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MACKEREL RESEARCH IN THE SOUTH-WEST

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AND
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by S. J. Lockwood and P. O. Johnson

INTRODUCTION

Records of the mackerel fishery off the coasts of Devon and Cornwall as early as 1602 may be found in R. Carew's "Survey of Cornwall", but until the late 1960s it was a minor fishery. It was pursued by east coast drifters in late winter following the East Anglian and Plymouth herring fisheries, and even after the demise of these fisheries. In 1926 over 5 000 tons of drift-caught mackerel were landed at Newlyn but this decreased rapidly to about 1 000 tons in 1950, less than 20 tons in the mid-1960s and the fishery had ceased before 1970 (Figure 1).

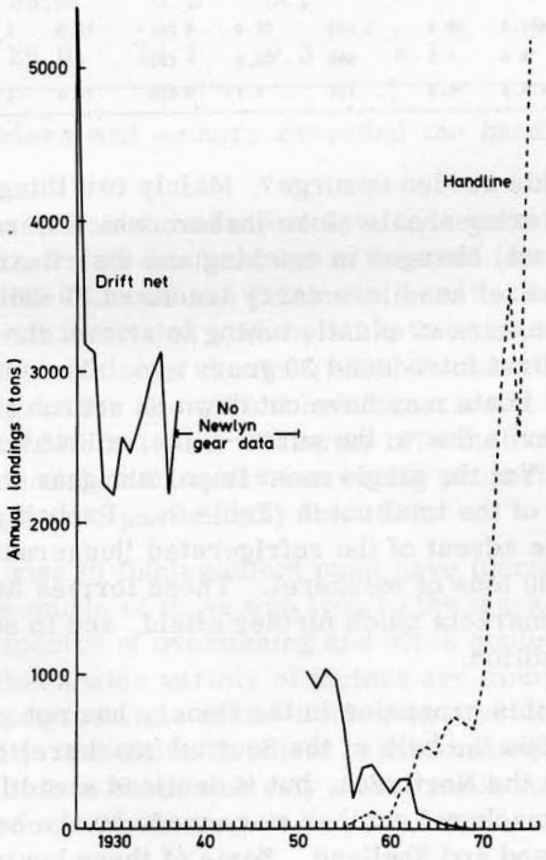


Figure 1 Annual mackerel landings by drifters and handliners at Newlyn, Cornwall, 1926-75.

Despite this decline in the drift fishery, in recent years the mackerel fishery has steadily grown to a boom industry. Between 1960 and 1970 in England and Wales total mackerel landings increased from 1 800 tons to more than 3 000 tons, but since then landings have increased dramatically to more than 30 000 tons in 1975, half of which was caught by handline feathering boats. In 1960 mackerel represented 6.1% of the total weight of fish landed at Newlyn, the major Cornish fishing port; in 1975 it represented 36%. At other ports, e.g. Looe and Mevagissey, it has assumed even greater relative importance (Table 1).

Table 1 Relative importance of selected fish species landed at Newlyn in 1960 and 1975 with the weights of fish landed at Mevagissey and Looe for comparison

	First sale value				Weight of fish landed							
	Newlyn				Newlyn				Mevagissey		Looe	
	1960		1975		1960		1975		1975		1975	
	£'000	%	£'000	%	Tonnes	%	Tonnes	%	Tonnes	%	Tonnes	%
All fish	270.4	100.0	1 322.2	100.0	3 904	100.0	8 593	100.0	1 818	100.0	2 562	100.0
All shellfish	7.2	2.7	82.4	6.2	46	1.2	113	1.3	193	10.6	91	3.6
All demersal fish	220.7	81.6	758.4	57.4	2 634	67.5	2 340	27.2	272	15.0	234	9.1
Skates and rays	68.4	25.3	106.0	8.0	773	19.8	338	3.9	29	1.6	10	0.4
Soles	26.2	9.7	90.8	6.9	80	2.1	57	0.7	2	0.1	1	0.06
Megrims	15.8	5.8	27.0	2.0	136	3.5	98	1.1	0.1	0.01	+	+
All pelagic fish	42.4	15.7	481.4	36.4	1 224	31.4	6 141	71.5	1 353	74.4	2 238	87.4
Pilchard	26.7	9.9	6.5	0.5	986	25.2	120	1.4	48	2.6	24	0.9
Mackerel	15.7	5.8	474.5	35.9	237	6.1	6 015	70.0	1 305	71.8	2 205	86.1

What has led to this sudden upsurge? Mainly two things: first, the presence of large overwintering shoals close inshore which were not present prior to the mid-1960s; second, changes in catching and distribution, particularly distribution. The mackerel handlines carry traces of 20-30 hooks, each bearing brightly coloured feathers or plastic tubing to attract the fish, and are much the same now as when first introduced 30 years ago. The increased use of echo-sounders in small boats may have cut down on search time but the greatest change in catching power is due to the purse-seine, midwater trawl, headline transducer and sonar. Yet the single most important gear is still the handline which accounts for 47% of the total catch (Table 2). Probably the most significant change has been the advent of the refrigerated 'juggernaut' lorry capable of carrying more than 30 tons of mackerel. These lorries have made it possible to find and exploit new markets much further afield, and to supply them with fresh fish in prime condition.

Naturally enough this expansion in the fishery has not gone unnoticed elsewhere. In the early 1960s the bulk of the Scottish mackerel catch (less than 1 000 tons) was taken in the North Sea, but it declined steadily until the late 1960s when increasing mackerel catches were made by the herring boats working off north-west Scotland and Shetland. Some of these boats tried fishing off Cornwall but it was not until the 1975-76 season that Scottish mid-water trawlers and purse-seiners fished there over a complete season. In 1975 the combined

Table 2 The annual catch of mackerel by gear as a percentage of the total catch in England and Wales

Year	Handline/ feather	Single boat trawl	Pair trawl	Beach seine	Purse seine	Drift net	Ring net	Fixed net	Freezer trawl
1964	86.0	3.2	-	1.9	-	6.1	2.3	0.5	-
1965	87.1	1.6	-	3.2	-	5.3	2.6	0.1	-
1966	88.3	1.3	-	3.2	-	3.1	3.9	0.2	-
1967	66.6	26.0	+	4.7	-	0.9	1.8	+	-
1968	74.4	18.0	+	4.6	-	0.2	2.8	+	-
1969	85.2	8.0	1.2	3.8	-	0.3	1.5	-	-
1970	85.8	7.9	1.6	2.7	-	0.7	0.6	0.7	-
1971	80.1	16.3	3.6	-	-	+	-	-	-
1972	89.2	3.3	6.8	0.4	-	0.4	-	-	-
1973	62.1	36.2	1.4	0.2	-	+	-	+	-
1974	55.7	35.8	8.3	0.1	-	-	-	-	-
1975	47.1	28.0	14.1	0.5	8.1	+	0.4	-	1.8

catch of the trawlers and seiners exceeded the handline catch for the first time (Table 2).

Although the UK catch and effort have increased considerably, they are still small compared with the increase in the total international catch of mackerel from the English Channel and Celtic Sea area*. Between 1926 and 1966 the total mackerel catch from that area by all nations reporting to the International Council for the Exploration of the Sea (ICES) fluctuated between 12 000 and 40 000 tonnes (Figure 2). By 1970 it had increased to 60 000 tons and in 1975 it was in excess of 300 000 tons. Prior to 1970 the bulk of this catch was taken by France, but since then a rapidly increasing proportion has been taken by Eastern Bloc countries, particularly the USSR.

This rapid rise in fishing effort must have increased the mortality rate of mackerel. In the minds of those who look to the mackerel for their livelihood it will raise the spectre of overfishing and stock depletion. To manage a fish stock it is vital that a wide variety of factors are monitored and used to compile a picture describing the state of the stock over a period of time in order to assess its stability, the ultimate object being to safeguard the stock and maximize the benefit both to those who rely on the stock now and to those who will rely on the stock in years to come.

*The Celtic Sea is defined as that area between 6 and 10°W, and between 48°30'N and St Georges Channel.

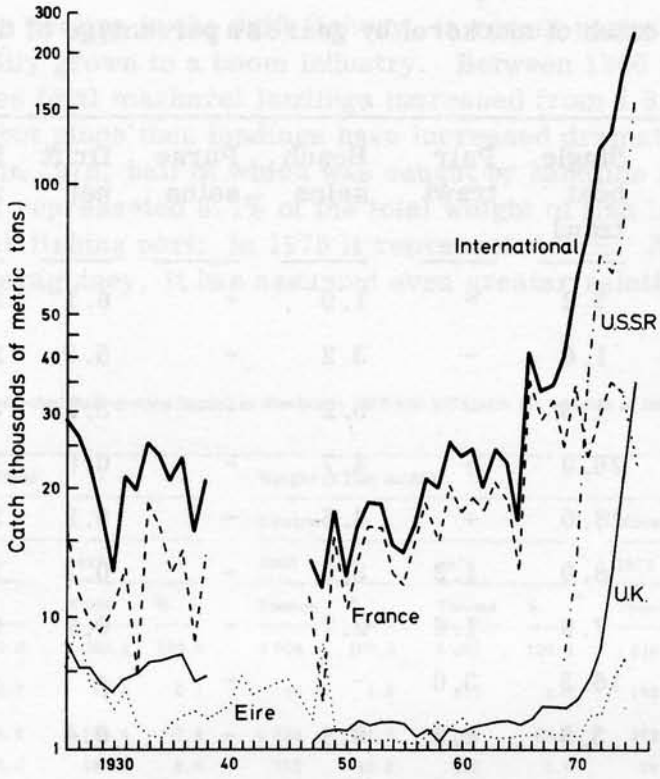


Figure 2 Total annual international mackerel catch from around the British Isles and catches by the major catching nations, 1926-76. (The Scottish catch is that from Scottish waters.)

