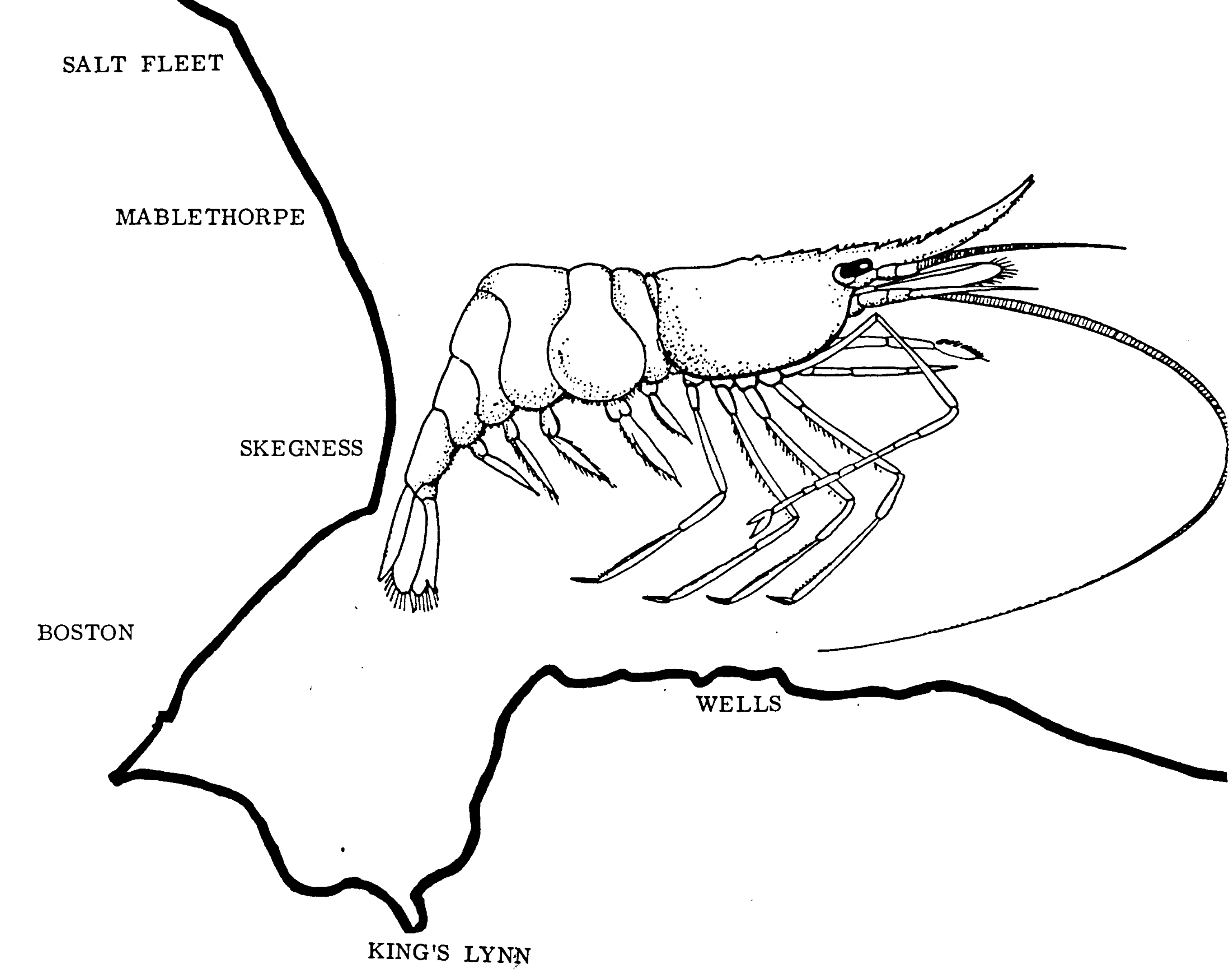
MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

THE FISHERY FOR THE PINK SHRIMP *PANDALUS MONTAGUI* IN THE WASH



BY P. J. WARREN

LABORATORY LEAFLET (NEW SERIES) No. 28
FISHERIES LABORATORY
LOWESTOFT
SUFFOLK
JUNE 1973

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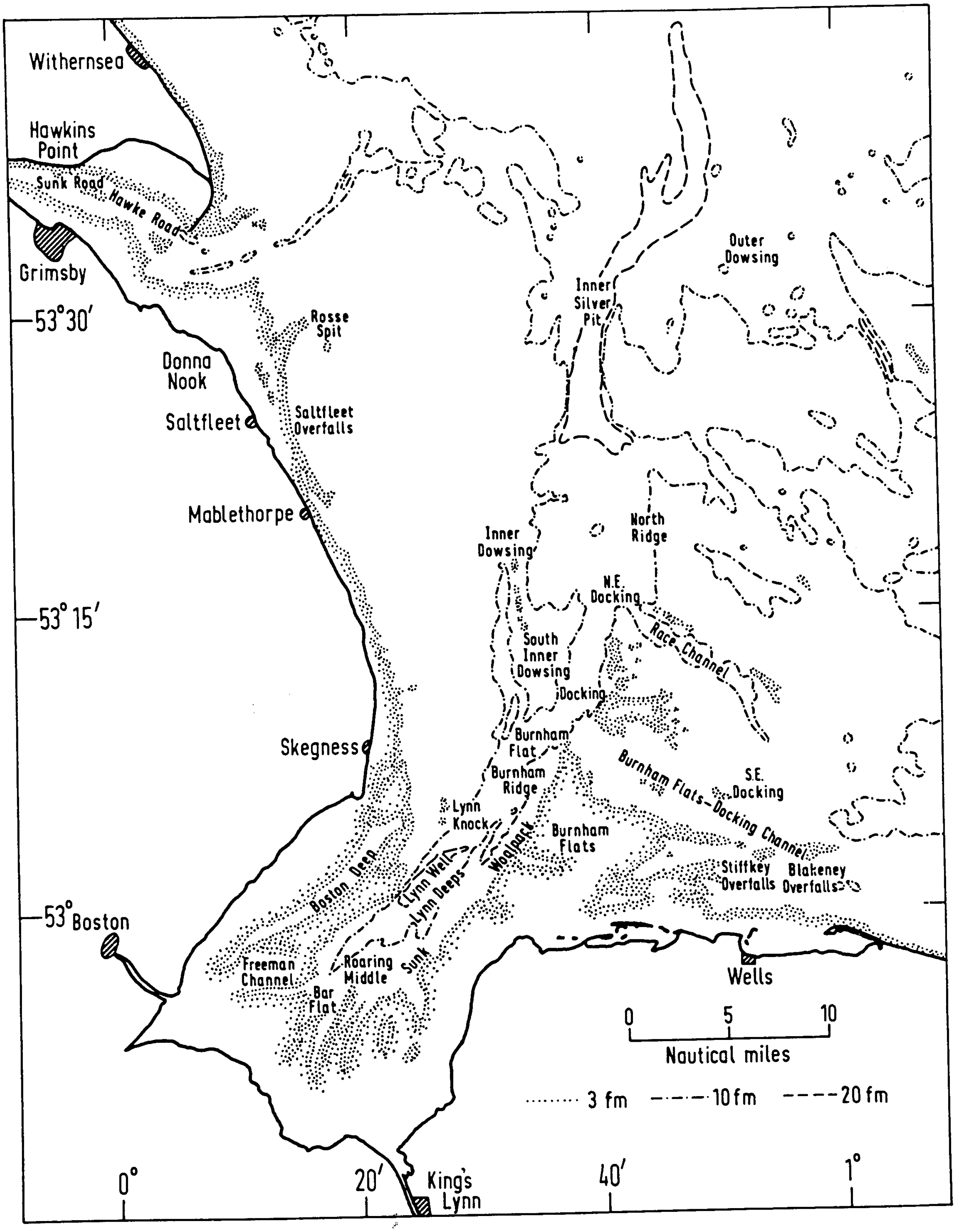

Figure 1 General topographical chart of the Wash area. The pink shrimp fishery is concentrated mainly in the deepwater channel between Roaring Middle and Burnham Flat.

THE FISHERY FOR THE PINK SHRIMP, *Pandalus montagui*, IN THE WASH

1 INTRODUCTION

The pink shrimp (*Pandalus montagui*) (Plates 1 and 2) is present along much of the coast of the British Isles. The species was originally described by William Leach in 1814 and subsequently given the name *P. montagui* after Montagu, the naturalist who is credited with its discovery in Devon. However, it is known that at the time it was described the species was already being commercially exploited. A written account from the early nineteenth century records that it "....was used at Yarmouth as an article of food and is at that place so esteemed for the table as to afford constant employment during the summer months to several fishermen, who take it in abundance at a considerable distance from the shore, and name it from that circumstance the sea shrimp".

The origins of the English trawl fisheries which developed to exploit the pink shrimp stocks have gone largely unrecorded, but the main commercial fisheries have been centred for many years in three areas - the Thames Estuary, Morecambe Bay and the Wash. These areas also support fisheries for the brown shrimp (*Crangon crangon*) (Plate 2), although the two species are usually taken on different fishing grounds. In the Wash, brown shrimps are always referred to as 'shrimps', but pink shrimps are called 'prawns'. The pink shrimp is not a true prawn, but the term is commonly used in the Wash fishery.

There has been a fishery for pink shrimps in the Wash for at least a century but the record of early landings is far from complete and it is difficult to assess the importance of the fishery in the past. However, approximate figures are available for the years 1925-35, when the average annual landings of pink shrimps at the main Wash ports of King's Lynn and Boston totalled about 14 000 cwt. During this period, the highest annual catch was 21 000 cwt in 1926 and the lowest was 8 200 cwt in 1932. By comparison, in 1970 some 12 500 cwt of mixed shrimps (pink and brown) were landed at Wash ports, and of these approximately 9 000 cwt were pink shrimps.

Although large fluctuations in landings occur in the fishery, the Wash continues to support the only remaining pink shrimp fishery in this country, for during the last two decades the stocks in the Thames and Morecambe Bay have declined and commercial landings from these areas have virtually ceased. In spite of outdated working methods and inadequate market facilities which make the Wash fishery something of an anachronism, its importance has increased steadily until it now accounts for approximately half the total shrimp landings in England and Wales. Total first sale value of all brown and pink shrimp landings in England and Wales is currently (1972) about £200 000 per annum, which may be compared with the value of £3 000 000 for imported peeled and frozen shrimp products.

Plate 1 The pink shrimp, Pandalus montagui.

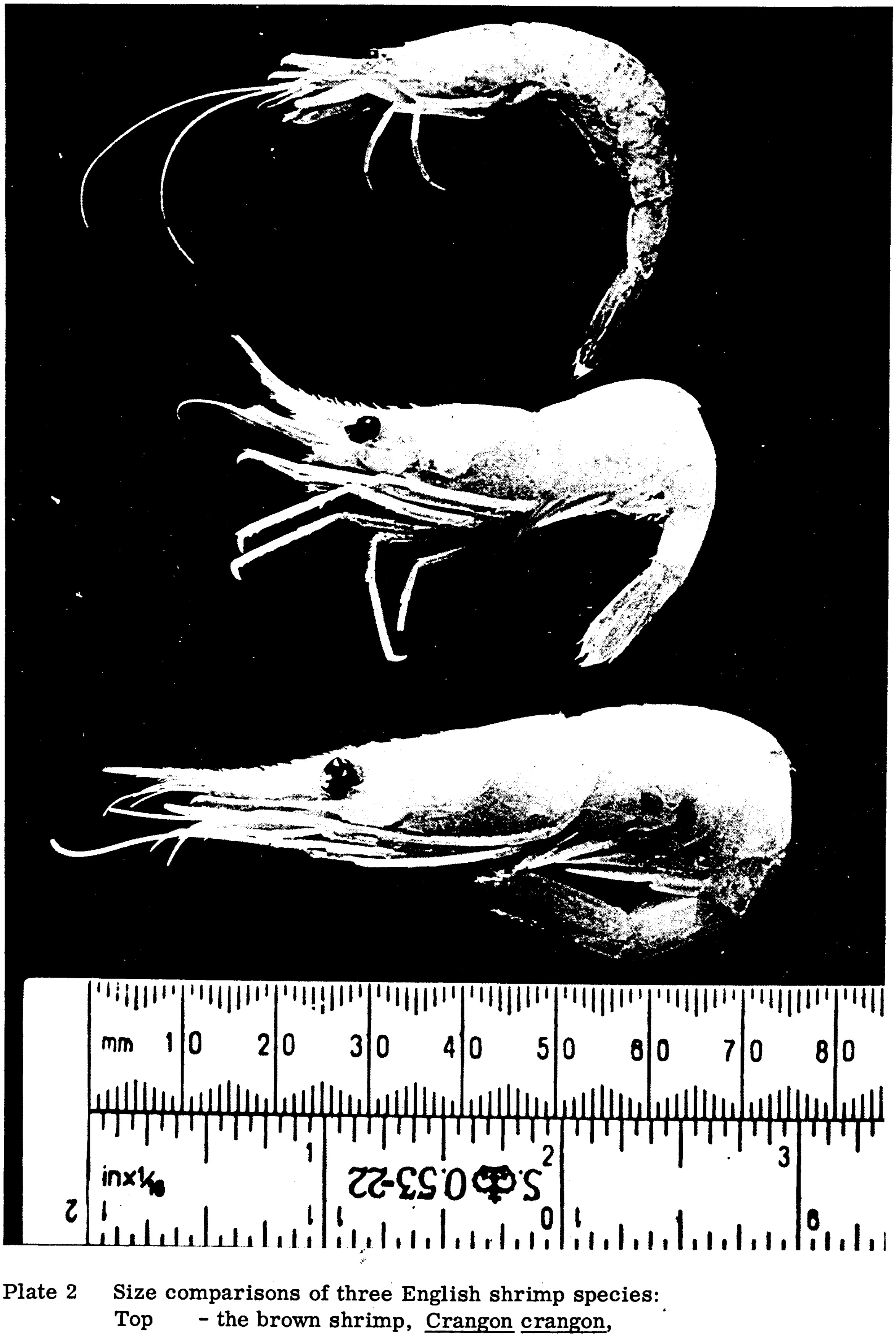

Plate 2 Size comparisons of three English shrimp species:
Top - the brown shrimp, Crangon crangon,
Centre - the pink shrimp, Pandalus montagui,
Bottom - the deepwater prawn, Pandalus borealis.

During the 1960s, a programme of research was initiated by the Ministry to study the Wash shrimp fishery and its problems. This investigation has provided new information on the biology and behaviour of the pink shrimp, and a knowledge of the history of the Wash fishery and of current commercial fishing techniques has been acquired. This leaflet brings together from a variety of sources some facets of the Wash pink shrimp fishery, past and present.

References to scientific papers have been omitted, but the reading list appended (pages 44-45) is intended to provide greater detail on many of the points discussed.

2 THE FISHERY, PAST AND PRESENT

a A short history of shrimp fishing

An early reference to shrimps in England is contained in the Wardrobe Accounts of Edward II in AD 1132, where an item of three pence is noted for shrimps. In 1440 Galfridus Grammaticus, a Dominican friar of King's Lynn compiled the first English-Latin dictionary and made reference to "the shrymp fysche - stingus", which appears to have been a mediaeval Latin term for shrimp. In 1622, two interesting gastronomic properties were attributed to shrimps by Drayton when he wrote of "the periwinkle, prawn, the cockle and the shrimp, for wanton women's taste or the weak stomach bought".

References like these provide no clue of the species of shrimp concerned, but it is likely that they refer to brown shrimps or possibly true prawns (Palaemon sp.), both of which may be taken along the water's edge with a simple push net; pink shrimps seldom venture into such shallow water. A probable reference to pink shrimps in the Wash was made in 1819 when it was reported that shrimps of "a very superior quality were caught in such immense quantities in Boston Deep that they formed a very considerable article of trade for the London market".

Early in the nineteenth century, the weight of shrimps dispatched from Lynn to London in one season was reported to have been 60-70 tons. Before the advent of rail transport, shrimps were sent to London by horse-drawn coach, in baskets, each containing 40 pounds weight of shrimps. It is interesting that this same method was used to transport brown shrimps from Leigh-on-Sea (Essex) to the London market, and an 1850 account of the sale of Leigh shrimps suggests that great quantities were bought by London street traders who paid 10d to 2s 6d per gallon for them at Billingsgate fish market and resold them in pennyworths to people in the streets. Thomas Mayhew recorded that 770 000 pints of shrimps, worth £6 000, were sold by London street traders in 1850.

