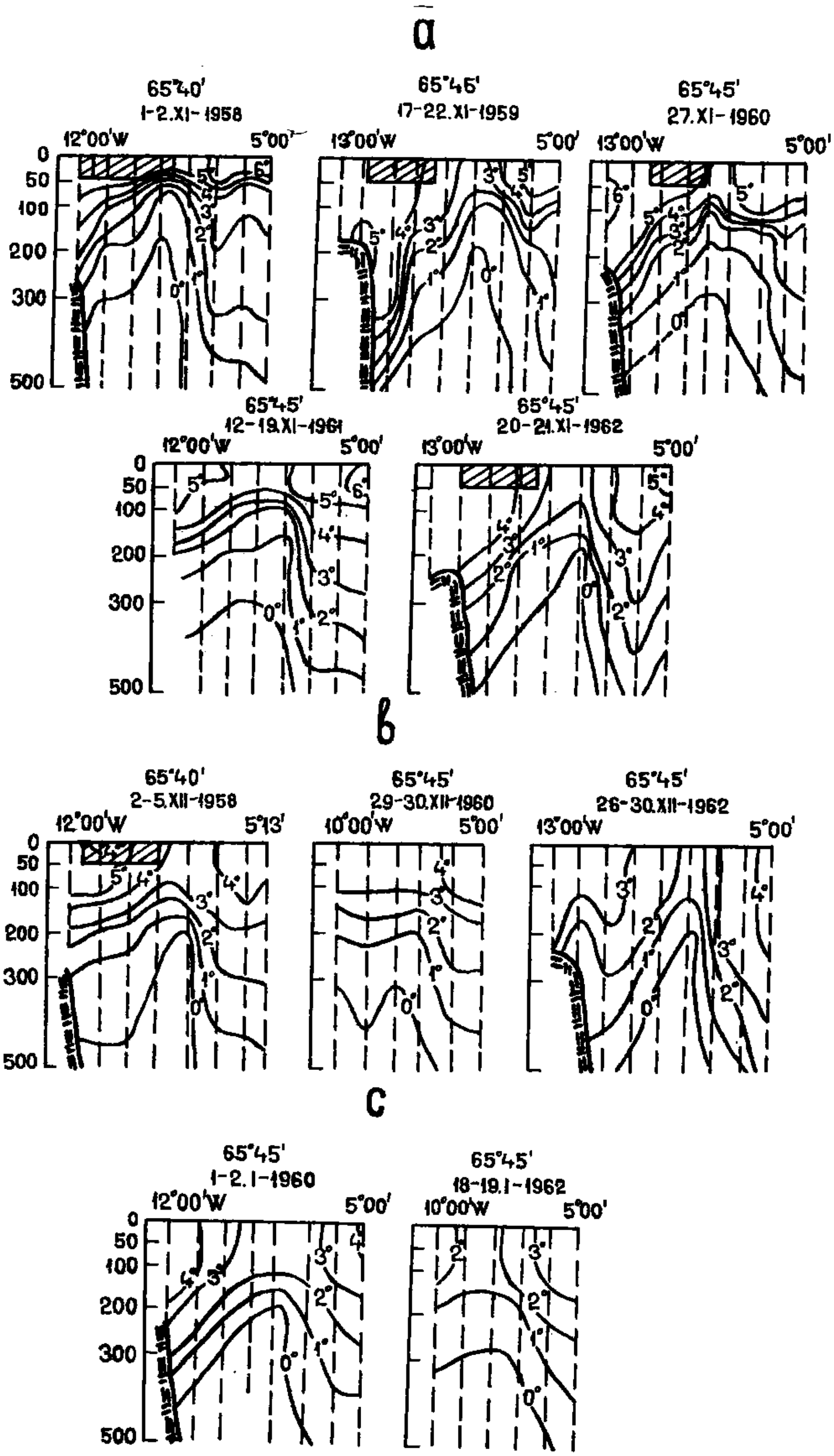


Fig. 1. Schemes of vertical temperature distribution and the limits of herring concentrations (shaded area) in the western part of the section along 65°45'N in winter.