Those factors which must be monitored to compile this picture form the basis of the scientific research programme carried out in connection with commercial fisheries. For some years past, both in the UK and in other European countries, a body of knowledge concerning the mackerel about our shores has been gathered. As the regional and economic importance of the mackerel has increased in recent years, so the research effort has increased, and we now have a full-scale research programme directed toward the management of the mackerel stocks. This leaflet has been prepared to inform all those with an interest in the well-being of the mackerel fishery as to what has been done, what is being done and what is still to be done to achieve the objectives outlined above. The information is presented in three sections: first, our present knowledge of the mackerel biology which is needed to understand any fishery; second, the recently-established catch data collection and market sampling programme, which relates the activity of the fishing fleet directly to the fish stock; third, the totally independent, and relatively new, technique of stock size estimation by use of echo-sounders. Readers may also be interested in the Torry Advisory Leaflet No. 66 by J. N. Keay on "Handling and Processing Mackerel" which also refers to some aspects of mackerel biology and the fishery.

THE BIOLOGY OF THE MACKEREL

During the summer months the mackerel (Scomber scombrus L.) is found throughout the waters of the European continental shelf. Throughout this period the fish are continually on the move, in small shoals, searching for their prey, smaller fish such as whitebait and sandeels as well as large planktonic copepods and krill. As summer turns to autumn the mackerel begin to converge on a number of discrete, but not yet well-defined, areas where they remain in winter time. There are three main overwintering areas around the British Isles, the positions of which are shown in Figure 3. They are in the Norwegian Deeps, south and west of Eire and off the Cornish peninsula. It is possible that those fish on the Cornish coast are an unstable offshoot of the overwintering fish in the outer part of the Celtic Sea, or they may represent the majority of the fish which overwintered in the outer Celtic Sea prior to the mid-1960s and for some unknown reason moved from the typical deep-water overwintering grounds to the, previously, unusual shallow inshore grounds. Since about 1965-66 large overwintering shoals have formed off the Cornish coast in October and dispersed during the period January to March. Nowhere else in the North Atlantic are overwintering mackerel found in a comparable position.

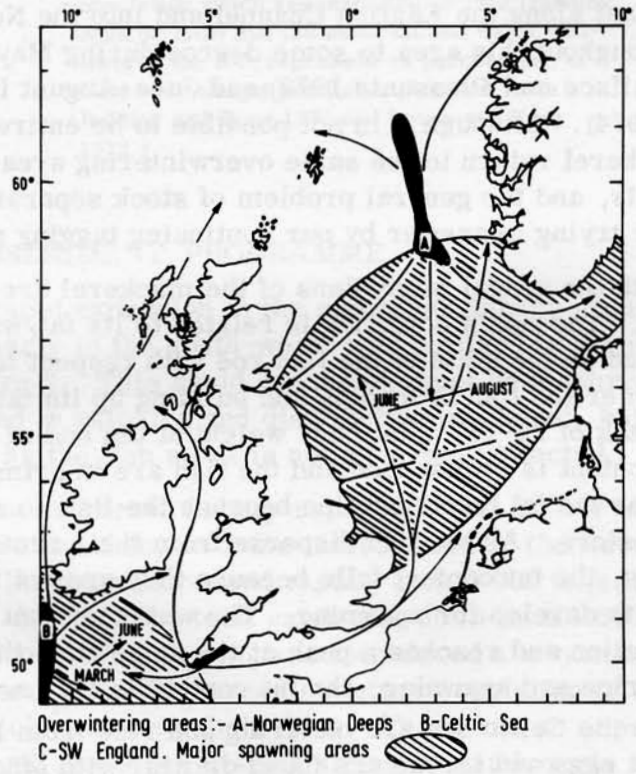


Figure 3 Distribution of mackerel around the British Isles. The mackerel spawn throughout the waters around the British Isles but the major spawning areas (hatched areas) are the Celtic Sea and central North Sea. The major overwintering areas (black areas) are: A the Norwegian Deeps, B along the continental slope of the Celtic Sea, C the relatively shallow water off the Devon and Cornwall coast.

While overwintering the mackerel do not feed, but neither are they totally inactive. During daylight they form large, readily identified shoals near the sea bed which rise and become less dense during darkness and concentrate again in daylight. Occasionally they may disperse for no obvious reason and reform again hours or even days later many miles from their previous position.

The directions in which the fish disperse from their overwintering grounds have been identified by tagging. Fish at the Norwegian Deeps move away in all directions, but it has been shown that a significant portion move into the Skagerrak to spawn from June to August before moving out into the North Sea (Lindquist and Hannerz 1974). No fish tagged in this area have been recovered south of 54°N. Fish which overwinter in the western Celtic Sea spawn in the Celtic Sea during March-June (Bainbridge et al. 1974), as do a proportion of the fish from off Cornwall. The fish that spawn in the Celtic Sea either go south and east toward the French coast or they move north (Bolster 1974). The northward migration takes some fish into the Irish Sea and along the west coast of Eire, where they are fished from April to November. Some go as far as Shetland, and even beyond, where they mix with fish from the Norwegian Deeps during July-September and are intensively fished by the Norwegian purse-seiners (240 000 tons in 1975). Of those 'Cornish' fish which do not go west to spawn, the majority move east along the English Channel and into the North Sea. Mackerel spawn throughout this area to some degree during May and June in the English Channel (Wallace and Pleasants 1972) and June-August in the North Sea (Bainbridge et al. 1974). Although it is not possible to be entirely certain, we believe that the mackerel return to the same overwintering area as they left to spawn and feed. This, and the general problem of stock separation, is among the questions we are trying to answer by our continuing tagging programmes.

Associated with the annual migrations of the mackerel are its condition and maturity cycles. The fish's condition is related to its fat/water content. Its maturity is defined as the state of the fish roe with respect to spawning. Throughout the summer the fish is feeding and building up its fat and oil reserves which reach a peak of 20-25% total body weight at the end of the year (Keay 1974). The water content is lowest then and the fish are in prime condition. Throughout the winter the fat levels decline because the fish do not feed but use the fat as an energy store. As the fish disperse from their winter areas toward the spawning grounds, the fat content falls because they are not feeding and also the roe is beginning to develop for spawning. The water content increases during this period of maturation and reaches a peak at the same time that the majority of fish are mature, ripe and spawning: the fat content is then as low as 5%. Fish which spawn in the Celtic Sea are maturing and ripe from March to June, the same period that eggs and larvae are found drifting with other plankton: those spawning in the North Sea mature two to three months later. Wherever they spawn they follow the same cycle, being in low condition over the spawning period and reaching peak condition prior to resting in winter. This annual cycle of sexual maturity and fat content is summarized in Figure 4.

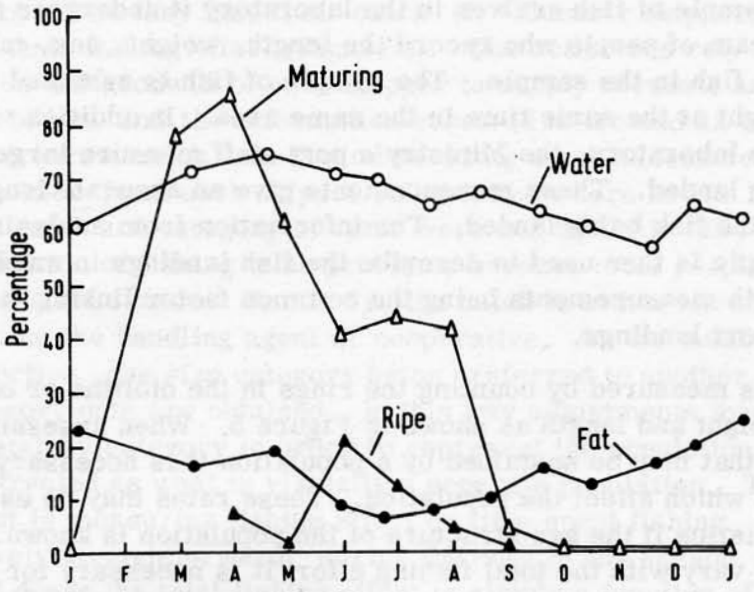


Figure 4 The annual fat, water and maturity cycles of mackerel, showing the percentages of the total population which are maturing or ripe (running eggs or milt) and the mean fat and water contents of the fish expressed as percentages of total body weight per fish. (Adapted from Bolster and Burd 1972 and Hardy and Keay 1972.)

