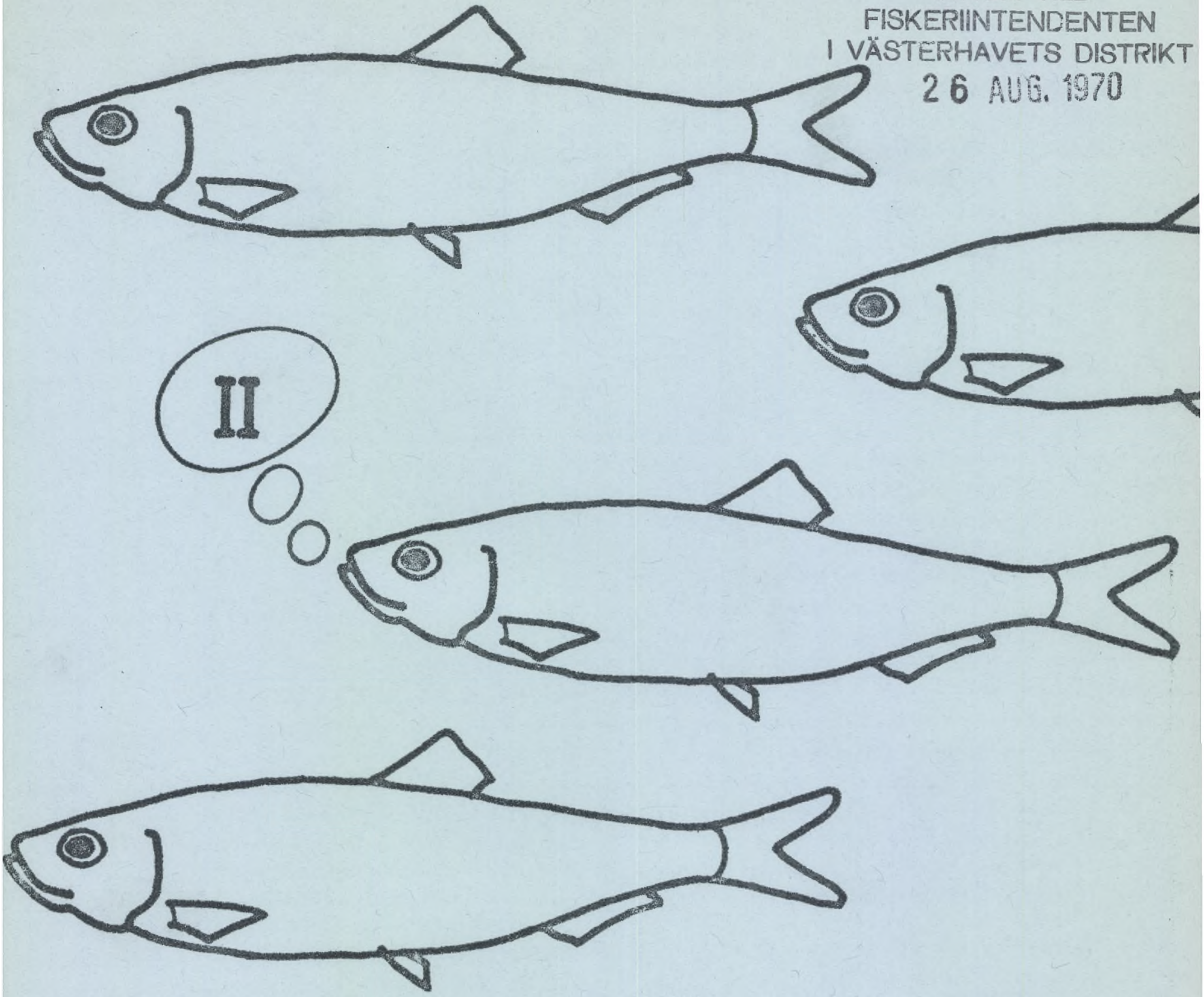
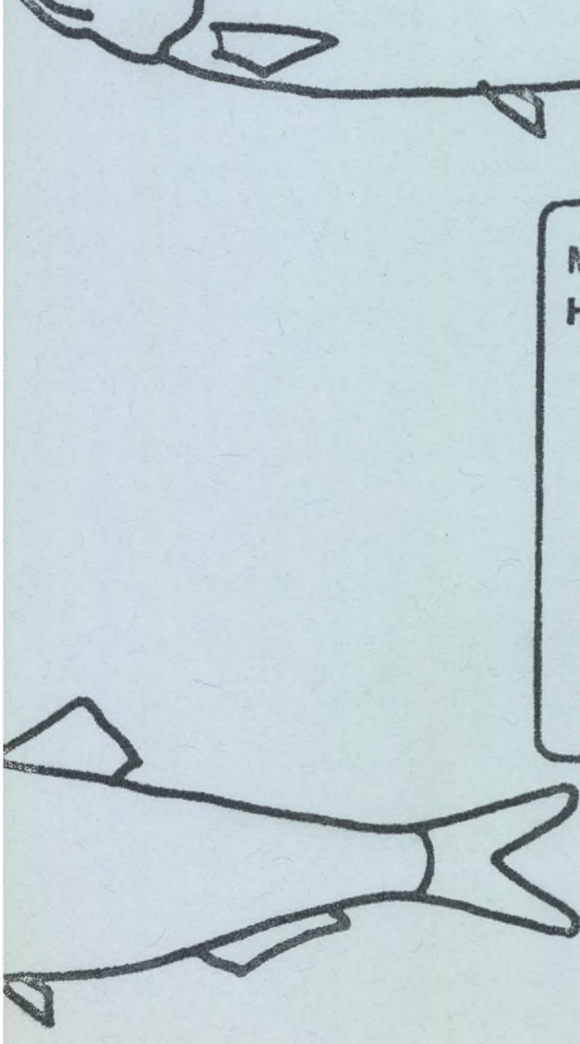


MEDDELANDE från HAVSFISKELABORATORIET • LYSEKIL nr 88

SPRAT SYMPOSIUM, LYSEKIL 1968

Papers (Second Part)

August, 1970



Index

INTRODUCTION

This is the second and last part of papers from the Sprat Symposium 1968. Due to unforeseen circumstances publishing has been delayed. It may therefore be of value to present a list of some of the papers on the sprat which have been published since 1968:

ARBAULT, S. & N. BOUTIN, 1968: Oeufs et larves de poissons téléostéens dans le Golf de Gascogne eu 1965 et 1966. - ICES, C.M. 1968, L:3, 7 pp+pls.

ARBAULT, S. & N. LACROIX, 1968: Oeufs et larves de clupéidés et d'engraulidés dans le Golf de Gascogne et sur le platean Celtique. - ICES, C.M. 1969/J:8, 4pp+pls.

HEMPEL, G. & W. NELLEN, 1969: Ichthyoneuston in the North Sea and the Baltic. - ICES, C.M. 1969/L:23, 1-14.

JOHNSON, P.O., 1970: The Wash Fishery. - Fish. Inv. Ser. II, Vol. 26(4): 1-77+tabs.

LINDQUIST, ARMIN, 1968: Meristic and morphometric characters, year classes and 'races' of the sprat (Sprattus sprattus). - Inst.Mar.Res. Lysekil, Ser. Biol., Rep. No. 17: 1-26

" 1970: Zur Verbreitung der Fischeier und Fischlarven im Skagerak in den Monaten Mai und Juni. - Inst.Mar.Res., Lysekil, Ser. Biol., Rep. No. 19; 1-82

WRZESIŃSKI, OLGIERD, 1969: Biologiczna ocena stada szprota w basenach gdańskim i gotlandzkim w latach 1967-68. - MIR Studia i materiały, Ser. B., Nr. 19: 17-47

ZAVODNIK, NEVENKA & DUŠAN, 1969: Studies on the life History of Adriatic Sprat. - FAO (GFCM) Studies and Rev. 40: 1-26

Armin Lindquist
August, 1970

DISCUSSION AND GENERAL CONCLUSIONS OF THE SPRAT SYMPOSIUM, LYSEKIL, JANUARY 1968

22 January   Sprat stocks and their separation

Meristic characters

(I) VS

There was some evidence from within the catch of a seine net, which was considered to be a single shoal, that the larger fish had more vertebrae than the smaller. Both 0-group and I-group sprats showed similar results. Catches taken from the same area within short periods showed considerable variation in mean vertebral sum. This might imply that the between-shoal variation was great and that taking a large area or many samples other relations between VS and total length might occur. (Dannevig)

No simple relation between VS and length could be demonstrated in Swedish material. Indeed over many year-classes there was a very low variance about the mean of the population which tended to be rather constant. No differences could be shown between the mean VS values for the Skagerak and northern Baltic fish. (Lindquist)

Using VS combined with K_2 it could be shown that grouping occurred in the plots from different areas. It was too simple to think of separations on only one character, a multivariate analysis was needed. (Jensen)

In the North Sea there is a great range in time over which sprats spawn and hence a great range in temperature. If vertebral number is dependent on temperature then one would expect a wide range of values. (Johnson)

Though Adriatic sprats could be separated into two populations on the numbers of scutellae and head length, there was no difference in mean vertebral number. (Zavodnik)

It appeared that mean vertebral number, as used at present, afforded little information on stock separation.

(II) Gill rakers

In the Swedish sprat there was a significant correlation between the number of gill rakers and total length. Some year-classes differed from others in mean gill raker count though the slope of the regressions were the same.

In 1960 during the main spawning season in May/June the weather was exceptionally calm and warm and the year-class spawned was found to have low gill raker counts. (Lindquist)

The question was raised as to whether the variance about the mean gill raker number also changed between year-classes. If the length of the spawning season was related to water temperature then this might increase the variability of the gill raker count. However, no information was available on these points.

(III) Keeled scales (K_2)

There was no relation between K_2 and total length in the Swedish sprats. Also there did not appear to be any variation in mean K_2 between year-classes. (Lindquist)

In the Adriatic the total number of ventral scales, not just K_2, appeared to afford a differentiation between a more Italian coastal stock and a Yugoslavian coastal stock. (Zavodnik)

(IV) Other characters

Head length expressed as a percentage of body length has been used in the Adriatic sprat. The populations differ with values of 18 per cent and 20 per cent. (Zavodnik)

No differences were observed in this character between Skagerak and Baltic fish. (Lindquist)

There was great variability in otolith characters in North Sea fish, particulary between the fish of the estuaries and the open seas. With the long length of the spawning time this might be expected but would result in a limitation of the use of this character. (Rauck, Johnson)

23 January Naevdal paper on serology

Some further points which arose in discussion were:

The variability in blood types within the sprat occurred within the catch of a simple purse-seine set. It is believed that this represents the variability within a shoal.

There did not appear to be any ontogenetic changes in blood types with length. This contrasts with the situation in herring.

Distribution of the adult sprat during the year

The sprat over its distribution appears tolerant of a wide range of temperatures and salinities. Sprats had been observed in surface water temperatures varying from 20°C to -1.0°C. Low temperatures reduce catch in the following year in Limfjord. In the Baltic sub-zero or near-zero temperatures appear to affect the subsequent catches.

Again, with salinity there is a great range of tolerance from 2-3°/oo in the Finnish seas to 34°/oo or higher in the North Sea and Western Approaches.

Though a great range of t°and S°/oo is observed to which the fish is adapted, rapid changes in these parameters might be unacceptable or even lethal to the sprat. (Lindquist, Dannevig, Johnson, Boetius, Zavodnik, Jensen)

0-group sprat are not often seen along Swedish and Danish coasts. They are seldom taken in trawls. Off the English east coast they are commonly taken but there tends to be a vertical stratification of fish with size. Echo sounder records show a double layering, the smallest fish being near the surface and the larger ones deep. (Lindquist, Johnson)

In the Baltic the sprats are generally distributed near to the coast in the Bothnian Sea, in the Bay of Riga, and at depth in the Gotland Basin. Few fish occur on the Swedish east coast, but between the Skerries. The area of greatest abundance is between the Swedish coast and the Danish coast.

(Lindquist)

The northern boundary of the sprat on the Norwegian coast is at about Trondheim Fjord. The area of greatest abundance is however in Oslofjord. In Hardanger Fjord.the fish usually concentrate near river mouths. (Dannevig)

The southern boundary was reported as being Vigo in northern Spain. (Johnson)

The sprat occurs in the northern Adriatic as far as Dubrovnik in winter. It occurs in the Black Sea but not on the Turkish coast. The Adriatic sprat migrates towards the coast for spawning, in contrast to the northern sprat. It spawns after the breakdown of the thermocline in winter and ceases in April - again a contrast with the northern sprat. Peak spawning is in December when temperatures are about 13-14°C, and end when temperatures are 7-8°C. (Zavodnik)

Distribution within the water column

Both the Swedish and English fisheries are based on overwintering concentrations. In the case of the Swedish fishery the total catch does not reflect the stock size as the fishery is regulated by a price structure.

Outside the Skerries the fishery is by bottom and midwater trawl, but when the fish move inside purse seiners make the catches. The sprats occur in daytime within the warm water lens. These lenses occur in Gullmarfjord and Uddevalla Fjord, and while in December offshore temperature may be 7-8°C, within the Skerries bottom temperatures of $>$ 10 or 12°C are found. At night the fish rise towards the surface into the colder water; but when the water is very cold the fishermen have difficulty attracting sprats to lights.

This situation is in marked contrast to the Wash, where there is no vertical stratification. The fish appear to be topographically maintained in this shallow area irrespective of temperature or salinity.

In both these fisheries and also the Danish fisheries the sprat is not feeding. The diurnal vertical migration cannot then be associated with feeding and it was suggested that it might be to enable the sprat to fix its position.

Evidence from drift-net catches off the English east coast would suggest that sprats have some form of navigation. The fish tend to be caught on one side of a drift-net irrespective of the tidal direction.

The level of attraction to light depends on the clearness of the water. In Swedish water when underwater television lights are dimmed sprats gather. However, the reactions of the fish to light may be affected by external factors, such as predators.

In the Baltic it appeared from the paper of Rechlin that fish were concentrated between the thermocline and oxycline. When the two were very close together the catches were high.

A halocline occurs in the Baltic at about 80 m, beneath it oxygen goes down quickly. In the Bornholm basin oxygen content may change quickly. Sometimes a layer of high concentration occurs below a layer of lower concentration. This is a change from the periods of long stagnation when H_2S occurred.

Sjöblom has shown changes in the halocline can be related to air pressure and wind. The distribution of the fish and the fishery being modified.

(Lindquist, Johnson, Otterlind, Svansson, Dannevig, Burd, Thurow, Boetius)

24 January <u>Long-term fluctuations in the sprat fishery and their causes</u>

The only stocks in which data were available were the Swedish and Norwegian and the Thames Estuary stocks. Papers and verbal contributions were presented by Lindquist, Dannevig and Johnson.

It appeared, in the case of the Swedish/Norwegian sprat, that from 1859-1900 most fish were caught south of Oslofjord, only before Christmas. After 1900 the centre of the fishery shifted to off Lysekil.

The change in the sprat fishery from northern Bohuslän occurs at about the same time as the herring change. It appears that there had been a relative rise in December-February mean temperature between the northern and southern Skagerak. That means the southern Skagerak is now somewhat warmer in relation to the northern parts of 2.5-3.0°C.

It was suggested that during the period of the "great fishery" prevailing winds had been easterly. This may have produced more rain with greater run-off.

(Lindquist, Jensen)

Off the Norwegian coast big fluctuations had occurred in Hordaland and Rogaland. In Rogaland the catch/stock had declined since 1910. In Hordaland there had been periodicity in abundance, low periods being 1915-20, 1930-35 and post-1950. In Oslofjord there were increasing catches since 1925.

It was possible that this area was the nursery area for the Swedish sprat in the present distribution. No information was available concerning the 0-group distribution at the time of the Bohuslän fishery. However, in the warm 1950s sprats had occurred in northern Bohuslän and 0-group had been found off-shore. (Dannevig, Lindquist)

Methods of exploitation

Denmark stake-nets, beach seine, bottom trawls, pelagic trawls.in Skagerak, few purse seines.

Sweden to 1899 - beach seines; since 1900 - purse seines in the fjords (since 1929 and during some seasons in the open sea; since 1963 - light fishing in the fjords); since 1933 - bottom trawls; 1950s - pelagic pair trawlers, no gill nets, no traps.

Norway to 1900 - beach seines; after 1900 - purse seines in fjords using lights in autumn only; bottom trawling in Kattegat, pelagic trawling in inner Skagerak.

Germany bottom trawl; pelagic trawls, 1 and 2 boats.

Poland bottom trawl; pair trawl in open sea.

Yugoslavia all light fishing with purse seines in Black Sea, pelagic trawl and underwater light fishing for attraction to conical net with pump. This is used on black nights with lights of 3000-4000 candlepower.

England now almost all by pelagic and bottom trawl; some drift-nets; stow nets in Thames Estuary no longer in use.

Use of underwater television for behaviour studies

Dr. Lindquist reported his experiences using underwater television. Using an oblique aspect for the camera, it appeared that in a layer of sprats the fish were not orientated at night. The camera with photoflash gave a sampling volume of about 2-3 m^3. The fish, a mixture of herring and sprat, gave counts of about 52 fish per m^3. This compared with an estimate from a 100 kH_z echo sounder of $35/m^3$ for fish in English waters.

Age composition of the catch

Otoliths were a popular method for age assessment, particularly in the northern sprat populations. Little difficulty was experienced with those from Swedish, Norwegian, eastern North Sea and English coastal waters. However, it was reported that in the Adriatic sprat there was a high degree of secondary calcification on the otoliths, which rendered them unreliable for age determination. Seventy per cent of the age determinations were made from scales. Only in this stock were difficulties experienced in interpretation of the ring structure of the scales. There were many accessory rings and it was thought that an individual sprat might spawn three times a year and might lay down an accessory ring each time. These difficulties did not appear in those northern sprats for which scales were used for age determination.