After his visit to King's Lynn in 1875, Frank Buckland, the eminent marine scientist, reported to the House of Commons that the principal fisheries in the Wash, at that time, were for eels, shrimps, oysters and mussels. Fishing for these and other species was carried out under sail with beam trawls of 18 to 35 feet. Buckland mentioned the introduction of a sieve to help conserve small or 'brood' shrimps, this sieve "having a mesh which shall just allow three new one penny pieces to pass between the cross wires, and that the smaller shrimp should be allowed to fall back into the water". Such a sieve was also proposed for the Yarmouth pink shrimp fishery and had already been successfully adopted at Leigh in the Thames Estuary.

Since about 1895, annual reports by the Inspectors of the Eastern Sea Fisheries Joint Committee are a source of much useful information relating specifically to the pink shrimp fishery of the Wash. These reports suggest that in the past the fishery for pink shrimps included grounds which are seldom worked by today's fleet. However, in the case of vessels under sail, conditions of wind and tide almost certainly determined the fishing area, and the inshore grounds were probably fished for this reason. There are occasional references to the landing of shrimps at Skegness in order to catch the train to London, and one would assume that this also influenced the area fished.

There is some evidence of the exploratory nature of the fishery in the past. One specific example of an attempt to extend the fishery is recorded in a report of March 1914, which also includes the first reference to the introduction of an engine into one of the fishing boats. The report is presented in full and should be read with reference to Figure 1.

"PRAWNERS - The pink shrimp fishery continues to increase in importance. From September to the New Year, the Lynn Knock, Dog's Head and Burnham Flat grounds were principally worked, the catch per trip of one or two days' duration generally varying from 25 pecks to 80 pecks* of the crustaceans.

In the past this fishing has been practically brought to a standstill between the middle of November and the latter part of March or early April, but this season for the first time, the larger craft ventured further away to entirely new ground, with good results. In January and February several of the smacks went so far as the NE Docking buoy before shooting their nets, towing seaward several miles, on one or more occasions as far as the Silver Pit, where the water suddenly deepened from 80 to 200 feet and over. The commencement of the Silver Pit lies 24 nautical miles from the nearest point on the Lindsay coast. From King's Lynn or Boston to the commencement of the Silver Pit and back, the distance is about 94 miles. A few years ago no one would have dreamt of going so far into the North Sea for prawns. The prawns taken, especially those of the outer grounds, were of large size and of excellent quality, for which high prices were received. Landings were light in February and up to the latter part of March when from 5 to 10 bags of prawns were obtained in trips of from two to three days' duration.

Additional vessels are joining the prawning fleet, including one which can be worked by motor in addition to sails. This experiment is being watched with interest."

Twenty years after the introduction of this first motor, engines were widely accepted and fitted but their use was still restricted in the Wash fishery; in 1932 the Eastern Sea Fisheries Committee Inspector reported that constant vigilance was necessary to prevent the use of engines while fishing and suggested that the by-law prohibiting their use should perhaps be amended.

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*The peck is a measure of volume equal to two imperial gallons, or approximately 12 pounds (5.5 kg) of shrimps. It remains the standard measure in the fishery. Before the shrimps are sent to market they are bagged in hessian sacks. At Boston a 'bag' contains slightly more than one peck of shrimps; at King's Lynn a 'bag' usually contains six pecks.

Among the Eastern Sea Fisheries Committee records there are relatively few references to the number of vessels from Boston and King's Lynn which normally trawled for pink shrimps. The Inspector's Reports for 1920-21 record a reduction from 41 to 24 vessels over that period, the result of poor landings. Later in 1921, the number rose again to 33 vessels as the fishery improved. There are also occasional references to the building of new vessels to swell the fleet. However, it must be assumed that vessels continued to enter and leave the fishery as the abundance of shrimps, or their market value, increased or declined.

In this connection, two nineteenth century reports relate to the overall employment of boats and men in the ports of King's Lynn and Boston. In 1875, Buckland reported that fishing provided employment for approximately 500 men and boys in King's Lynn. At the time of his visit, 50 decked boats and a further 100 half-decked and open boats worked daily from the port under sail, but not all fished for shrimps. At Boston in 1899, the Encyclopaedia Britannica records that 61 trading vessels were registered there; 76 registered fishing boats worked from the port, and there was a deep-sea and steam trawling fleet of 40 vessels employing in all 2 200 hands.

b The fishery today: boats, gear and fishing methods

Bordered by the low-lying land of Lincolnshire and Norfolk (Figure 1), the shores of the Wash consist of extensive areas of intertidal sand and mud which are intersected with shallow channels. Beyond low-water mark the water deepens to 3-5 fathoms (5-9 m), and a well-defined centre channel divides the shallow water to east and west. This channel is at least 10 fathoms (20 m) deep, and increases to a depth of 25-30 fathoms (45-55 m) in the vicinity of the Lynn Well lightvessel. The pink shrimp can be found over a wide area of the Wash, but in recent years the main commercial fishery has been concentrated within this deepwater channel and covers an area approximately 15 miles (24 km) in length and 2-3 miles (3-5 km) wide. For many years the shrimp fishery was conducted by vessels under sail, and even today several of these ex-sailing hulls (Plate 3) remain in the fishery, but they are now powered by engines of up to 100 hp. At present (1972) about 25 vessels are engaged in pink shrimp fishing; these range between 35 and 50 feet (12-16 m) in length and are crewed by two or sometimes three men. Beam trawls remain in exclusive use and each vessel tows a single trawl of up to 26 feet (8 m) beam length with its headline about 3 feet (1 m) above the bottom. The trawl beams may be of steel or wood; trawl heads are often additionally weighted (Plate 4) to ensure that the gear continues to fish on the bottom during strong tides. These trawls are rigged with chain groundropes, rubber discs and 8-10 inch wooden rollers to reduce the collection of rubbish (Figure 2 and Plate 4). The mesh size of the net is generally 18-25 mm and the trawls are protected with covers of large-mesh netting. Additional rubber and plastic chafers are fitted beneath the belly and cod-end for extra protection, and buoyed lines are attached to the cod-end to indicate the position of the trawl and to assist in clearing the gear in the event of it coming fast.

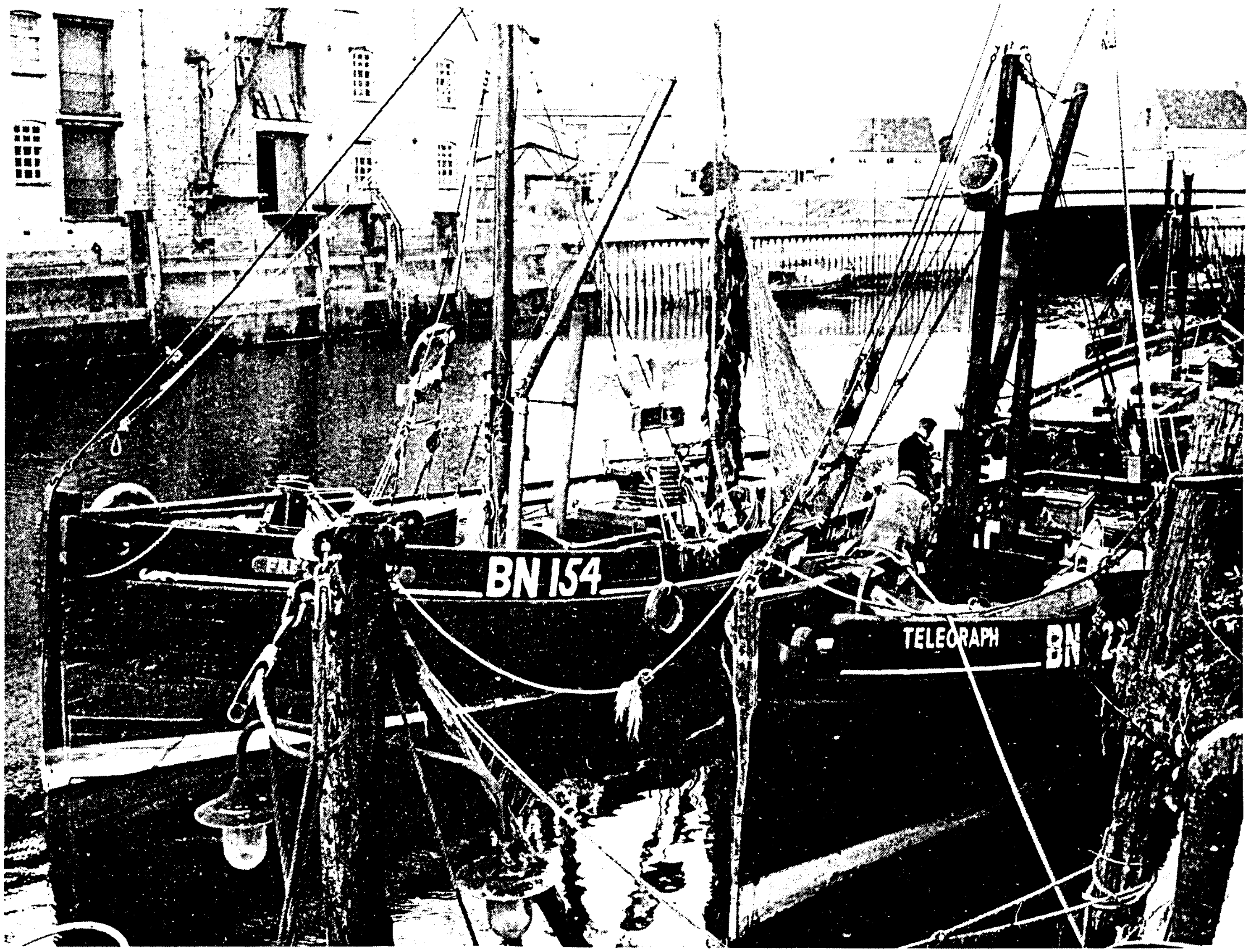


Plate 3 The port of Boston, 1969. Two of the fishing smacks which remain from the days when shrimp trawling was conducted under sail.

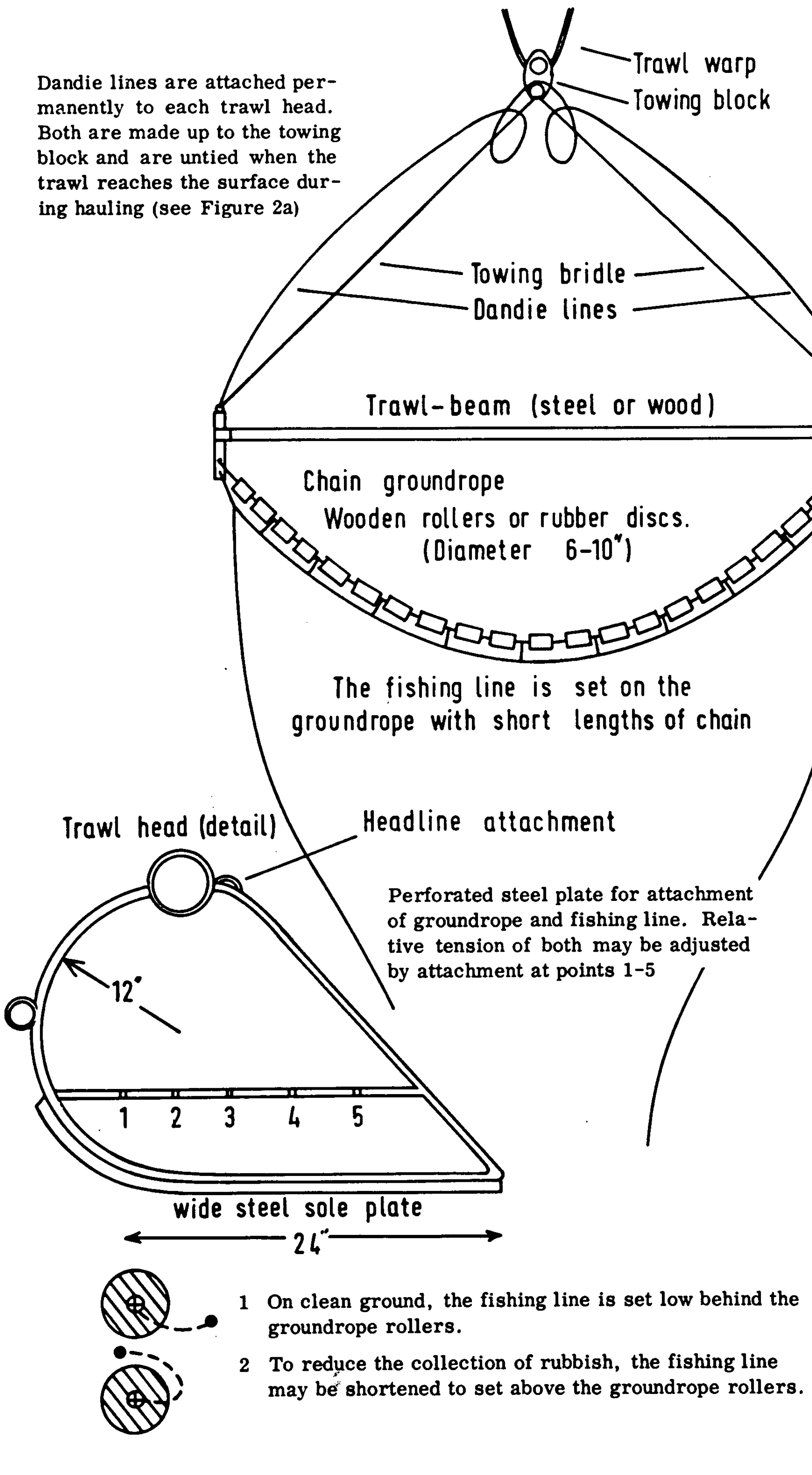


Figure 2 Trawl layout and adjustment.

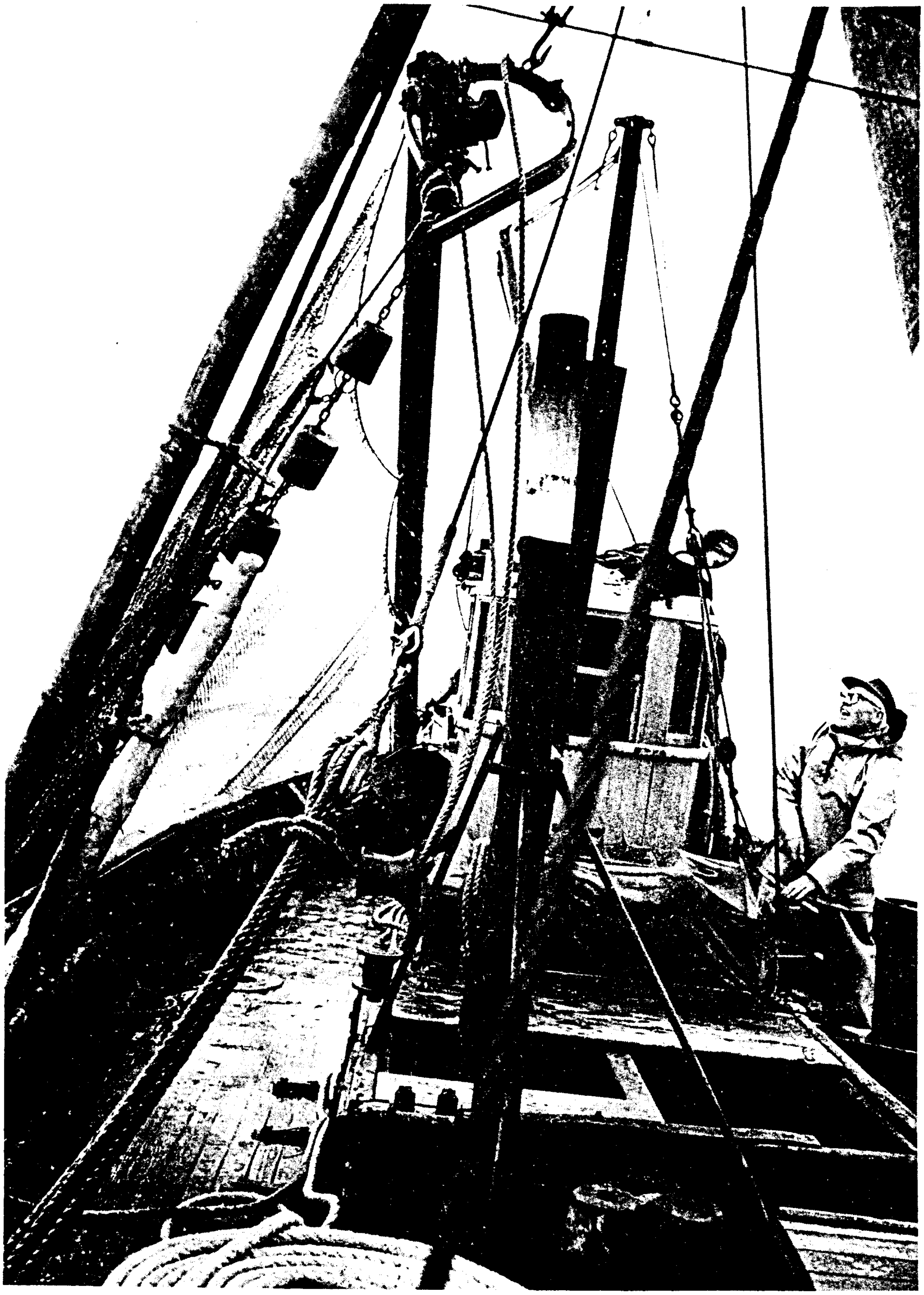


Plate 4 Hauling the gear. The fore trawl head is raised high while the after head is made fast and the groundrope bobbins are brought aboard. The trawl beam is wood and added weights in the trawl head (top) ensure that the gear remains on the sea bed. Wooden bobbins are spaced along a chain groundrope.