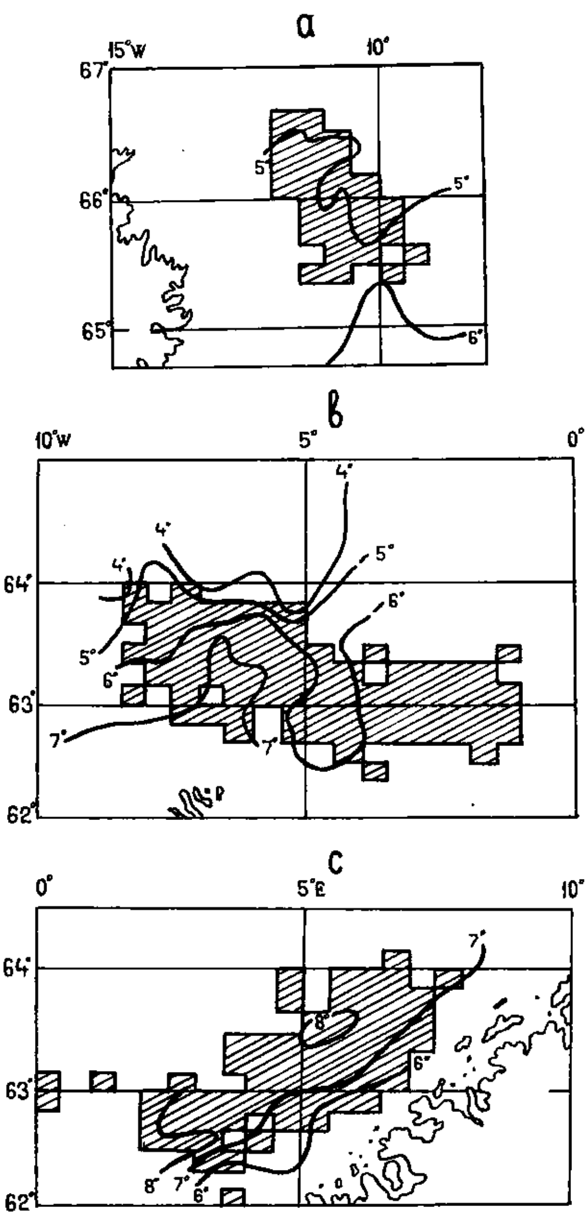


Fig. 2. Distribution of temperatures of the sea surface and the area of herring concentrations (shaded) in winter: 1958-1959.

6.4°C. Commercial herring concentrations were distributed northeast of the Faroes (Fig. 2b).

In January and at the beginning of February pre-spawning herring concentrations moved in the direction of the Norwegian Shallow. In early February, the water temperatures at the sections along 63°00'N in the Norwegian Current were homogeneous at 7.4°C.

In the waters of the continental shelf the highest mean temperature (7.73°C) for the period in question was observed. Herring came to spawn at the beginning of February and their concentrations were located near the coast (Fig. 2c).

WINTER SEASON OF 1959-60

Since the end of 1959 increased influx of the Atlantic waters into the Norwegian Sea was observed. In November 1959, however, "the dome" of the cold waters of the East-Icelandic Current at the section along 65°45'N was still well developed and its waters (2° to 3°C) reached the surface (Fig. 1a).

Herring concentrations were distributed along the western edge of the East-Icelandic Current about 20-30 miles farther to the south than in 1958 (Fig. 3a).

From November 1959 to January 1960, due to the increased inflow of the Atlantic waters, the wedge of the East-Icelandic Current displaced to the west, mean temperature at the section along 65°45'N in the 0-50 m layer having decreased by 0.9°C. Commercial herring concentrations were located over a small area north-west of the Faroes (Fig. 3b). Spawning migrations of the winter concentrations of herring to the Norwegian Coast took place in February and was a little bit prolonged (Fig. 3c). In February 1960 mean temperature in the 0-50 and 0-200 m layers at the section along 63°N in the Norwegian Current was 0.4° to 0.5°C higher than in the same period of 1959. The bulk of herring came to spawn in the beginning of February, but part of the concentrations kept north-east of the Faroes (Fig. 3c).

WINTER SEASON OF 1960-61

In November of 1960 in the waters of the East-Icelandic Current at the section along 65°45'N the highest mean water temperatures were registered, which in the 0-50 and 0-200 m layers were 5.37°C and 3.83°C respectively.