Otoliths in some cases were examined in xylol, or canada balsam, or even dry. It was pointed out that in herring otoliths these acted as clearing agents, altering the appearance of the otolith with time. It was suggested that examination of the otoliths fresh from the fish, before the otic fluid had dried, might make easier determinations. This had been successful with South African hake, and otoliths of cod kept in glycol with a little formalin retained their fresh appearance. (Dannevig, Burd)

No age composition data were available from the commercial catches in the Adriatic, but biological samples showed the commonest age groups to be I and II with few III and rarely IV and V. Occasionally in some otter trawl catches in summer O-group fish, 8-9 cm, were taken in deep water. (Zavodnik)

The German fishery in the Elbe and Weser estuaries and off Helgoland and Amrum has yielded catches of 4000-10000 t per annum during November-Februrary. It is mainly based on 0- and I-group fish, no more than 10 per cent being II-group.

(Rauck)

In the Baltic there appear to be two stocks, those fished in the Bay of Gdansk and another in the Gotland Basin. Year-classes vary, as can be seen below:

Age composition in per mille

Months		Year-class					
		1966	1965	1964	1963	1962	1961
I-III	Bay of	331	-	299	178	81	15
	Gdansk	267	-	337	187	80	92
III-V	Gotland	45	-	345	278	165	123
	Basin	48	-	306	200	248	180

The fish of the Bay of Gdansk are thought to have only a short migration. Those of the Gotland Basin spawh in the deep areas in May and move north into the entrance of the Gulf of Bothnia and Finnish Gulf. (Wrzesinski)

Longevity, greatest size and growth

Maximum ages of 11-12 years were reported from the Gotland Basin. Some samples of average age 10 had been noted. In the Skagerak the oldest fish are about 5 years. In the English fisheries emigration of older fish takes place from the inshore stock so good estimates of length for age in the old ages are not obtainable from the fishery.

Some additional age/length data are given below:

	Baltic	Eastern North Sea (Rauck)	Adriatic (Zavodnik)
0	8-12	8.0	8.7
I		10.1	11.4
II		11.2	12.5
III		12.2	13.2
IV			14.0
V			15.0

Food, nutrition and competitors

In the Adriatic the food in the stomachs of sprat consisted of copepods (Centropages) and zoea of decapods. More rarely there were eggs of decapods, other fish such as sardine and sprat eggs and larvae. Comparison with plankton samples taken at the time the sprat were caught showed Centropages and zoea larvae to be abundant but it appeared that the sprat was selectively feeding on other organisms. No observations were available for the summer. (Zavodnik)

The sprat of the English east coast and in the Skagerak do not feed in the winter to any extent. It appeared that small fish in the Bay of Gdansk were found with food in the gut in winter, but not bigger fish in the Gotland Basin. A comparison of the gut contents of small sprat and small herring taken in mixed catches on the English coast showed that though the copepods Temora and Pseudocalanus featured in both fishes in the larger herring Amphipods appeared to be the main diet, together with clupeid larvae.

(Johnson, Thurow, Wrzesinski)

Predators

Sprats had been found in the stomachs of dolphins, mackerel, garfish and loligo in the Adriatic. Tuna were also found with sprat and also hake. Sardines fed on sprat eggs. (Zavodnik)

In the Baltic salmon were considered to be a main source of predation. Otoliths of sprat had been found in young salmon stomachs and an extensive analysis had been made of salmon gut contents during 1957-61. Estimates of the average gut content in salmon was 24-50 g, of which 75 per cent was sprat and 13 per cent herring. From experimental work it was thought that for maintenance a 70 cm salmon would need about 92 g per day. These fish had a weight increase of about 4000 g per year. Taking 24 g and 50 g as the daily ration, it has been calculated that the Baltic salmon stock of some 1.1 million salmon at that time would have eaten some 10000-20000 t of sprat per year. This is to be compared with a total Baltic sprat catch of 26000 t in the same period. Porpoises have also been shown to be major predators in the Baltic.

(Lindquist, Thurow)

The main predator in Norwegian waters is the mackerel, but saithe and pollack also feed heavily on sprat. (Dannevig)

Cod were considered to be a major predator in the Skagerak and southern Baltic. They were reported to attack sprat shoals so that the latter were broken up. (Jensen, Wrzesinski)

In the winter concentrations off the English east coast the absence of large predators was notable. It was thought that in the summer much predation took place in the open sea by mackerel and gadoids, Indeed, in some areas sea birds might be a major source. (Johnson)

25 January <u>The spawning of the sprat and the recruitment to the stock</u>
Chairman was Dr. Zavodnik

In the Baltic there are considered to be two stocks. The southern Gotland stock shifts south from wintering areas in the entrances to the Gulf of Bothnia and Finnish Gulf and spawns on the southern edge of the Gotland Deep in April/May. A stock in the Basin of Gdansk winters in the bottom layers and only migrates a short distance into the Bay of Gdansk to spawn.

During the maturation process the fat contents decline from 17 per cent in January to about 6 per cent in May. There is some evidence that low temperatures delay spawning and that good year-classes have generated in years of higher temperature.

It appeared that there were changes in the sex ratio with length. The proportion of females increased with length. A similar feature occurred in the Adriatic sprat. The lengths of the smallest spawning fish found were of the order of 9-10 cm. (Wrzesinski)

Two metre ring trawls had been used for examining spawning of sprat in the northern Kattegat and Skagerak. Eggs were only found in June, few being taken in July. There is an important spawning in the Kattegat east of Laesö. (Jensen)

The spawning of the Swedish sprat in the Skagerak between Lysekil and the Skaw is associated with the presence of a cold water dome in the central Skagerak. Spawning begins in May, continues in June and declines in July.

The spawning area is only on the south side of the dome and begins when the sea temperature reaches $6^{\circ}C$. Höglund's data on 7 years of observations of spawning in Uddevalla Fjord suggest that the timing of spawning is dependent on temperature.

The eggs hatch in about 3 days at $10^{\circ}C$ and drift northwards into Oslofjord. Sometimes they also drift into the Kattegat.

When winds are strong the surface waters can be blown into the Kattegat and egg patches carried with them have a sharp front. The Baltic water flows closely along the Swedish coast, while the Jutland current follows the isobaths and bends south into the Skagerak before turning north again towards the Swedish coast. The dome is a constant feature of the area and the sprat spawning is associated with it. (Lindquist, Svansson, Jensen)

Spawning occurs in Oslofjord in most years. There has been a decrease in spawning in recent years which may be associated with increased pollution. Outside the southern Norwegian Skerries large accumulations of sprat larvae occur. They are located in the Baltic current in decreasing numbers to the westward. Few have been found west of Lindesnes, though much sampling has taken place out to 40-50 miles from the coast. A few larvae have been taken in Hardanger Fjord.

The origin of the sprat populations supporting the Hordaland and Rogaland fisheries is an open question, as almost no spawning has been found on the coast. (Dannevig)

Little is known of the spawning of sprats in the central North Sea. In the Southern Bight eggs have been taken in plankton surveys from January to August, with the peak values in April, May and June. The length of the spawning season is in contrast with that in the Skagerak. Larvae are taken in all months of the year.

There is a trend towards earlier spawning to the west of the British Isles. Thus, the fish spawn in February off the south of Ireland. No information is available on the spawning times of the extensive sprat stocks of the Hebrides and north-western Scotland.

Spawning takes place at temperatures greater than $6^{\circ}C$ in the Southern Bight. The older fish appear to mature earlier and spawn first.

(Johnson, Burd)

In the Adriatic Sea a more or less uniform distribution of eggs is found in January in offshore regions. The spawning areas are not known. Histological studies have shown the existence of oocytes in different stages of development at the same time, indicating a serial spawning. Empty follicles were seen in March. It might possibly be that the different sized eggs reflected a continuous development process but which might be modified by changing temperature regimes. Thus cod stop spawning if the temperature drops $1-2^{\circ}C$ and recommence when the temperature rises again. Development of eggs might be affected in the same way. (Zavodnik, Dannevig)

27 January <u>Parasites and diseases</u>

The degree of importance of parasites in contributing to natural mortality in fishes is not understood. Contracoecum is a nematode parasite of the sprat. It is common in the North Sea and has been observed in the Adriatic, where in some years it can reach 75 per cent infestation. It does not appear to be responsible for a large physiological drain, as fish with and without the parasite have the same fat contents.

Other parasites which occur are copepods of the genus Lernaeenicus. They do not appear to be very common. (Dannevig, Zavodnik, Lindquist, Burd)

Bacteria have been recorded from sprat. They have been responsible for death in coalfish, pollack and cod off the western Norwegian coast between Stavanger and Trondheim in 1967. (Naevdal)

Fungi have been found infecting cod eggs in a hatchery. The infection is greatest in cold weather when overcast. Cod eggs from the open sea have similarly been infected. If the sea water is passed through a sand filter there is no infection.

General conclusions

While a considerable amount of information was available on the sprat, there were still some considerable gaps in the understanding of its relation with the environment. The following points cover the main areas in which further work is indicated.

1 Unity of the stocks It was evident that the methods used to date, such as VS, K_2 and head line, did not individually indicate any local stock differences. Serological techniques might afford separations but little work has been done.

2 Fecundity There were little data available and the presence of many - sized oocytes at any one time resulted in a confused picture. A more intense investigation of spawning of the sprat was indicated and it was proposed that some work could be done easily in captivity.

3 Distribution in relation to the environment It was evident that the relation between a stock's distribution at any one time appeared to be related to very different environmental parameters in any area studied. Perhaps there was no generalized relationship.

4 Though the location of spawning areas from plankton surveys was well known and also the areas of distribution of 0-group (7 cm and over) sprat were documented, little information was available on the distribution of the intermediate stages. It was suggested that the use of high-speed plankton samplers might provide information on this development stage.

5 There was little information on the extent and importance as a cause of mortality of parasitism or diseases.

Annex

Papers

(Dr. Johnson has summarized his contributions to the symposium in the following two papers)

THE ENGLISH SPRAT FISHERIES.

by

P.O. Johnson

Contents

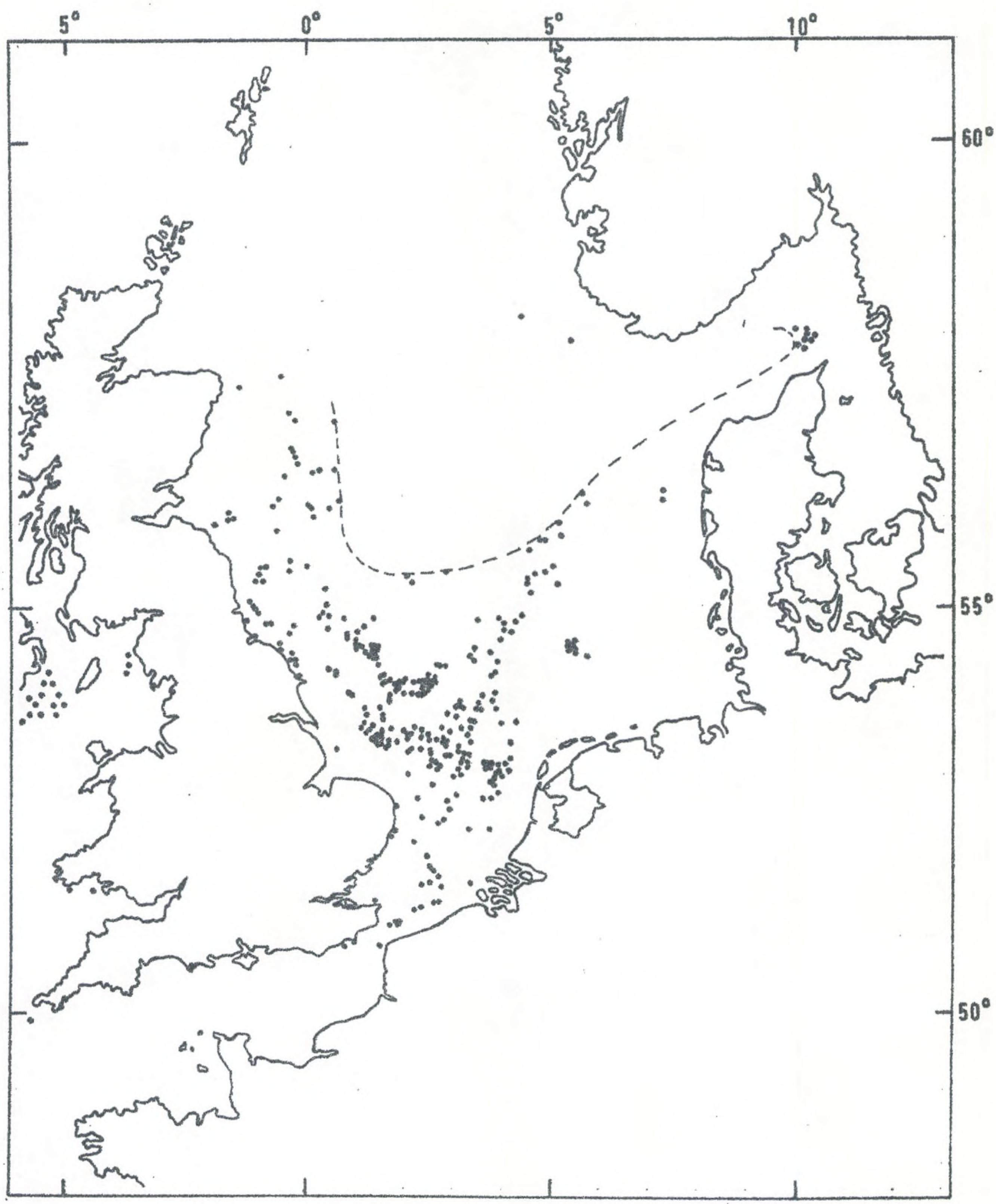


Figure 1 Distribution of sprat in the central and southern North Sea, 1954-66, as shown by research vessels samples.

THE ENGLISH SPRAT FISHERIES.

by

P.O. Johnson, Ministry of Agriculture, Fisheries and Food Fisheries Laboratory, Lowestoft

THE DISTRIBUTION OF THE SPRAT IN THE NORTH SEA

A distribution chart for sprat in the central and southern North Sea is presented in Figure 1. This has been compiled from positions of capture noted in the log books of Ministry research vessels between 1954 and 1966. None of these trips was made specifically for sprat, the species only being noted as a by-catch when fine-meshed nets or covers had been used for other purposes. The majority of these observations have thus derived from surveys for young herring or sandeels, and the distribution of these positions of capture for sprat is to some extent governed by the areas of operation for other species. However, the area covered by most of the young herring surveys does enable an approximate boundary to be drawn in the central and western part of the North Sea. The sprat is probably scarce north of the Dogger Bank, where the water increases in depth fairly rapidly, and also beyond the southern part of the Great Fisher Bank. However, it is found offshore in deeper water (up to 100 metres depth) out to around 1°E off the north-east coast of England and east coast of Scotland.

Environmental factors determining the limits of distribution are not very obvious. Topographically the main centres of population lie generally within the 40-fathom (73-metre) contour, although they can be found over greater depths in some of the deeper pits and gullies in the western half of the North Sea. The average maximal depth contour for the species in the North Sea could probably be taken as 50 fathoms (91 metres), and in this context it is interesting to note that egg surveys made off the south coast of Ireland showed very little spawning beyond this depth. However, it is difficult to envisage how depth alone could be a limiting factor to the distribution of a pelagic species such as sprat. In parts of the Baltic (e.g. Gotland Basin) it is commonly found in water over depths of 100-120 fathoms (183-219 metres), whilst in the Black Sea it regularly spawns over depths near to or greater than 1 000 fathoms (1 829 metres) and eggs have been recorded at depths of 55-82 fathoms (100-150 metres) below the surface. The latter depth zone may provide some indication of the actual maximal limit to which the species can descend.

The salinity patterns in the central and northern North Sea do not correspond exactly with the limits of sprat distribution, although these fish are generally less common or absent within the tongue of more saline (> 35‰) Atlantic-type water extending into the northern North Sea and penetrating as a deeper layer into the central Skagerrak region. However, high-salinity water does not seem to be a real barrier for the species, since sprats are often found in water exceeding 35‰ in the English Channel (even southern North Sea on occasion) and Atlantic coastal regions, whilst in some parts of the Mediterranean they have been found in even higher salinities (up to 36-37‰). Evidence from the Black and Baltic Seas indicates a lower level of salinity tolerance around 5‰, and sprats disappeared from the Zuider Zee after its enclosure when the average salinity level had decreased to this value.

Temperature also seems unlikely as a limiting factor in the more northern parts of the sprat's range, although evidence from the Kattegat/Baltic area suggests that they prefer to remain within relatively warmer (> 4°C) water in winter, but can survive at sub-zero temperatures (down to -0.5°C). In the Mediterranean and Black Sea an upper temperature limit of around 24°C has been noted, which, together with a preference for relatively lower salinities, may contribute towards the localized distribution of this species in these areas. Here the sprat is chiefly found in the northern parts, where freshwater run-off is high and the water tends to be relatively cooler and less saline.

In many parts of the sprat's range there is found to be some association with rivers and estuaries, particularly during the periods when it shows localized aggregations, usually during the winter months. The diffusion pattern of river water in the marine environment brings about obvious physical changes in the levels and gradients of temperature, salinity and turbidity, and these, together with possible olfactory stimuli, may assist the fish in "homing" to a focal point of aggregation, but the actual sequence of events controlling the larger-scale movements of sprats is not known.

CHANGES IN THE TYPE OF GEAR USED

During the present century four main types of fishing gear have been used in the English sprat fisheries; these are the stow net, drift net, seine net (mainly shore-seines), and trawls (bottom and midwater). Table 1 summarizes for each type of gear the mean values of total catch and the percentage contribution of each to the grand total. This clearly shows the changes in the predominant type of gear over the last 60 years.