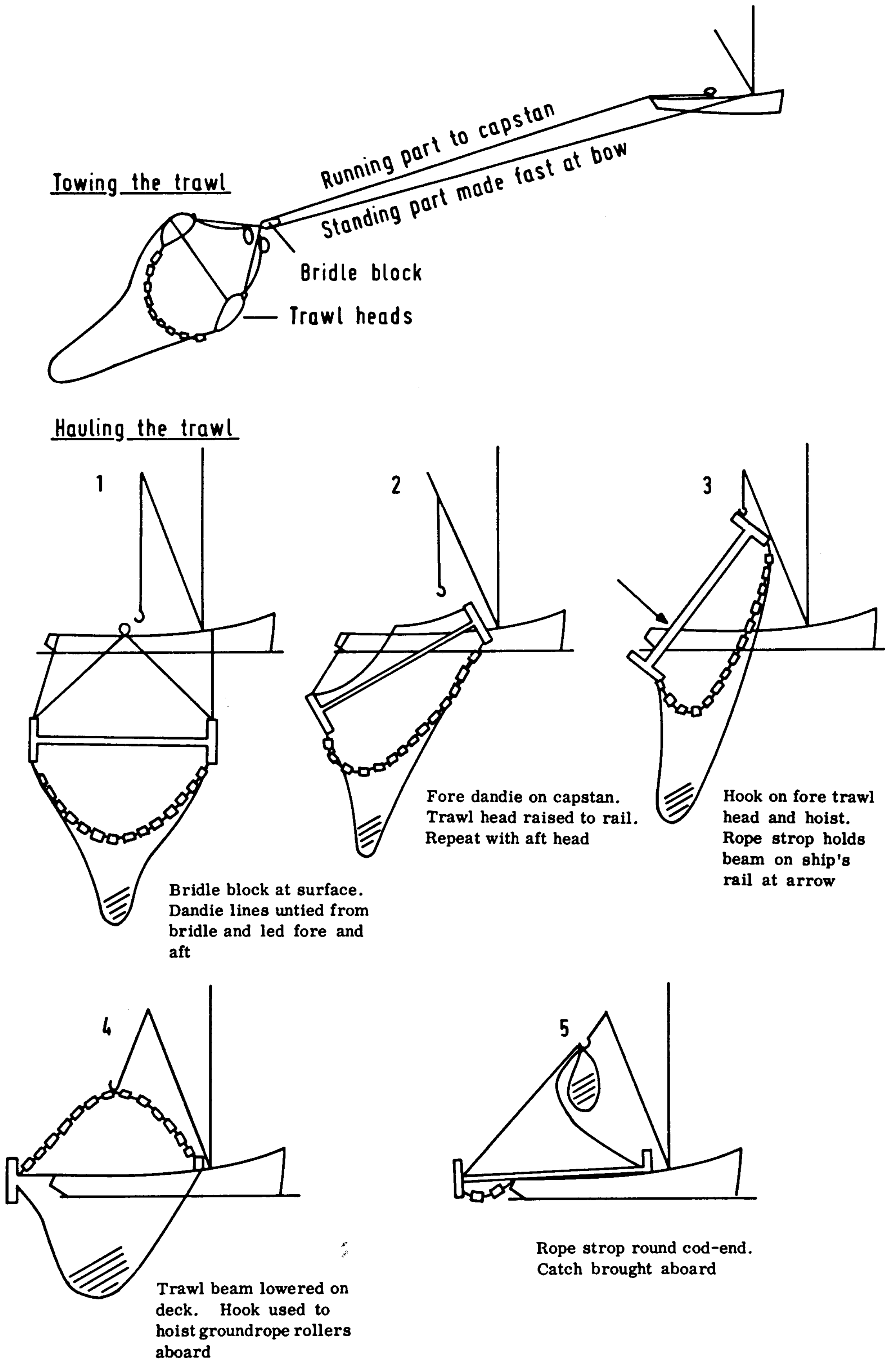


Figure 3 Towing and hauling the trawl.

The boats which fish the Wash for pink shrimps are based at Boston and King's Lynn. Because the approach channels to these ports are not navigable over the period of low tide, the fishery is nowadays conducted on a daily basis between successive periods of high water. Trawl hauls are of 1-3 hours' duration and only two or three hauls are completed during a normal working day. The fishing technique is as follows: after shooting (Plate 5), the trawl is towed downtide at speeds slightly faster than the run of tide. The towing warp is made fast at the bow of the vessel, led down to a block on the trawl bridle, brought back aboard and cleated. This layout enables the vessel to be turned head to tide in the event of coming fast. The two parts of the towing warp may be pegged at separate points on the vessel's rail to improve control of direction at slow towing speeds. For gear operated in 20 fathoms of water, it takes 3-4 minutes to shoot and about 15 minutes to haul, when the complete trawl is hoisted aboard using 'dandie' lines attached to the trawl heads (Figure 3 and Plate 4). A capstan or warping drum is used to haul the gear (Plates 5 and 6).

While the main trawl is fishing, an additional small try-net is sometimes towed at intervals to check the concentration of shrimps on the ground. When they are used, try-nets are shot and hauled by hand and a typical one is shown in Plate 7.

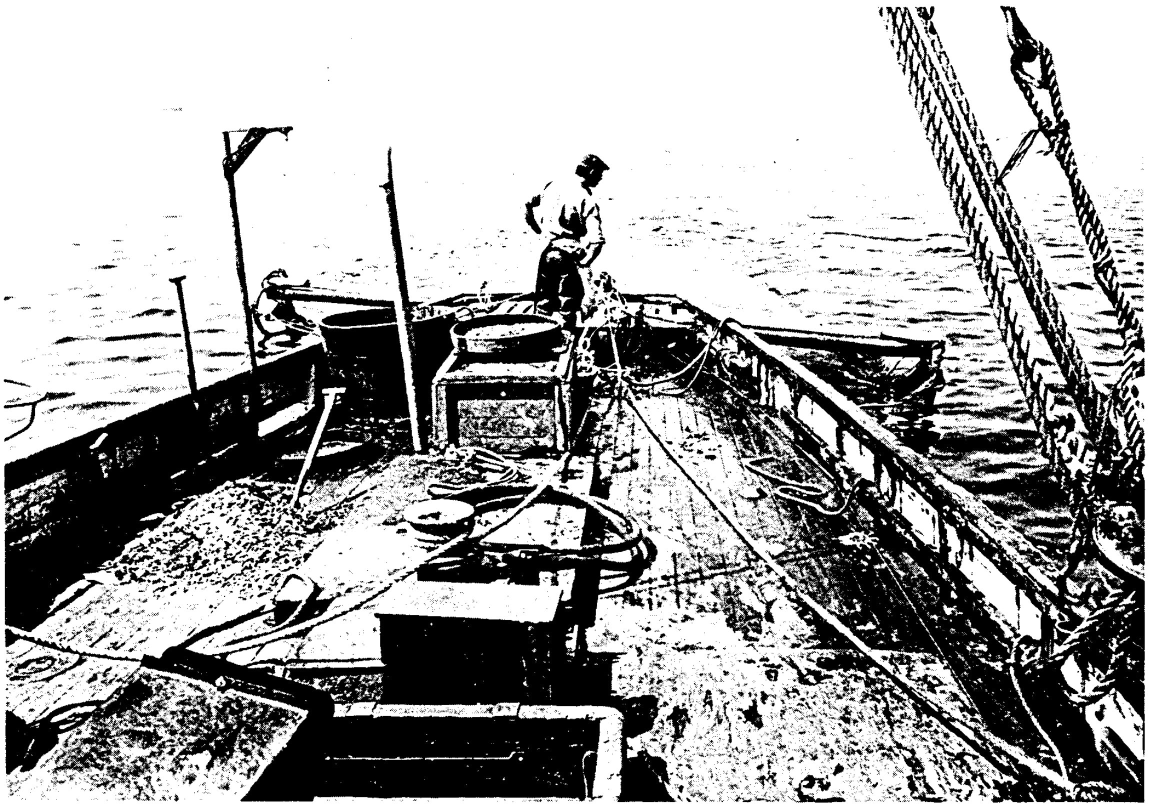


Plate 5 The trawl is squared across the stern to check that all is well before shooting begins. The trawl warp is led round the capstan. Shrimps from the previous haul are on the deck (left) and hand-sieves and wash-tub are ready to begin sorting the catch.

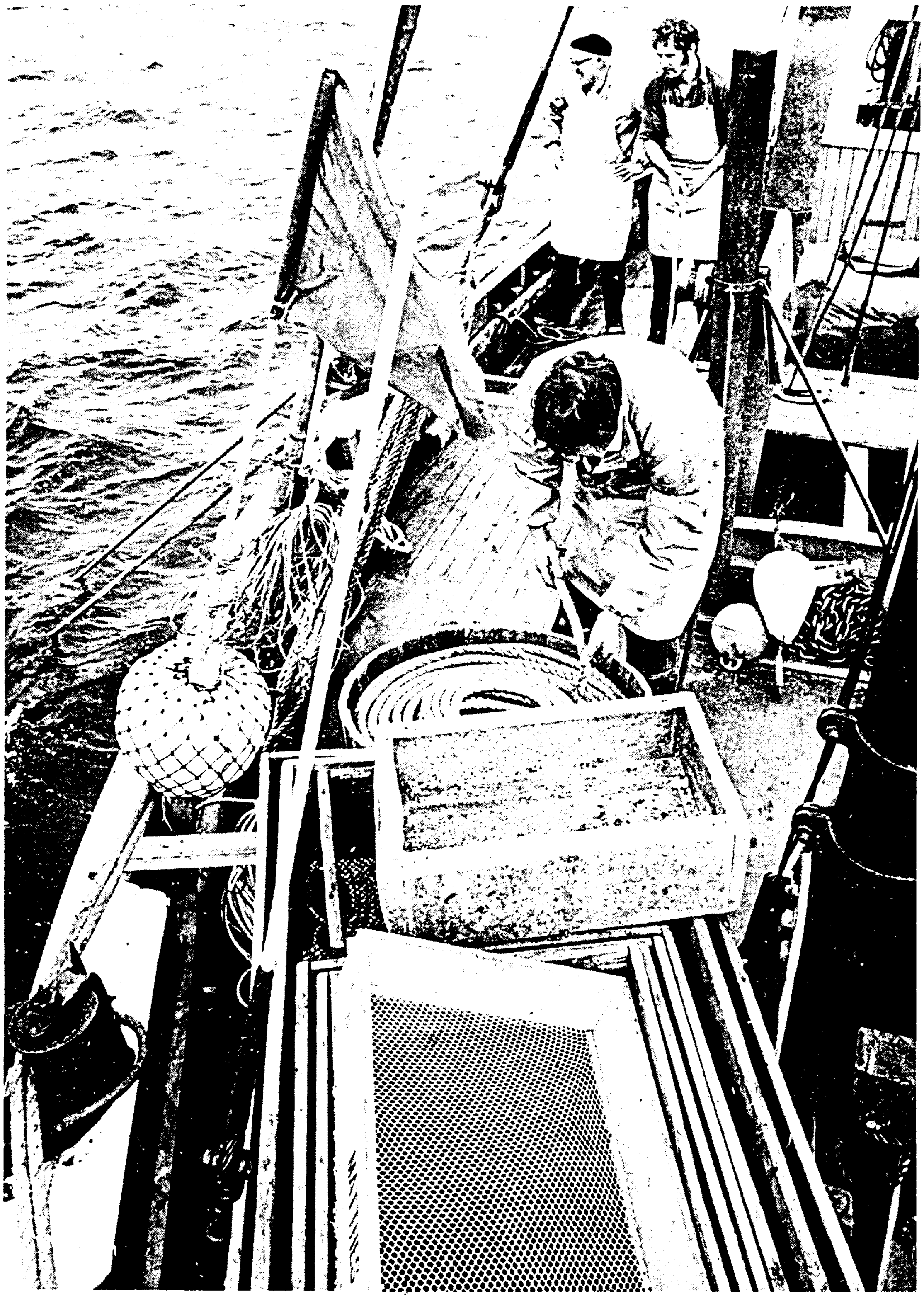


Plate 6 The trawl is hauled. Mid-foreground, the stacked trays in which cooked shrimps are cooled and dried. Note the double trawl warp with, left foreground, the standing part lead forward to the bow of the vessel; the running part is hauled by capstan or warping drum. The dahn buoy may be anchored to mark shrimp concentrations.

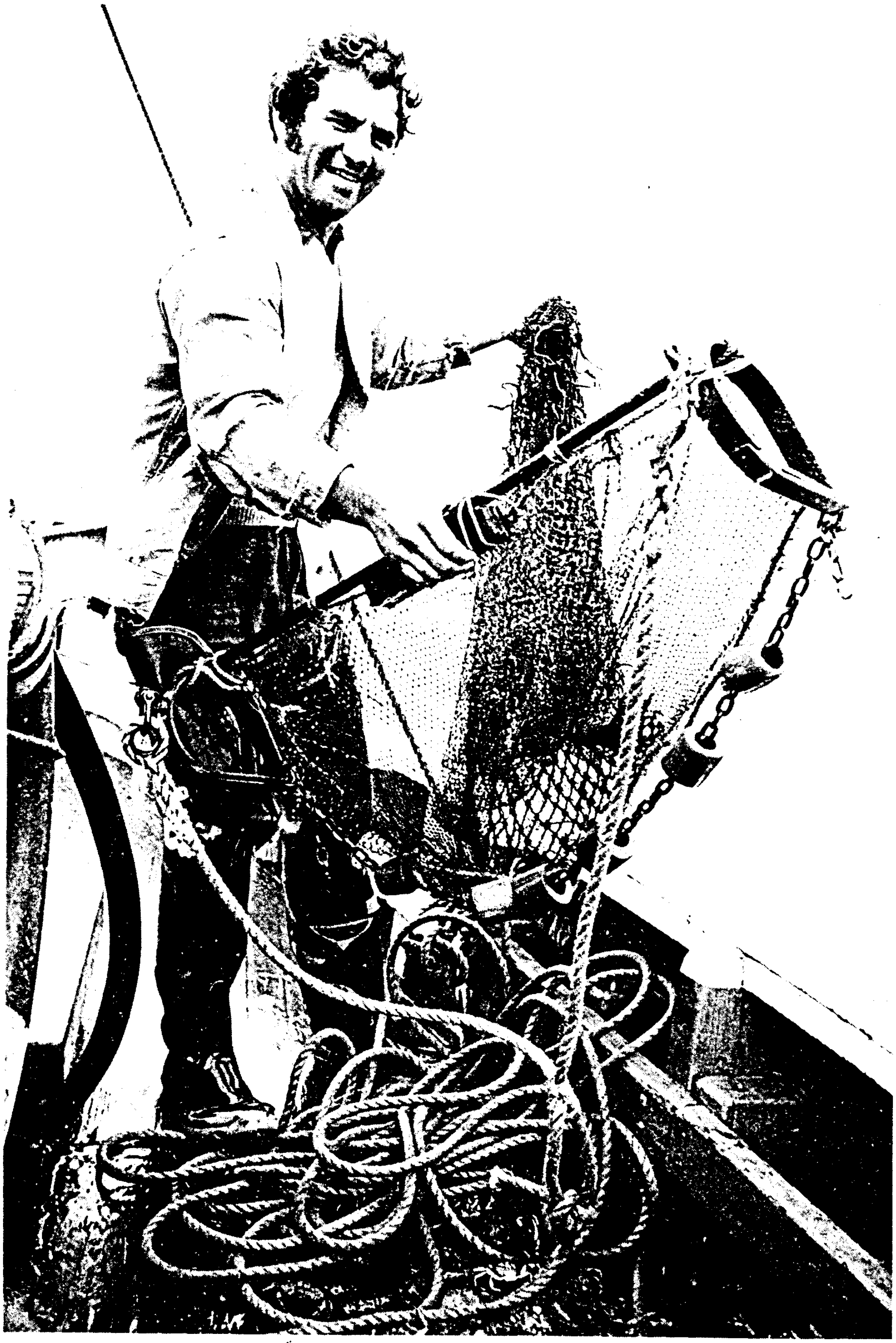


Plate 7 A 'try' net provides an indication of shrimp concentration while the main trawl is fishing.