THE FISHERY ASSESSMENT PROGRAMME

The recent rapid expansion in the mackerel fishery around the British Isles, and particularly in the south-west, was outlined in the introduction and illustrated in Figure 2. This rapid expansion must be a source of satisfaction to all those involved in catching and distributing mackerel, but it can only remain so as long as the fish stock is not adversely affected.

The North Sea mackerel fishery expanded from 20 000 tons in 1945 to 115 000 tons in 1964 and then, with the introduction of the Norwegian purse-seine fishery, the landings increased rapidly to 930 000 tons in 1967 (Revheim and Hamre 1968). By 1973 the total catch was down to 318 000 tons, but the damage had been done. The Norwegians introduced a minimum size of 30 cm, which is now an internationally agreed statutory regulation in the North Sea, and they placed catch quotas on their fleet. There are no signs of a rapid recovery of the North Sea stock despite stringent catch quota regulations which have lowered quotas successively over the last year or so. Nobody would wish to see the same dismal succession of events affect the mackerel stock to the south-west of England.

Fisheries stock management needs the collection of detailed information so that a constantly up-to-date picture of the stock may be formed. The current mackerel research programme in Devon and Cornwall is directed toward this objective. The programme requires that detailed catch information is collected from fishing vessel skippers and that samples of fish from the commercial catch are regularly sent to the Fisheries Laboratory, Lowestoft for biological analysis.

When a sample of fish arrives in the laboratory it undergoes a standard analysis by a team of people who record the length, weight, sex, maturity stage and age of each fish in the sample. The sample of fish is assumed to represent all the fish caught at the same time in the same area. In addition to the samples examined at the laboratory, the Ministry's port staff measure large numbers of fish as they are landed. These measurements give an accurate length-frequency distribution of the fish being landed. The information from analysis of the laboratory sample is then used to describe the fish landings in much greater detail, the length measurements being the common factor linking the laboratory sample to the port landings.

The age is measured by counting the rings in the otoliths or earstones. Age is related to weight and length as shown in Figure 5. When assessing the potential total catch that may be sustained by a population it is necessary to know the mortality rates which affect the population. These rates may be estimated from the landing statistics if the age structure of the population is known. Because mortality rates vary with the total fishing effort it is necessary for us to collect detailed catch information. This is being done in two ways: (1) MAFF staff

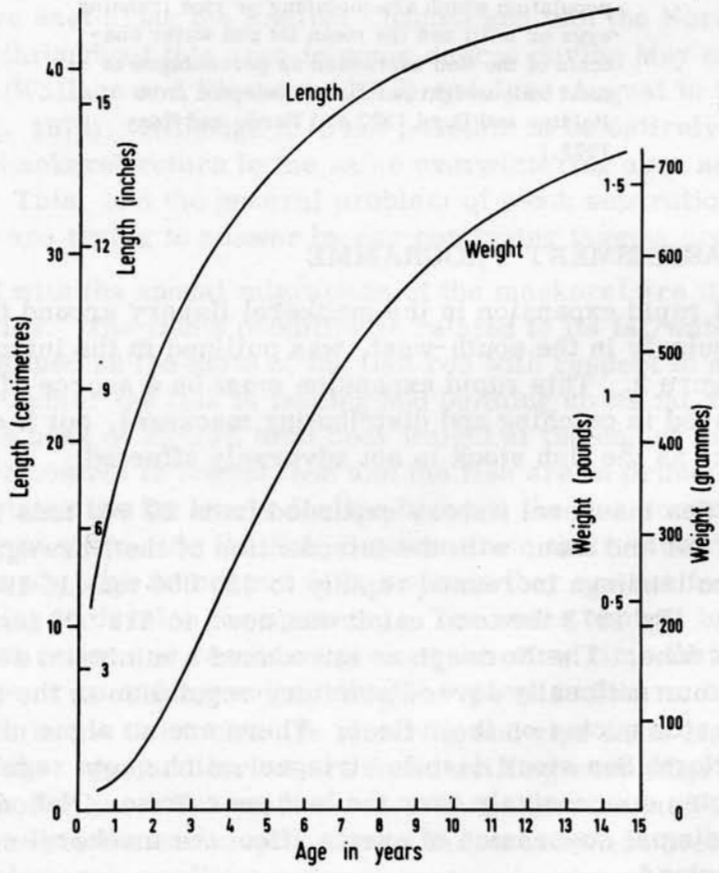
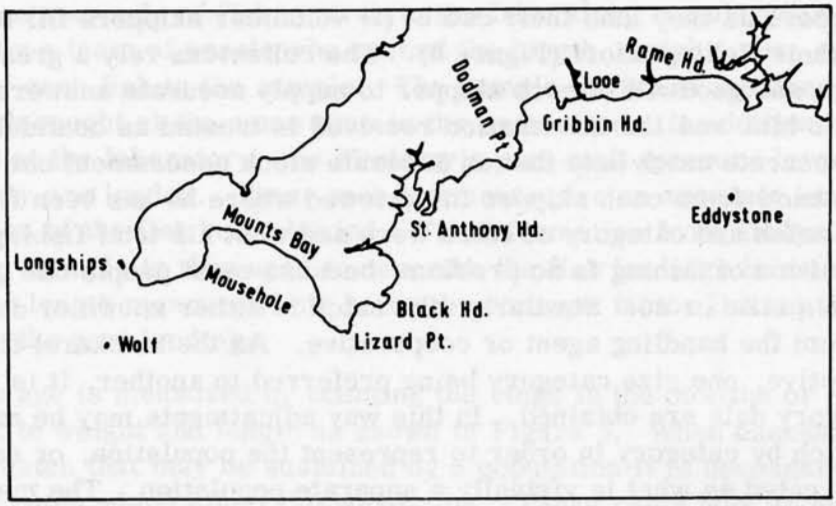


Figure 5 Growth in weight and length of mackerel from Cornish waters.

interview skippers as they land their catch (2) volunteer skippers fill in detailed log sheets of their fishing effort (Figure 6). The collectors rely a great deal on the cooperation and goodwill of each skipper to supply accurate answers to the questions put to him and the information received is treated as confidential. It is only from accurate catch data that an accurate stock assessment can be made. We require to know from each skipper interviewed where he has been fishing, what his total catch and category of catch were and what his total fishing effort has been. Position of fishing is no problem, because most people can give their position within a mile or so. Similarly, the catch is either known or details can be obtained from the handling agent or cooperative. As the mackerel fishery is so highly selective, one size category being preferred to another, it is vital that accurate category data are obtained. In this way adjustments may be made to the data on catch by category in order to represent the population, or each category may be treated as what is virtually a separate population. The main problem at present is measuring fishing effort or time spent fishing. For trawlers this is relatively straightforward; during the peak of the season, when shoals are large and dense the total fishing effort is simply a function of the time spent trawling. The purse-seiners' effort is less readily quantified. Searching time can exceed the time the net is being used and if they shoot and surround a shoal they may not land the fish, either because they escape or because they are released. This is still part of the total fishing effort but it may fluctuate widely with the catch landed. Similarly the measurement of effort by the feathering boats is not simple, for when they leave harbour they search, fish a while, search and fish a bit more. The time spent fishing and that spent searching are mixed, so we ask when fishing started and when it stopped and include searching time in fishing time. As the number of hooks on a feather trace tends to vary with port and boat size, we express the fishing effort in terms of 'hook hours'. The catch per 100 hook hours is then our measure of catch per unit of effort (cpue), which is the fishery biologist's standard index of fish population abundance. To ensure that a correct assessment is made, accurate abundance index data are vital, but in this respect the mackerel feathering fishery is very difficult. Not only is the total effort difficult to measure, but also a true abundance index is difficult to obtain because it is such a highly selective fishery. This is either because there are premium payments on a particular size of fish, or because there are quota restrictions in force.

Each change in abundance index tells a different story and the action which can or must be taken as a result of this change varies with the nature of the change. A rise or fall in the total landings of fish at a port may be the result of a change in absolute abundance but it may also be due to changes in fishing effort or even a shift by the fish from traditional grounds. A good example of this last possibility is, in fact, the 'Cornish' mackerel. Prior to the mid-1960s there were no major winter shoals and no winter fishery. Since then a regular winter fishery has been established and total landings increased every year. This alone does not indicate a change in total stock size. However, a rise or fall in cpue generally does indicate that there has been a change in population size. It is in analysing these changes that maximum use is made of the age distribution of the population, as ascertained from the samples dealt with at Lowestoft, and the measurements taken on the quay.



MACKEREL FEATHERING LOG

VESSEL & REG. NO. ..... TOTAL FISHING TIME*

SKIPPER & NO. OF CREW ..... TOTAL NO. OF HOOKS*

DATE ..... FISHING EFFORT IN HOOK HOURS*

TIME OF SAILING ..... CATCH/100 HOOK HOURS*

TIME OF RETURN .....