Until 1949 (except during the war years) about half the total catch was taken by stow net; this was a large fixed net attached to the anchor chain of a vessel held in the tideway, and was employed in areas with strong tidal currents such as the Wash and Thames Estuaries, the Solent and Morecambe Bay. It continued in use in the Thames area until the early 1950s, when it was rapidly replaced by midwater trawling.

The drift net was next in importance until the second world war period, after which its relative and actual contribution to the total catch rapidly declined. It accounted for between one-quarter and one-third of the total up to 1939. It was and is still principally used along the southern part of the East Anglian coast between Lowestoft and Aldeburgh and along the south-east coast between Ramsgate and Newhaven. In these regions the coastal waters are very turbid and the sprat shoals rarely aggregate sufficiently to make trawling profitable.

The seine net has been used mainly in the fisheries of the south coast (Poole) and south-west coast (Lyme Bay/Tor Bay). In these areas the coastal water are generally less turbid and shoals approach fairly close to the shoreline, particularly where the depth increases rapidly close to the coast.

The seine-net's contribution to the catch has been very variable and relatively small, although it made a fairly important part of the catch during the war years when restrictions on the east coast fisheries increased the demand for fish from the south and south-west coast. Like the drift net, it has greatly declined in use since the second world war and is now only used on a very small scale in a few localities.

The trawl-net method has shown the greatest changes over this period, both in type of gear and importance to the fishery. Prior to the second world war trawls were used mainly in the Poole area, where a specially developed beam trawl, known as the Poole sprat trawl, was in use. This contributed only a few per cent to the total catch except in the war periods. Immediately after the second war modified demersal trawls and later Vinge trawls were introduced into and increasingly used in the Tor Bay fishery. However, the main developments took place in the early 1950s, when the four-panel Larsen-type midwater trawl was introduced into the Thames Estuary fishery, this gear being operated by pair-boats. It proved very successful and by the late 1950s had spread to the Poole, Tor Bay and Wash fisheries. Since 1963 single-boat midwater trawling has also developed on a large scale, principally in the Wash and North Shields fisheries. At the present time trawling (mainly midwater) is by far the most important fishing method, accounting for nearly the entire catch.

Most of the existing sprat fishing grounds are situated fairly close inshore, mainly within 10 miles from the coast and in depths of between about 5 and 20 fathoms (9-36 metres), although more recently a fishery has developed between 10 and 20 miles off the north-east coast of England in much deeper water of between 30 and 50 fathoms (55-91 metres).

THE THAMES FISHERY

Changes in total catch, number of landings and catch per landing are shown as a time series in Figure 2. This covers the period 1905-68 (seasonal totals) except for the second world war period (1939-45), for which only total catch is available. The stow-net was the traditional gear in this fishery until the introduction of midwater trawling in the early 1950's.

Effort has always been sensitive to the marketing situation and a brief background to the economic history of the fishery will help in understanding at least some of the effort changes. Prior to 1900 the main fresh outlet for sprats was Billingsgate (London) market, and any surplus, apart from small quantities to satisfy limited local needs, was disposed of to farmers for manure. In the early 1900s an increasing demand arose from Continental sources for British sprats for preparation as delicatessen products. This led to the development of a curing and export trade centred on Brightlingsea in the Thames Estuary, with barrelled sprats exported to Belgium, Germany, Sweden and various Baltic countries. This was mainly responsible for the increased effort and catch just prior to the first world war, which severely curtailed this industry. However, it developed and expanded considerably in the inter-war period, although the Continental demand tended to fluctuate, usually being inversely related to the success or failure of their own fisheries. A small home canning industry also provided a limited outlet over this period.

Immediately after the second world war the export contacts were re-established but the fishery was not very profitable due to scarcity of fish, and the number of vessels operating was reduced to about one half of the number in the immediate pre-war period. The fishery remained in a depressed state until the advent of pair-boat midwater trawling in the early 1950s; this led to renewed interest, with considerable capital investment in new boats and gear. In 1951 only two or three pairs were operating, but in 1955 the fleet had grown to 22 pairs. This produced the major increase in effort over the first half of the 1950s, and at this time most of the catch went to the home canning market, which closely

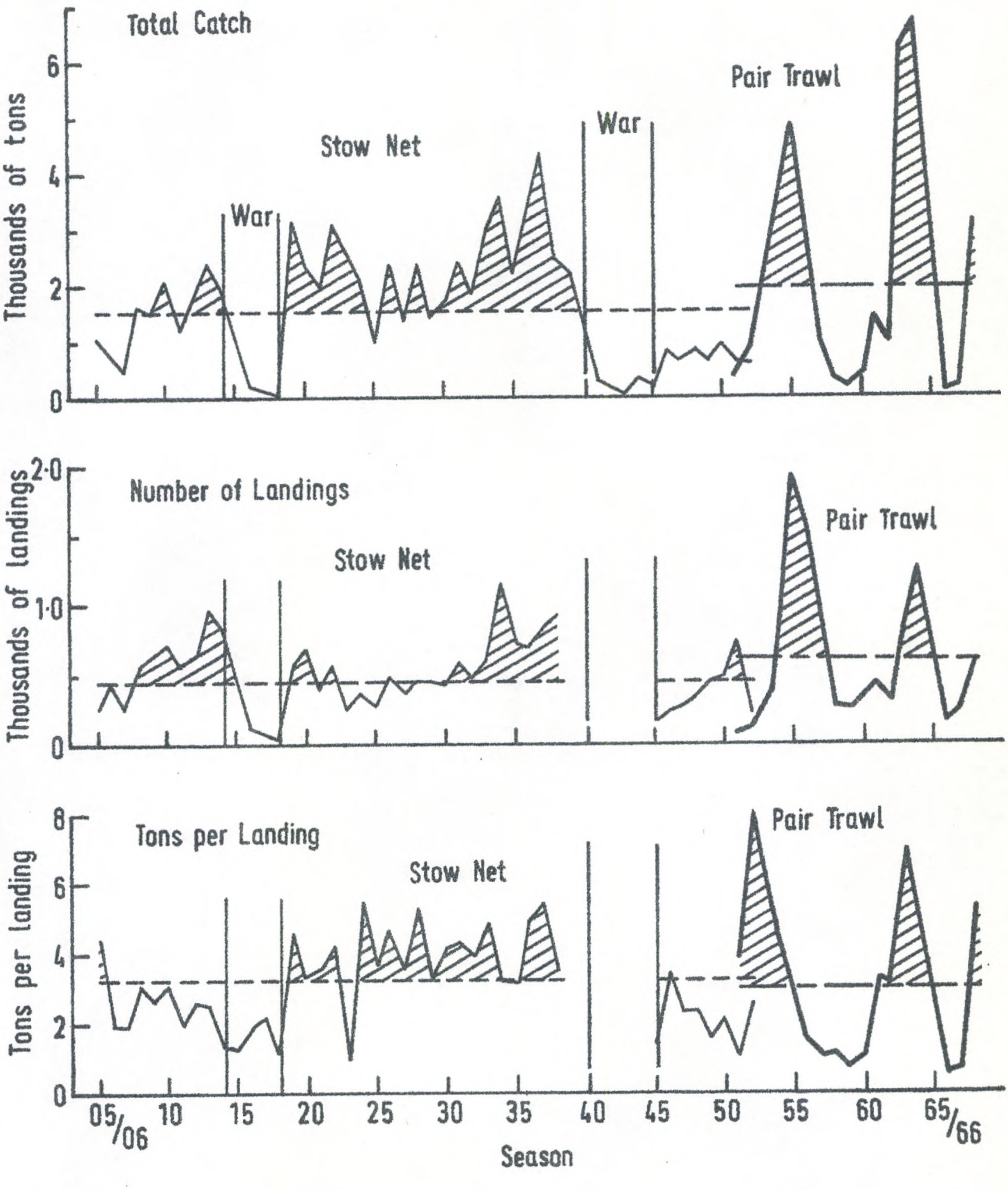


Figure 2 The Thames sprat fishery - total catch, number of landings and catch per landing, 1905-68.

controlled fishing effort and prices. A period of fish scarcity followed and the second major increase in effort came in the early to mid-1960s when most of the catch was used for meal and oil reduction, the canning market now being reduced to an insignificant level. In this period also an alternative fishery had developed in the Wash area, and a large part of the Thames effort was diverted to this region when the fishery in home waters showed poor results. At the present time the fish-meal market is the major one, with smaller quantities being used for pet food, export and canning.

The effort data are in the form of numbers of landings, and the catch per unit effort is expressed as tons per landing. The actual total fishing effort in terms of searching and "net in the water" time could be somewhat variable, particularly for pair-boat fishing, because these are day-boats. Their movements in and out of port are strictly governed by tidal considerations; thus the maximum fishing time available is limited. The stow-boats probably showed less variability in this respect, because, although they too were basically day-boats and also closely committed to tidal phases for operating their gear, if catches were poor they might fish two or more tidal cycles and remain out overnight.

NP Changes in the levels of catch per landing over the stow-net fishery period (1905-52) show three well-defined phases: the first was prior to and during the first world war (1905-18) when it fluctuated around an average level of just over 2 tons per landing; the second followed immediately after the war, when it rose abruptly, to fluctuate about an average level of nearly 4 tons per landing until 1939; in the third phase, after the second world war, it had dropped again to an average level similar to that prior to 1918. The vessels and gear remained substantially unchanged over the whole period, the standard type of vessel employed being a fully decked single-masted boat known as a "Thames bawley", a design of considerable antiquity. The original motive power was sail, and the main change during the stow-net era was the introduction of motorization in the early 1920s, which was virtually completed by the early 1930s. However, catch per landing showed no trend over this changeover period, nor was there any indication of an overall increase in fishing effort.

The introduction of pair-boat midwater trawling changed the whole character of the fishery and it is difficult to make comparisons between the two types of gear, since there was only a relatively brief period of overlap. It seemed from the evidence of the stow-net returns that pair-boat fishing commenced at a time when the Thames sprat stocks were at a low ebb. The new method showed a peak in catch per landing over the first few seasons (when only a few pairs were operating), but from the 1953/54 season onwards a progressive decline became evident. Nevertheless, increasing effort more than compensated for this decrease in catch per landing, resulting in the total catch showing a progressive increase until the 1955/56 season, after which it slumped badly. The initial decline in catch per landing may have been partly due to more and more inexperienced pairs taking up the fishery in each successive season, resulting in an overall reduction in efficiency of the fleet. This was also a time when the market (mainly canning outlets) was unable to absorb the increasing catch and this led to quota fishing and even complete stoppages at times. The Fisheries Inspectorate Reports outline these background difficulties, which restricted the expansion of the fishery, and also provide some information on the relative scarcity or abundance of fish in each season. The first season in which a decline in the fishery - in terms of average size of fish and patchy distribution of shoals - is commented on is that of 1954/55, and in the following season it was noted that the vessels were having to fish for much longer than previously to achieve the same catch. The 1956/57 season was clearly a failure from all aspects and it thus seems that the decline in catch per landing did reflect a genuine reduction in stock level between at least 1953/54 and 1956/57. Catch per landing (or per trip) will not provide an exact measure of changes in abundance, due to the differences in actual fishing time per trip between extremes of stock density. At the upper stock levels, fishing time (net in the water) may be only a few minutes and limited by the ultimate carrying capacity of the vessel, whereas at the lower levels the fishing time necessary to obtain a minimum economic payload may be up to five to six hours per trip. This compensatory effect of actual fishing time on catch per landing may be sufficient to modify the slope of change in abundance, but not sufficiently great to mask it entirely or obscure long --term trends of change. Catch per landing remained at a low level until the early 1960s, when it rose rapidly to another peak in the 1963/64 season; it then declined yet again, falling to very low levels in the 1966/67 and 1967/68 seasons, and has recently shown another increase. As far as can be judged from subsidiary evidence provided by research vessel echo surveys, these latter fluctuations have mirrored real changes in stock abundance.

These variations in total catch, number of landings and catch per landing are summarized in Table 2, which presents an analysis for the two types of gear over different time periods. The stow-net fishery is divided into three periods, each characterized by a distinct change in the average level of catch per landing, whilst the pair-trawl fishery has been grouped into "good" and "poor" seasons. An overall assessment for each type of gear is also shown. Each factor has been separately analysed without any weighting applied.

This tabulation enables a more critical analysis to be made of the general changes in the fishery commented upon earlier. The stow-net fishery showed an increase in average seasonal catch and catch per landing of around 1.5 times between the first and second periods, with effort increasing by about 1.2 times. Tests of significance ("t" tests) show that the change in catch per landing was highly significant ($P < 0.01$), that of total catch only marginally so (P 0.05) and the change in effort non-significant. The third period shows the average levels of total catch dropping to one-third, catch per landing reducing to one-half and effort decreasing to about three-quarters of those of the middle period levels. The changes in catch per landing and total catch are highly significant ($P < 0.01$), whilst the effort reduction is non-significant. A comparison between the first and third periods shows that the only significant difference ($P\ 0.01$) was in total catch.

The pair-trawl analysis shows much larger differences between the good and the poor seasons. The average catch and the catch per landing differ by nearly 4.5 times, and these differences are highly significant ($P < 0.01$), whilst the effort changes are much less (1.3 times) and in fact non-significant. A fairly high level of effort was maintained even when stocks were low.

A comparison between the overall values for the stow-net and pair-trawl fisheries shows no significant differences in total catch, number of landings or catch per landing.

The statistical parameters also provide an indication of the relative magnitudes of variation within each period, and clearly show the greater stability of the fishery during the stow-net period.

Interrelationships between total catch, number of landings and catch per landing

In this type of fishery the interrelations between catch, effort and catch per unit effort can be highly variable, due to the background economics which often result in a certain amount of "feed-back" between all three. Changes in total catch have certainly closely paralleled the changes in total effort, and there is a highly significant correlation ($P < 0.01$) between these two factors in both the stow-net and pair-trawl fisheries. There is also a highly significant relationship ($P < 0.01$) between total catch and catch per landing in the stow-net fishery and in the pair-trawl fishery if the first few seasons are excluded. Any relationships between effort and catch per landing are more tenuous, and overall are non-significant. A period of developing and favourable markets may show an overall increase in effort while catch per landing is declining (i.e. 1905-13; 1945-51; 1952-56), or, on the other hand, the effort and the catch per landing may show more parallel changes when the market is fairly stable (as in the 1920s and 1930s).

It is clear that the Thames sprat fishery has undergone some quite dramatic changes over the period 1905-68, but unfortunately available information on accompanying changes in the population age/length structure is rather limited. This mainly covers the periods 1929-34 and 1961-68, with rather more scattered and incomplete data covering the period from 1946/47 to 1959/60. A detailed analysis of this information will be presented elsewhere, but it shows that on average, in both the pre- and post-war periods, two- and three-year-old fish contribute between them about 85 per cent by weight to the total catch. The magnitude of individual year-classes and the frequency with which the larger ones appear in the fishery are thus of prime importance in determining its stability, since there are not great reserves of older fish to smooth irregularities in year-class abundance. The success or failure of the fishery (excluding problems of availability changes) thus hinges on the size of the brood recruiting at two years of age, and fluctuations in the fishery will mainly be due to differences in the strength of recruitment of successive year-classes.

Fluctuations in the fishery, and environmental changes

These differences in year-class strength may be affected by a number of environmental factors: variations in temperature, salinity and freshwater run-off, predation (at all stages of development), loss of eggs by wind-induced turbulence, dispersion of larvae by wind, and, above all, optimum feeding conditions for the larval stages. The latter factor is closely linked with the general production cycle and its variations. Hence it is unlikely that there could be a simple link between any one of these factors and fluctuations in year-class strength. However, some of the possibilities have been examined in considerable detail.

VELEY (1952) examined possible relationships between year-class fluctuations and wind conditions during the spawning period in the Thames sprat fishery between 1929 and 1934 and the Swedish west coast sprat fishery between 1932 and

1938. In the case of the Thames sprat good broods were associated with low west wind resultants from May to July and poor broods with high ones, implying a wind dispersion effect operating in the larval stage which either maintained them closer to the English coast or carried them away to an area where they would be lost to the fishery $1\frac{1}{2}$ years later. In the Swedish fisheries the largest year-classes were associated with a resultant west wind component of a certain critical velocity and any departures from this value resulted in reduced broods; again, dispersal effects in the larval stages were thought to be involved. However, there were anomalies in even these short series of data and it was clear that much longer time periods would need to be examined before any such relationships could be conclusively proved.

NIKOLAEV (1958) noted similar fluctuations in the catches of Baltic sprat and smelt over a 50-year period, which were of interest since one species was predominantly marine and the other a brackish-water coastal and lake type. The common link was thought to be through changes in the productivity cycles of their environments, which in turn were associated with variations in the freshwater run-off from the main river systems draining into the Baltic basin. A general correlation was found between periods of high run-off and increased catches of sprat and smelt, although a variable delay period between the two events was involved (averaging about two years) and there were some exceptions. It was concluded that the relationship between run-off and increased productivity could only be an indirect one as far as the more open parts of the Baltic were concerned, due to the immediate freshwater flow being rapidly assimilated and contained within a fairly restricted coastal belt. The causal factor was more likely to be differences in the associated wind regimes normally prevailing over the region during "wet" or "dry" periods. The direction and intensity of the wind could directly influence the productivity cycle by its effects on nutrient turnover in the deeper water where very pronounced vertical stratification is usually found. Other factors such as changes in the winter or summer temperature regimes were also thought to play a part in determining stock abundance.