Handling the catch

After the cod-end has been emptied on deck the catch is sieved by hand to extract marketable shrimps. A large-meshed sieve is sometimes used first to remove starfish, crabs and weed (Plate 8). The shrimps are then sieved to separate them into 'large' and 'small' (Plates 9A, B, 10, 11), using the measurement of body width as the basis of selection. Buckland's 'threepenny sieve' is still in general use but other sizes of sieve are available. All are based on the thickness of duodecimal pennies and halfpennies. The metric equivalents of 'penny' sieves are approximately as follows: twopenny (3.4 mm), twopenny ha'penny (4.9 mm), threepenny (5.2 mm), threepenny ha'penny (6.6 mm), and fourpenny (6.9 mm).

The sizes of shrimps retained by twopenny ha'penny and threepenny sieves (the retention curves) are shown in Figure 4. The average carapace lengths of shrimps (see section 3b) retained by these sieves are approximately 9.6 mm and 12.4 mm; these shrimps have approximate individual weights of 0.7 and 1.5 grammes respectively.

Pink shrimps live only a short time on deck once they are removed from sea water, so there are practical difficulties inherent in catching large quantities of shrimps and conserving the small individuals by returning them to the sea. When large catches are made, virtually all shrimps are dead before they can be cleared from the deck. The combination of long trawl hauls and vigorous hand-sieving results in most shrimps being damaged either in the cod-end or on the wires of the sieves. Therefore, the number of live, undamaged, small shrimps which are returned to the fishery is negligible. In practice, when large catches are taken they are not always sorted, with the result that the despatch to market of small shrimps returns a lower price to the fishermen.

After sieving, batches of washed, market-sized shrimps are cooked on board in sea water to which extra salt has been added. Boilers (Plate 12) often contain 10 gallons of water, and with each 2-3 gallon batch of shrimps a handful of salt is added. When raw shrimps are first introduced into boiling brine they sink to the bottom of the cooking pot, but after 2 or 3 minutes they are cooked, and then rise to the water surface. After cooking, they are spread out to drain and cool on net-bottomed trays (Plate 13). When they have cooled, the catch is measured by volume into hessian sacks in readiness for market.

Referring to the practice of transporting shrimps in hessian bags, the Eastern Sea Fisheries Committee Inspector included the following item in his 1923 report:

"It is the practice to send away bags of six pecks of pink and brown shrimps from King's Lynn and bags of two pecks from Boston. The result is that the latter make higher prices per peck. The small bags are easier to move about, the shrimp do not get crushed so much and they have a quicker sale in the wholesale markets."

This use of hessian bags has been continued at the Wash ports until the present day, and Boston shrimps still tend to command a higher price in the markets than those from King's Lynn.

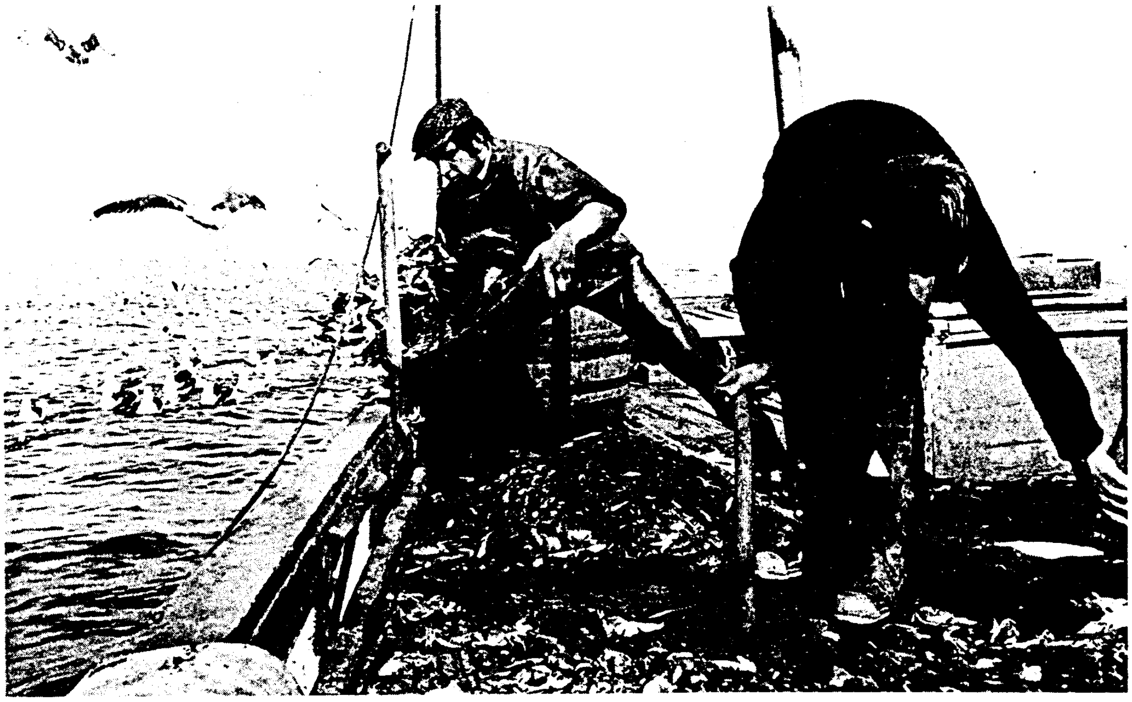


Plate 8 Sorting the catch. When necessary, a coarse sieve is used first to remove unwanted material from the shrimp catch.

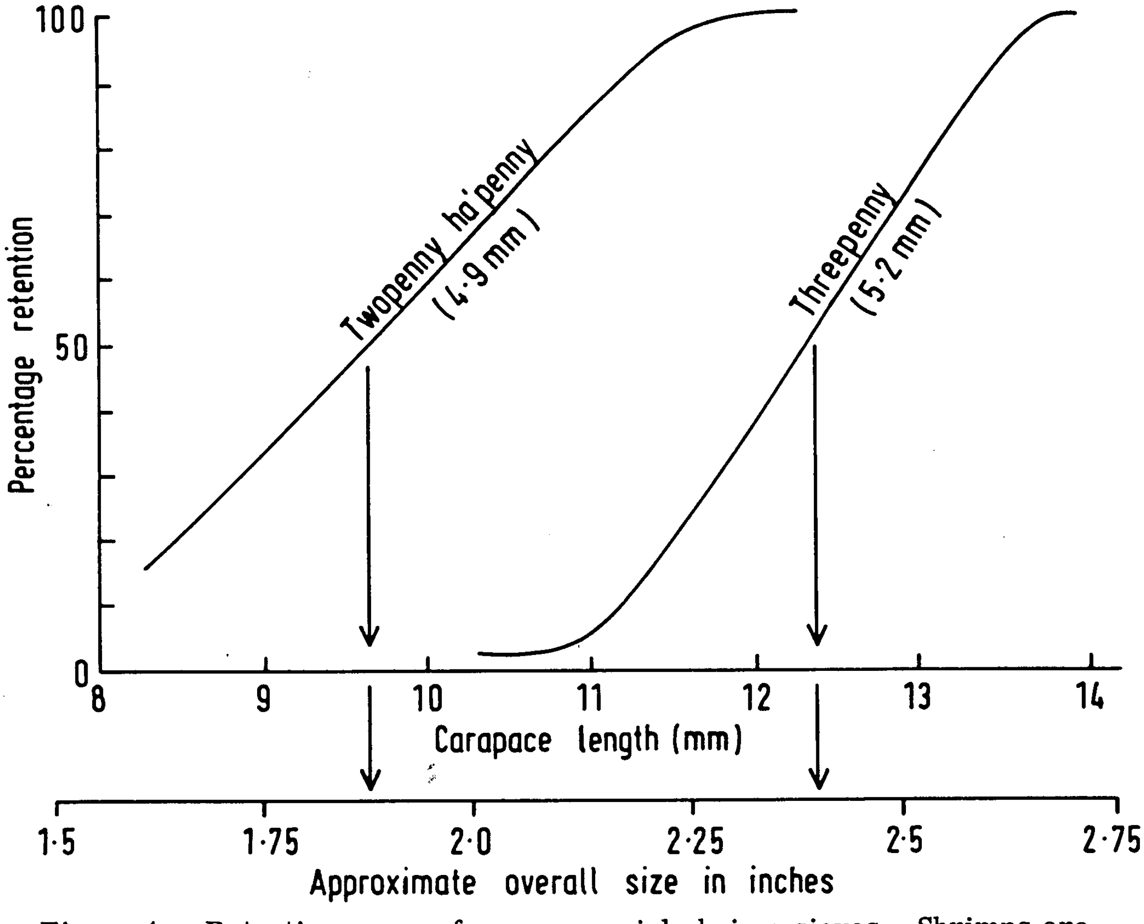


Figure 4 Retention curves for commercial shrimp sieves. Shrimps are graded into large and small, using hand sieves. Two common sieve sizes are twopenny ha'penny and threepenny. The 50 per cent retention point is that where half the shrimps pass through the sieve and half are retained.

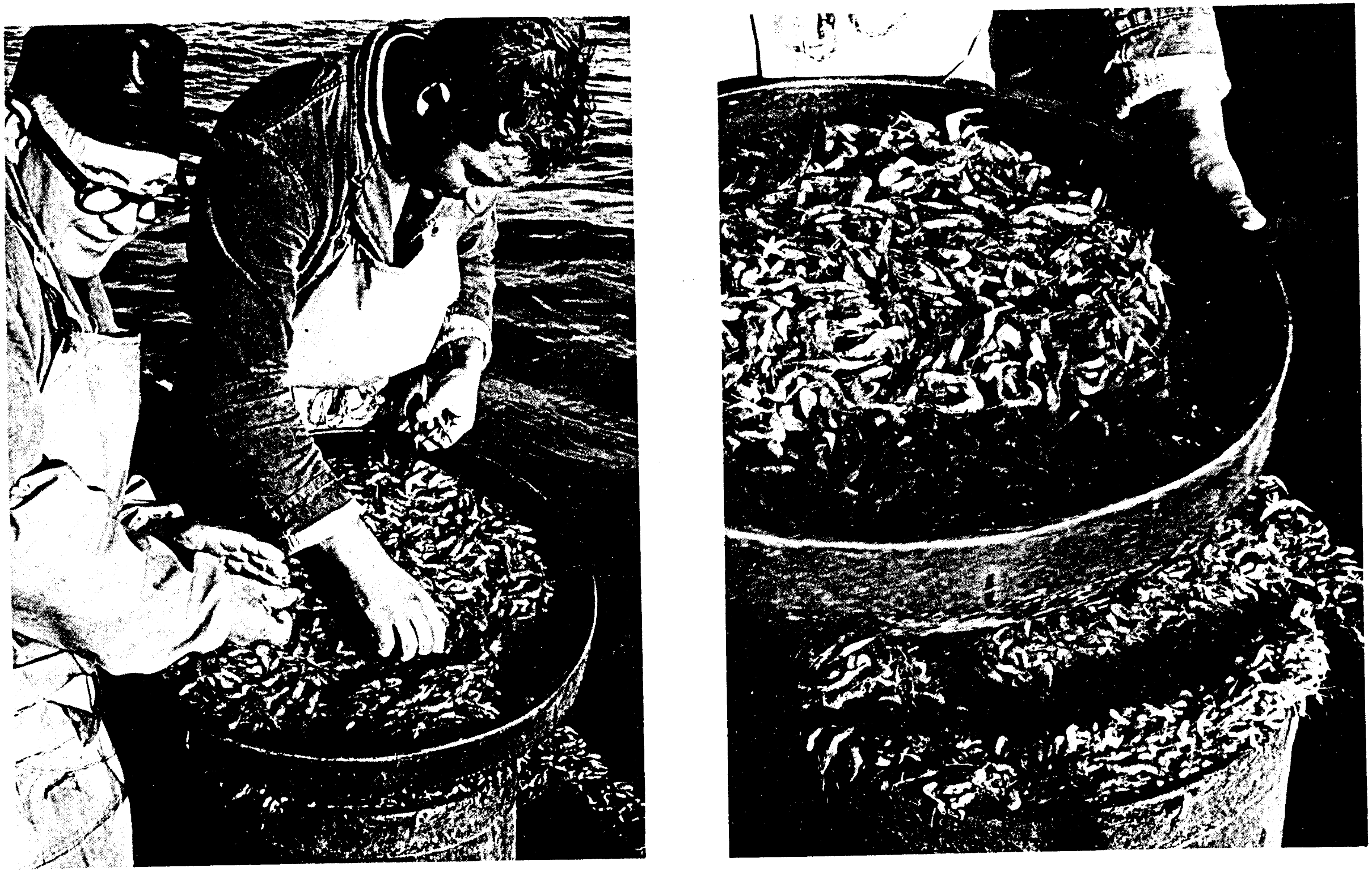


Plate 9   Sieving the catch. Shrimps are sieved on a threepenny riddle to separate market shrimps from smalls and assorted by-catch species.

Plate 10 A mixed catch may be sorted very effectively in a tub of water. Sand and by-catch species are quickly separated from shrimps by this method. Clean shrimps are boiled in baskets or net bags.

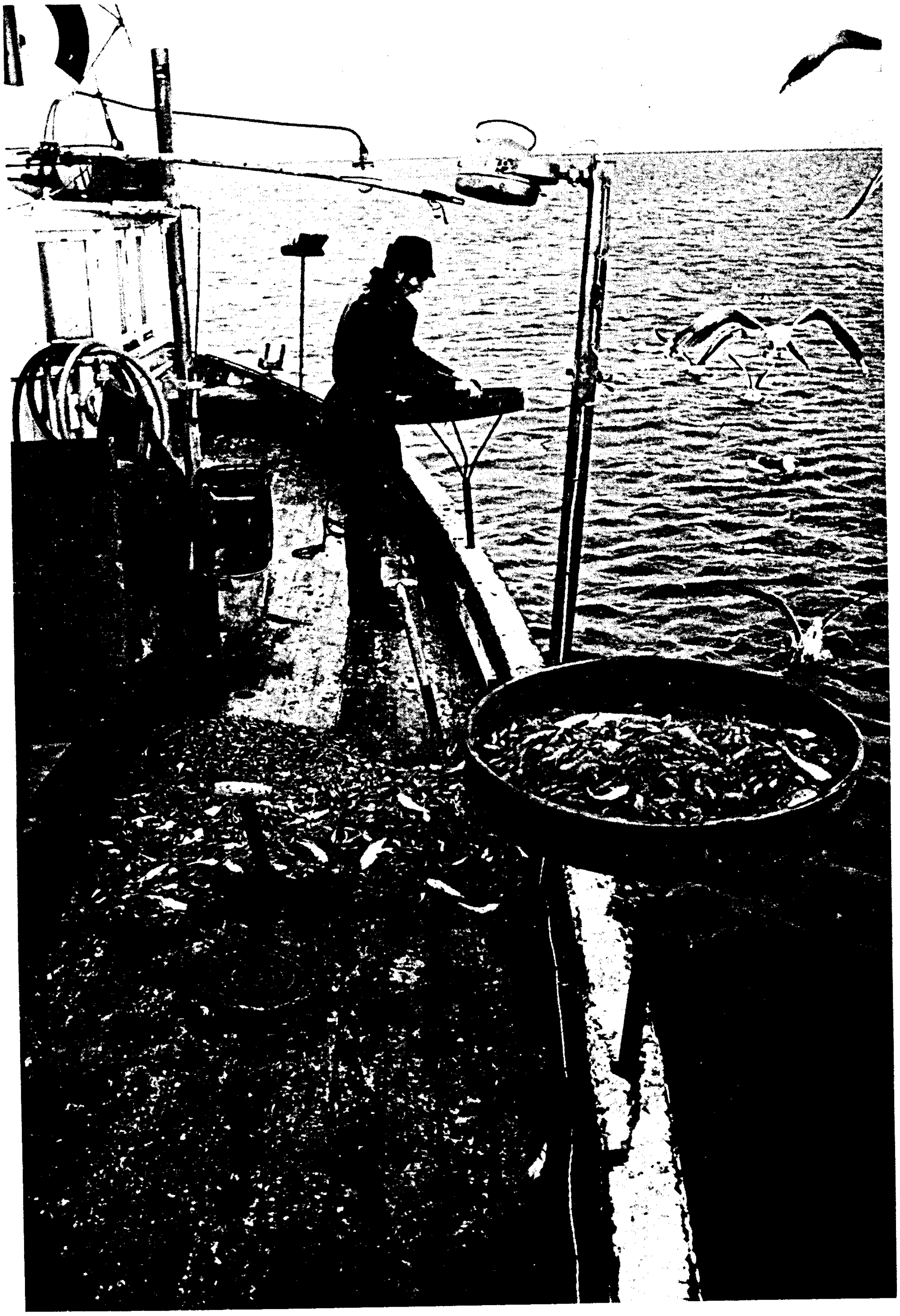


Plate 11 Sorting the catch. Sieve stands like these are used to sort the catch at the ship's rail.