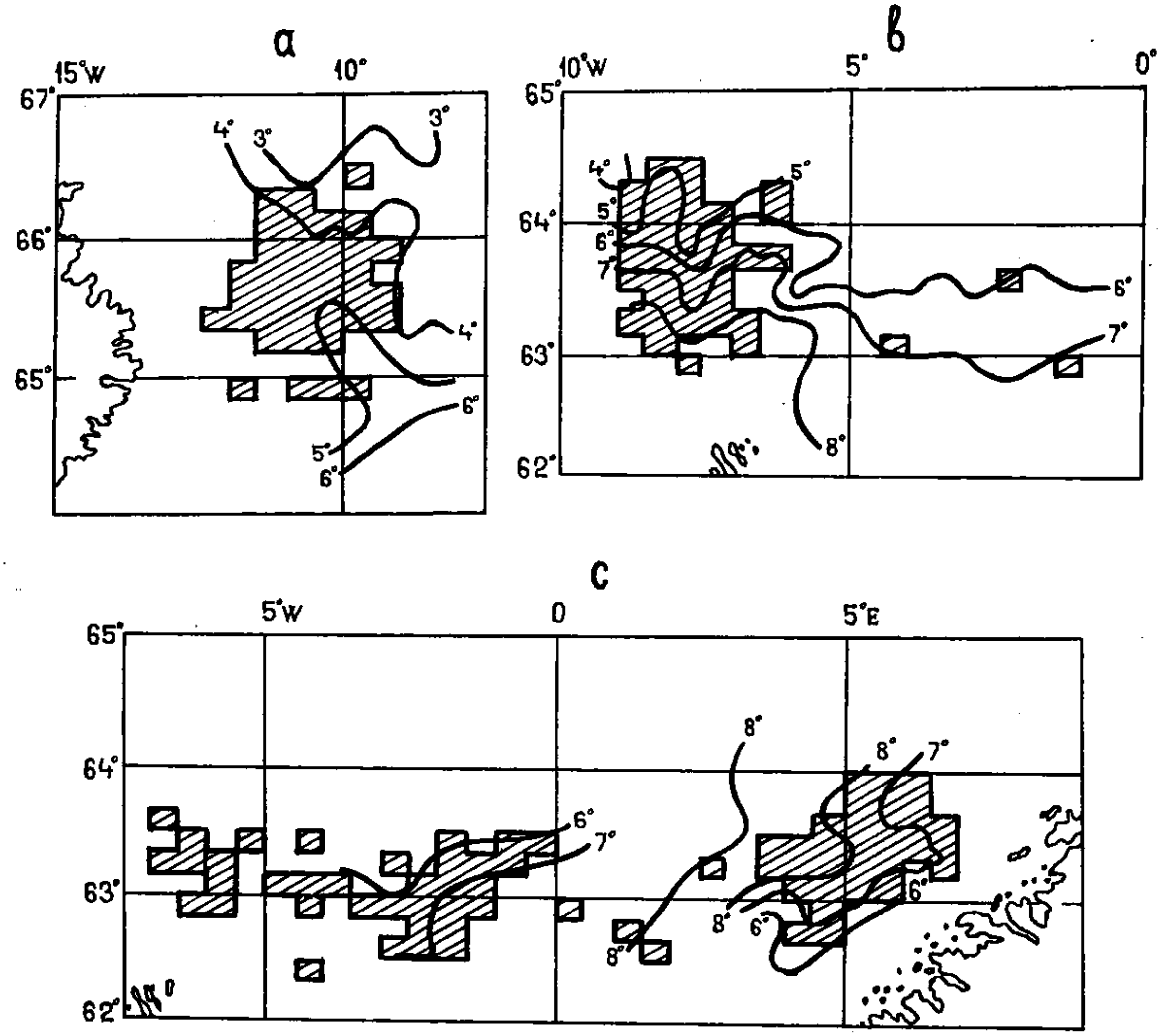


Fig. 3. Distribution of temperatures of the sea surface and the area of herring concentrations (shaded) in winter: 1959-1960.

"The dome" of cold waters was developed poorly (Fig. 1a). Warm waters of the Norwegian Current spread far out to the north-west. During December no appreciable changes in temperature distribution in the area of the wedge of the East-Icelandic Current took place.

In the beginning of January 1961, in the southern part of the Norwegian Sea (section along 63°00'N) the highest water temperature for the whole period examined was observed in the East-Icelandic and Norwegian Currents. In the East-Icelandic Current mean temperatures at the above-mentioned section were 7.1° to 7.3°C in the 0-50 and 0-200 m layers, whereas in the same layers of the Norwegian Current 8.2° to 8.3°C. Commercial herring concentrations were distributed farther to the north-west than in 1959-60 (Fig. 4b).