Statistics of the total catch of the English east coast sprat fisheries (most of which is taken from the Thames Estuary) are available from 1886 onwards; also available are data on the freshwater run-off from the River Thames, from 1883 to the present. Both series of data have been smoothed by taking running means of three seasons, and the results are shown in Figure 3. It was concluded that no reliable association between run-off and fluctuations in the fishery was evident, and in fact no significant relationships emerged even when the two variables were plotted against each other with different time-lags allowed for between each event.

Information on the relative magnitudes of different year-classes is very limited and only available for the periods 1929-34 and 1961-68. The relative strength of a given year-class was estimated from its contribution to the fishery when two or three years old, but again no consistent relationships with run-off were evident.

Other aspects of environmental change examined in relation to fluctuations in the fishery were temperature, salinity and wind in the Southern Bight off-shore from the Thames during the main spawning and larval dispersion periods (April-June and July-September respectively). There was again found to be no significant correlation between fluctuations in the fishery and any of these factors when tested independently and allowing varying time-lags between them.

A more complex analysis combining all the environmental variables including meteorological data in some form of multiple correlation might yield more positive results, but so far no simple correlation reliable enough for prediction of the likely strength of future recruitment has emerged.

THE WASH FISHERY

A full account is given in "The Wash sprat fishery" by P. O. Johnson (Fishery Investigations, London, Series 2, Vol. 26, No. 4, published April 1970).

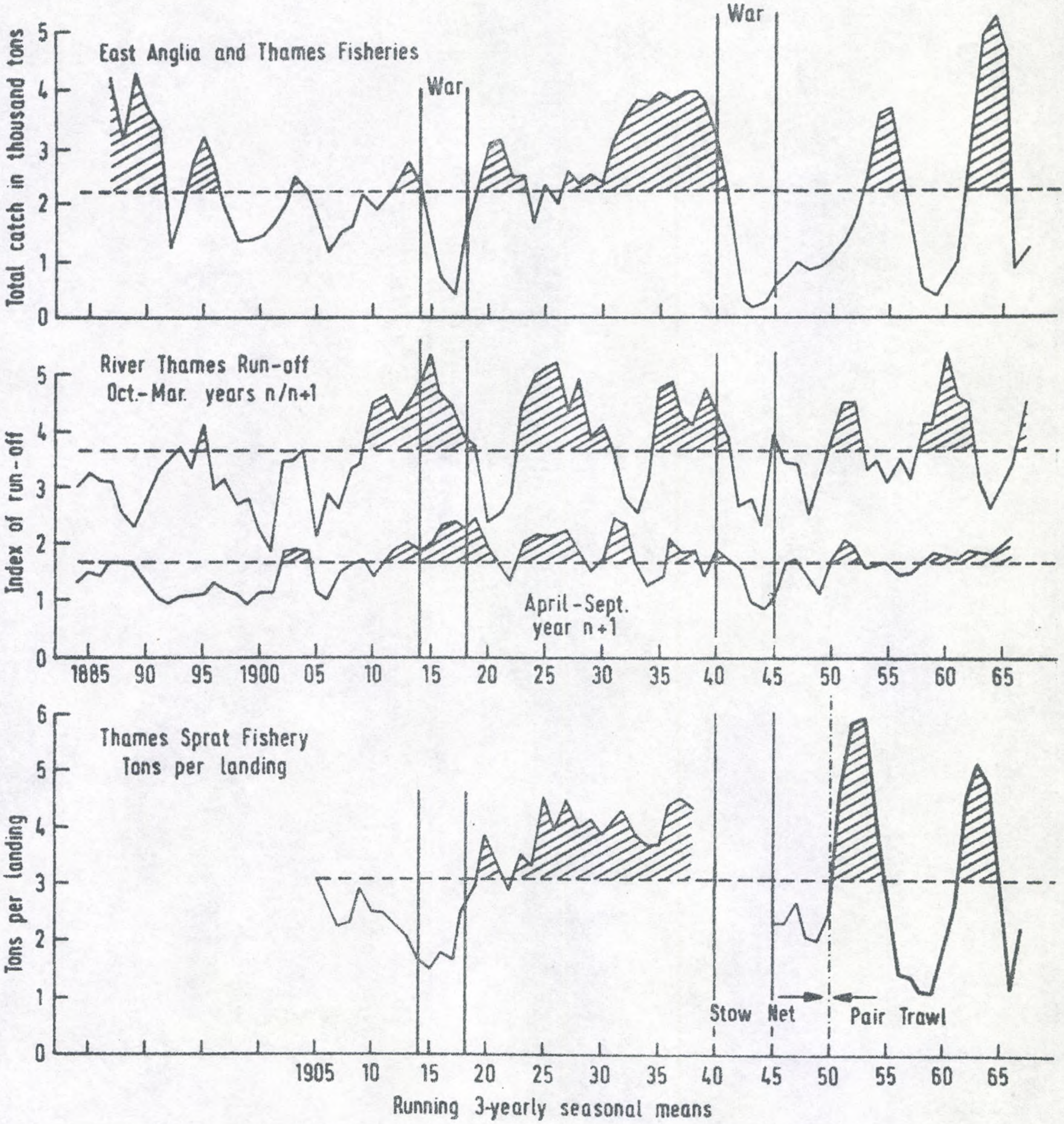


Figure 3 Total catch and catch per landing in the Thames sprat fishery in relationship to freshwater run-off from the River Thames.

The fishery is strictly seasonal in nature, usually commencing in the latter half of November, rapidly increasing to and maintaining a good productive level in December and January, declining in February and ending in the first half of March. There have been relatively small differences in this seasonal pattern, mainly involving the time of commencing and the timing of peak periods.

The success of the fishery is very dependent on the sprat shoals aggregating into fairly localized high-density patches, which may measure up to several miles in extent. These overwintering concentrations can remain fairly static for most of the season, though there is usually a progressive shift seawards from January onwards; they begin to break up and disperse towards the end of February.

No food is taken during the overwintering period, the fish subsisting on fat reserves, which show a steady decline from November to March and which are presumably also involved in the initial period of maturation. Feeding and spawning probably commence almost simultaneously, April-caught spawning fish often showing signs of fairly heavy feeding.

In most seasons two- and three-year-old fish contributed on average 80 per cent of the catch by weight; the overall mean age was 2.5 years, so this is basically a recruit fishery very dependent on the strength of the brood in each season. Full recruitment takes place when the fish are two years old (i.e. in their second winter). Fish beyond the age of three years are generally scarce, and there is some evidence to suggest that this is primarily due to emigration offshore.

The level of fishing effort to date has had no measurable effect on the total yield of the stock, and the mortality rate shown between the younger age-groups is very close to that expected from natural causes alone.

ECHO SURVEYS FOR SPRAT

The technique of echo survey has been used since 1958 to study the seasonal changes in distribution of sprat shoals around the English coast and to provide a measure of changes in abundance from year to year in the different fisheries.

The surveys have mainly covered the east coast region, with particular emphasis on the Wash and Thames areas, and more recently the North Shields region. General identification of shoals has been established by sampling, either from a research vessel with a midwater trawl or from an established commercial fishery. The results of this work will be described in more detail elsewhere but some of the preliminary findings are outlined here.

Most of the surveys were carried out using a standard Kelvin and Hughes MS 29 commercial sounder working at a frequency of 30 kHz with a depth scale of 0-30 fathoms (0-55 metres). In more recent seasons some surveys have also used a high frequency (100 kHz) sounder with a narrower beam (13°) and shorter pulse length (0.1 ~~metre/sec~~ millisecond), with a cycle counter and print-out system attached, thus providing a better quantitative estimate of the targets recorded (CARPENTER 1967). Vessel speed was maintained as constant as possible on each survey, and was usually within the range 8-10 knots.

In surveys carried out with the 30 kHz equipment both the horizontal and vertical extent of recorded traces were measured in mm to provide an approximate quantitative equivalent. Measurements of this type are subject to error and involve subjective judgement, particularly where the trace is very broken or diffuse. Relations between the horizontal and vertical extent of recorded traces and the actual dimensions of the original targets are also complex. The relative packing density of fish within shoals or layers can also vary and produce differences in the extent and intensity of recorded traces.

In inshore shallow-water areas of mainly less than 20 fathoms (36 metres) the majority of shoals occurred within the range 3-10 fathoms ($5\frac{1}{2}$-18 metres), whilst in deeper water offshore, down to 50 fathoms ($91\frac{1}{2}$ metres) the maximum range was about 40-45 fathoms (73-82 metres). It was also noted during daylight surveys that these shoals usually occurred in discrete layers occupying a fairly restricted depth range, the depth of the layer being variable and probably dependent on the light levels, water turbidity and also the size of the fish. There was some evidence that the smaller fish tended to form layers closer to the surface than the larger ones, this stratification by size often registering as a double-layered trace on the echo record.

In the Wash surveys the positions of the main fish concentrations were corrected by a computer programme to allow for distortion factors produced by tidal movement. This resulted in all the observations being corrected to a common state of tide corresponding with the situation at the moon's meridional passage at Greenwich, which in this area corresponds with the period near slack low water. It was then possible to contour the major concentration areas and, by planimetering these, to estimate their total area, and from their average vertical extent the volume of trace. Subsidiary information on catch per unit effort from the fishing fleet was also used to provide an indication of changes in average density from which a minimum estimate of stock could be made.

Most of these surveys took place during the fishing season (November-February) although sufficient were also made at other times of the year (usually in conjunction with egg and larvae surveys) to provide some indication of changes in shoal distribution and type outside this period.

Diurnal changes

Figure 4 shows the diurnal changes in the vertical distribution of sprat shoals. There is a gradual ascent towards the surface as the light intensity declines, and the shoals then break up fairly rapidly. At first light the reverse process occurs, the fish descending as full daylight approaches. The horizontal scale of this figure gives an idea of the extent of these "patches", which in some instances measured up to a mile or more across. In the early afternoon the shoal concentrations lay some 30-40 fathoms (55-73 metres) below surface, and measured some 5 fathoms (9 metres) in vertical extent, whilst in full darkness fish were observed breaking surface and also extending in places on the echo record to at least 30 fathoms (55 metres) below surface. These records enable an estimate to be made of the average rates of ascent and descent shown by these

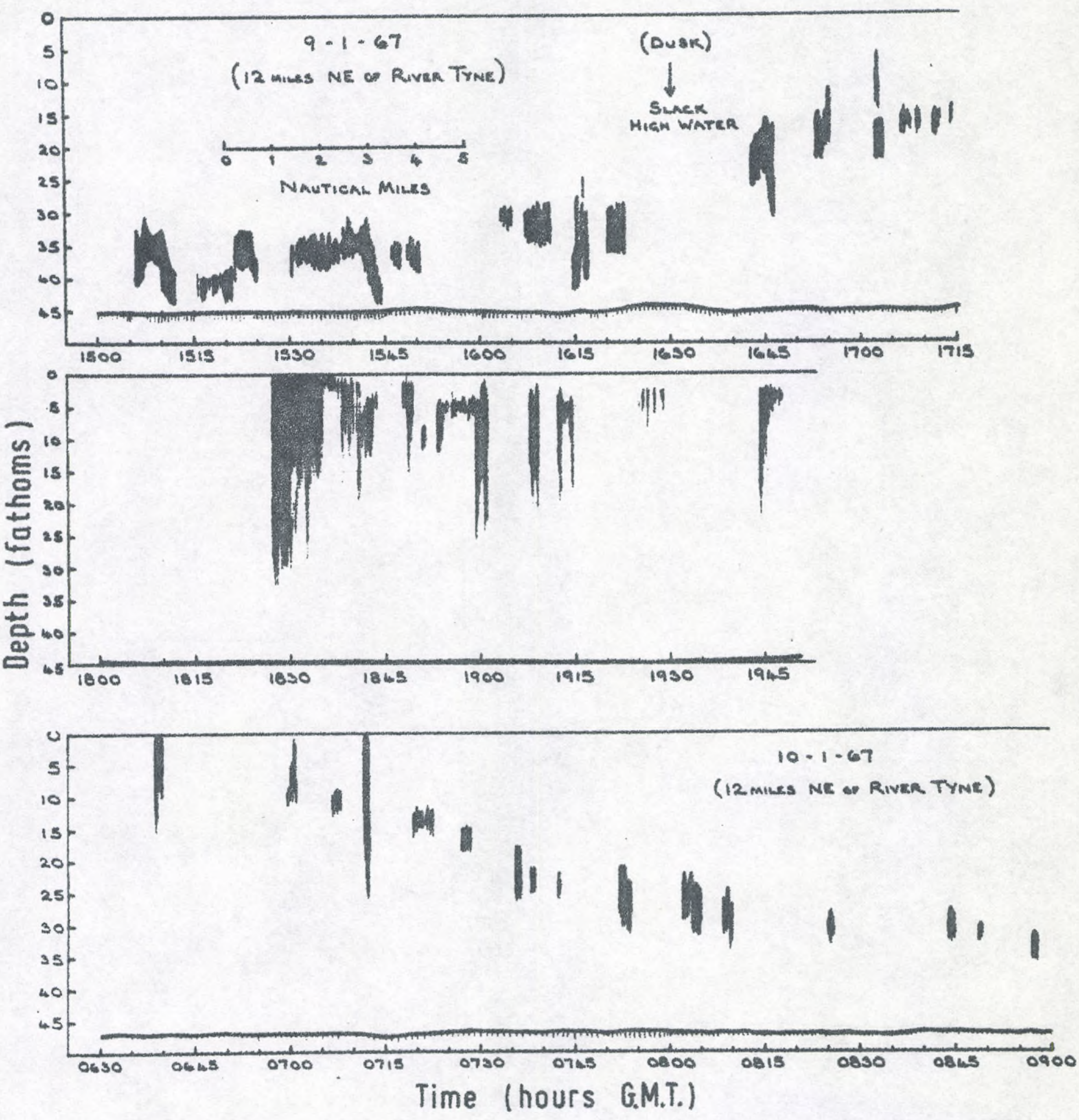


Figure 4 Echo-records from the North Shields sprat fishery, showing diurnal movements; the true bottom and surface are also indicated.

shoals around dusk and dawn. These rates, measured from and to about 30 fathoms (55 metres) below the surface, worked out at 1.7 cm/sec. ascending and 1.5 cm/sec descending, the surface water temperature ranging between 6.5 and 7.0°C.

Seasonal changes in the distribution and size of shoals and shoal aggregations

The sprat fisheries around the English coast are of a seasonal nature, usually commencing in November and ending in late February or early March. Outside this period fish are not present in exploitable quantities on the overwintering grounds. Some fishing has taken place as early as September and as late as April, but at these times the catch per unit effort has only been a small fraction of that recorded at peak season. Clearly, availability changes are involved and the echo surveys have enabled a more detailed study of these changes to be made, particularly in the Wash area. In late October, just prior to the fishery commencing, the pattern of shoal distribution is still very similar to that found in the summer, with numerous small shoals scattered over a wide area within and beyond the estuary. At about this time the fish cease feeding. The next phase usually takes place in November, when distinct and localized high-density shoal aggregations first become apparent; at first these may be quite limited in extent but they can build up quite rapidly into much more extensive high-density patches, which is often reflected in the rapid increase in catch per unit effort shown at this time. In some seasons, when these patches are fully developed, they may extend as an almost unbroken layer of shoals for up to 10-15 nautical miles along the main deeper water channel of the Wash Estuary and measure up to 2-3 nautical miles in width, thus covering a very considerable area.

Catch per unit effort sometimes declined as the total extent of trace increased and it became more diffuse in appearance. This could have been due to an expansion of these patches resulting in a lower average packing density of fish within the concentration area, although this would still be fairly discrete with distinct boundaries.

Once these major concentrations become established they usually remain fairly static for several weeks, although severe storms may cause temporary disintegration, depending on wind strength and direction. In some seasons a gradual shift seawards is evident by January, and at times there have been larger-scale movements early in the new year into very shallow water off the Lincolnshire coast or even further north to the Humber Estuary. A fairly precise boundary can usually be located around these patches and the shoal layer can often be observed to end very abruptly with no signs of fish beyond. This enables these major concentration areas to be defined reasonably accurately on a chart after tidal corrections have been applied. At this time there is usually very little trace to be found for a considerable distance around these concentration areas and they must represent the major part of the total stock immediately associated with the region. This same general sequence of events has also been observed in the Thames Estuary and off North Shields, where the fish aggregate further offshore in much deeper water.

The overwintering concentrations usually break up and disperse during March about the time spawning commences, and during April, when spawning is well under way, the fish are mainly found in very small shoals scattered over a wide area. In May and June only thinly scattered small shoals are evident within the Wash estuary, most of the adult fish having now moved well to seaward. The next phase appears to commence in July-August when in some years fairly extensive patches of small shoals consisting of immature feeding fish build up inshore, whilst in deeper water offshore large shoals and concentrations of post-spawning feeding sprats (often associated with immature or maturing herring) have sometimes been located. In September-October these large feeding concentrations seem to disperse, possibly when the fish enter a more active migratory phase, and scattered small "plume" traces again predominate, which leads to the inshore aggregation period in late autumn and completes the annual cycle.

<u>Results of surveys carried out using the 100 kHz sounder with a cycle counter attached</u>

A high-frequency sounder has been used on some of the more recent surveys; a cycle counter was incorporated which had a print-out unit attached to record the total cycles summed over unit time intervals (one-minute period totals were used). This system produced a better quantitative assessment of the recorded signals than measuring the echo traces. An example of a high-frequency echo record showing the very good relationship between numerical equivalent cycles and trace density is shown in Figure 5. The vertical lines represent one-minute interval marks, and the numbers between them are the total cycles (thousands) recorded. On this occasion the shoals were often so closely aggregated as to merge for considerable distances to form an almost continuous high-density layer.

The rather restricted depth zone occupied by this shoal layer is also well illustrated by this example. The rather ragged signals immediately following the transmission line are due to aeration in the surface layer, sea conditions being rather rough at the time.