WERE QUOTAS IN FORCE? YES / NO

TIME FISHING STARTED ..... (TICK AS APPROPRIATE)

TIME FISHING FINISHED ..... IF YES, PLEASE GIVE DETAILS

NO. OF LINES USED .....

NO. OF HOOKS PER LINE .....

			*				*
CATCH RETAINED (STONES)	MINIS			ESTIMATED QUANTITIES REJECTED WHEN QUOTAS IN FORCE	MINIS		
	SMALL				SMALL		
	SMALL/MED				SMALL/MED		
	LARGE/MED				LARGE/MED		
	LARGE				LARGE		
	TOTAL				TOTAL		

BOXES MARKED * SHOULD BE LEFT BLANK.

PLEASE MARK FISHING POSITION AND AREA SEARCHED ON CHART TOGETHER WITH ANY COMMENTS ON FISH DISTRIBUTION.

REMARKS:

Figure 6 The mackerel catch and effort log sheet used to collect information on shoal distribution and abundance.

Figure 7 shows the changes in cpue of 2-year-old mackerel caught by the Dutch herring fleet in the North Sea for the period 1959-69. The 2-year-old fish were the youngest fish caught and hence have been subject to no previous mortality as a result of fishing. These data show that, in keeping with other pelagic fishes, there have been quite large fluctuations in cpue. The 2-year-

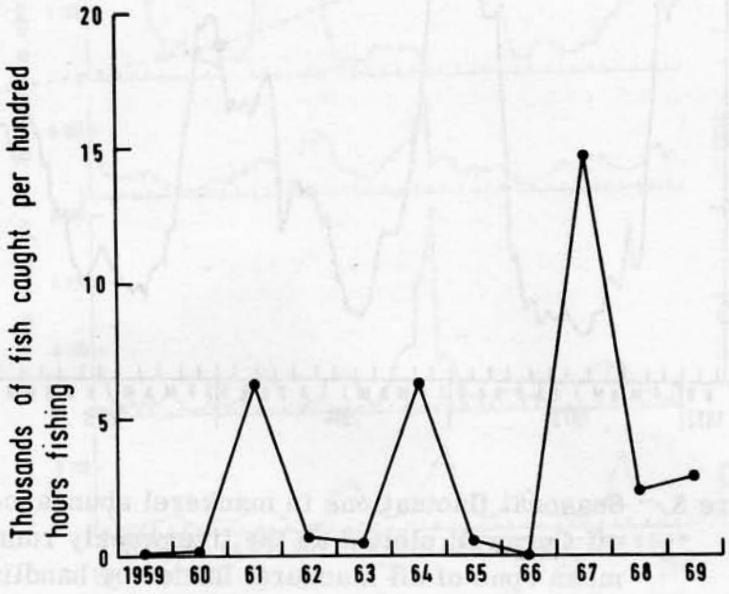


Figure 7 Annual fluctuations in abundance of 2-year-old mackerel in the North Sea, 1959-69, from catch per effort of Dutch herring trawlers (Postuma 1972).

olds were most abundant in 1961, 1964 and 1967: these were the fish spawned in 1959, 1962 and 1965 respectively. For the period since 1969 we know that the 1968 Celtic Sea spawning and the 1969 North Sea spawning were above average. Figure 8 shows the changes in the abundance index of mackerel off Cornwall for 1972-76 as calculated from the log sheets completed by some skippers. The results show a very clear seasonal pattern of mackerel abundance, which is familiar to every mackerel fisherman. The catch rates are lowest from May to August and highest from October to February, with 1973-74 and 1974-75 the apparently best and poorest seasons in that the cpue reached the highest and lowest seasonal maximum respectively. When the seasonal mean cpue for the period 1 November-28 February is calculated it is seen that there has been a steady decline in the total mackerel catch over the four years from about 0.5 tonne per 100 hook hours to a little over 0.33 tonne per 100 hook hours. This suggests a declining stock but it is only when the catch is looked at by cate-

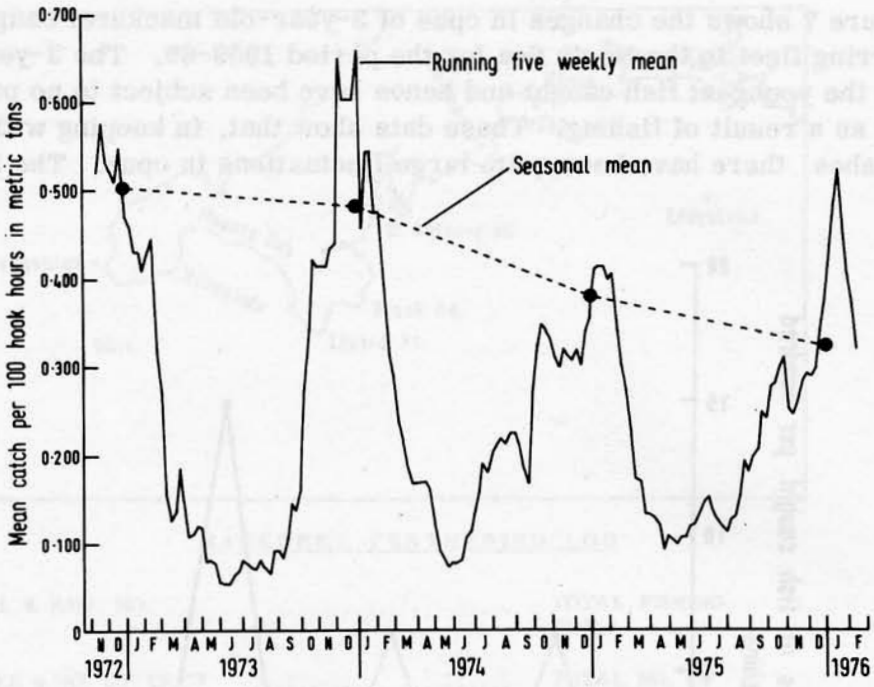


Figure 8 Seasonal fluctuations in mackerel abundance off Cornwall plotted as the five-weekly running mean cpue of all mackerel landed by handliners, 1972-76.

gories that the true picture can be seen. Figure 9 shows that it is the large category, fish over 1 lb, which have decreased in abundance but the other categories have apparently remained relatively stable. The decrease has been about 50% over four seasons. As there is a very strong market preference for large mackerel this may be the result of overfishing, but there is also a biological explanation for the decline, to some extent at least. By referring back to Figure 5 it can be seen that mackerel reach a mean weight of 1 lb at about six years of age, and we know that the fish spawned in 1968 in the Celtic Sea were more abundant than average broods. This 1968 brood of mackerel will have joined the existing population of fish in 1972-73; they probably dominated the large category in 1973-74 and, because the subsequent broods are not as numerous, the large fish are being fished out faster than they are being replaced. This in itself does not imply overfishing because there would be a natural decline in large category abundance in the absence of fishing as the 1968 brood dies off.

As well as monitoring the size of the population, the abundance index for each age group of fish provides a measure of the mortality rates affecting the population, e.g. a cpue of ten 5-year-old fish in one year and five 6-year-old fish the following year tells us that the total mortality of 5-year-olds is 50%. If we are able to collect this information over a number of years, for several levels of fishing intensity we are able to assess what part of the total mortality is due to fishing. We are then in a position to assess what level of total mortality will not affect the stock adversely and hence what the maximum fishing intensity (Total Allowable Catch) should be.

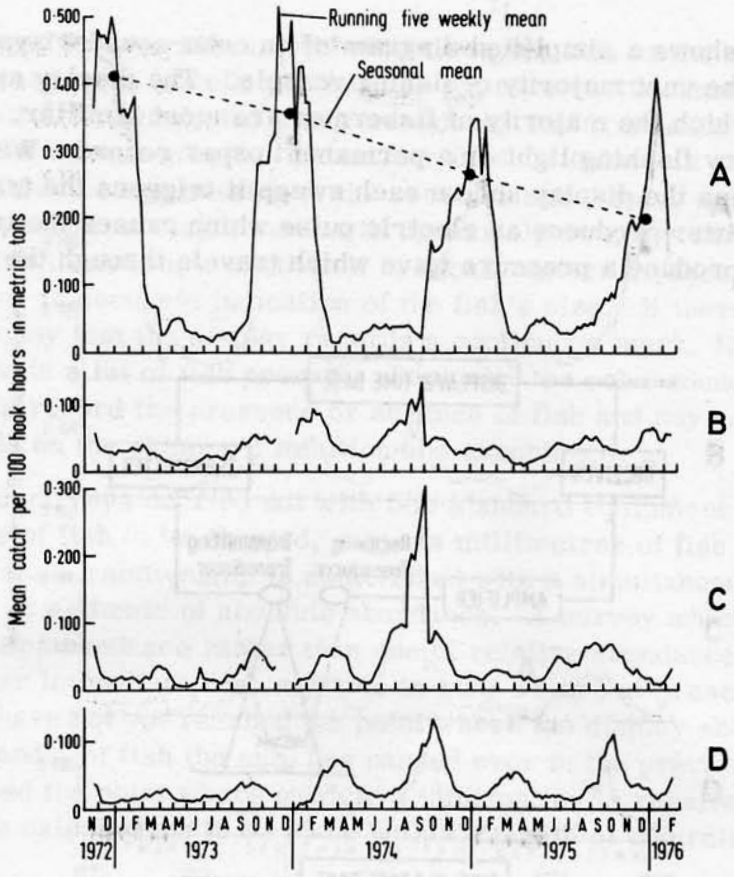


Figure 9 Seasonal fluctuations in mackerel abundance, by categories A large, B large-medium, C smal -medium, D small (The break during the autumn of 1973 was the result of strict quota fishing due to distribution problems resulting from the Arab oil embargo and also a shortage of the cardboard packing boxes.)