At the beginning of February 1961, the mean temperature in the 0-50 and 0-200 m layers of the Norwegian Current at the section along 63°00'N decreased by 0.5° to 0.6°C in comparison with November 1960, but was somewhat higher than in February 1959, while temperature on the continental shallow was 0.9°C lower. Part of the herring concentrations approached the Norwegian coast for spawning in the early February and was distributed farther to the south-west in comparison with the same periods of 1959 and 1960. Main concentrations of herring delayed in the area north of the Faroes and came to spawn later (Fig. 4c).

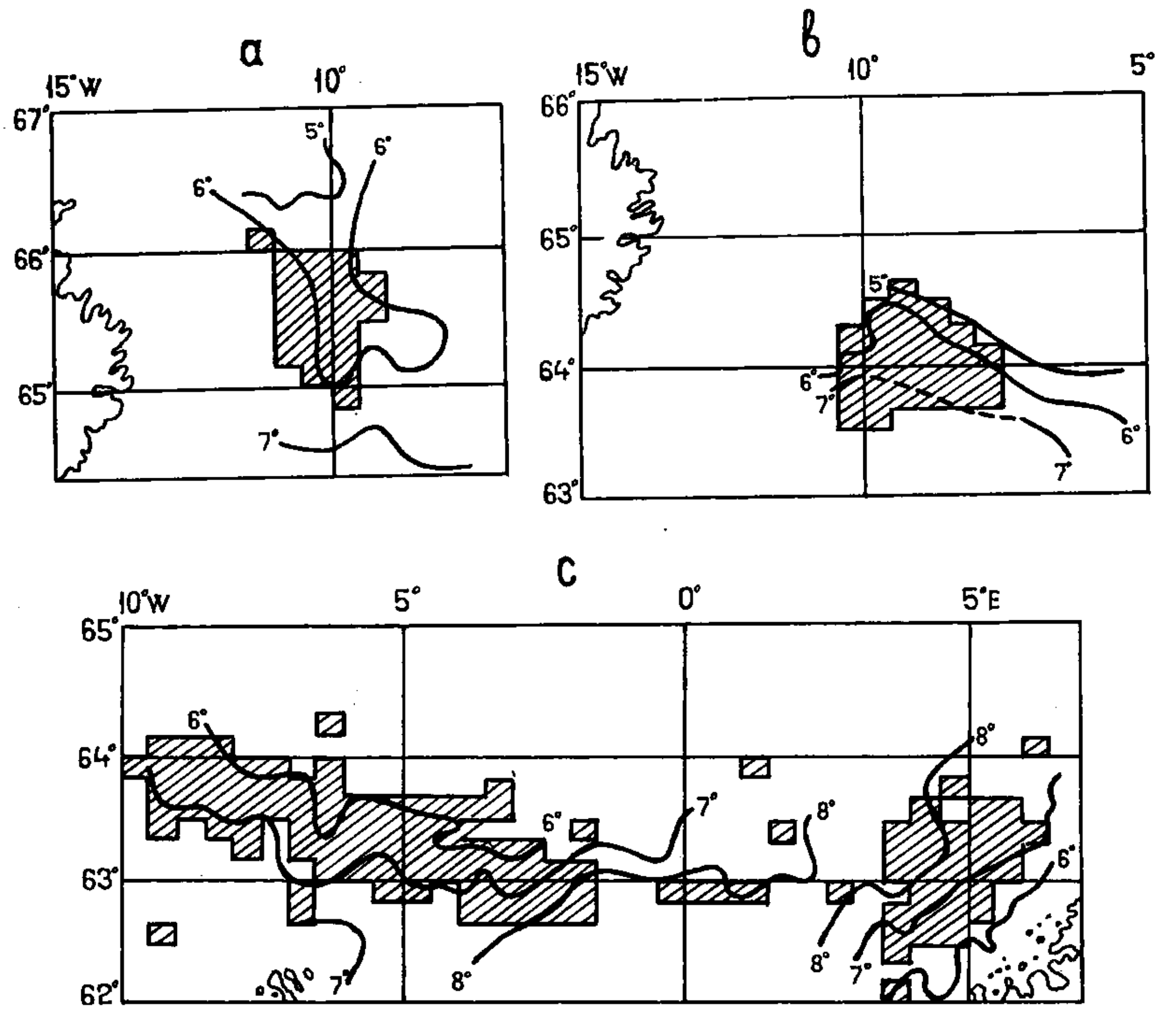


Fig. 4. Distribution of temperatures of the sea surface and the area of herring concentrations (shaded) in winter: 1960-1961.