The shorter wavelength and pulse length, and the narrower beam and wider paper display of the 100 kHz sounder resulted in much better target resolution than that shown by the 30 kHz unit. Individual sprats were readily detectable and showed up very clearly on the paper record. An example is shown in Figure 6; in this experiment dead sprats about 10-11 cm in length were attached individually, varying distances apart, to a thin monofilament nylon line weighted with a lead sinker at one end. This was then lowered over the side of the stationary vessel into the beam of the sounder. Seven fish were used in this lowering, an upper one well clear of the remainder and two groups of three spaced as individuals varying distances apart. The minimum spacing used in the lower group was about 20 cm and the record showed that these fish could be discriminated as individual targets, although very narrowly separated on this vertical scale. The unit has a continuously variable transmission rate and the

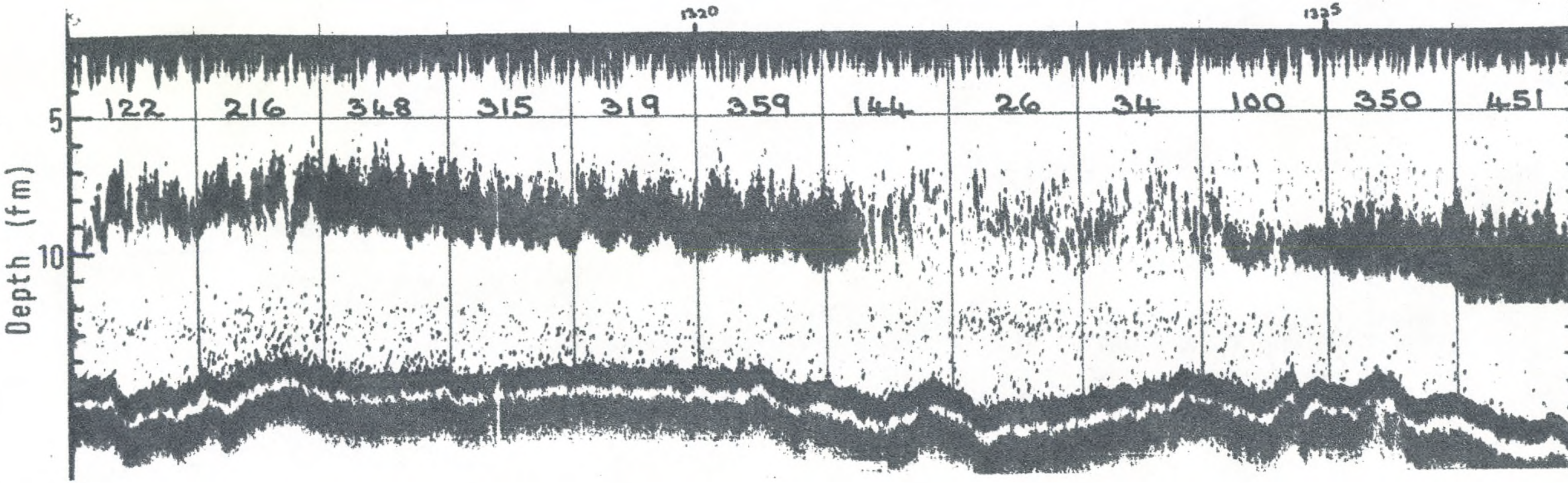


Figure 5 100 kHz echo-record showing layer of sprat shoals and cycle-counter values at one minute intervals (Wash, November 1965).

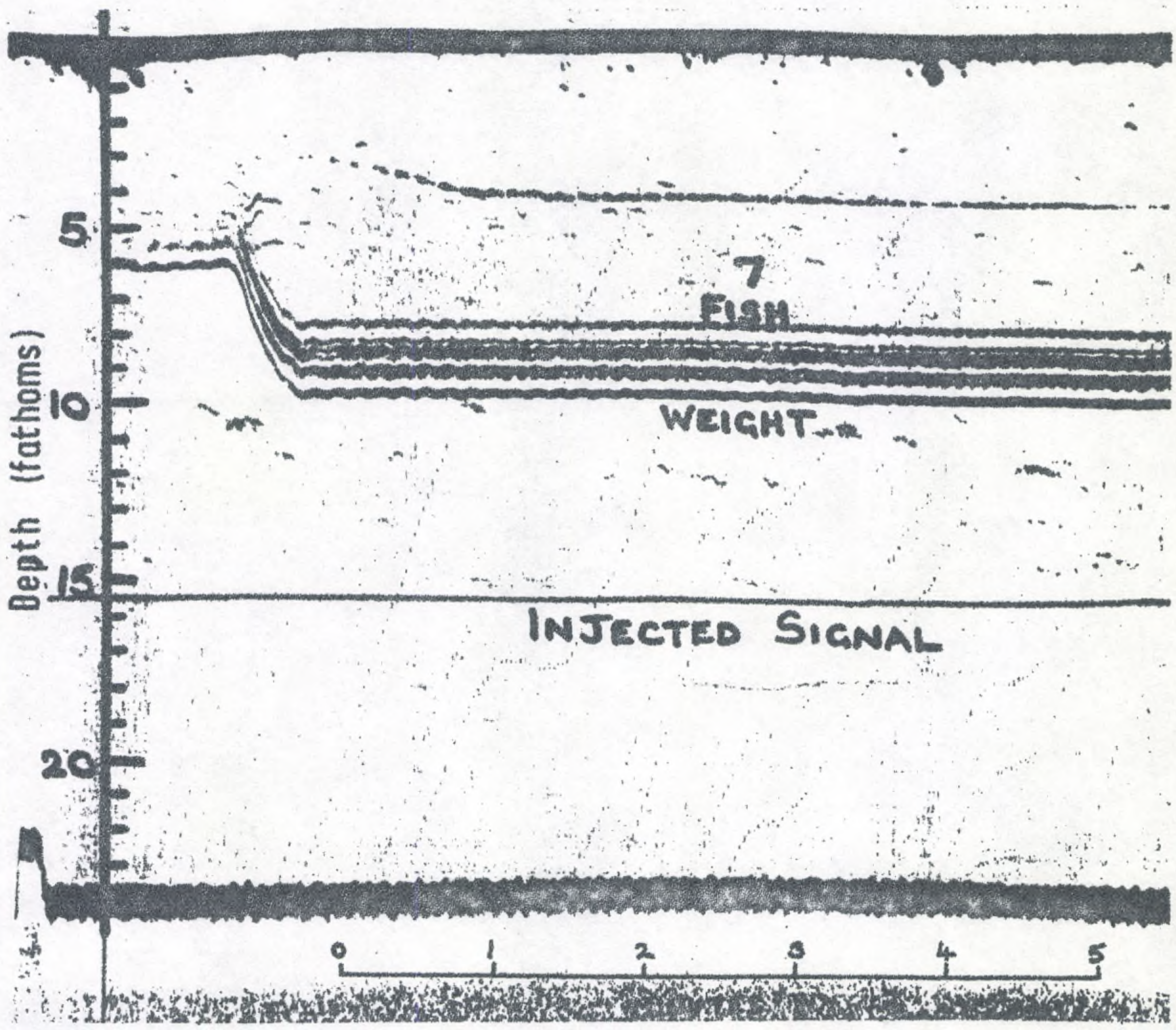


Figure 6 100 kHz echo-record showing signals recorded from single sprats lowered into the sound cone on a weighted monofilament nylon line.

vertical depth scale can be expanded to provide full use of the paper width in a depth of 15 fathoms if required. It was concluded that the unit should be capable of resolving individual targets at least a pulse length (15 cm) apart over shallow-water ranges.

There is also a facility for "gating" the signals between predetermined depth ranges, which enables the counting zone to be restricted if required. This is useful for avoiding aeration layers near the surface; also, where the shoals are found within a narrow layer the counting can be restricted to this zone. The breakdown of trace density into quantitative equivalents over fairly short time intervals has enabled a more critical analysis to be made of changes in the distribution of these fish concentrations in space and time, and has also provided a numerical index of total population.

A typical "density profile" of the fish concentrations recorded on a straight run down the middle of the Wash Estuary is shown in Figure 7. The total cycles recorded in each minute interval have here been plotted against time with an equivalent distance scale. The sector within which fishing vessels (single-boat midwater trawlers) were operating at the time is also indicated, together with their average catch-rates. It is clear from this diagram that the fleet was working on only a limited portion of the total fish concentration area then available, but they had selected a zone of maximum density for their operations; potentially equally good concentrations were present only a few miles away. The fairly clear-cut boundaries to these high-density patches are shown by the very rapid changes in density when entering or leaving them.

At this stage it has not been possible to estimate the absolute relation between cycle counts and numbers of fish, although some idea of the likely catch-rates has been arrived at by comparing counter results obtained in the vicinity of fishing vessels with their catch per unit effort. However, only a few observations are available and they are insufficient for a reliable calibration to be made. Escape under different conditions of water clarity, light

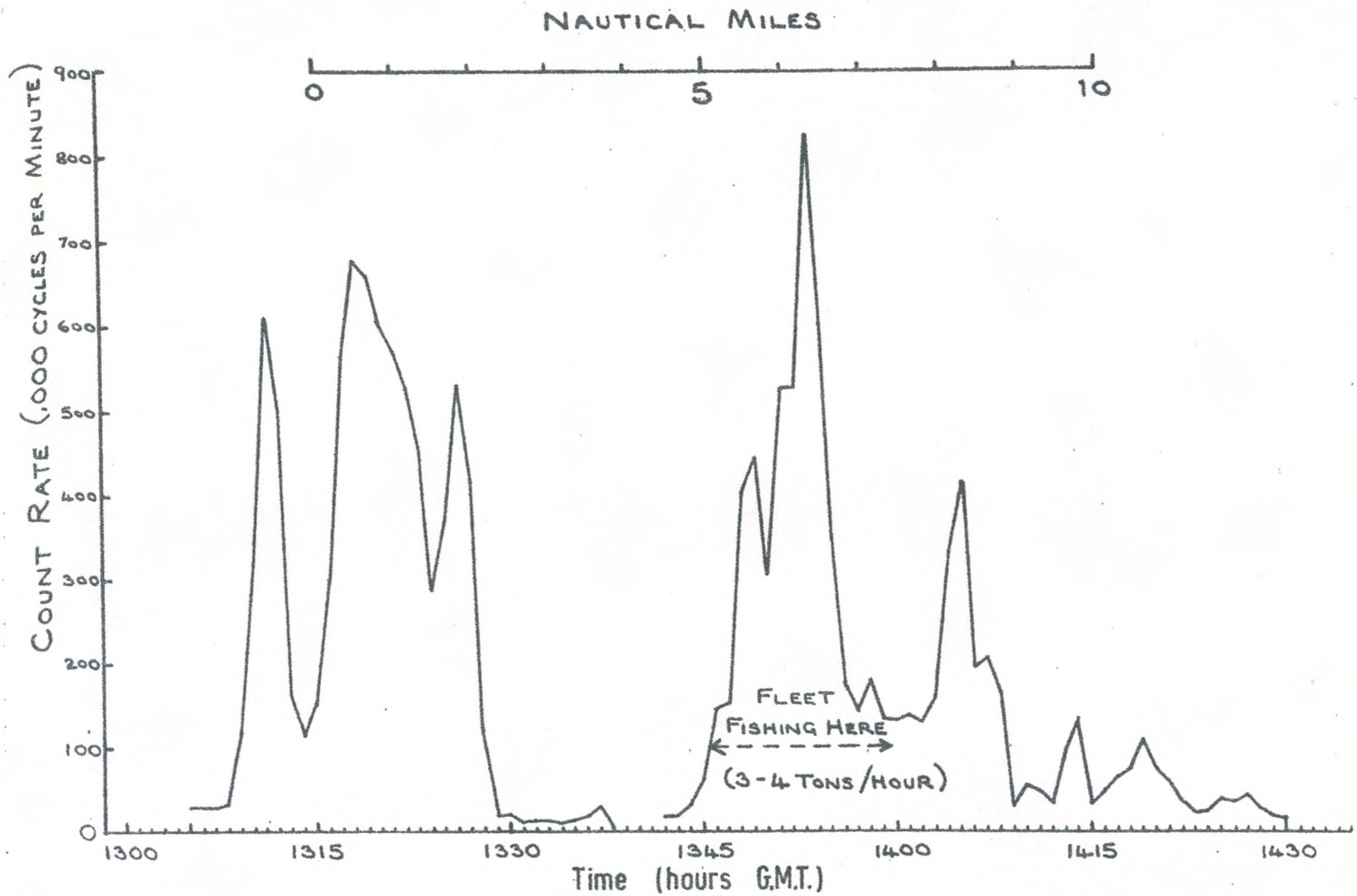


Figure 7 100 kHz cycle counter results, showing a density profile of sprat shoals along the Wash estuary in December 1965.

intensity, temperature, etc. in relation to the type of net and method of fishing used would result in increasing the variability of the estimate of "stock" from the echo count. Nevertheless the cycle counts can be used as a relative index of abundance to indicate changes in density distribution and total quantity of fish within and between seasons.

The results of counter surveys carried out in the Wash area during the 1965/66 and 1966/67 seasons are presented in this form in Table 3. The two seasons differed in several respects; that of 1965/66 showed an exceptional abundance of two-year-old fish (the 1964 year-class), and it was hoped that in the following season these would still be sufficiently abundant, as three-year-olds, to support a successful fishery. However, the 1966/67 season initially proved rather disappointing, with few signs of fish in quantity up to the new year. By this time most of the Grimsby vessels had given up in the Wash and in January they switched to the highly productive fishery that had developed off North Shields. Early in January the first indications of high-density aggregations appeared in the Wash area, but most of these lay well to seaward beyond the daily working range of the smaller pair-boats remaining in the fishery. Three-year-old fish did predominate in the catch (as expected) but did not appear in great quantities and were very small, the larger members of the brood apparently being missing. This became evident when comparing the distributions of otolith first-winter ring diameters between the two- and three-year-old fish of this year-class.

The counter results clearly support the differences registered by the fishery between the two seasons and also show a close correspondence with the changes in catch per unit effort within each season. Unfortunately it was not possible to compare catch per unit effort indices between seasons, due to the fact that only single-boat midwater trawlers were available at the time of the surveys in 1965/66 and only pair-trawlers in 1966/67. Within each season there was an interval of three to four weeks between surveys, each of which covered the area very thoroughly. A simplified representation of the results is shown in Figures 8 and 9.

Table 3 shows that there was an almost identical ratio of change (around two times) in average density, total numbers and catch per unit effort between the two surveys in each season. The total areas of high-density trace (i.e. potential fishing ground) also showed considerable increases between months in each season. A comparison of the total population estimates shows that the maximum value in the 1966/67 season (recorded in January) was only about one-quarter of the highest level in the previous one (December 1965). This reduction in abundance between the two seasons was reflected in the change in catch per unit effort registered by the Grimsby vessels, but not in that of the smaller pair-boats. In 1966/67 only a few pairs were operating and these were highly efficient boats which were able to locate and work very successfully on the comparatively small shoal aggregations within their range of operation.

Preliminary results from the high-frequency cycle-counter method of echo survey have thus proved very promising when used as purely relative indices of abundance, but further work is required before these results can be reliably translated into real terms of fish numbers or weight.

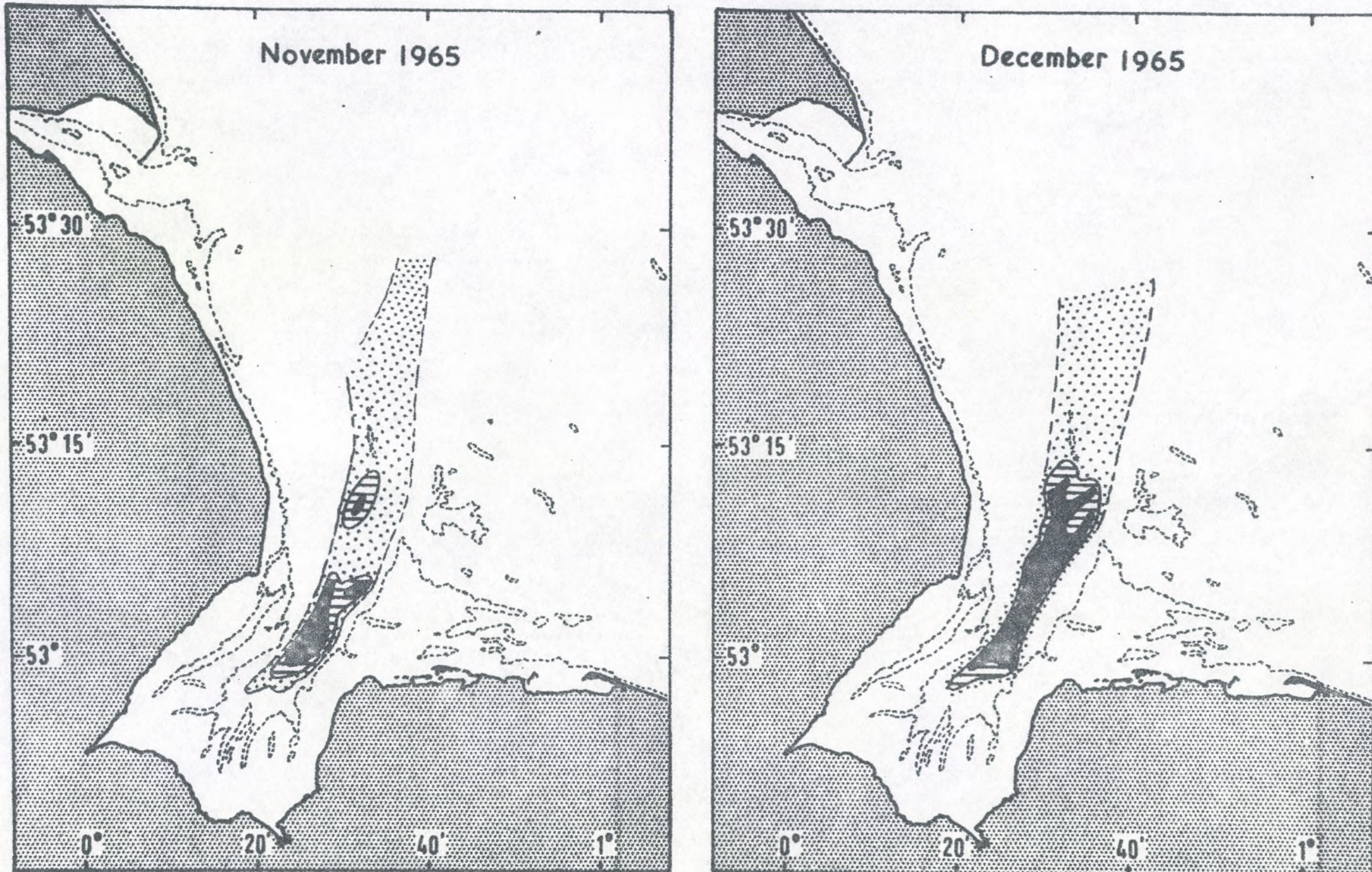


Figure 8 Results of counter surveys of sprat in the Wash area in the 1965/66 season.
Key: dotted areas, thinly scattered echo-traces; horizontal shading, medium echo-traces; black areas, heavy continuous echo-traces.