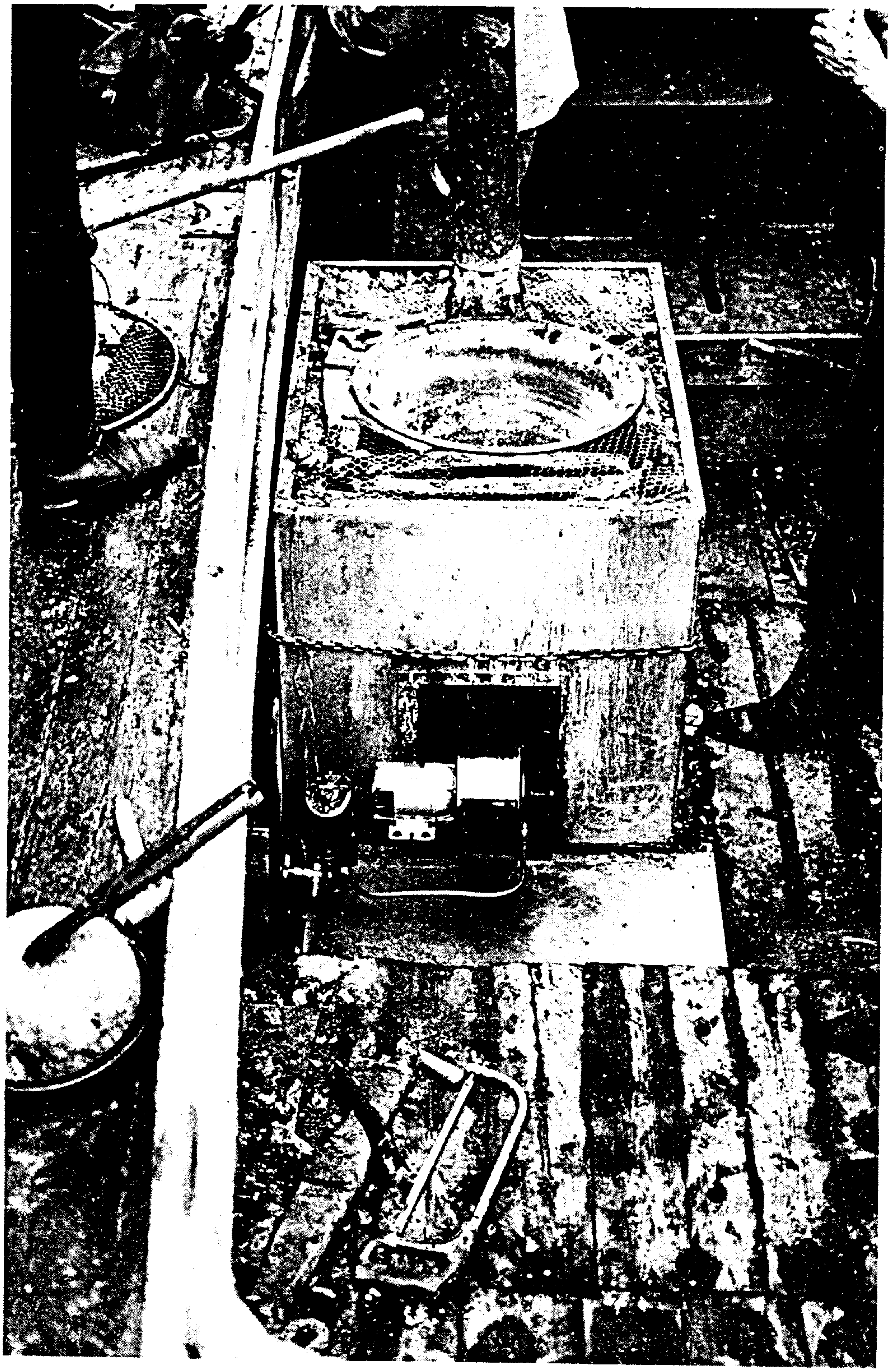


Plate 12 Shrimp boilers. For many years, shrimps were cooked in coal-fired boilers. Now, most boilers have been converted to use diesel oil. This boiler is being changed from coal to oil.

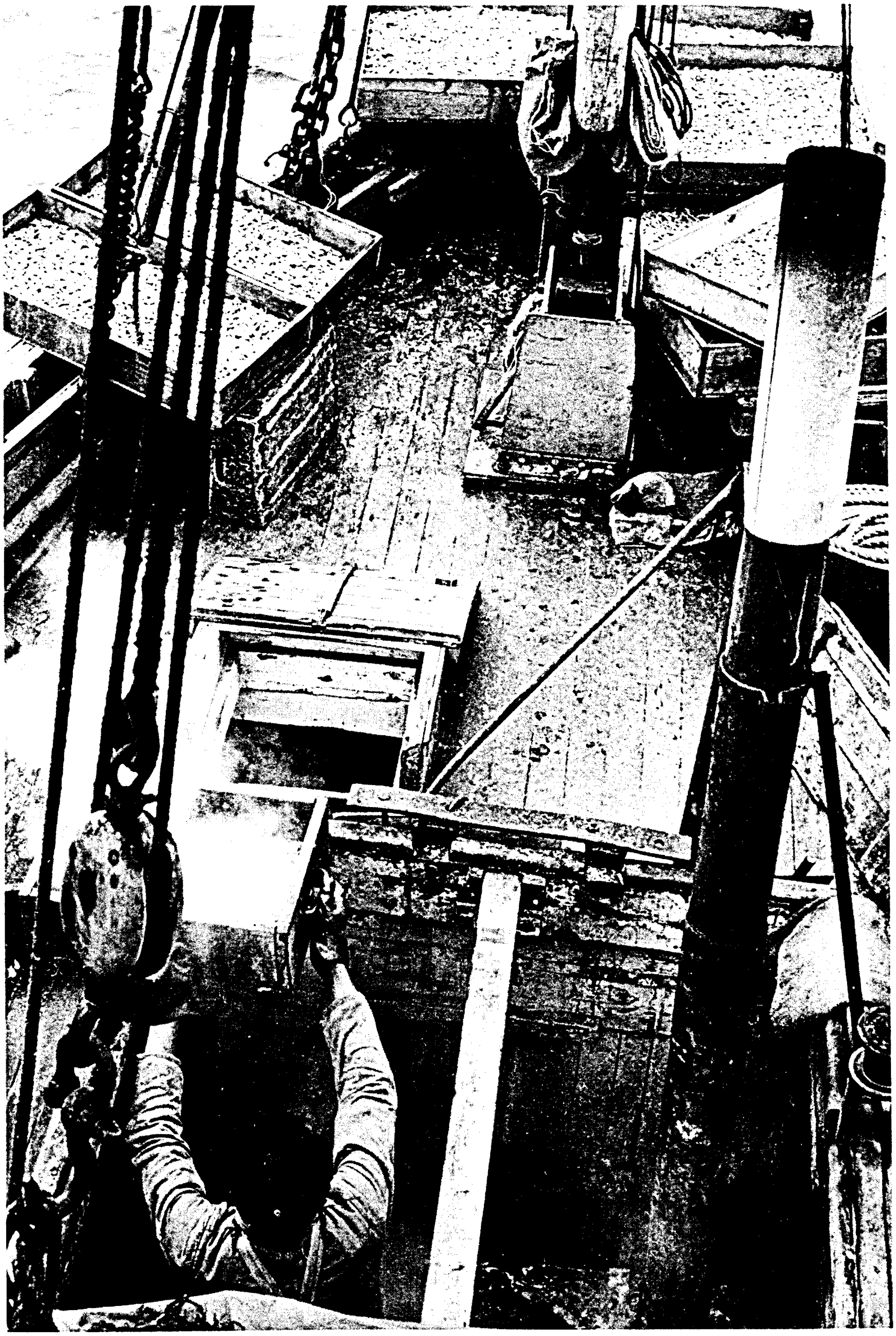


Plate 13 When they have been cooked, shrimps are spread in trays to cool and dry, before being bagged for market.

c Annual and seasonal landings in the fishery

For the past fifty years, the Ministry's Sea Fisheries Statistical Tables, published annually by HMSO, have included a record of the landings of shrimps in England and Wales by both weight and value. In these statistics the landings of pink and brown shrimps are combined into a single entry under 'shrimps'.

The statistics show that between 1920 and 1970 the total annual landings of shrimps at Boston and King's Lynn have undergone considerable fluctuations (Figure 5). At King's Lynn, for example, a total of 21 000 cwt was taken in 1926, whereas only 2 000 cwt were landed in 1932. However, it is known that during the late 1920s and early 1930s a number of shrimp boats which had fished from King's Lynn were sold to new owners at Boston and subsequently landed their catches at that port. Once it became the major port, Boston landings continued at 10 000 to 16 000 cwt until the outbreak of the second world war. Post-war landings at Boston have varied from a maximum of 16 000 cwt in 1948 to 1 500 cwt in 1961 and 1963. By contrast, those at King's Lynn have remained fairly steady between 4 000 and 7 000 cwt. However, in the last five years, additional large vessels have swelled the King's Lynn fleet and the pattern of landings has begun to change again. In 1970, King's Lynn landings of pink and brown shrimps were approximately equal, and totalled 7 100 cwt. In the same year, Boston landings amounted to 5 400 cwt and consisted largely of pink shrimps. When the major ports are considered together, it is quite evident that wide fluctuations in landings are a normal feature of the Wash shrimp fishery, and probably reflect changes in natural abundance of the stock. There are also signs of cyclic fluctuations in landings from the fishery, although the reasons for this are not clear. There appears to have been a general downward trend in landings which needs to be considered in relation to changes in the strength of the fishing fleet. Unfortunately, no information on fishing effort is available before 1961.

From Eastern Sea Fisheries Committee reports it has been possible to compile the approximate landings of pink shrimps. The information is only available for three periods: for Boston and King's Lynn between 1925 and 1946, for Boston between 1944 and 1959, and for King's Lynn between 1960 and 1970. Landings from the first two periods are combined in Figure 6 to illustrate the variable pattern of landings of pink shrimps.

The Boston and King's Lynn landings of pink shrimps are shown as monthly totals in Figure 7 to indicate the seasonal nature of the fishery. Fishing normally begins in late spring with the return inshore of shrimps which migrated offshore at the end of the previous year, and continues until Christmas, when the population usually moves offshore again. Figure 7 shows the severity of the decline in landings at King's Lynn in the early 1960s. In 1961, total annual landings at the port are recorded as being only $1\frac{1}{2}$ cwt; by 1970 landings had improved to exceed 200 tons.

In order to eliminate the effect of changes in the size of the fleet on total landings, and so obtain an estimate of the size of the stock, since 1960 catch-per-unit-effort data have been calculated for the King's Lynn fleet (top line, Figure 8) and expressed as hundredweights of shrimps per day's fishing. Monthly means of catch per unit effort have shown considerable variation over the last seven years, ranging from 1-6 cwt (50-300 kg) per day. During this period there has been a steady increase in landings until, in November 1970, they reached a maximum for the period (see section 4b).

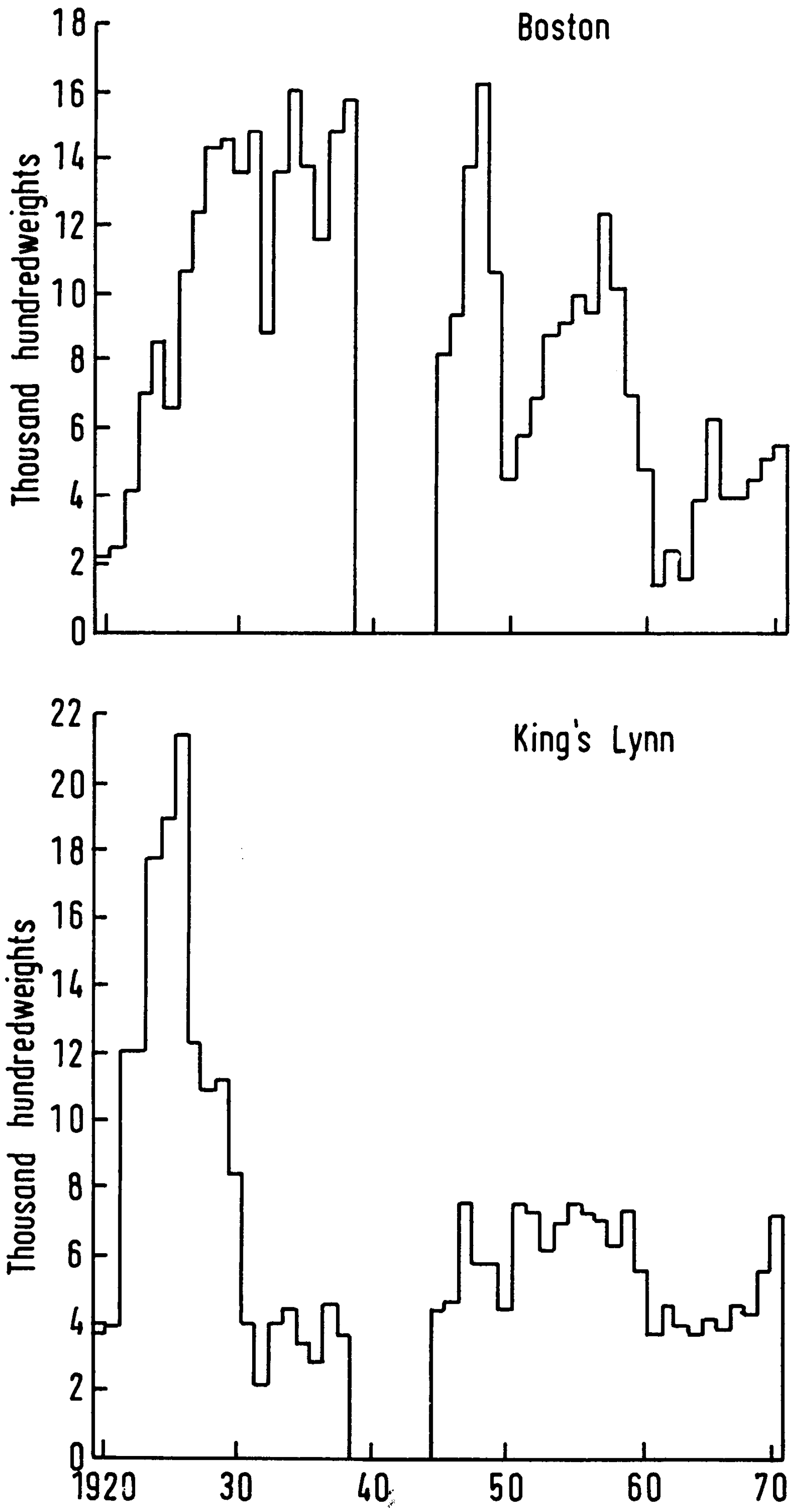


Figure 5 Total annual landings of pink and brown shrimps at Wash ports, 1920-70. Data from HMSO fishery statistics for England and Wales.