WINTER SEASON OF 1961-62

In November 1961, in the southern part of the Sea, relatively great warming of the Norwegian Current was observed. At the section along 65°45'N "the dome" of the cold East-Icelandic Current was poorly developed (Fig. 1a). Mean temperature in this Current in the 0-200 m layer was at the level of the warm year of 1960. Herring concentrations were located in the north-western part of the area (Fig. 5a).

In November-January in the area of the wedge of the East-Icelandic Current considerable decrease in temperature took place. In January 1962 at the section along 65°45'N the waters of the East-Icelandic Current, the area of mixed waters, the western branch and the waters of the continental shallow were much colder than in 1959 and 1960. In the East-Icelandic Current mean water temperature in the 0-200 m layer decreased by 1.5°C in comparison with that in November 1961. In the period from November to January the southern boundary of herring concentrations displaced 60 miles to the south. In February, herring concentrations spread along the western edge of the cold current (Fig. 5d) and moved very slowly eastwards.

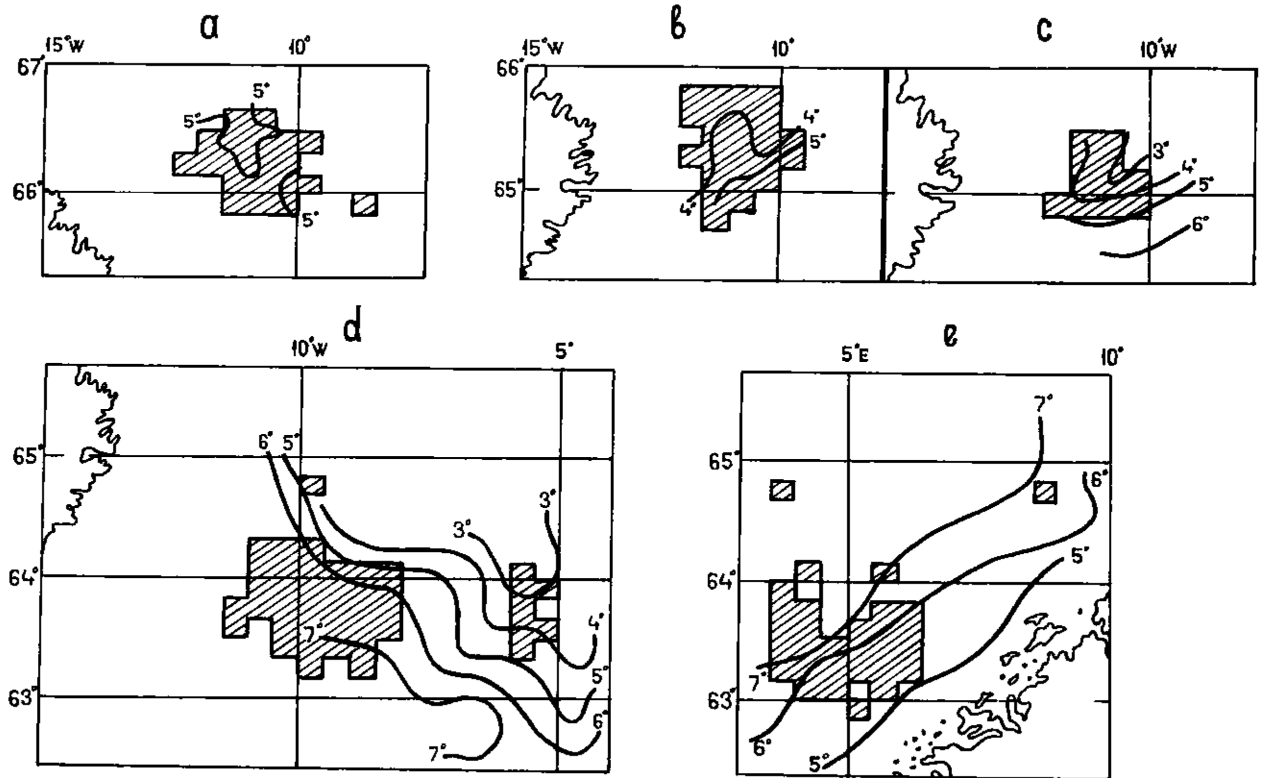


Fig. 5. Distribution of temperatures of the sea surface and the area of herring concentrations (shaded) in winter: 1961-1962.

In March of 1962 in the southern part of the Norwegian Sea (section along 63°00'N) mean temperature of the waters of the Norwegian Current in the 0-50 and 0-200 m layers was 0.9° to 0.6°C lower than that in 1959. Herring came to spawn to the western coast of Norway at the beginning of March, *i.e.* a month later than in 1959 (Fig. 5e).