STOCK ASSESSMENT BY ACOUSTIC SURVEY

O ·er the past few years staff of the Fishe ·ies Laboratory have been involved in developing ech -sounding equipment th . will quant ·y the amount of fish beneath the ship. Many Cornish fishermen will have got to know RV CIROLANA, the ship used both in this development programme and, more recently, to carry out actual acoustic surveys off the Devon and Cornish coasts in winter. The following is a brief account of this work and the equipment used in an acoustic survey stock assessment.

Figure 10A shows a simplified diagram of an echo-sounder system typical of those fitted to the vast majority of fishing vessels. The display and time base is that part with which the majority of fishermen are most familiar. The display may be a temporary flashing light or a permanent paper record. With the paper record a pen sweeps the display and on each sweep it triggers the transmitter unit. The transmitter produces an electric pulse which causes the transducer face to move and produce a pressure wave which travels through the water.

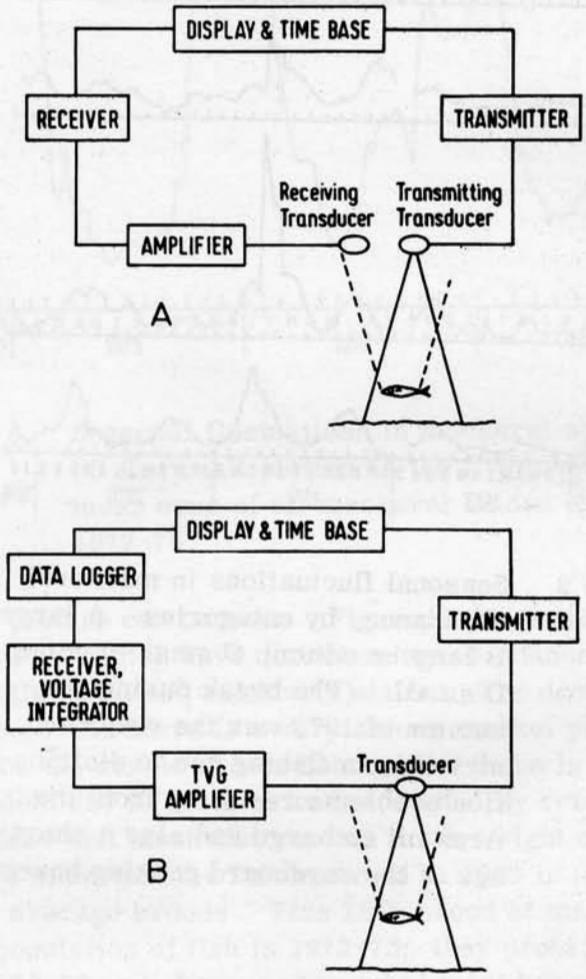


Figure 10 (A) Simplified diagram of the echo-sounder system fitted to most fishing boats.
(B) The more advanced system fitted in some research vessels to measure the quantity of fish passing through the echo-sounder beam.

When this pressure wave hits a solid object, e.g. a fish or the sea bed, a smaller pressure wave is reflected back to the receiver transducer (shown separately, but it is usually the same transducer that transmits and receives). As the pressure wave moves the transducer face, it induces a small voltage, which is amplified before passing to the receiver and display units. If the echo is from a single fish, a single mark will appear showing how far that fish is from the hull, but it will not show whether it is ahead, astern or abeam of the hull. Nor will it give an accurate indication of the fish's size. If there are more than one fish, so many that the display records a continuous mark, little more can be said than there is a lot of fish present. Basically the echo-sounders fitted to fishing vessels record the presence or absence of fish and any additional information depends on the skipper's intuition and experience.

Acoustic surveys carried out with this standard equipment enable the relative abundance of fish to be charted, e.g. as millimetres of fish marks per mile, but, unless a close relationship is established with a simultaneous fishing survey, it cannot give an estimate of absolute abundance. A survey which gives an estimate of absolute abundance rather than one of relative abundance will clearly be of much greater immediate use, and this is what we are at present trying to achieve. We have not yet reached the point where the display shows how many tons (or thousands) of fish the ship has passed over in the previous mile; but we have reached the point where sufficient information is received and recorded to enable these calculations to be made within a month of returning to the laboratory.

Stock assessment by acoustic survey requires a modified echo-sounding system which is shown in simplified outline in Figure 10B. The display, transmitter and transducer are, to all intents and purposes, the same as in a standard echo-sounding system. The main modifications are in the receiving part of the system. Each transmission from the hull transducer is produced at a fixed known strength and as the pressure wave passes through the water it loses strength at a known rate. The pressure wave hits a fish and the echo returns to the transducer, still losing strength. When this signal is processed at the amplifier a correction is made to allow for the time lapse between transmission and reception. This process, carried out by the Time Varied Gain (TVG) amplifier, ensures that the received signal strength from say a 40 cm fish is the same whether the fish is 10 or 100 m below the transducer. The received voltages are then added together over a predetermined time interval (which may be as little as one transmission, but more usually the time to steam one nautical mile) and recorded in both graphical (Figure 11) and numerical form.

To convert these recorded voltages to a quantity of fish involves a series of calculations for which it is necessary to know not only the physical characteristics of the echo-sounder being used but also the species and mean size of fish being recorded. At present this information on the fish is obtained by

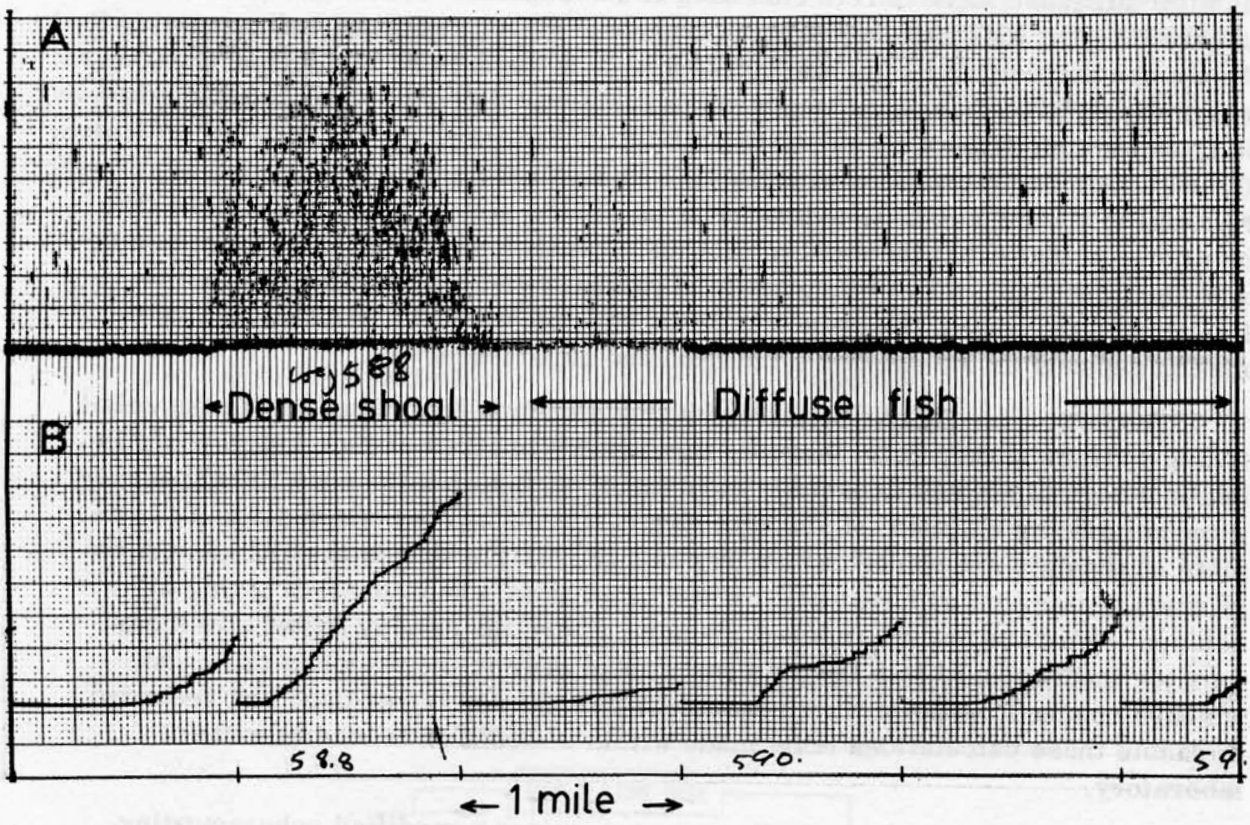


Figure 11 Record of echo signal strength made on an acoustic survey. Part A shows the individual signal strengths recorded for each transmission. Part B shows the running total signal strength recorded over each mile of survey.

trawling periodically throughout the survey, but attempts are being made to use a towed underwater camera instead (Figure 12). It is necessary to know the size and species of the fish as the strength of the echo (target strength) varies with both size and species. A large fish has a higher target strength than a small one, and fish with swimbladders (e.g. pilchard) have higher target strengths than those without (e.g. mackerel). At present we are still involved in making accurate target strength measurements of mackerel (and other species) to enable us to raise the voltages recorded on surveys to accurate absolute abundance estimates.