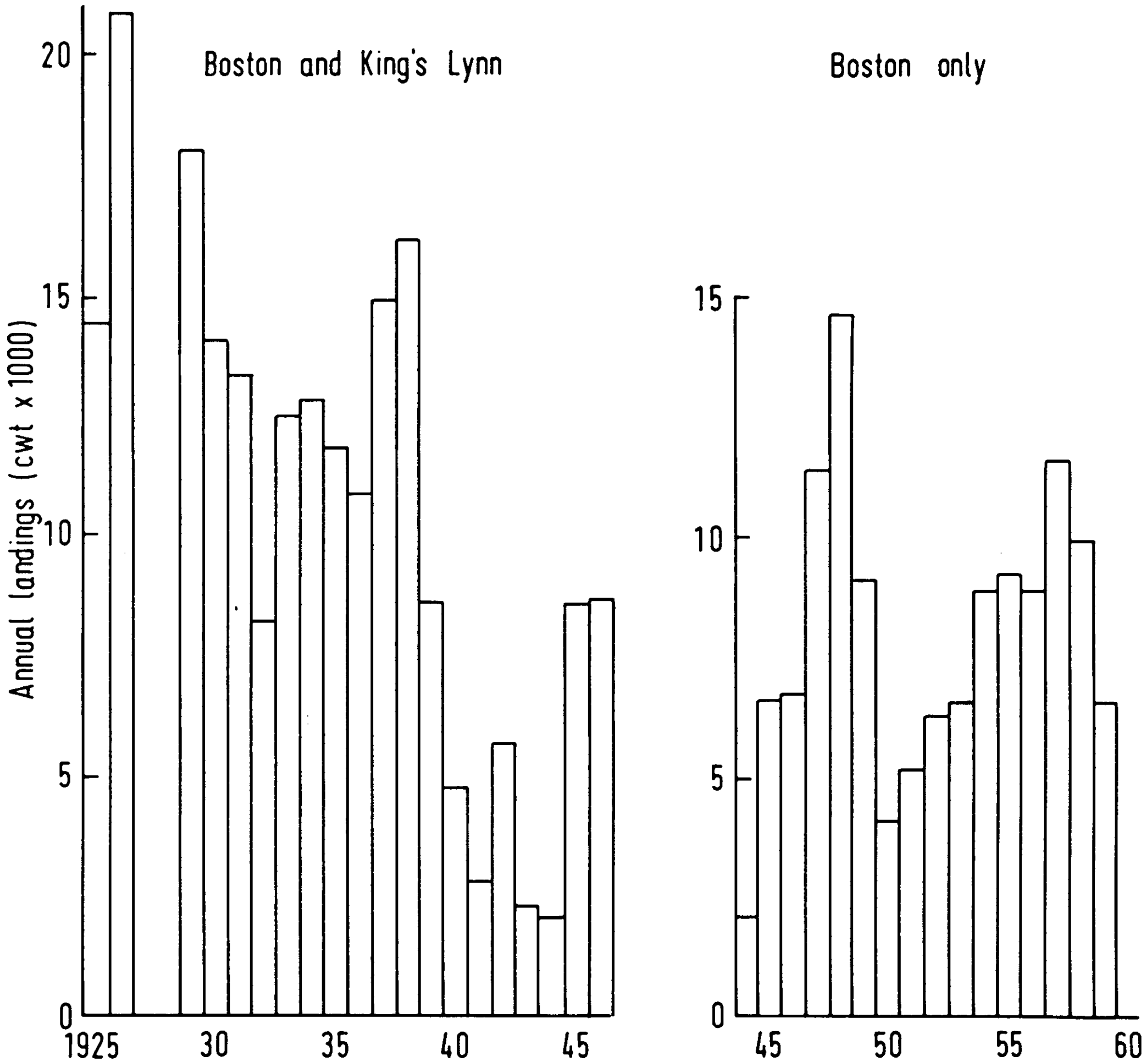


Figure 6 Pink shrimp landings in the Wash, approximate annual totals, 1925-59. (Data from ESFJC Inspectorate.)

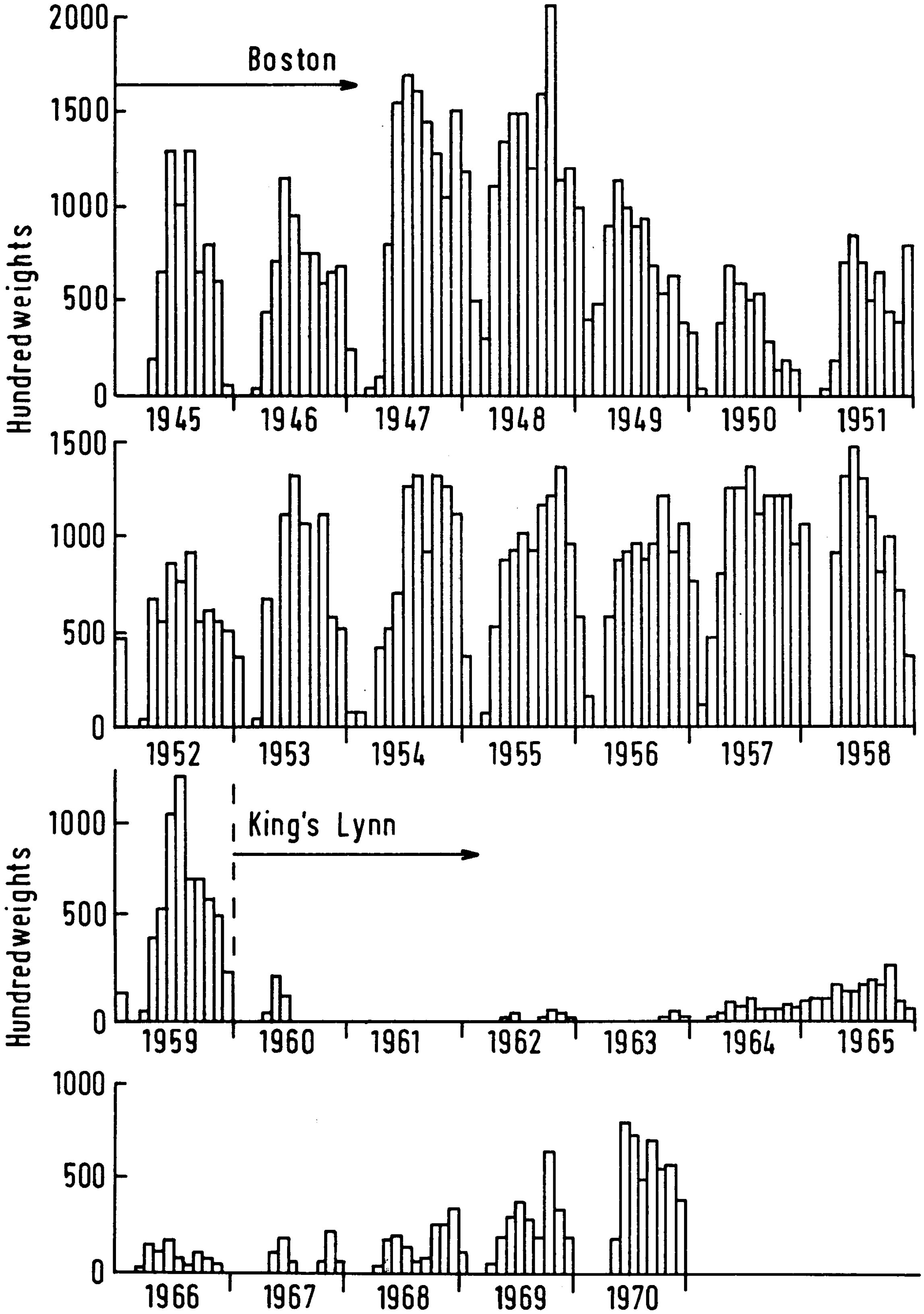


Figure 7 Monthly landings by weight of pink shrimps at Boston (1945-59) and King's Lynn (1960-70). 1 cwt = 50 kg approximately.

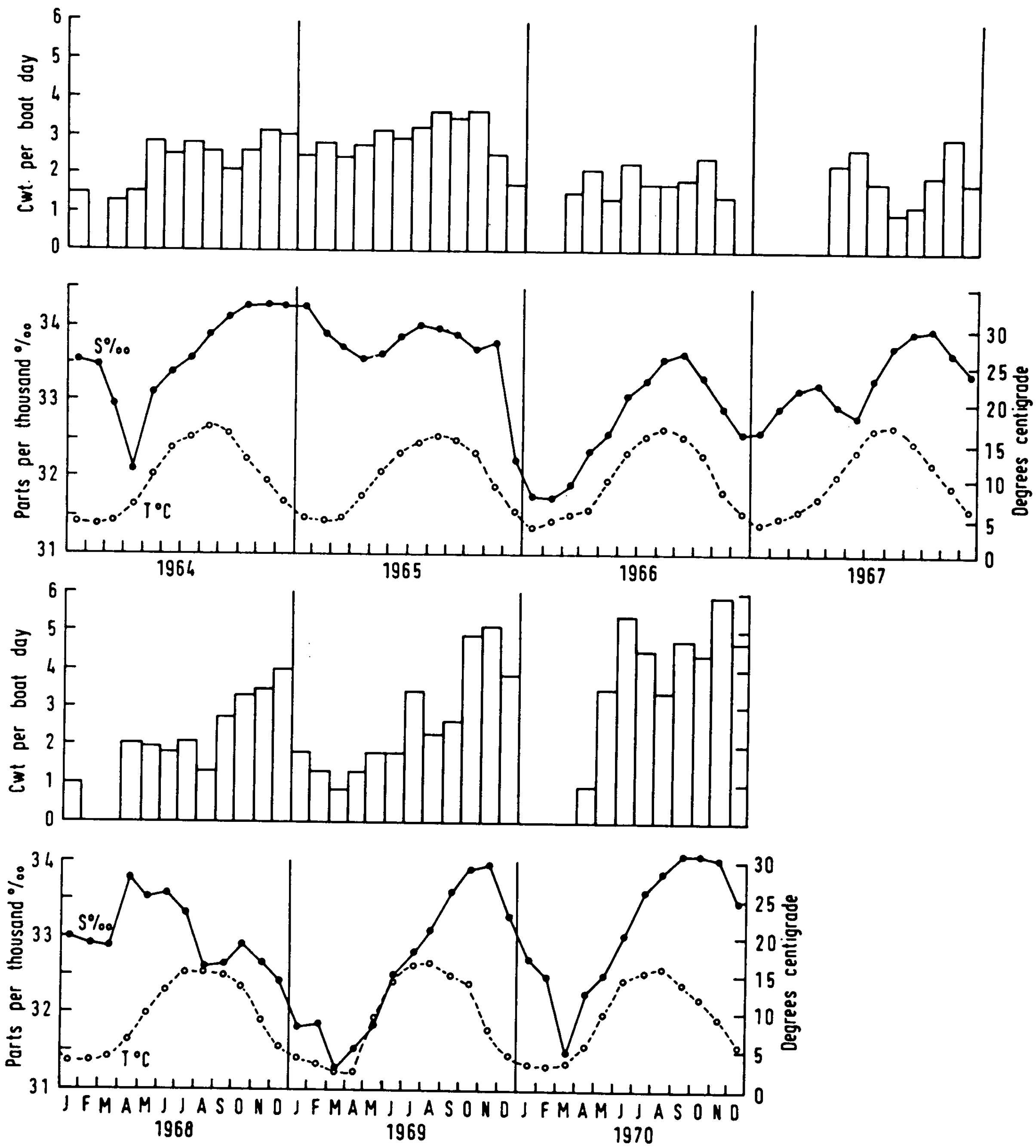


Figure 8 Pink shrimp catch per unit effort, King's Lynn, related to mean temperature and salinity at Lynn Well lightvessel, 1964-70.

3 GENERAL BIOLOGY OF PINK SHRIMPS: GROWTH, AGE AND LIFE-HISTORY

a The Pandalid shrimps

The pink shrimp, Pandalus montagui, is one species in the group of Pandalid shrimps which are widely distributed in northern seas in water depths down to 400 fathoms (730 m). Other Pandalid shrimps occur in British waters, including the northern shrimp or deepwater prawn, Pandalus borealis, which supports considerable commercial fisheries along the coasts of north-west Europe, Iceland, Greenland and the Atlantic and Pacific coasts of North America. There are at least twenty species of Pandalid shrimps in the world, and some of them are fished along the Pacific coast of the USA, Canada and Alaska; others are found in the Far East, including Japan.

All these Pandalids belong to the Decapod order of Crustacea and have a common arrangement of their five pairs of walking legs which distinguishes them from other shrimps (Figure 9A). Four pairs of these legs have pointed tips, but the remaining pair, the second, have small claws at their extremities which are used while feeding. The wrist, or carpus, of this limb is multijointed and therefore very flexible.

The two species of Pandalids which occur along the east coast of England are Pandalus montagui and Pandalus borealis (Plate 2). At present, Pandalus borealis is not found in the Wash, occurring only in deep water off the Farne Islands, but it is interesting to speculate whether or not it has occurred in the Wash in the past. The local name 'jackprawn' was used in the fishery to describe shrimps, which differed, at least in size, from pink shrimps. Descriptions of the 'jackprawn' suggest that it might have been Pandalus borealis, but it is possible that a few true prawns, Palaemon serratus, were taken with pink or brown shrimp catches.

In any event, although the Pandalid species are rather similar, they may be readily distinguished by the shape of the rostrum or 'nose', and the number of spines along their upper and lower edges (Figure 9B). The rostrum of Pandalus montagui turns sharply upwards toward the tip and the outer third of its upper edge carries no spines. Along the remainder of the upper edge there are 10-12 spines, and along the lower edge there are 5-6. Pandalus borealis has a rostrum which is almost straight and spines are present along the whole length, totalling 14-16 above and 9-10 below.

Both these Pandalid species are very different in colour and shape from the commercially fished brown shrimp, Crangon crangon (Plate 2). Crangon has only a short rostrum and is caught in a range of shades from light grey/brown to almost black, but all these colours are turned to sandy brown after cooking. The brown shrimp has a burrowing habit, not shared with the Pandalids.

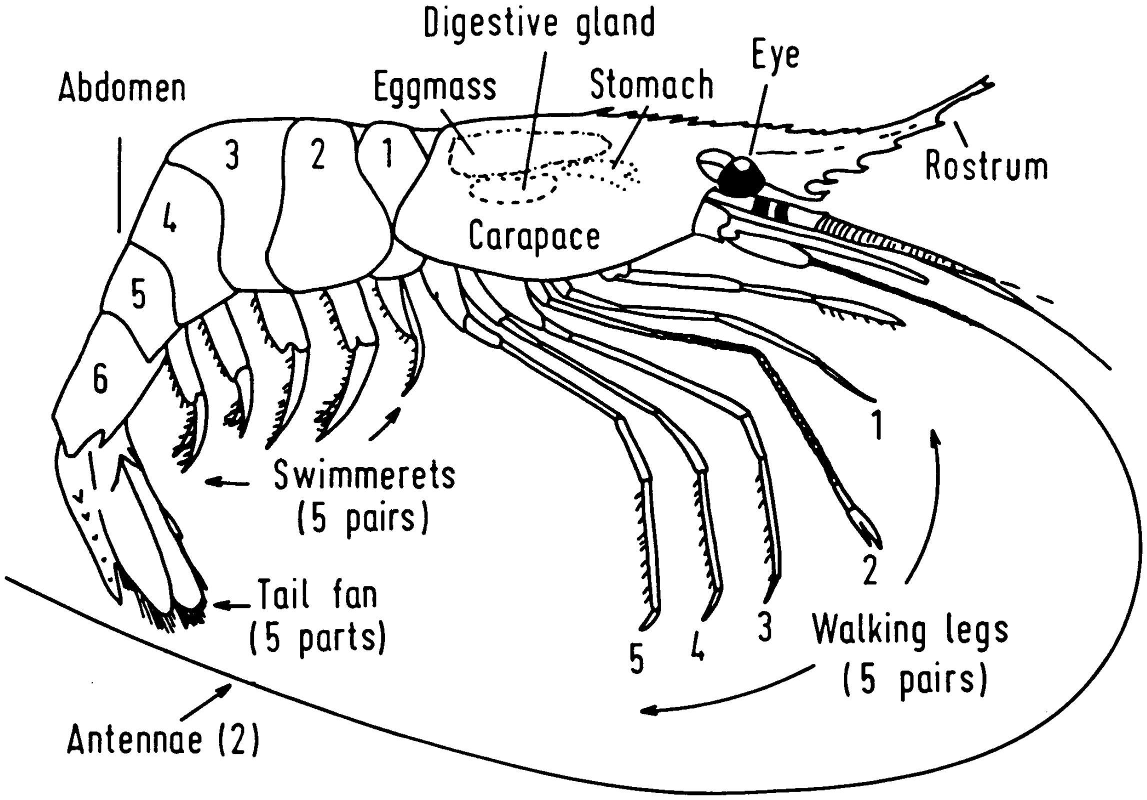


Figure 9A A Pandalid shrimp.