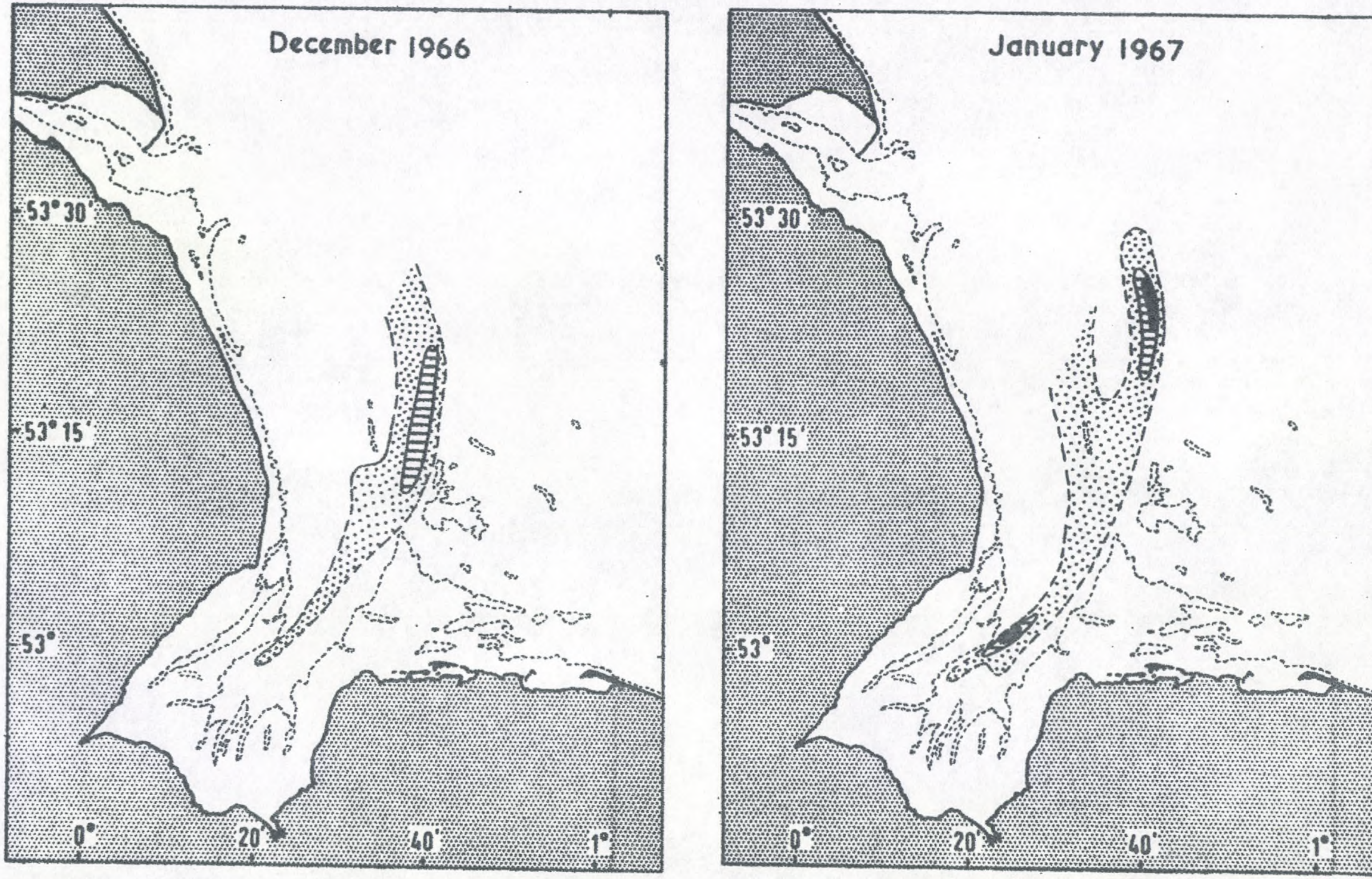


Figure 9 Results of counter surveys of sprat in the Wash area in the 1966/67 season.
Key: dotted areas, thinly scattered echo-traces; horizontal shading, medium echo-traces; black areas, heavy continuous echo-traces.

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Table 1 English sprat fisheries: average quantities (thousand tons) taken by each of the principal types of gear. The figures in parentheses are percentages of the total catch

Period	Stow net	Drift net	Seine net	Trawl	Other types and unknown	Totals
1906-09	1.19 (41.3)	0.90 (31.3)	0.65 (22.6)	0.09 (3.1)	0.05 (1.7)	2.88
1910-14	1.72 (46.1)	1.40 (37.5)	0.33 (8.8)	0.25 (6.7)	0.03 (0.8)	3.73
1915-19	1.15 (30.5)	0.67 (17.8)	0.91 (24.1)	0.81 (21.5)	0.23 (6.1)	3.77
1920-24	2.26 (54.1)	0.85 (20.3)	0.80 (19.1)	0.14 (3.3)	0.13 (3.1)	4.18
1925-29	1.81 (58.0)	0.78 (25.0)	0.23 (7.4)	0.30 (9.6)	- -	3.12
1930-34	2.40 (55.8)	1.34 (31.2)	0.31 (7.2)	0.25 (5.8)	- -	4.30
1935-39	2.96 (52.8)	1.74 (30.9)	0.35 (6.3)	0.56 (10.0)	- -	5.61
1940-44	0.36 (15.7)	0.43 (18.5)	0.87 (37.1)	0.67 (28.7)	- -	2.33
1945-49	0.62 (41.6)	0.38 (25.5)	0.06 (4.0)	0.43 (28.9)	- -	1.49
1950-54	0.45 (12.6)	0.41 (11.5)	0.11 (3.1)	2.59 (72.8)	- -	3.56
1955-59	- -	0.06 (1.8)	0.02 (0.6)	3.30 (97.6)	- -	3.38
1960-64	- -	0.25 (3.2)	0.04 (0.5)	7.52 (96.3)	- -	7.81
1965-67	- -	0.12 (1.0)	0.03 (0.2)	11.95 (98.8)	- -	12.10

Table 2 The Thames sprat fishery: total catch, number of landings and catch per landing (CPL) over different periods of time

	No. of seasons	Mean	Variance	Standard deviation	Standard error	% mean standard error
(a) Stow-net fishery (1905-38; 1945-52)						
1905-18	14					
Catch (tons)		1 477	665 498	815.8	226.3	15.32
No. of landings		449	56 831	238.4	66.1	14.74
CPL (tons)		2.24	0.7431	0.862	0.230	10.26
1919-38	20					
Catch (tons)		2 125	1 007 151	1 003.6	224.4	10.56
No. of landings		521	62 864	250.7	56.1	10.76
CPL (tons)		3.95	1.0677	1.033	0.231	5.85
1945-52	8					
Catch (tons)		667	46 178	214.9	76.0	11.39
No. of landings		353	31 122	176.4	62.4	17.68
CPL (tons)		2.05	0.5096	0.714	0.252	12.28
Overall	42					
Catch (tons)		1 635	1 002 037	1 001.0	156.3	9.56
No. of landings		465	565 311	751.9	117.4	25.24
CPL (tons)		3.02	1.6255	1.275	0.197	6.51
(b) Pair-trawl fishery (1951-68)						
Good seasons	11					
Catch (tons)		2 900	482 047	694.3	209.3	7.22
No. of landings		678	299 957	547.7	165.1	24.34
CPL (tons)		4.66	3.1590	1.766	0.532	11.43
Poor seasons	7					
Catch (tons)		689	835 339	914.0	345.4	50.17
No. of landings		514	248 688	498.7	188.5	36.67
CPL (tons)		1.03	0.1795	0.424	0.160	15.57
Overall	18					
Catch (tons)		2 040	4 360 693	2 088.2	492.2	24.13
No. of landings		615	271 031	520.6	122.7	19.95
CPL (tons)		3.25	5.2116	2.283	0.538	16.58

Table 3 Summary of the results of counter surveys for sprat in the Wash area, in the 1965/66 and 1966/67 seasons

	Mean count rate (thousand cycles/minute)		Area of high-density trace (naut. miles^2)	Total population (cycles x 10^{-9})	Catch per unit effort (thousand fish per hour)*
	Whole area	Fishing area			
November 1965	70	140	6	53.2	186
December 1965	150	250	18	99.5	303
Ratio Dec:Nov	2.1	1.8	3.0	1.9	1.8
December 1966	8	20	0	13.6	264
January 1967	18	36	6	26.9	510
Ratio Jan:Dec	2.3	1.8	-	2.0	1.9

* 1965/66 single-boat midwater trawl.
1966/67 pair-boat midwater trawl.

SPRAT SPAWNING SURVEYS OFF THE BRITISH ISLES IN 1959-67.

by

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Contents

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INTRODUCTION

Between 1959 and 1967 a series of spawning surveys was made covering the Wash and its offshore region, the Southern Bight of the North Sea, and in some cases the eastern part of the English Channel. The earlier surveys (between 1959 and 1961) used the Helgoland larvae net, whilst the later ones employed a high-speed tow net towed at about 5 knots. In addition, larval herring surveys carried out in 1959 and 1960 off the south coast of Ireland also yielded some information on the distribution and intensity of sprat spawning.

Earlier information on the spawning distribution of sprat in the southern North Sea was rather limited and based on the work of BOEKE (1906), TESCH (1909, 1913) and BUCHANAN-WOLLASTON (1911). Their results indicated that spawning commenced in February-March, extended until July-August, and probably showed a peak in May-June. The pattern of egg density distribution was somewhat irregular, with spawning taking place in both inshore and offshore waters within a fairly wide range of temperature and salinity.

SIMPSON's (1949a, b) plaice-spawning surveys covered the commencement of sprat spawning in the Southern Bight during the winters of 1946/47 and 1947/48. In the first winter, when very low temperatures prevailed, there were no indications of sprat spawning even by early March (the mean water temperature in the central Southern Bight then being only 3.5°C), but in the second winter, with temperatures in the central Southern Bight ranging from 8-9°C in January-February to 6-7°C in February-March, there were signs of a small amount of sprat spawning towards the end of January, and by February-March fairly high densities were recorded, mainly towards the Continental coast off the Scheldt Estuary.

The station pattern adopted during the present series of surveys has varied somewhat, but in the more open offshore water it has been a rectangular grid, with stations spaced at intervals of 10-15 nautical miles, whilst in inshore waters, where the configuration of banks and shallows makes it very difficult to work a regular pattern, the spacing has generally been much closer, between 3 and 7 nautical miles. The total area covered on each survey has also varied, being dependent on weather, time available and the vessel used.

The total numbers of eggs or larvae per haul were expressed as numbers under a square metre of sea surface. These values were then plotted and contoured to give a density distribution. The total area of each density interval was measured with a planimeter, to give the total number of eggs or larvae within each density range and an estimate of overall area-weighted density. Surface temperature and salinity observations were also made at most sampling positions; over most of the areas surveyed strong tidal currents are present, these ensuring almost complete mixing of the water column and so preventing vertical stratification of temperature or salinity.

The main results of the surveys are summarized in Tables 1 and 2 and the general findings are given below.

THE WASH AREA

The topographical limits defined for this area are from the Norfolk coastline to latitude 53°45'N (just north of the Humber Estuary), and eastwards from the coast to longitude 01°00'E. Some of the surveys in this region also extended well beyond these limits, but these results are not discussed here.

Duration of the spawning period, and egg and larval distributions

Very few fish have been recorded actually in spawning condition during the fishing season, even in March, though spawning may commence in this month since egg surveys in April have shown that it is then well under way. This is supported by observations on the maturity stages of fish taken towards the end of the commercial fishery in early March. Peak spawning takes place between April and June, and spawning has almost ceased in August.

The patterns of egg density distribution were rather complex and variable between surveys. In general a zone of fairly high-density spawning was evident in April and May along most of the main deeper-water channel leading from offshore into the Wash Estuary (a distance of about 30 miles), this also covering the main fishing grounds. On some surveys an outer limit to this Wash spawning was apparent, but on others boundaries were not found within the limits of the area surveyed. This was particularly noticeable later in the spawning season (June), when the pattern of spawning tended to become much more widespread and complex, often merging with a more extensive offshore spawning area of generally lower density, and showing signs of a northerly shift in the main locus.

Larval densities were generally much lower than egg densities, although on the earlier surveys (1959, 1960 and 1961) the use of a fairly slow-moving vertically-hauled Helgoland larvae net probably introduced an additional source of sampling error in the form of net avoidance, particularly for larger larvae in daylight hauls. An analysis made on the July 1961 survey showed a 6:1 difference in the average number of sprat larvae (all stages) taken between night and day hauls. The 1962 surveys used a high-speed tow net which was able to provide better estimates of larval densities.

Relation between spawning and temperature and salinity

Temperature and salinity distributions in this region are rather variable and can show fairly wide differences both between months and also between years in the same month. The average seasonal values within the main deeper-water channel (observations from the Lynn Well Lightvessel) show temperatures ranging from a minimum of about 4°C during January-February to a maximum of 16-17°C in August, whilst salinity shows a minimum level of 32-33‰ during March-April and a maximum of 33.5-34.0‰ in September.

At the time when spawning probably commences the water temperature is around 6°C and salinity near its minimum; at its end both temperature and salinity are near their maximum values. Peak spawning has taken place within the temperature range 8-13°C and salinity range 33-34‰.

There was no indication that the area and intensity of spawning was in any way related to the hydrographic regime, other than by the gradual shift in the main area of spawning from inshore to offshore as the spawning season progressed. The seasonal differences in spawning pattern are probably due to differences in the dispersal rate of the overwintering concentrations of sprat. Echo surveys show that in some years this can be quite a rapid process from March onwards, but in others it may take much longer and there have on occasion been signs of high-density patches of fish still apparent in April or even May. In the summer period (July-August) samples of fish from the inshore area (within 10 miles or so from the coast) show mainly immature feeding fish of the O- and I-groups with few larger older fish, most of these having by then presumably dispersed seawards.

Although the average egg densities and total numbers of eggs recorded did show considerable differences between months and seasons there was no evidence from echo surveys and catch data that the adult stock underwent any major changes in abundance over the period covered by these surveys.

THE THAMES AREA

The limits for this area are defined as from the coast, between latitudes 51°20' and 52°00'N, eastwards to longitude 02°00'E.

Duration of the spawning period, and egg and larval distributions

The results suggest that spawning commences in March, the peak months being April-June, and probably ends in August. There have been differences between years both in the patterns of egg distribution and in the total quantities present, and although some spawning has been evident in the channels within the inner part of the estuary, the major egg concentrations have usually been found further seaward. These have often extended as a fairly narrow band in an easterly or north-easterly direction from the Kentish Knock region (situated in the immediate eastern approach to the estuary) into the deeper water of the Southern Bight. Maximum spawning levels within the estuary limits are found in April, with more intense spawning further offshore in May and June.

Relation between spawning and temperature and salinity

In this area, also, the hydrographic regime is highly variable and rather complex. It is influenced chiefly by the freshwater outflow from the River Thames, with peak run-off from December to March, and an inflow of high-salinity Channel water entering through the Straits of Dover, mainly in November and December. Within the inner part of the estuary fairly steep horizontal gradients of temperature and salinity can arise, although the strong tidal currents do ensure complete vertical mixing. Regular observations from two lightvessels show the following seasonal changes:

	Land-bounded part of estuary		Immediate offshore area	
	Temp. (°C)	Sal. (‰)	Temp. (°C)	Sal. (‰)
Min.	4-5, Feb	34.0-34.5, Apr/May	6.5, Feb	34.6-34.9, May/Jun
Max.	17, Aug	34.8-34.9, Sep/Nov	16-17, Aug/Sep	34.8-35.2, Nov/Jan

Spawning commenced at about 6°C, with inshore salinity near its minimum. Maximum spawning took place over the range 8-14°C, in a period of increasing salinity, and had ceased before maximum temperature and salinity levels were reached. In some surveys increasing egg or larval densities appeared to be related to either an increasing or decreasing gradient of temperature or salinity. As also noted in the Wash area, this was dependent on the degree to which the main concentration area was situated offshore or inshore at the time, and on its spatial extension across the temperature or salinity gradients between the two areas. There were indications of a seawards shift in the spawning population as the season progressed, with the main dispersion in an easterly or north-easterly direction from the eastern approaches to the estuary. Samples of fish taken in the summer period from within the estuary show mainly immature O- and I-group feeding fish, most of the adults having dispersed into the deeper water offshore.