WINTER SEASON OF 1962-63

In November - December of 1962, the cold waters of the East-Icelandic Current at the section along 65°45'N extended to the surface (Fig. 1 a,b); mean temperature in the 0-50 m layer was the lowest (3.77°C). Commercial concentrations of herring were displaced to a considerable extent to the south-east.

In December - January further cooling of the East-Icelandic and the Norwegian Current took place. In the middle of January 1963, mean temperature of the East-Icelandic Current (section along 63° 00'N) in the 0-50 and 0-200 m layers was at the level of the same period of 1962. In the 0-50 m layer the waters of the Norwegian Current were 0.3°C colder and those of the continental shallow more than 1°C colder. Herring concentrations were observed north-west of the Faroes (Fig. 6c).

In February 1963, in the waters of the Norwegian Current and those of the continental shallow minimum temperature was observed for the whole period considered. Herring concentrations were distributed in a large area from the Faroes along the edges of the East-Icelandic Current and in the warm waters of the Norwegian Current (Fig. 6d).

In March, in the waters of the Norwegian Current and the continental shallow temperature conditions analogous to those in March of 1962 were registered. As in the previous year, herring came to the Norwegian coastal shallows in the beginning of March (Fig. 6e).

For the characteristics of year-to-year displacement in the position of the wedge of the East-Icelandic Current in winter, a chart of the position of 5°C isotherm on the sea surface for the second part of November 1959-62 was drawn, where the boundaries of herring distribution were marked (Fig. 7).

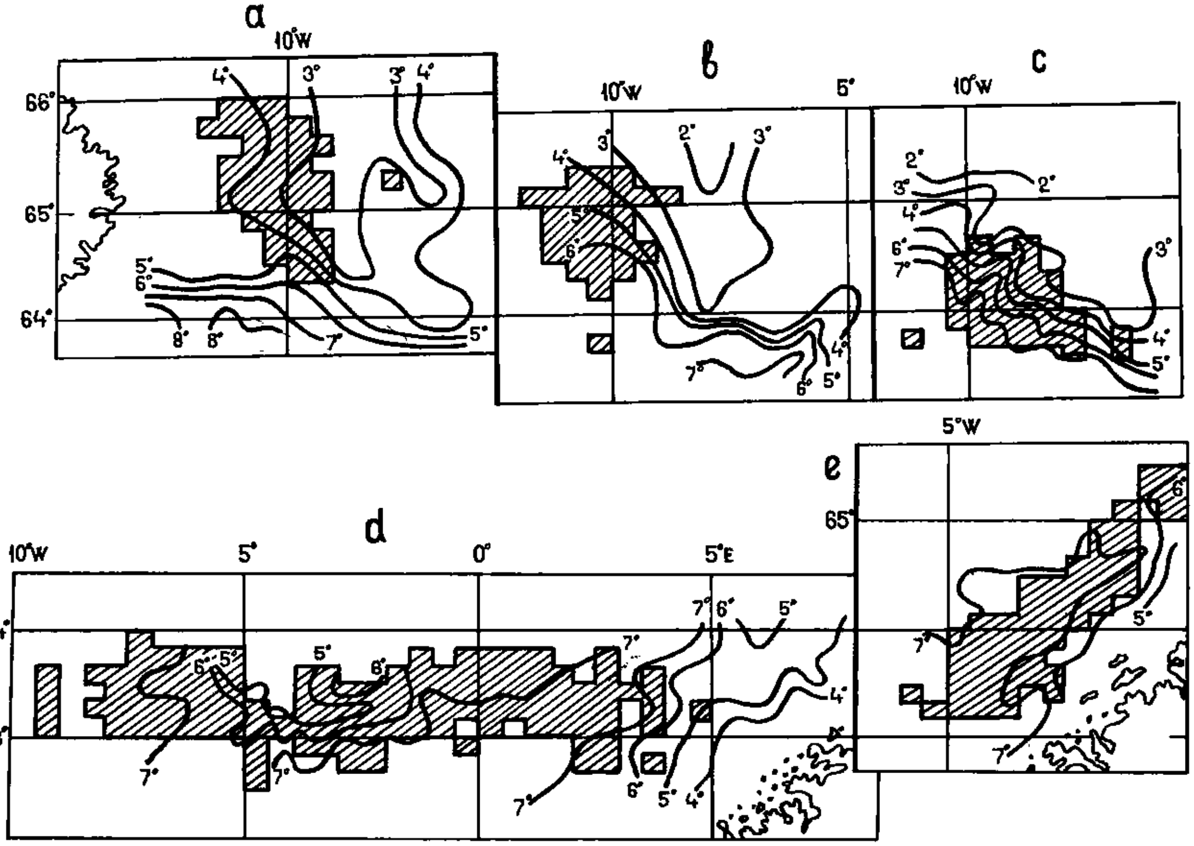


Fig. 6. Distribution of temperatures of the sea surface and the area of herring concentrations (shaded) in winter: 1962-1963.