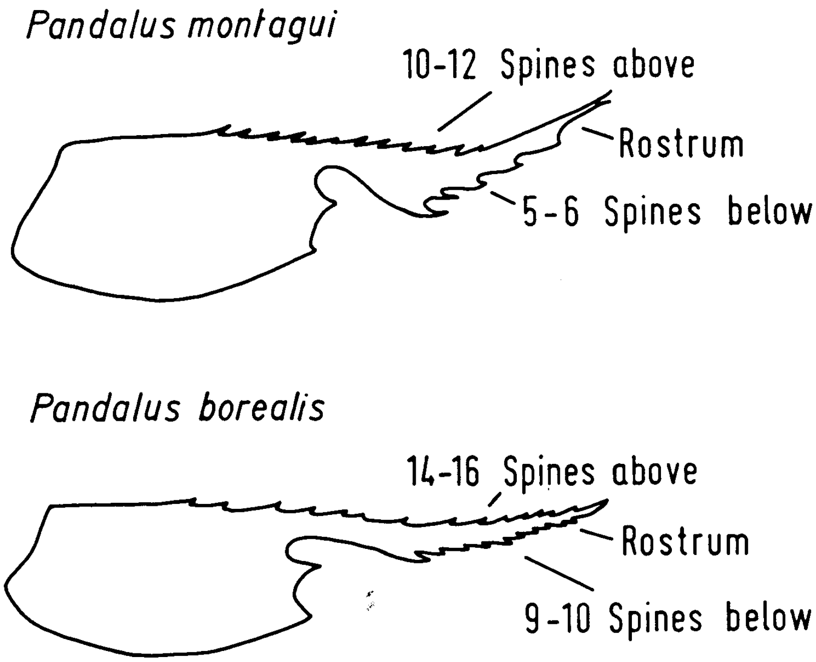


Figure 9B Difference in structure of the rostrum in two Pandalid species.

b Growth and age of pink shrimps

In common with crabs, lobsters and all other shrimps, growth among Pandalid shrimps is not a continuous process, but is accomplished immediately following the periodic cast, or moult, of the shell. The moulting shrimp emerges through a split which forms between the carapace (or head) and the abdomen (or tail) of the outer shell. When the old shell has been shed successfully, the shrimp absorbs water until it reaches a larger size and then the new shell begins to harden. The cast shell often remains complete in every detail and exactly represents the shrimp in the premoult stage (Plate 14).

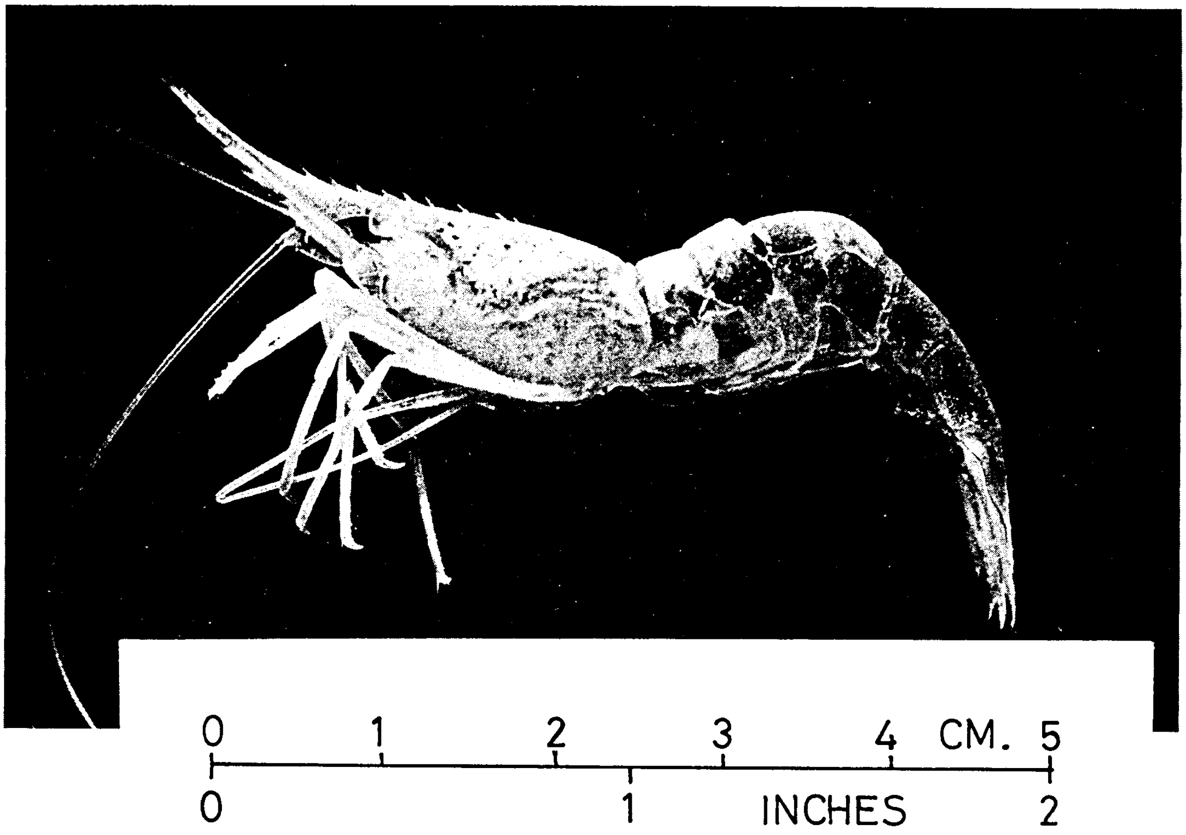


Plate 14 Pandalus montagui. After moulting, the cast shell often remains complete as a record of the premoult size of the shrimp.

Because of the difficulty of measuring the total length of preserved specimens or those whose tails are tucked forward beneath the body, for scientific purposes the carapace is measured from the back of the eye socket to its rear edge. The relationship between carapace length and weight of individual shrimps is shown in Figure 10.

In the Wash, pink shrimps do not usually exceed a carapace length of 18 mm ($3\frac{1}{2}$ inches total length) and a weight of 4 grammes (Figure 10). At this size and weight, Wash shrimps are normally two years of age, and these shrimps form the basis of the commercial fishery. In addition to these larger individuals, considerable numbers of small shrimps are taken in commercial catches during the latter part of the year. Some measured samples taken from commercial catches have been selected to show the two main year-groups of shrimps in the fishery (Figure 11).

Shrimps in the smaller size group, 8-10 mm carapace length, are less than one year old. The larger size group, 12-16 mm carapace length, are in their second year of growth. There appear to be few third-year shrimps.

In England, Pandalus montagui is known to be at the southern end of its geographic range and its maximum age has been estimated to be three or possibly four years. In extreme northern latitudes, populations of Pandalids which live in much lower water temperatures are reported to contain individuals whose ages reach six or even eight years.

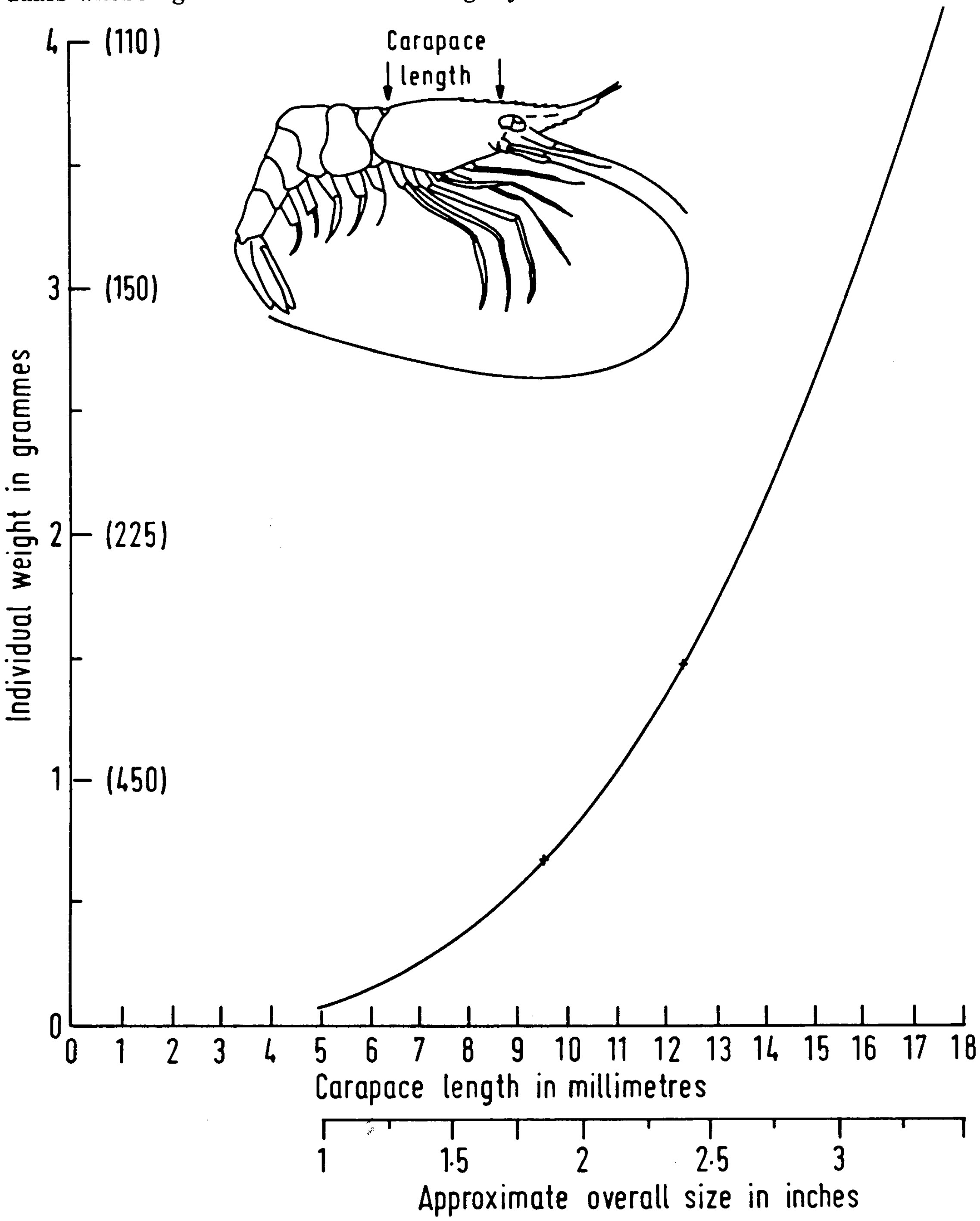


Figure 10 Carapace length/weight relationship for pink shrimps from the Wash, August 1965. Individual weights are in grammes (numbers of shrimps per pound weight are in parentheses).

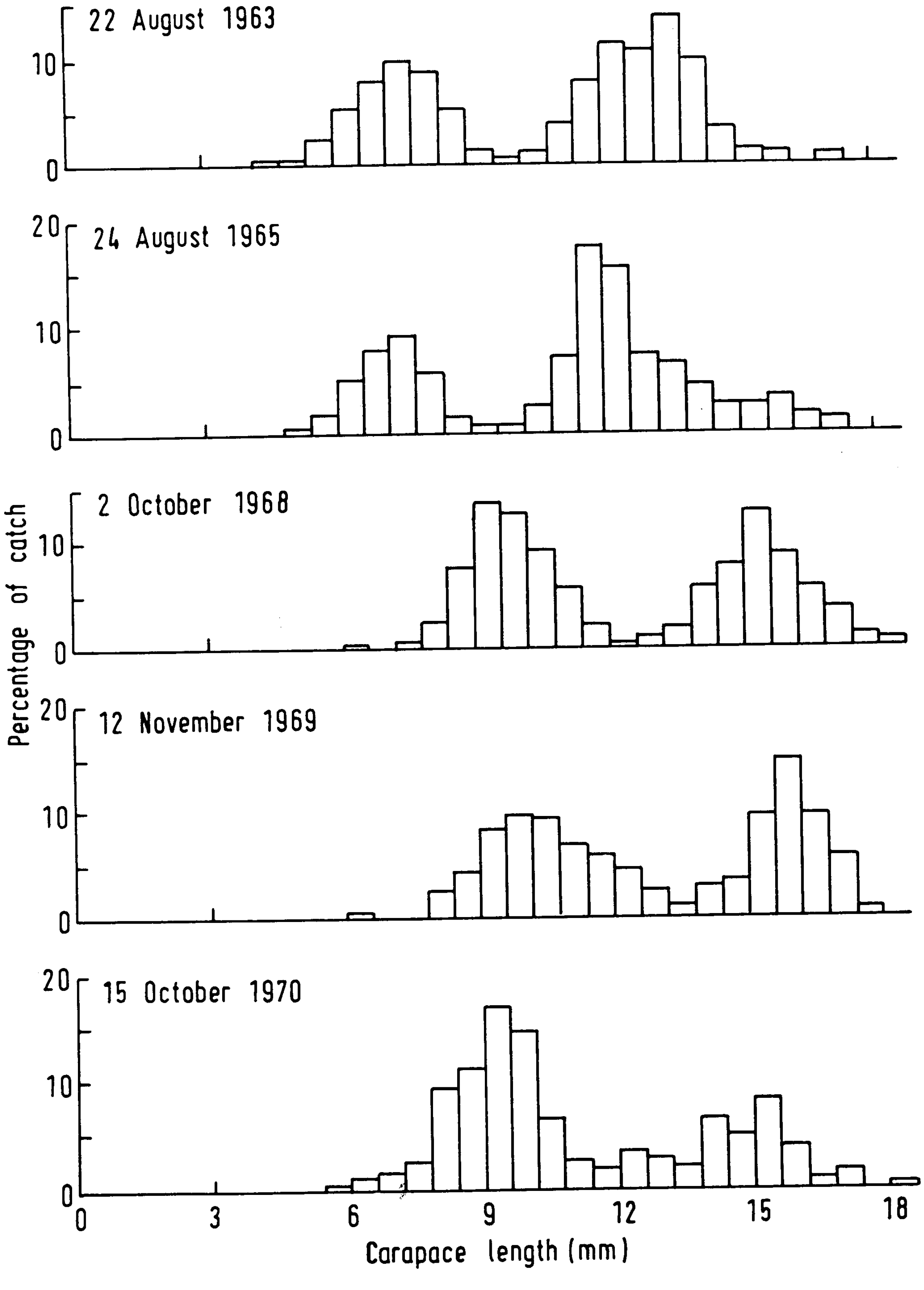


Figure 11 Length/frequency distributions of pink shrimps from the Wash.

c Life-history of pink shrimps

Since the pink shrimp appears to reproduce only once each year, it is convenient to begin an account of the life-history in August when the ovaries of 18-month-old female shrimps are beginning to develop. During the following three months an increasing proportion of the females are found to have a developing egg mass under the carapace. As the egg mass develops, it becomes larger and can clearly be seen in the head. In the period immediately before the eggs are laid, they may extend forward to envelop the stomach and reduce feeding activity. Although isolated berried females may be seen in October, most females begin to lay in November when the bright green eggs appear, attached to swimmerets (Figure 9) beneath the tail. During the period of egg carriage, the eggs would be lost if the female cast its shell, so growth is halted until the eggs are hatched. When the berried females move out of the fishery in December or January their eggs continue to develop. Fully developed eggs are oval in shape and smaller than a pin's head, measuring approximately 0.8 mm long and 0.6 mm in diameter. The number of eggs carried by a female is related to its size, and may vary between 200 and 3 000. The egg masses disappear from the swimmerets with the onset of hatching, which probably begins in early March and reaches a peak in April; when it is completed, in late spring, the spent females begin to return inshore.

Young shrimps grow rapidly during their first season; brood shrimps are first caught by commercial bottom trawling in mid-summer when their total length is less than one inch. During the first year, many brood shrimps become mature males and the remainder begin and continue their lives as females, called primary females. In the course of the first or second year most of the shrimps which developed as males change sex to function as secondary females and subsequently carry eggs.