The Thames sprat fishery was almost a complete failure in the 1958/59 and 1959/60 seasons. It first showed signs of a revival in 1961/62, and this may have resulted from the increase in average spawning intensity noted between the earlier (1959/60) and later (1962) surveys. The fishery showed a major recovery between the 1962/63 and 1964/65 seasons, but no egg surveys were made over these years.

The recovery of the fishery was primarily due to the superabundant 1961 year-class when two and three years old, but unfortunately the year of origin for this brood was not covered by a survey in this region. The 1962 year-class showed increasingly strong representation in the fishery as it became older, becoming extremely abundant in its third winter, when it was mainly responsible for the record fishery in the 1964/65 season. The 1962 egg surveys showed that although fairly high egg and larval densities were present within the Thames Estuary region the main concentrations of both tended to be further offshore, and generally centred closer to the Continental coast. This distribution may have been partly responsible for the apparent scarcity of this brood in the Thames area when younger, although the very severe winter of 1962/63, with its exceptionally low inshore water temperatures, might also have influenced its early distribution. It later became increasingly available to the Thames sprat fishery, and probably also strongly contributed (together with that of 1961) to the big increase in the Continental coast fisheries over the same 1962/65 period.

THE SOUTHERN BIGHT AND EASTERN ENGLISH CHANNEL

Due to limitations of time and weather most of the 1959 and 1960 surveys were unable to provide full cover for the whole Southern Bight, and were confined mainly to the western half, between the entrance to the Straits of Dover and 52°30'-53°00'N. The 1962 surveys were able to provide full coast-to-coast cover, extending from latitude 53°45'N southwards to the eastern end of the English Channel. The May 1967 survey covered the central part of the Southern Bight and the whole of the English Channel, although the results currently available only extend to 2°W, between the Cherbourg peninsula and the English coast.

Duration of the spawning period, and egg and larval distributions

Spawning commenced earlier towards the Continental coast than on the English side, and was well under way in February-March. Peak spawning was evident from April to June and had finished by September, when only larvae were present.

There were differences between surveys and between years, both in the general level of spawning and in patterns of distribution. On the 1959 and 1960 surveys the general level of spawning was low compared with that encountered in 1962, and the main spawning areas were generally nearer to the coastal regions, with less in the central part of the Southern Bight. On most surveys a high-density patch was apparent immediately offshore from the Thames Estuary, as were similar patches towards the Continental coast. The 1962 surveys showed much higher spawning levels, with a very extensive fairly high density of eggs from coast to coast across the Southern Bight and the eastern end of the English Channel. There were indications of more localized higher-density patches between the offshore Thames and the entrance to the Straits of Dover, and off the Scheldt Estuary. Larval distributions on these 1962 surveys showed the main concentrations to lie between the Thames and Scheldt Estuaries, principally in the central deeper-water area. Examples of egg and larval distributions from some of the 1960 and 1962 surveys are illustrated in Figures 1-3.

The May 1967 survey (which did not extend into immediate coastal waters) showed spawning taking place over the whole survey area, with fairly high egg densities through the whole central Southern Bight extending well into the eastern half of the English Channel. Major concentrations were evident in about mid-Channel off the Seine Estuary, in the Dover Straits/offshore Thames area and off the Scheldt Estuary. The general density of sprat larvae was high over most of the survey area, and the distributions of three different size categories (< 10 mm, 10-15 mm and 15-25 mm) were analysed on this survey. The smallest larvae were the most abundant and mainly concentrated in much the same areas as those for maximum egg densities. The medium size group were less abundant, showing a more diffuse and lower-density distribution with a main concentration area between the Cherbourg peninsula and the Isle of Wight, and others off the French coast and through the central Southern Bight. The largest size group were the least abundant and more patchily distributed; these showed a principal concentration area extending from the English coast to about mid-Channel east from the Isle of Wight.

On all these surveys the patterns of egg or larval density distribution did not relate in any way to either temperature or salinity contours. When spawning intensity was greater nearer the coast higher egg densities corresponded with lower salinities, whilst the reverse applied when the main spawning activity was centred further offshore. On some occasions patches of high-density eggs or larvae extended across fairly steep gradients of temperature and salinity. Spawning commences at temperatures not much above the winter minimum and ends when they are approaching their maximum. The lower temperature limit for the onset of spawning appears to lie between 5 and 6°C and the time of commencing may be influenced by the winter temperature regime. ELWERTOWSKI (1964) has commented on the later onset of sprat spawning in the Baltic following

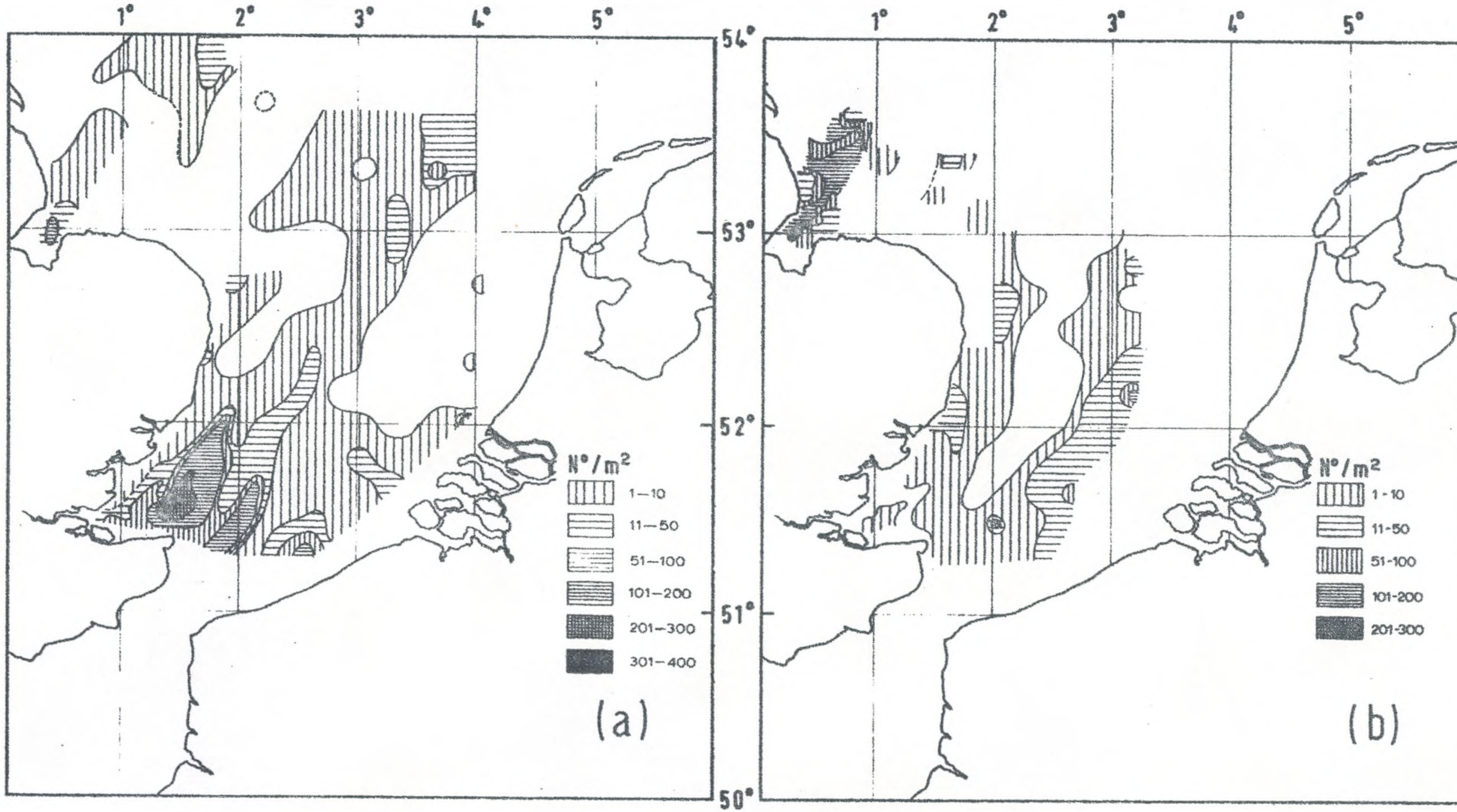

Figure 1 Distribution of sprat eggs in (a) April and (b) May 1960.

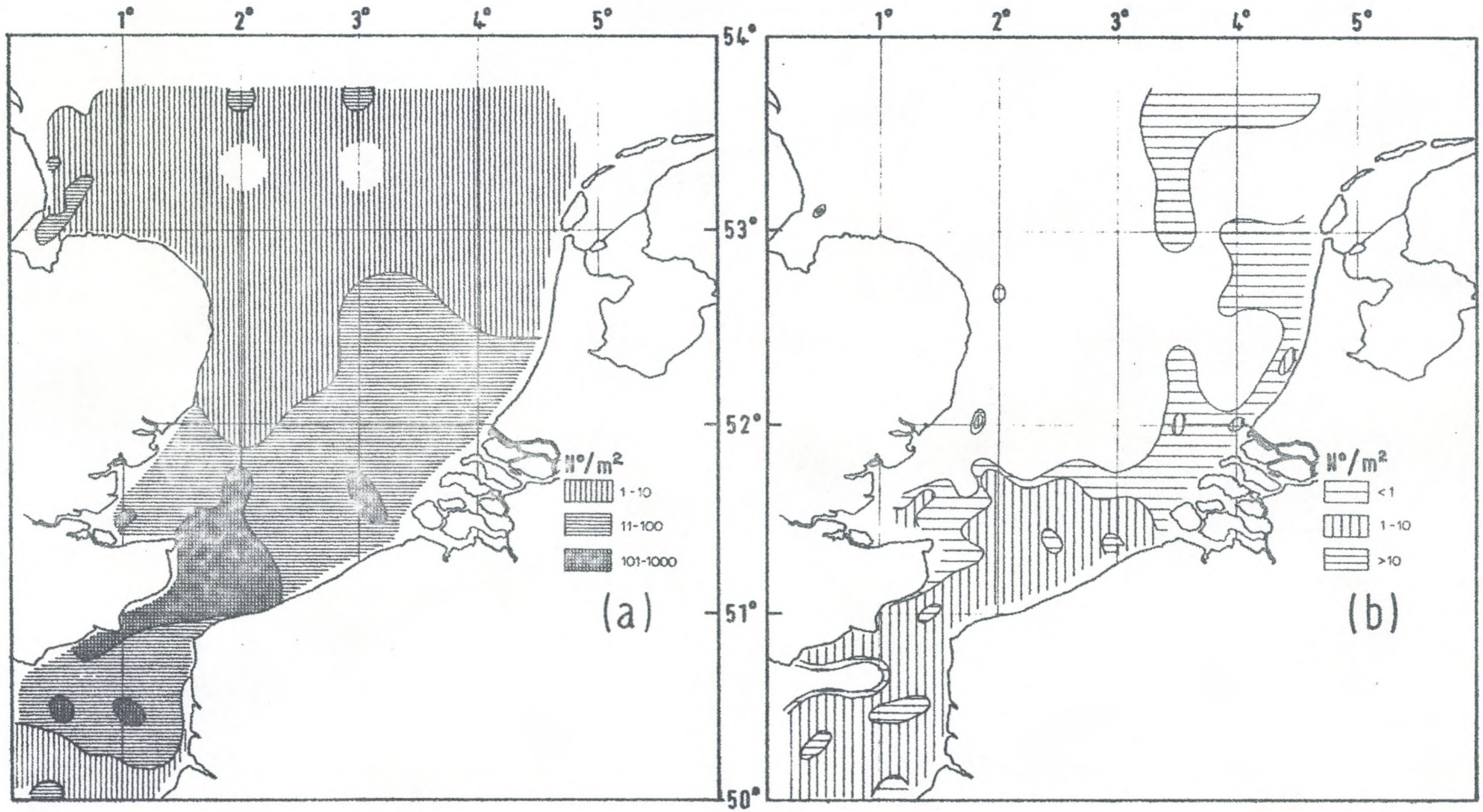

Figure 2 Distribution of (a) sprat eggs and (b) larvae in April 1962.

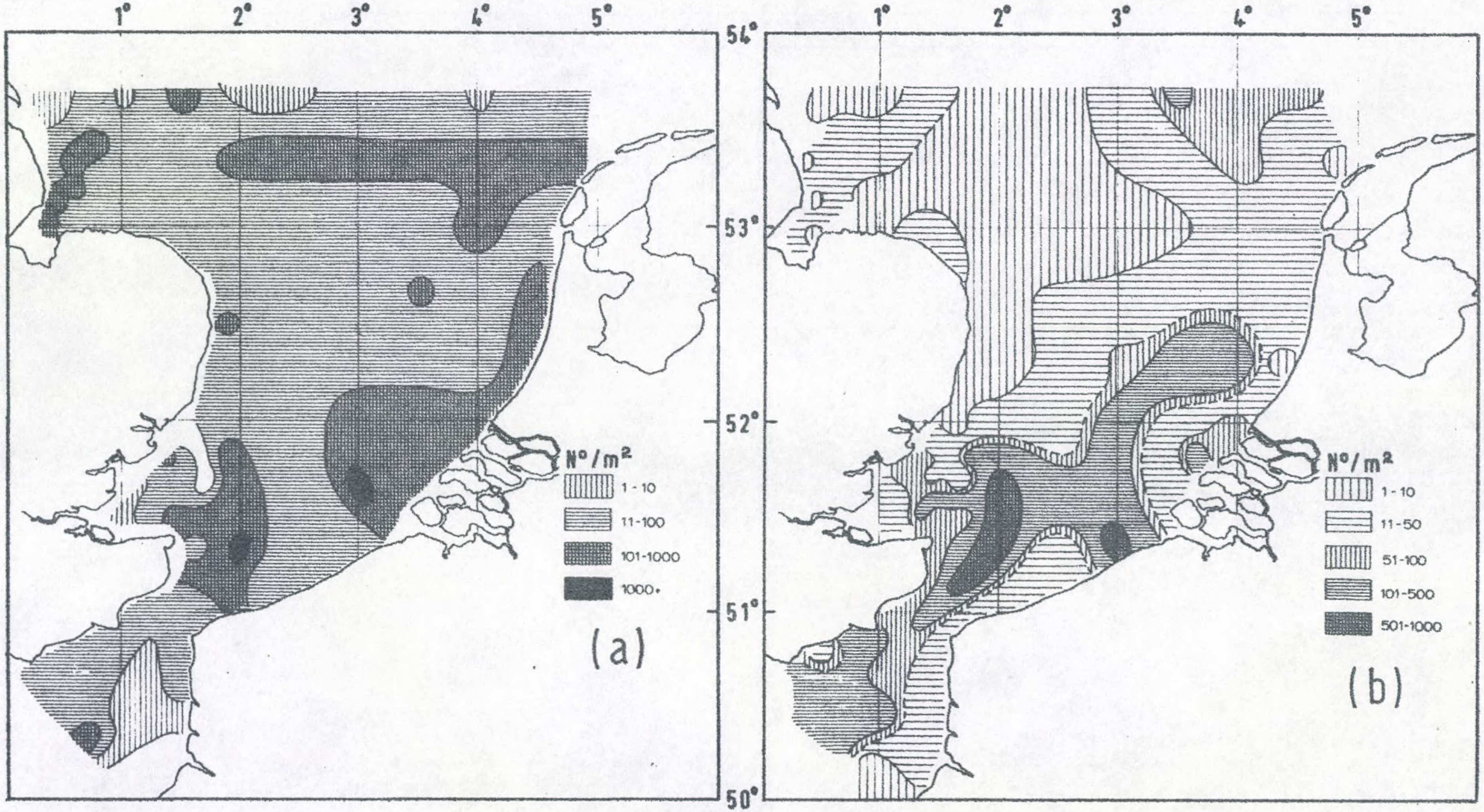

Figure 3 Distribution of (a) sprat eggs and (b) larvae in June 1962.

severe winters, confirming the evidence from the 1947 and 1948 Southern Bight surveys noted by SIMPSON (1949a, b).

GENERAL HYDROGRAPHIC CONDITIONS WITHIN THE SOUTHERN BIGHT

Although these surveys have been summarized by area they cannot really be considered in isolation when examining the relation between spawning and the stock supporting a particular fishery, especially when the area surveyed may not represent the entire spawning limits of the population concerned.

In the southern North Sea evidence from surface and bottom drifters shows that the residual current systems are somewhat variable and can be influenced by wind speed and direction. The basic system in this region involves a fairly strong residual flow (up to several miles per day) entering the Southern Bight through the Straits of Dover, which continues in a north-easterly direction through the centre of the area and finally loses its identity in the shallow water south-east of the Dogger Bank. On either side of the main drift there is a tendency for onshore movement towards either the Thames Estuary and the English east coast or the Continental coast, although the drift circulation pattern is probably broken and rather complex in the vicinity of the sandbank systems close to the coast. Under these circumstances most of the spawning products in the central area of the Southern Bight might be expected to carry on towards the German Bight and be lost to this region, although there could be some compensation from eggs and larvae carried into the Southern Bight from the Straits of Dover and the eastern end of the English Channel. The development time for sprat eggs is fairly rapid (estimated at 3-4 days) and they would not be carried any great distance in such a short time, but the duration of the larval and immediate post-larval existence is much longer and the main dispersal phase must involve this stage.