As is evident from the chart, in November 1961, when in the waters of the East-Icelandic Current high temperatures were observed, the 5°C isotherm was in the most north-western position. In November 1962, considerable decrease in temperature in the surface layers of the Current was registered; the waters of the Current being wide spread on the sea surface. The 5°C isotherm was 120-130 miles farther south-east than in the previous years. In 1959 and 1960 the isotherm took the central position.

Thus, the distribution of herring concentrations in the southern part of the Norwegian Sea in winter (November-December) depends to a considerable degree on the temperature conditions in the wedge of the East-Icelandic Current. For example, in November - December 1961 when in the waters of the East-Icelandic Current high temperatures were observed, commercial concentrations of herring were displaced far to the north-west. In 1962, low heat content of the waters of this current was registered and herring concentrations were located at the most south-eastern position. In November-December 1959, 1960 (the years with moderate thermal conditions) the position of herring concentrations was intermediate (Fig. 7).

The water temperatures in the southern part of the Norwegian Sea in January - February 1959, 1960 being higher, herring came to spawn to the western coast of Norway earlier, whereas in the same period of 1961, 1962 and 1963 when the heat content of the waters of the Norwegian Current and those of the continental shallow was low, the arrivals of pre-spawning herring were late and their concentrations spread more to the west and south-west in comparison with the position they had in 1959 and 1960 (Fig. 8).

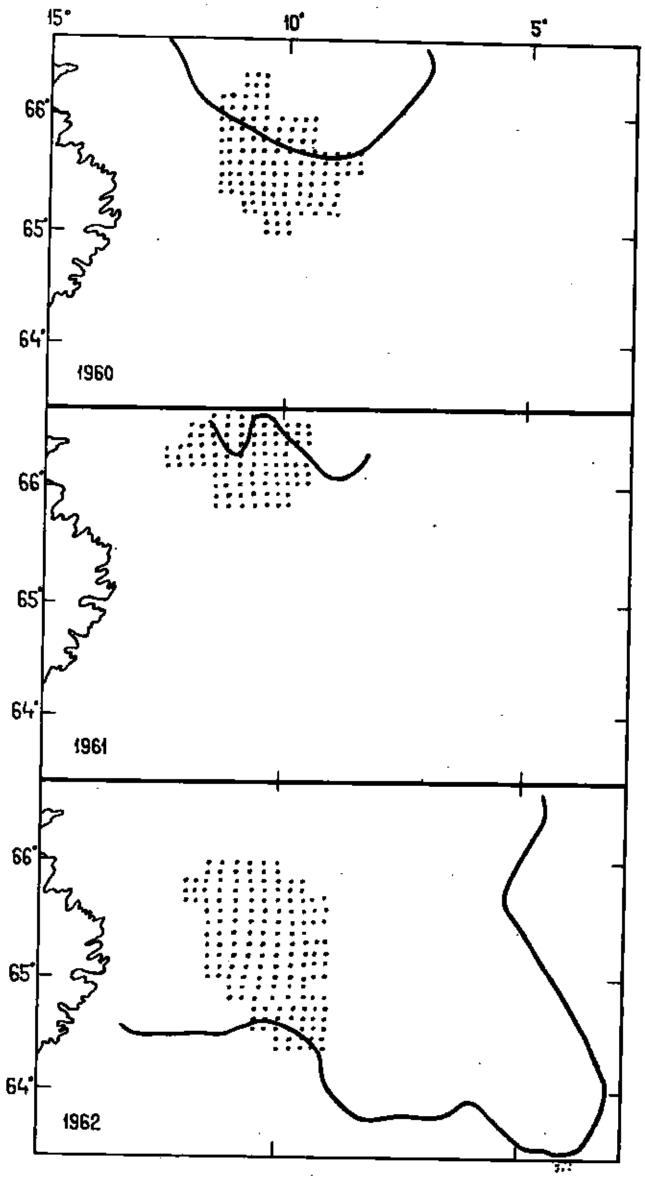


Fig. 7. Position of 5°C isotherm on the sea surface and boundaries of herring distribution in the wintering period, 1960-1962.