The mackerel acoustic survey grid covers an area off the south-west coast of England between Start Point (03°30'W) and Land's End (06°00'W) and extending offshore to the median line of the English Channel. It covers an area of approximately 5 250 square miles. The legs of the grid are spaced at 10 ft (6.3 n mile) intervals.

Figure 12 Part of a dense mackerel shoal photographed at night about 3 miles east from Manacles Point in February 1973. (The density was about 136 fish per cubic metre and the fish were swimming with the tide.)

During the 1974-75 mackerel season three surveys were made, one each in October, December and January. The fish traces recorded were identified either by pelagic trawling or by reference to commercial fishing vessels. A more tentative identification of some traces was made by comparison with previous records and what might be expected in the area. The principle shoals in the area were mackerel, horse mackerel (scad), pilchard and sprat, but occasionally shoals were found to overlap and to include some herring and anchovy. Such mixed species shoals are difficult to quantify as each species has a different target strength. Fortunately the major shoals were, to all intents and purposes, single species. Once the shoal distribution over the survey area was established, individual shoals were surveyed in greater detail to measure their total volume. Summary charts showing the ship's track and the distribution of the various fish traces during the three surveys are given in Figure 13.

The survey during October 1974 (Figure 13A) took place when the winter mackerel fishery had commenced but had not reached the level of later months. Most of the fishing activity was associated with the shoals in Mount's Bay and off Dodman Point. These and other major concentrations of fish were all within the 12 mile limit but there were also extensive mackerel-type traces in the western area outside this limit. Between Eddystone and Start Point the fish traces varied and differed from the mackerel-type trace.

The main features of the December survey (Figure 13B) were the localized, extremely dense concentrations of mackerel found 3-6 miles from the coast between Manacles Point and Looe, the extensive layer further offshore, and a large shoal of horse mackerel 6-10 miles off Start Point. The offshore layer was patchy in distribution and irregular in appearance which made it difficult to identify over large areas with any certainty.

Compared with December, the distribution of the main mackerel concentrations in January showed notable differences (Figure 13C). The concentration off the Manacles had dispersed but other concentrations had formed in Mount's Bay and east of Eddystone. The fish previously found off Dodman Point and Looe were still present. The diffuse offshore fish layer appeared to be predominantly mackerel south of the Lizard whereas south of Eddystone-Start Point it was possibly horse mackerel.

The overall picture from these three surveys is one of a widespread mackerel distribution in October, at the start of the fishing season. This becomes much more concentrated in the inshore area to the south-east of Cornwall in December, and by January it appears to be dispersing prior to the start of the annual spawning migration.

At the end of each of these surveys, in addition to the normal echo-sounder records, we had a continuous record of the total echo strength per nautical mile surveyed. This was proportional to the total number or weight of fish which passed through the acoustic beam. From these records the mean number of fish per cubic metre or per square metre was calculated and this value was raised to the total volume or area of water surveyed.

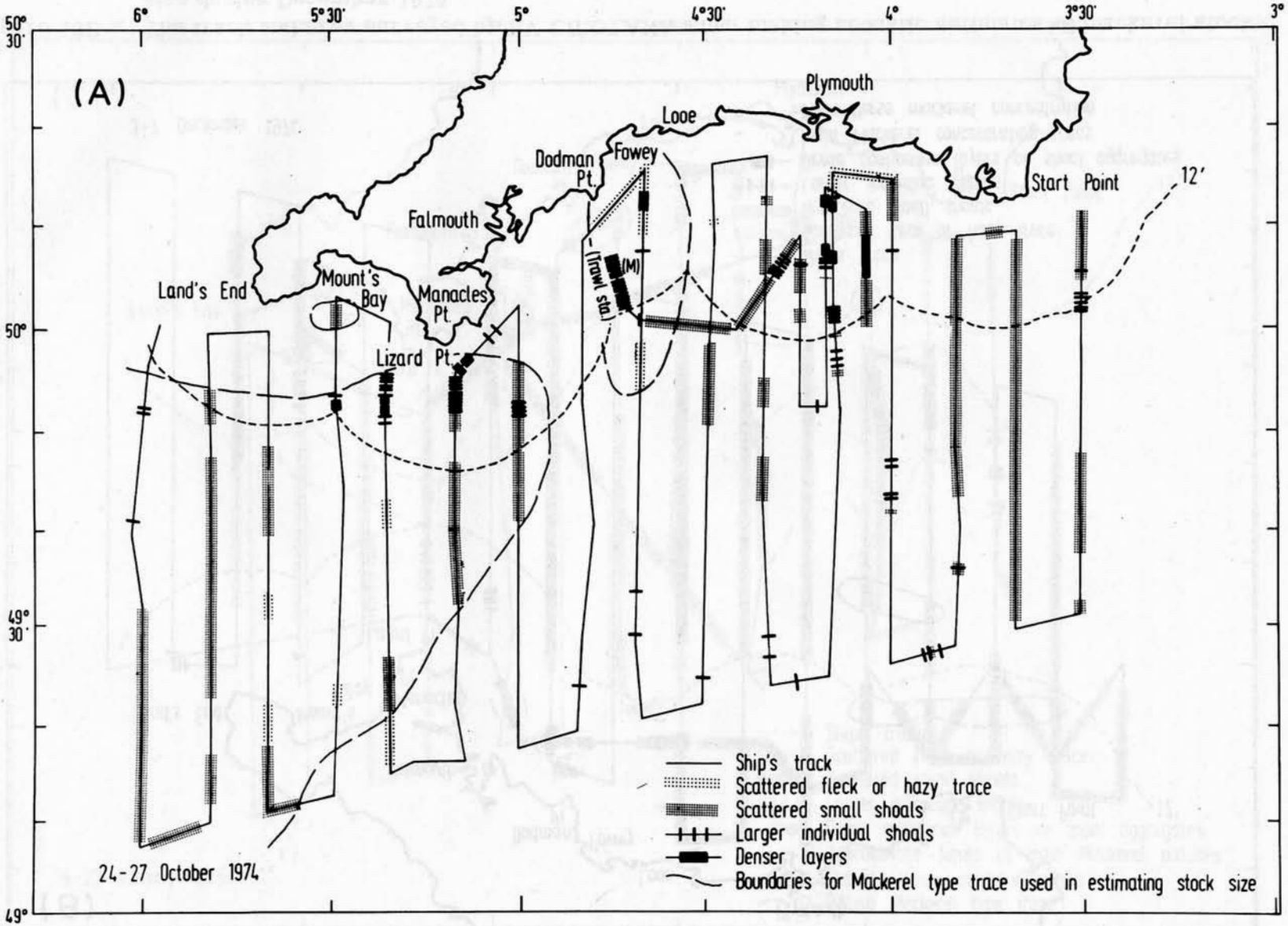


Figure 13A The track and area surveyed by RV CIROLANA when making acoustic estimates of mackerel stock size during October 1974.