The predominant wind direction across the Southern Bight is from the south-west and strongest in the winter months, but between March and June the frequency of winds from the north-east increases, with a north-easterly airflow predominating in May. The prevailing wind pattern during the main spawning period is thus one which would tend to maintain eggs or larvae within the Southern Bight or even assist drift towards the English coast. Along the east coast of England and in the Thames Estuary there are extensive "whitebait" grounds where the first signs of the current sprat year-class usually appear in July, when the fish are 2.5-3.5 cm in length, although they are not generally evident in large quantities until the early autumn (September-October). However, the likely spawning origins of the young fish entering and accumulating in these coastal nursery areas is not known and would be very difficult to establish without almost continuous monitoring of large--scale changes in larval distribution over a fairly wide area.

THE SOUTH COAST OF IRELAND

Duration of the spawning period

These surveys were made, using a Gulf III high-speed tow net, between January and March in 1959 and 1960. The grids covered an area lying between Galley Head in the west (09°00'W) and Tuskar in the east (06°20'W), with some stations off the southern part of the east coast of Ireland, and were designed to cover the herring spawning areas. The offshore limit of the survey area ranged between about 30 and 50 nautical miles (generally extending out to the vicinity of the 50-fathom depth contour). The January surveys showed only very small quantities of sprat eggs, spawning probably commencing at this time, but in the February and March surveys of each year very large quantities of sprat eggs were recorded, these months probably representing the peak or near-peak period of spawning, although its end was not covered.

Relation between spawning and temperature and salinity

The survey results for February and March 1959 and 1960 are summarized in Table 1. Temperature differences between months and years were rather small, high egg densities (> 100 per m^2) being recorded over the range 7.7 to 9.1°C, with conditions generally a little cooler in 1960 than in 1959, whilst salinity conditions were rather more variable, with high egg densities within a salinity range of 33.9 to 35.0‰. There were fairly marked differences between the patterns of egg density distribution in the two years. In the 1959 surveys the limits of the spawning area lay further from the coast than in 1960, when the main spawning area was confined within a much narrower coastal band with maximum egg densities falling mainly within 15 nautical miles from the shore. This difference was possibly associated with the patterns of salinity. In 1960 the 35‰ isohaline lay somewhat closer to the coast than in 1959, and in both years approximately bounded the main sprat spawning area, although some stations in water exceeding 35‰ did show high egg densities, particularly in the March 1959 survey.

In these southern Ireland coastal waters salinity is basically governed by the interrelation between freshwater run-off from the various river systems and the inflow of high-salinity Atlantic water into St. Georges Channel offshore. The seasonal salinity cycle shows a maximum in December and January and a minimum about June, the Atlantic inflow usually commencing in August. The temperature cycle shows a minimum level of 8.0-8.5°C in February-March and a maximum of 15.5°C in August. Sprat spawning is thus well under way when temperatures are at or near their winter minimum and when salinity is still relatively high but beginning to decrease from its winter peak; it is not known when spawning ceases. Spawning off the east coast of Ireland seemed to be later; the March surveys did show some signs of it commencing about then. Spawning terminated fairly abruptly in the vicinity of Tuskar, although it was clearly evident that it extended to the west beyond the limits of these surveys.

There are no large-scale fisheries for sprat in this area and no estimate of the general strength of the sprat population can be made from this source. However, the average density of eggs within the spawning area (which ranged between about 2 000 and 2 500 square nautical miles at least) was much higher than those recorded in the same years for the Thames Estuary and Southern Bight where the fisheries had been generally low, and it was not until the 1962 surveys in the southern North Sea that comparable levels of spawning intensity were recorded in that region.

Larval densities were generally higher in 1959 than in 1960, but the relative strengths of the year-classes resulting from the periods covered by these surveys are unknown.

SPRAT FECUNDITY AND ESTIMATES OF TOTAL SPAWNING STOCK

Existing information on the fecundity of sprat is rather limited and this raises difficulties when attempting to estimate the size of parental spawning stock from the total number of eggs found on each survey. At the beginning of the spawning season the ovary contains a number of discrete size groups of oocytes, or batches, each group being characterized by a certain stage of yolk development. The total fecundity is estimated as the total number of oocytes (exceeding a certain minimum diameter) present, just before or early in the spawning period, it being assumed that all these will ultimately mature and be shed. The total fecundity/weight relationships for the sprat of the Kiel Fjord (HEIDRICH 1925), the Baltic (ASLANOVA 1954) and the Black Sea (PETROVA 1960) all show almost identical linear regressions. The combined regression shows that the total number of eggs produced per gramme of body weight increases slightly as the fish become larger, ranging from about 1 320 ova per g in a fish weighing 5 g (c. 9 cm) to 1 560 ova per g in one weighing 30 g (c. 15 cm).

Estimates of the number of egg batches released during the season range from seven to ten, although the average number of eggs per batch varies, depending on both the size of the fish and the stage reached by the individual in its spawning cycle. HEIDRICH's data suggest that in all size groups the number released per batch is small at the beginning of the spawning period, reaches a maximum around the middle of the period and declines again towards the end, the order of difference between minimum and maximum being two to three times.

The average number of eggs released per batch ranged from about 1 200 in a 10.5 cm fish to 3 600 in a 13.5 cm fish, the overall average for the population being about 2 000 eggs per release.

The procedure adopted in calculating the weight of spawning fish is as follows. Firstly, the total number of eggs (estimated by contouring density intervals and planimetering the areas within each of these) was corrected to allow for mortality reduction of the original numbers laid over the previous four days (assuming a four-day developmental period and a constant level of egg production spawned in discrete daily batches). The next stage was to divide this corrected total number of eggs by the average number of eggs likely to be released per batch by one ton of spawning fish (assuming a 50-50 sex ratio), which gave an estimate of the total weight of fish involved in four days' egg production. Finally, this total weight was doubled to allow for continuity of spawning, with an eight-nine day recovery interval between successive batches. Many assumptions have had to be made, particularly regarding the mortality rate in the egg stage and the average weight of individual fish in the spawning population. As this was not known, an average weight of 10 g per fish (equivalent to a length of about 10.5 cm) was used throughout. This method only provides an approach to tackling the problem, and more information is needed on many aspects of sprat spawning before more reliable estimates of spawning stock can be made from egg surveys.

The results of these calculations are presented in Table 2. The estimated values of spawning tonnage show a considerable range, probably due mainly to real changes in the strength of spawning stock with time and area, but also partly to differences in the relative cover of the actual spawning area on each survey, particularly within the Southern Bight, where the Continental coastal grounds were only partially covered on most of the earlier surveys.

These data could be adjusted to a more comparable level by arbitrarily defining fixed limits to the survey area and raising to this standard area.

This assumes that on each survey sufficient cover was provided to give a valid estimate of spawning stock density within the total survey area, and if the average distributional pattern was similar immediately around, then this average density could be raised to give a population estimate within the standard area. However, the greater the raising factor the more the errors implicit in this assumption will be magnified. Nevertheless, this procedure was tried out and the results are shown in the final column of Table 2. The standard areas used were similar in magnitude to those covered on the 1962 surveys in the Wash/Thames/Southern Bight, whilst off the south of Ireland the average area covered on the four surveys was used.

These raised values of total spawning fish show estimates for the Wash area ranging from around 1 400-2 000 tons up to a peak value exceeding 30 000 tons. The fishery in this region was fairly stable over the period covered by these surveys, and, as far as can be judged from echo surveys, the total stock accumulating in this area in the fishing seasons prior to these spawning periods did not change a great deal. Extremely high densities of fish are found here between November and February, dispersion of these over-wintering concentrations normally commencing in February, so that by the time spawning commences (March-April) the density of fish should have thinned out considerably. It is difficult to interpret events from echo surveys during the spawning period, due to the lack of discrimination between immature and mature fish, and within the latter group the spawning and non-spawning components. An attempt was made to relate echo densities with egg densities but no consistent relationships could be established. The estimated densities of spawning fish per square nautical mile in this region ranged from about 1 ton to a maximum of nearly 20 tons.

The Thames/Southern Bight estimates of total spawning population show a range from 7 000 tons up to a maximum exceeding 300 000 tons, with average densities of spawning fish ranging from less than 1 ton to 17 tons per square nautical mile. The maximum spawning populations show an increase of about ten times between the 1959/60 surveys and those in 1962, this period also marking the beginnings of an upward trend in the fisheries on both the English and the Continental coasts.

The survey carried out in May 1967 is of particular interest in that it followed after the worst Thames sprat fishery on record. The Continental coast fisheries had also shown poor results and the stock situation seemed generally low. However, good spawning concentrations were found, although these were mainly centred away from the coastal regions, and the resulting total population estimate was fairly high. A very large year-class originated from this spawning, which has since produced a great improvement in the English east-coast and south-coast fisheries.

The results from the surveys off the south coast of Ireland give spawning stock estimates ranging between about 10 000 and 50 000 tons, with densities from 3 to 16 tons per square nautical mile, but as the effort devoted to sprat fishing at that time was so small it is not possible to assess the general level of the stock from the fishery returns (a total catch of 22 tons was shown for 1959 and only 5 tons for 1960).

These estimates of spawning population weight are certainly within the bounds of possibility when compared with the likely magnitudes of stock accumulating during the winter period in estuaries such as the Wash and Thames in good seasons. Although the average "take" from the Wash fishery averaged only around 2 000 tons in the seasons preceding these spawning surveys, this was essentially effort-limited, and, judging from the evidence of echo surveys, represented only a very marginal exploitation of the total sprat population present in the area.

The fishery in the Thames area was genuinely low prior to the earlier surveys (1959 and 1960), averaging only a few hundred tons, whilst in the 1961/62 season it rose to nearly 1 500 tons. In the best Thames seasons

(1963/64 and 1964/65) the catch increased to 6 000-7 000 tons, and echo surveys suggested that this total represented only a very small portion of the quantity potentially available, effort and marketing restrictions preventing fuller exploitation of the resource.

The Continental coast fisheries (Belgium and Holland) averaged about 4 500 tons per year between 1959 and 1961, showing a peak value of 13 000 tons in 1964. These fisheries probably also only marginally exploit the full potential, since not a great deal of fishing effort is devoted to the capture of this species.

DISCUSSION

In all areas peak spawning took place over a fairly wide range of temperature and salinity, and the density distributions of eggs and larvae were not related to the distribution patterns of temperature and salinity. Temperature possibly has some influence on the onset of spawning in the southern North Sea, with a "threshold" in the 5-6°C range, although it would not have any limiting effects in the southern coastal waters of Ireland, where the average winter minimum is a degree or two above this level.

The general timing of the maturation cycle is probably more closely linked with that of the marine production cycle, this ensuring maximum egg and larval production over a period when suitable food organisms for the early stages are normally present in quantity. LEBOUR (1919) analysed the gut contents of larval and post-larval sprats from the Plymouth area. The results showed primarily diatoms and flagellates in the yolk-sac stages, diatoms, small nauplii and eggs of copepods, in larvae from yolk-sac absorption to 8.5 mm length, and between this size and metamorphosis (30-40 mm) nauplii and copepodite stages. NIKOLAEV (1961) and LISIVNENKO (1961) discuss the interrelationships between survival in early development and food availability for both Baltic herring and sprat, concluding that good year-classes are basically dependent on an abundance of suitable small zooplankton (mainly copepods) during the larval and immediate post-larval stages.

COLEBROOK and ROBINSON (1965) outlined the average seasonal cycles of change in the timing, duration and abundance of total phytoplankton and copepods in sea areas around the British Isles, and it is of interest to relate the peak spawning period of sprat determined from these surveys to the seasonal production cycle in the appropriate sea area. The total copepod production cycle within the western half of the southern North Sea shows a clear peak abundance between June and August; this follows the main sprat spawning period (April-June) and probably covers the period when larval numbers are at or near their maximum. HENDERSON (1961) analysed the distribution of young fish taken in the continuous recorder surveys from 1948-56. This shows a clear summer peak of clupeid larvae between June and August over a wide area of the southern North Sea southwards from the Dogger Bank, with a fairly broad band of higher density extending from the Thames area/East Anglian coast into the German Bight. The majority of these larvae were young sprat. A further point of interest is that sprat spawning commences about one month earlier (February) off the Continental coast compared with the English coast, which is paralleled by an earlier build-up of the copepod population in the eastern half of the southern North Sea, fairly high densities being reached there during March.

In the sea area off the south of Ireland, where high sprat egg densities were recorded in February-March, the copepod population normally shows a rapid build-up over the period February-April, with a rather flattened peak level between May and October. The total duration of the sprat spawning period is not known, although in the Plymouth area eggs have been recorded between mid-January and mid-July (HOLT and SCOTT 1897-99, HEFFORD 1913), with the peak spawning between March and June. This would again cover the period of most rapid increase in copepod population for this area.

In all these areas sprat spawning appears to commence as early as possible in relation to the copepod cycle, and reaches its peak intensity over the period when the copepod population shows its maximum rate of increase. However, more recent information from a series of surveys carried out between December 1967 and June 1968 shows that there is some flexibility in the timing of sprat spawning. These results showed spawning taking place in the first half of December within the Continental half of the Southern Bight and at the eastern end of the English Channel (this marking the western survey limit). The egg density and pattern of distribution were very similar to those normally found in February-March over this area. This spawning continued through the winter months at least until May, although full details are not yet available, and the reason for this earlier spawning has not been established. It is clear that within a specific area eggs may be present in quantity for three-four months, with the total duration of spawning extending up to five-six months. This extended spawning time is primarily due to two factors. The first is the "serial" nature of spawning in the individual fish, which has been commented on by a number of workers (HEIDRICH 1925, ASLANOVA 1954, PETROVA 1960). The second reason is that spawning activity is not synchronized throughout the population, this extending the spawning period for the whole population well beyond that of the individual. Often fish from the same sample will show varying degrees of maturation, and samples taken from the winter pre-spawning period show that the larger fish tend to mature sooner than the smaller ones and thus may very well spawn first. Serial spawning should ensure that at least a portion of the individual's total egg quota hatches at a period favourable for survival, whereas if the eggs were all discharged over a more limited period the chances of total loss or greatly reduced survival due to short-term periods of bad weather, or "patchy" distributions or low densities of food organisms, would be greater.

However, in spite of this safeguard for spawning success the relative strengths of different year-classes in the southern North Sea have undergone extreme variations in recent years. In the Wash area between 1958 and 1967 (a fairly stable period as far as the fishery was concerned) it was estimated that a difference in magnitude of about five times existed between the largest and smallest year-classes in terms of their relative contributions to the fishery. In the Thames area between 1961 and 1967 the differences between large and small year-classes have been much greater, this being a very unstable period for that fishery.

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Table 1 Summary of the results of the spawning surveys, showing the overall mean densities of eggs and larvae, and the average temperature and salinity in each spawning area

		Numbers per m^2		Temperature (^oC)	Salinity (‰)
		Eggs	Larvae		
The Wash area					
1959	February	Nil	Nil	5.0	33.05
	April	27.8	1.4	8.5	33.05
	May	21.0	7.1	11.5	33.66
1960	April	9.7	1.0	6.1	33.02
	May	127.1	31.5	11.4	33.41
	June	10.3	3.1	14.2	34.08
1961	July	9.2	16.4	14.2	34.12
	August	1.0	1.5	15.3	34.04
1962	April	68.7	2.0	6.7	33.52
	June	73.6	19.3	12.6	33.75
	September	Nil	1.9	13.3	34.05
The Thames area					
1959	February-March	1.1	Nil	5.8	-
	April	28.2	11.1	9.4	-
	May	2.3	3.6	12.5	33.50
1960	April	121.3	20.6	9.0	34.36
	May	4.1	1.9	11.6	34.17
	June	13.7	12.9	15.3	34.51
1962	April-May	71.9	2.3	7.3	34.30
	June	53.7	57.5	14.0	34.41
	September	Nil	0.4	15.1	34.91
South coast of Ireland					
1959	February	42.8	5.4	8.7	34.71
	March	128.2	69.6	8.9	34.89
1960	February	104.8	2.7	7.8	34.79
	March	98.6	13.4	8.5	34.44

Table 2 Summary of the results of the spawning surveys, showing the total areas surveyed and the density of the sprat spawning population within those areas

	Total number of eggs ($x10^{-9}$)	Total area surveyed (naut. miles^2)	Total spawning area (naut. miles^2)	Estimated spawning population (tons)	Density of spawning population (tons per naut. mile^2) within spawning area	Density of spawning population (tons per naut. mile^2) overall	Raised total spawning population (tons), adjusted to standard survey areas
The Wash area							
1959 April	45	550	459	2 080	4.5	3.8	7 182
May	20	306	275	893	3.2	2.9	5 548
1960 April	49	2 889	1 469	2 187	1.5	0.8	1 444
May	228	522	522	10 396	19.9	19.9	37 829
June	14	457	408	640	1.6	1.4	2 660
1962 April	43	1 865	1 804	1 960	1.1	1.0	1 995
June	464	1 835	1 835	21 158	11.5	11.5	21 907
Thames Estuary and Southern Bight							
1959 February-March	120	4 587	1 529	5 356	3.5	1.2	20 475
April	125	2 966	2 538	5 602	2.2	1.9	33 075
May	57	4 189	2 171	2 544	1.1	0.6	10 675
1960 April	560	9 841	6 887	25 534	3.7	2.6	45 325
May	93	3 313	2 579	4 240	1.6	1.3	22 400
June	24	2 758	1 501	1 094	0.7	0.4	7 000
1962 April	2 176	17 553	16 941	99 220	5.9	5.6	98 875
June	6 751	17 675	17 492	307 824	17.6	17.4	304 675
Southern Bight							
1967 May	813	3 063	2 898	36 286	12.5	11.8	207 375
Eastern end of Channel							
1967 May	1 004	5 913	5 704	44 810	7.8	7.6	-
South coast of Ireland							
1959 February	294	4 536	2 000	13 114	6.5	2.9	9 421
March	1 211	3 368	2 752	54 070	19.6	16.0	52 323
1960 February	835	3 178	2 320	37 270	16.1	11.7	38 240
March	587	1 968	1 739	26 270	15.1	13.3	43 521