More north-western and south-eastern positions of herring concentrations in November - December in the wintering area are in good consent with the analogous displacement in the spawning area in February, which is due, apparently, to the temperature regime of the waters of the Norwegian and the East-Icelandic Currents in the southern part of the Sea in this period of time.

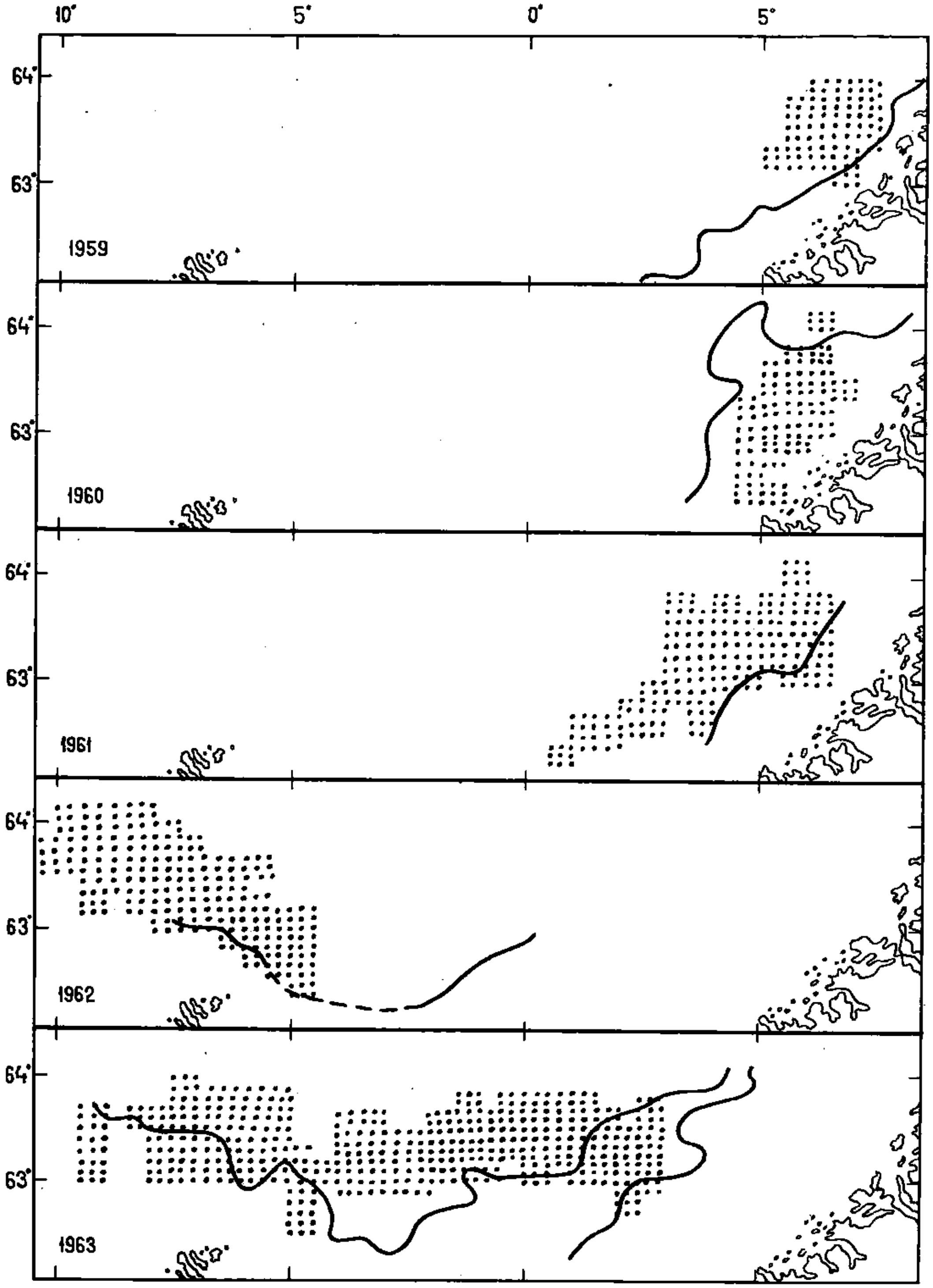


Fig. 8. Position of 7°C isotherm on the sea surface and the boundaries of herring distributions during the spawning period, 1959-1963.