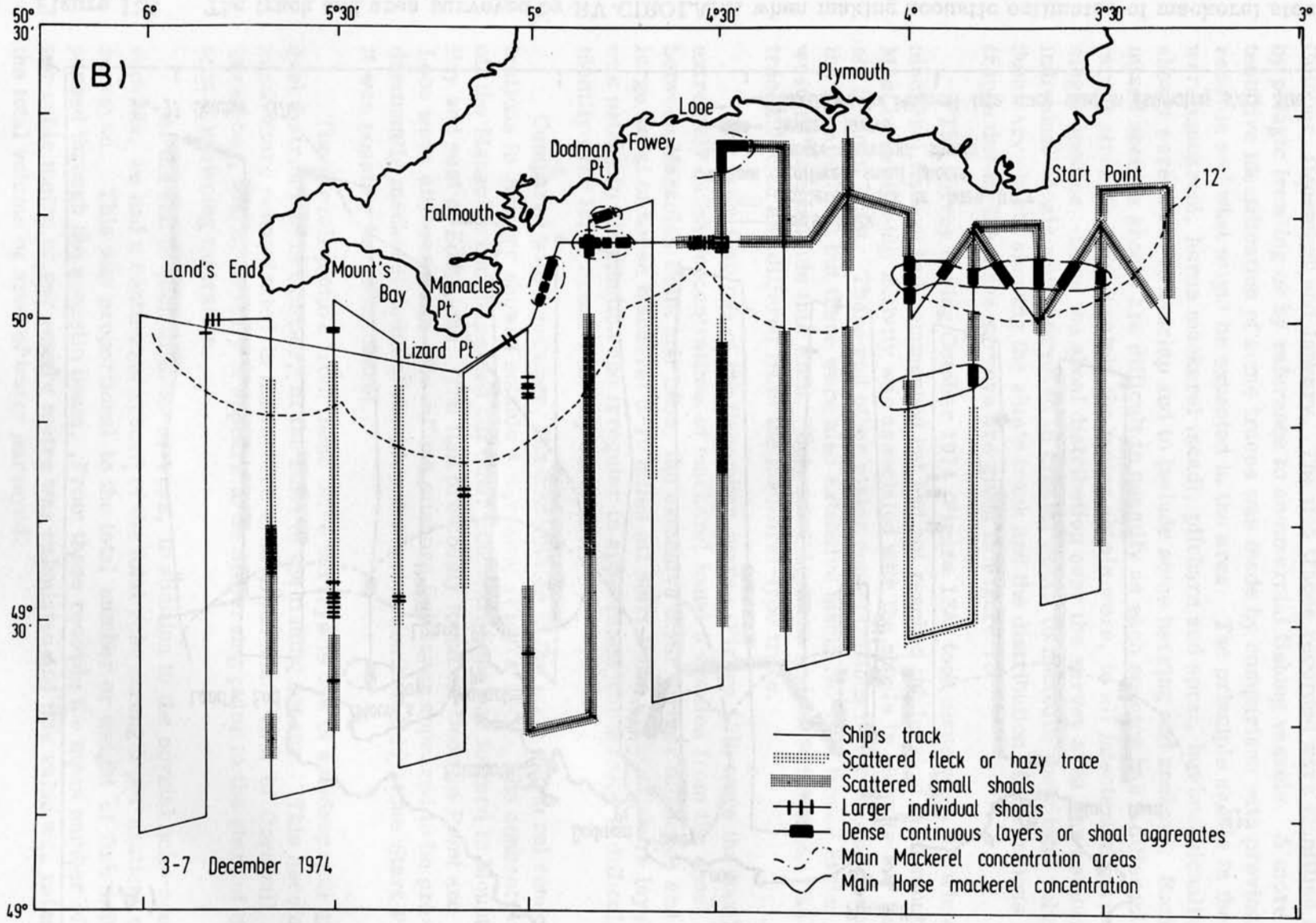


Figure 13B The track and area surveyed by RV CIROLANA when making acoustic estimates of mackerel stock size during December 1974.

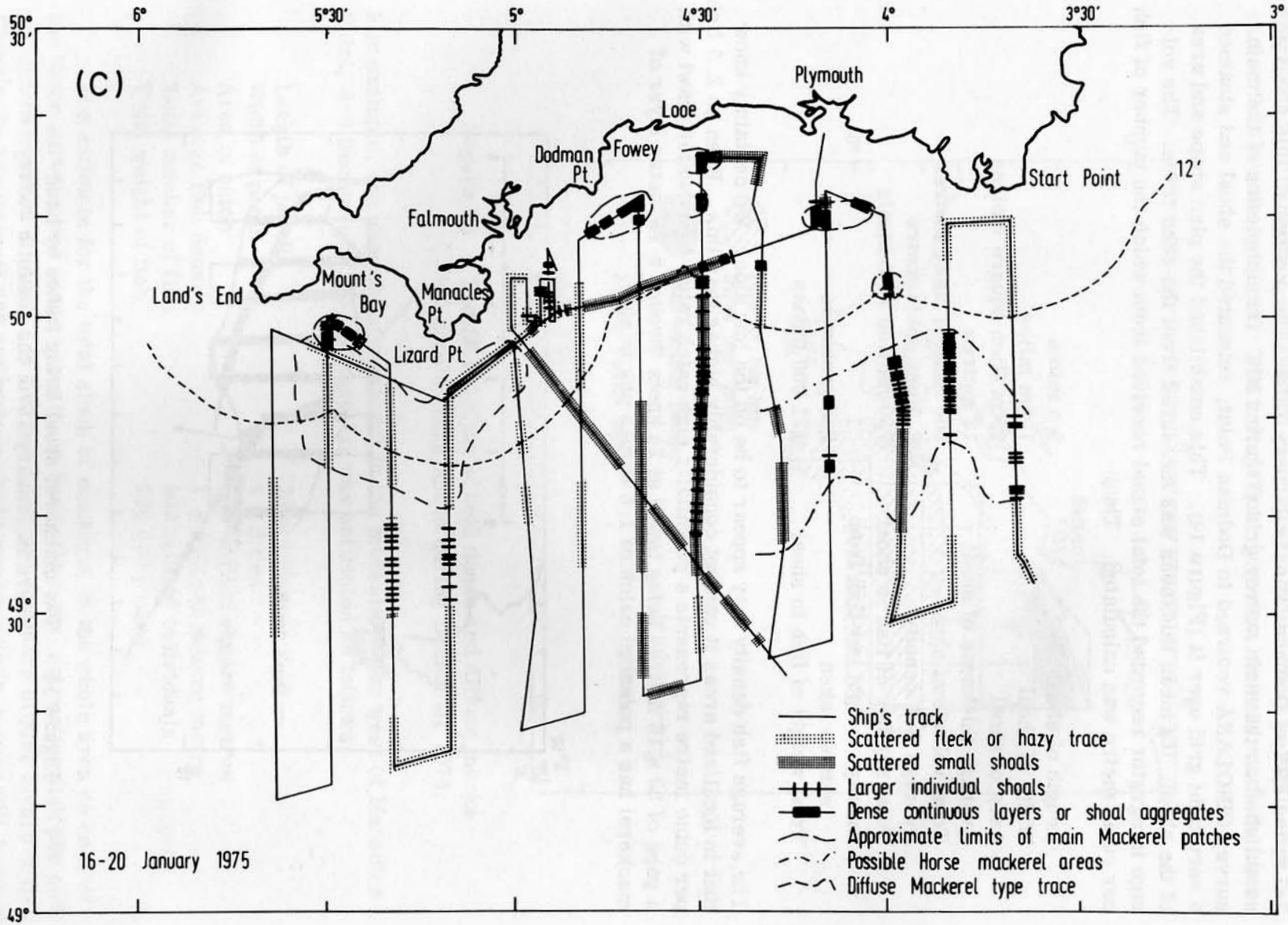


Figure 13C The track and area surveyed by RV CIROLANA when making acoustic estimates of mackerel stock size during January 1975.

We will consider a relatively small shoal as an example - the shoal 2-7 miles ESE of Dodman Point in January 1975. The position of this shoal was established on the main survey grid (Figure 13C). On completion of the main survey CIROLANA returned to Dodman Point, relocated the shoal and steamed a very tight grid over it (Figure 14). This established the plan shape and area of the shoal; its mean thickness was measured from the echo trace. The voltage integrator recorded the total signal received from which the number of fish per cubic metre was calculated. Thus:

Length of shoal	5 n miles
Width of shoal	1.5 n miles
Area of shoal	25 million square metres
Average thickness of shoal	12 metres
Total volume of shoal	300 million cubic metres
Average fish density	2.5 per cubic metre
Total number of fish in shoal	750 million individuals
Average weight per fish from sample taken	228 grammes
Total weight of fish in shoal	171 000 tonnes

The average fish density may appear to be on the low side. We certainly know that in localized areas it can get considerably higher than this. Even so 2.5 fish per cubic metre represents a potentially high catch rate. A midwater trawl with a gape of 30 x 16 metres being towed at $2\frac{1}{2}$ knots through a 12 metre layer of mackerel has a potential catch of 1.5 tonnes per minute.

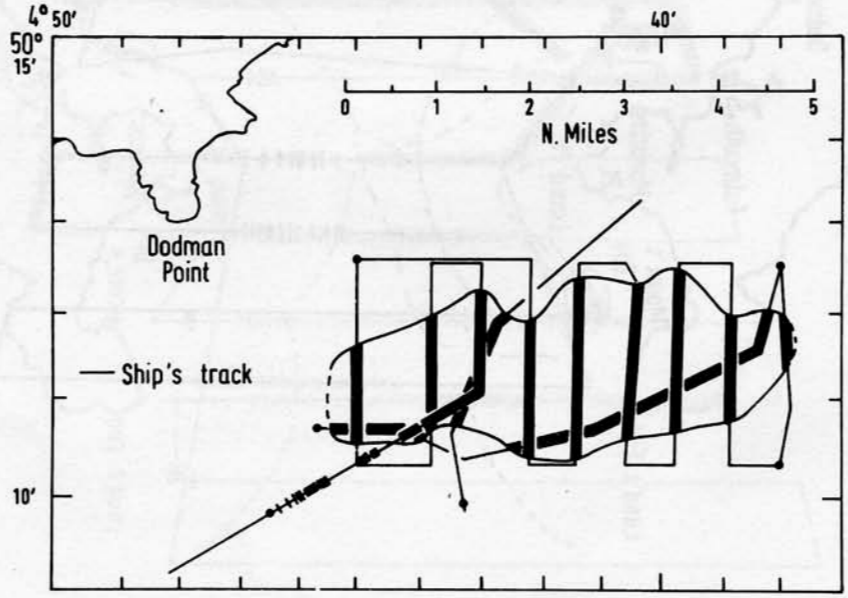


Figure 14 The mackerel shoal being fished by handliners in January 1975: the acoustic survey estimated it to contain 170 000 tonnes.

Where the fish traces are more diffuse, as they were farther offshore (Figure 15), it is more convenient to calculate the fish density per unit area rather than per unit volume. The calculation, however, is very much the same.

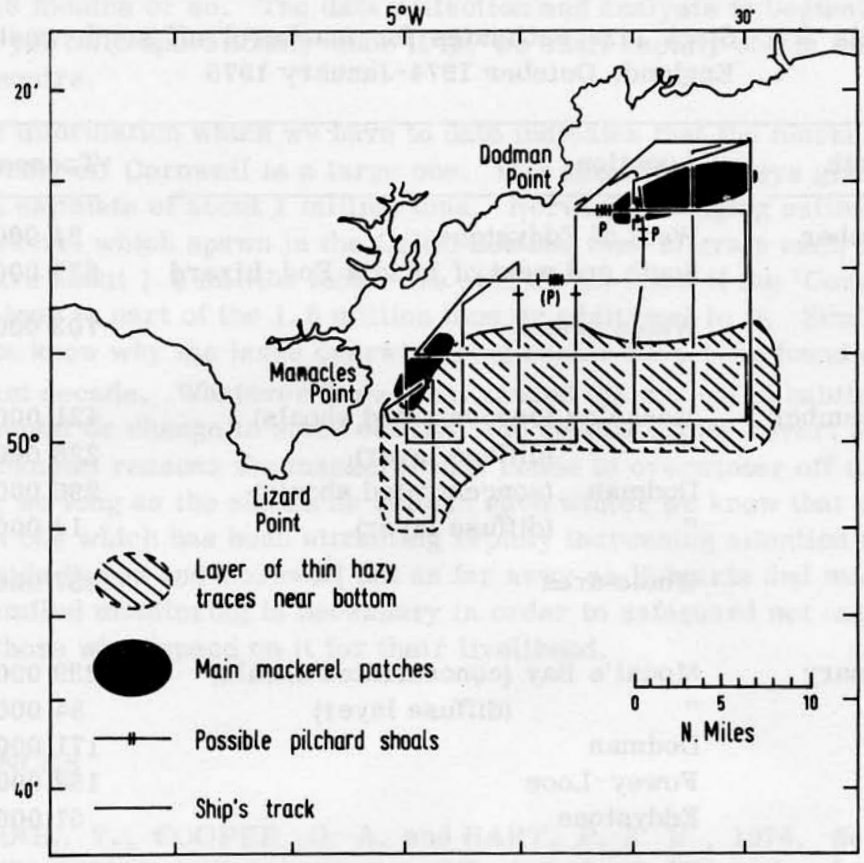


Figure 15 The distribution of both dense and diffuse mackerel shoals being fished during December 1974.

For example, the quantity of mackerel in the midwater layer west of Manacles Point, 8-9 December 1974, (Figure 11) was estimated as follows:

Length of patch	24 n miles
Width of patch	7 n miles
Area of patch	550 million square metres
Average fish density	1.8 fish per square metre
Total number of fish	990 million individuals
Total weight of fish	226 000 tonnes

The estimate for the total stock of mackerel in the whole area on each of the three surveys was made using these two techniques, estimating fish per unit volume in a compact shoal, and fish per unit area for more diffuse layers of fish. Clearly the accuracy of any estimate made from an acoustic survey will improve if the distance between survey lines is reduced. Each of the three surveys described here followed an almost identical track and they are therefore directly

comparable. It can be seen in Table 3 that the three estimates are of the same order of magnitude. The actual differences in value reflecting the seasonal rise and fall in the fishery, maximum stock size coinciding with peak fishing activity and being in line with our knowledge of the fishes' migratory habits in the area.

Table 3 Stock size estimates for mackerel off south-west England, October 1974-January 1975

Month	Location	Tonnes
October	West of Eddystone	24 000
	South and west of Land's End-Lizard	679 000
	Whole area	703 000
December	Manacles (concentrated shoals)	421 000
	" (diffuse layer)	226 000
	Dodman (concentrated shoals)	296 000
	" (diffuse layer)	14 000
	Whole area	957 000
January	Mount's Bay (concentrated shoals)	239 000
	" (diffuse layer)	84 000
	Dodman	171 000
	Fowey-Looe	158 000
	Eddystone	57 000
	Whole area	709 000

A survey carried out during November 1975 gave results comparable with the three 1974-75 surveys detailed here. The total quantity recorded was 488 000 tonnes. Toward the end of November there was a sudden influx of large mackerel (Figure 9) which would have brought the total up to the levels recorded in 1974.

CONCLUSION

This, then, is an outline of our current programme of data collection on mackerel in Devon and Cornwall, our methods, objectives and first results.

The samples analysed at the laboratory provide the fine biological detail which can be applied to the large-scale fish measuring programme to describe the population. This is used in conjunction with the catch and effort data supplied by the skippers and the volunteer log keepers to make the stock assessments necessary for successful management. The account of the methods used is to some extent simplified but it does show how these assessments may be made and, most important, how reliant we are on the goodwill and cooperation of the industry to get them right.

We can make single season stock size estimates by the acoustic survey technique, or by the large-scale mackerel egg and larval surveys which we shall carry out in 1977, but these are no substitute for assessments based on good long-term data collection such as we have been trying to establish over the past 18 months or so. The data collection and analysis is beginning to work but is not yet fully operational; once it is, we shall rapidly obtain the information we require.

The information which we have to date indicates that the mackerel stock overwintering off Cornwall is a large one. Our acoustic surveys give a seasonal maximum estimate of about 1 million tons. Norwegian tagging estimates for those mackerel which spawn in the Celtic Sea and then migrate each summer to Shetland are about 1.5 million tons. We still do not know if the 'Cornish' 1 million tons is part of the 1.5 million tons or additional to it. Similarly we still do not know why the large overwintering shoals have been found off Cornwall for the last decade. Whatever it was that caused the change in habits, whether environmental or change in stock density, the condition may revert and for equally unknown reasons the mackerel may cease to overwinter off Cornwall. However, so long as the shoals do reform each winter we know that the stock is a large one which has been attracting rapidly increasing attention not only from outside Devon and Cornwall but as far away as Bulgaria and more recently Cuba. Detailed monitoring is necessary in order to safeguard not only the stock, but also those who depend on it for their livelihood.

REFERENCES

BAINBRIDGE, V., COOPER, G. A. and HART, P. J. B., 1974. Seasonal fluctuations in the abundance of the larvae of mackerel and herring in the northeastern Atlantic and North Sea. pp. 159-170 In: Blaxter, J. H. S. (Ed.), The Early Life History of Fish. Berlin, Heidelberg, New York, Springer-Verlag. 765 pp.

BOLSTER, G. C., 1974. The mackerel in British waters. pp. 101-116 In: Jones, F. R. H. (Ed.), Sea Fisheries Research. London, Elek Science. 510 pp.

BOLSTER, G. C. and BURD, A. C., 1972. The mackerel of the western English Channel. ICES C.M. 1972/J:7, 6 pp. (Mimeo).

HARDY, R. and KEAY, J. N., 1972. Seasonal variations in the chemical composition of Cornish mackerel, Scomber scombrus (L.), with detailed reference to lipids. J. Fd Technol., 7, 125-137.

KEAY, J. N., 1974. Handling and processing mackerel. Torry Advisory Note No. 66.

LINDQUIST, A. and HANNERZ, L., 1974. Migrations of the mackerel in the northern North Sea and in the Skagerrak. J. Cons. int. Explor. Mer, 35, 276-280.

POSTUMA, K. H., 1972. On the abundance of mackerel (Scomber scombrus L.) in the northern and north-eastern North Sea in the period 1959-1969. J. Cons. int. Explor. Mer, 34, 455-465.

REVHEIM, A. and HAMRE, J., 1968. A brief statement on the present state of the Norwegian mackerel fishery. ICES C.M. 1968/H:24, 4 pp. (Mimeo).

WALLACE, P. D. and PLEASANTS, C. A., 1972. The distribution of larvae of some pelagic fish species in the English Channel and adjacent waters in 1967 and 1968. ICES C.M. 1972/J:8, 4 pp. (Mimeo).

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NOTE
Although the complete list of Laboratory Leaflets is given to show the scope of the series, it will be appreciated that many of these leaflets are topical and therefore of interest chiefly at the time when they are written. For this reason most of the earlier ones are being allowed to go out of print when present stocks are exhausted; few copies are available of those prior to No. 13.

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