Much of the egg production which maintains the fishery depends upon second-year females, but when first-year females develop sufficiently rapidly, they almost all carry a batch of eggs. These tend to be produced later than those of the older shrimps, and may not have been laid before the population migrates offshore.

Except when the females are carrying eggs there is no simple method of determining the sex of pink shrimps. However, under microscopic examination it is possible to identify male, female and intersex individuals by differences in the shapes of the first and second pairs of swimmerets.

4 SCIENTIFIC INVESTIGATIONS AND RESULTS

a Shrimp landings: the influence of environmental factors

It has long been known that the shrimps migrate offshore in winter, when a high proportion of females are carrying eggs. On their return inshore in the following spring, very few females remain berried, so it is clear that the seasonal migration occurs at an important period of the breeding cycle. It has been suggested that shrimps may embark upon these seasonal migrations to find more stable conditions of temperature, salinity, wave action or food supply.

The possible influence of temperature and salinity upon the Wash shrimp stocks has been examined during the present investigations. Seawater temperature and salinity observations representative of this area have been made weekly since 1964 at the Lynn Well lightvessel. These have been compared with shrimp landings and catch per unit effort of the King's Lynn fleet for the years 1964-70.

Monthly mean temperature observations at Lynn Well lightvessel indicate a regular annual temperature cycle covering the range 3.0-17.5°C (Figure 8). Predictably, mean temperatures were lowest from January to March and highest in August. During the periods of low water temperatures the pink shrimp population usually moves offshore, and as a result landings in the fishery fall sharply. However, during some periods of minimum water temperature the landings in the fishery have not fallen to the same extent, and in 1964/65, for instance, shrimp fishing continued throughout the winter. This suggests that although temperature may be an important factor associated with seasonal migrations it is unlikely to be the only factor involved.

The effect of salinity on catches has also been examined. Freshwater run-off from the land contributes largely toward changes in salinity within the Wash. The surrounding agricultural land is drained by the local rivers, but the movement of freshwater is controlled by locks and sluices and mainly affects the shallow coastal waters of the Wash. It has little influence on the salinity of the deeper water in the channel. Also, the tidal movements within the Wash are strong and complex, so that mixing of surface and deeper waters is virtually complete and the influence of fresh water is kept to a minimum. Monthly mean values of salinity at the Lynn Well lightvessel have varied between 31°/oo and 34°/oo during the seven-year period of observations but do not follow a seasonal pattern of change similar to that of temperature (Figure 8). Reductions in salinity are governed by rainfall and subsequent freshwater run-off from the land, but during the period 1964-70 there seemed to be no clear association between salinity and catch per unit effort. However, it is interesting that when fishing continued through the winter of 1964/65, salinities remained unusually high, while water temperatures were similar to those observed in other years. The examination of these data makes it clear that shrimps usually undertake a migration to deeper waters when temperature and salinity are falling and that they remain offshore while adverse conditions prevail, but the timing of the migration does not appear to be related to a particular value of water temperature or salinity. It is popularly believed that a sharp fall in temperature combined with a drop in salinity, such as occurs when snow falls over the fishery, provides a stronger stimulus for migration than a change of either water temperature or salinity by themselves.

While a number of factors may play their part in influencing the offshore winter migration of the parent stock, it is perhaps as important to relate this migration to the time required for egg development and hatching, the subsequent growth of young shrimps, and their food requirements in the following year. Most eggs hatch in the months of March and April when temperature and salinity in the southern North Sea are showing upward trends. The development of larvae and juvenile shrimps then continues until August whilst temperature and salinity continue to rise. It is during this period that food suitable for juvenile shrimps is usually present in its highest annual concentration (see section 4c). Brood shrimps from the new year-class are first taken inshore in commercial trawls when water temperature and salinity are reaching their maximum values.

It therefore appears that the large-scale winter migrations to deeper waters are timed to provide the best environmental conditions for the developing eggs and for the feeding and growth of larval and brood shrimps during the following spring and summer.

The inshore migration of spent female shrimps has been referred to earlier. The arrival of young shrimps was investigated in August 1965, when trawling was carried out across much of the Wash. The results showed that although a few young shrimps were already present inshore, larger concentrations were present in the deeper water of the Inner Silver Pit (Figure 1), where 30 per cent of the total catch consisted of brood shrimps. These shrimps subsequently moved inshore and entered the fishery.

In addition to these large-scale annual migrations, more random movements continue throughout the year which are probably associated with shrimp feeding. The result of this activity is reflected in day-to-day variability of landings made by the shrimp fleet. The short-term nature of these fluctuating landings suggests that shrimps either move only a limited horizontal distance with the tide, or possibly rise vertically into the water column, so that they are not caught by bottom-trawling gear. However, during the summer, as can be seen from Figure 7, the catches over the whole fishery may be depressed during a short period.

Investigations have suggested that depressed summer landings are likely to be the result of a temporary change in shrimp behaviour which influences their 'catchability', rather than a migration from the fishery. An examination of the monthly landings statistics for 1970 at King's Lynn shows that after fishing had become well-established, catch per unit effort was depressed during August, when it was 37 per cent less than that recorded in June and 43 per cent less than in the subsequent November. Trawl surveys in July, August and September 1970 gave no indication of any migration which would account for these changes in landings. During this summer period when landings often decline, two notable changes occur in the commercial trawling routine which suggest changes in shrimp behaviour. Landings are often improved tenfold by changing from daylight to night trawling, and pink shrimps are often seen at the water surface (see section 4d).

The tidal cycle is believed to have an effect upon landings. In reports of the Eastern Sea Fisheries Committee there are occasional observations which refer to the fluctuating volume of pink shrimps caught in the fishery during periods of spring and neap tides. For example, the 1922 report includes the following paragraph: "....the catches varied more than usual during each round of tides, the pink shrimps being in good quantity during the springs and scarce when the neaps are on. The fishermen said the shrimps 'sulked' when the tides were small or dead. At the commencement of the season, the quantity obtained in one or two days' trip was generally about 40 pecks during the springs and 12 during the neaps; in July 100 and 20 pecks respectively and in November from 80 to 40." Although current landings do not show such clear variations as these, it has been possible to relate the 1970 catch to tidal heights. Results confirm that the volume of pink shrimps landed tends to increase during springs and fall off during neap tides, but it is difficult to suggest a reason for this change.

b Annual landings: a relationship with temperature

The short life-history of pink shrimps in the Wash, and the dependence of the fishery on only two year-classes, means that changes in the abundance of eggs, larvae or juvenile shrimps, due to any cause, are closely followed by changes in the volume of commercial landings. The partial failure of one year's brood may be seen the same year and is necessarily followed by a decline in commercial landings in the following year. Shrimps are also taken as food by many fishes.

In other shrimp fisheries, it has been found that the level of commercial landings may be related to water temperature at the time of egg hatching. To establish a possible relationship between temperature and landings in the Wash, weekly water temperature observations for the past fifty years from the Smith's Knoll lightvessel have been compared with annual landings of pink and brown shrimps in the Wash. After statistical analysis, it is evident that annual mean water temperature is in some way related to the total landings of shrimps in the following year. Over the major part of this fifty-year period, low values of annual mean water temperature are usually related to increased commercial landings in the following year. High water temperature values are also related to reduced commercial landings in the following year. This relationship is statistically significant, although there have been many changes in the numbers of boats operating in the fishery during this period. Since 1945, however, fishing from Boston has been concentrated upon pink shrimps, the number of boats has remained comparatively stable, and annual landings at the port therefore reflect the changes in pink shrimp abundance in the fishery. In 1950, and to a greater extent in the early 1960s, the annual landings of pink shrimps fell sharply, but after each decline the landings have improved again. Statistical examination of the data for annual mean water temperature and annual landings of pink shrimps at Boston for the period 1948-62 (Figure 12) shows a similar significant negative correlation between temperature and landings. During this time, high values of water temperature appear to be associated with reduced landings in the following year. In the years 1960-61, annual mean water temperatures which were the highest since observations were begun in 1920 were followed in 1961 and 1962 by the lowest commercial landings of shrimps for many years.

Since 1963, this relationship appears to have changed, and increased landings appear to be associated with high annual temperatures during the previous year. The changed relationship between temperature and landings since 1963 may be only temporary, but at the moment there is no adequate explanation. Since 1963, it is true that the pattern of Wash landings has shown a generally upward trend, and this may be taken as an indication that the fishery is simply returning to its pre-1963 state. Alternatively, in the past few years there have been larger concentrations of cod in the southern North Sea than has been known for many years. It is possible that the quantities of pink shrimps taken as food by these and other fish may have affected the strength of the Wash stock. Certainly, there has been reported a change in a similar relationship between low water temperatures and high commercial landings of brown shrimps in Holland, where it has been shown that the effects of predation by cod resulted in a sharp decline in shrimp landings during 1970-71.

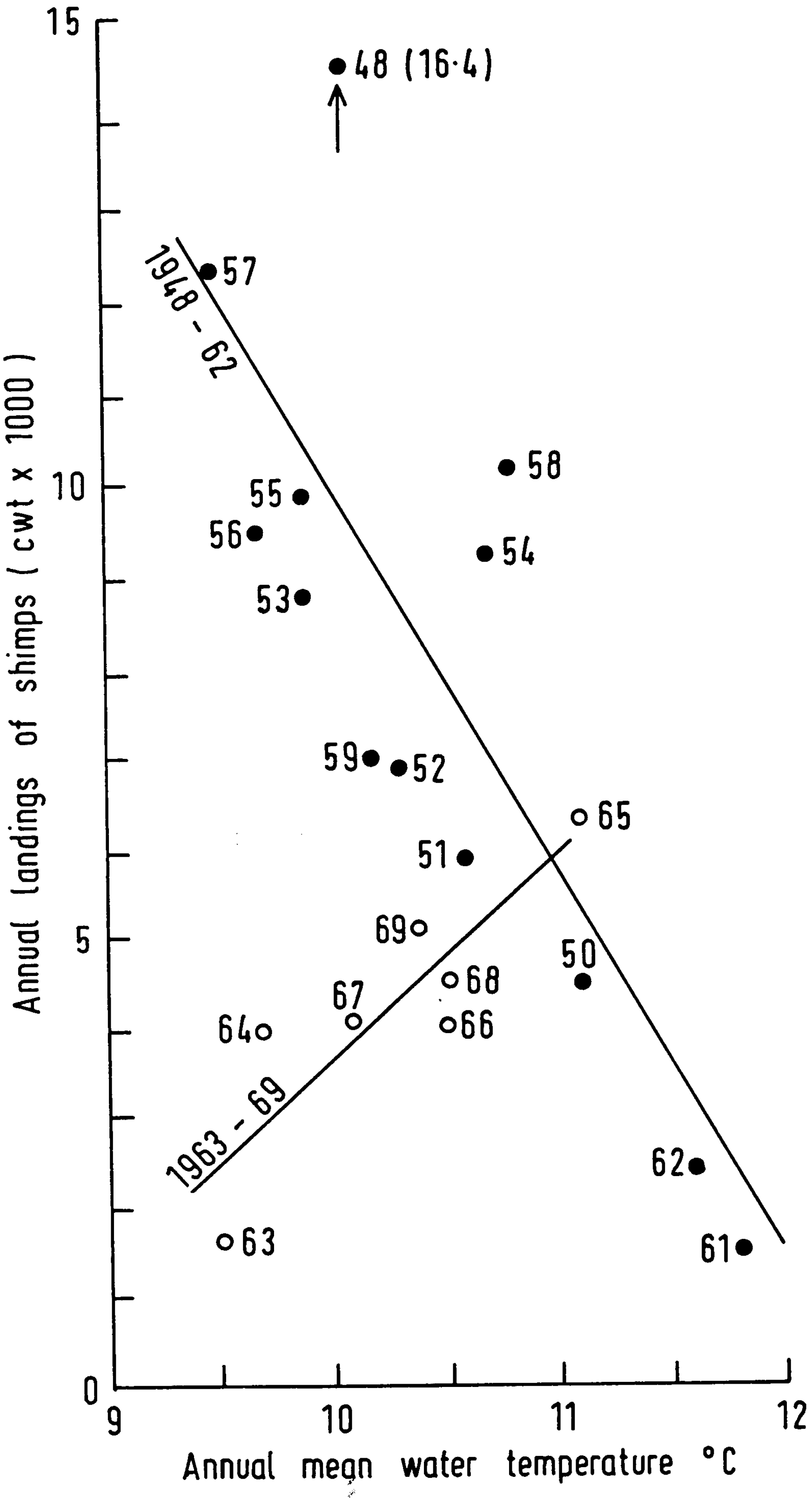
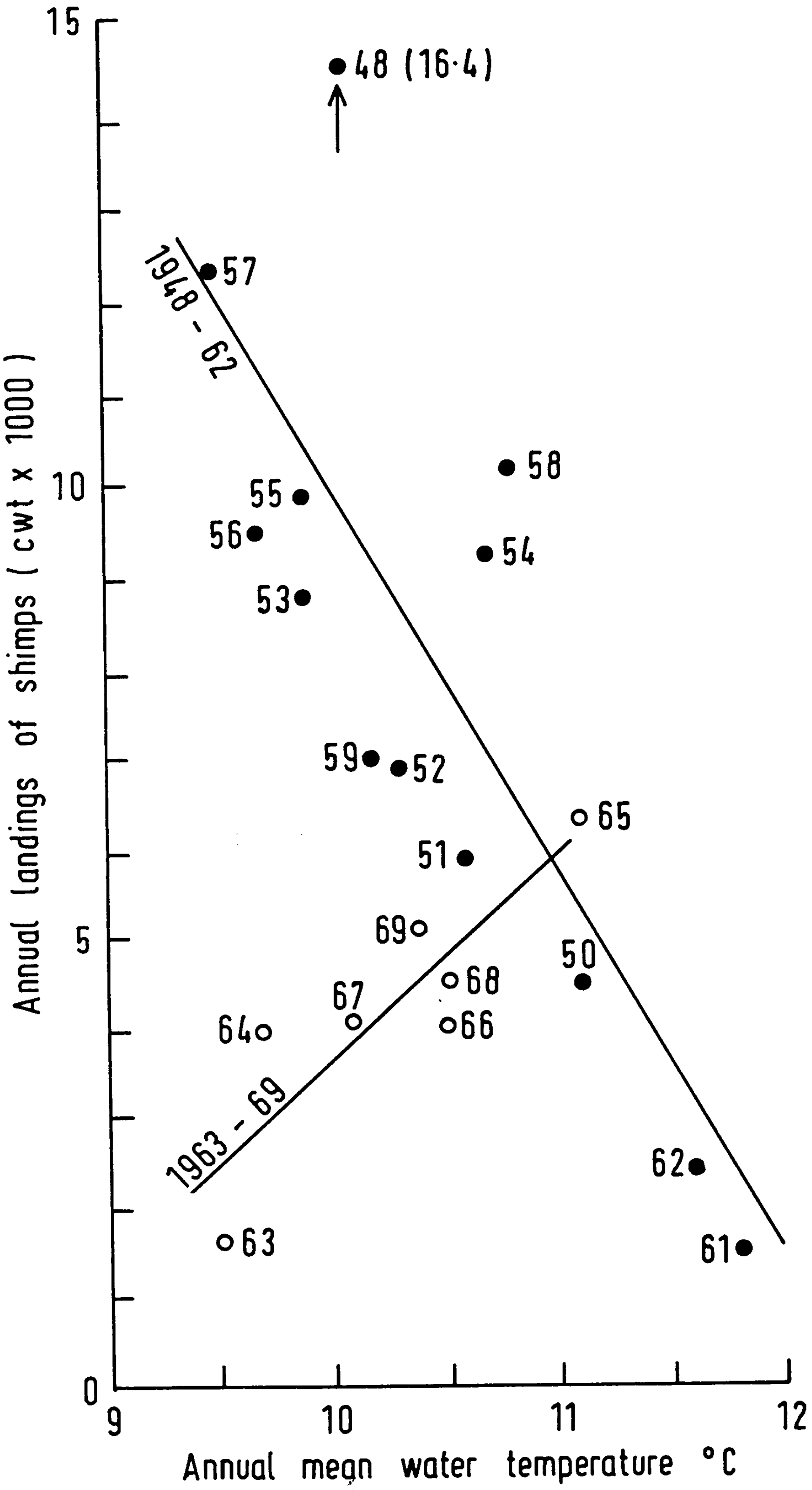


Figure 12 Annual mean water temperatures at Smith's Knoll lightvessel related to landings of pink shrimps at Boston in the following year (1948-62). NB Dates on the figure refer to the year of landings.



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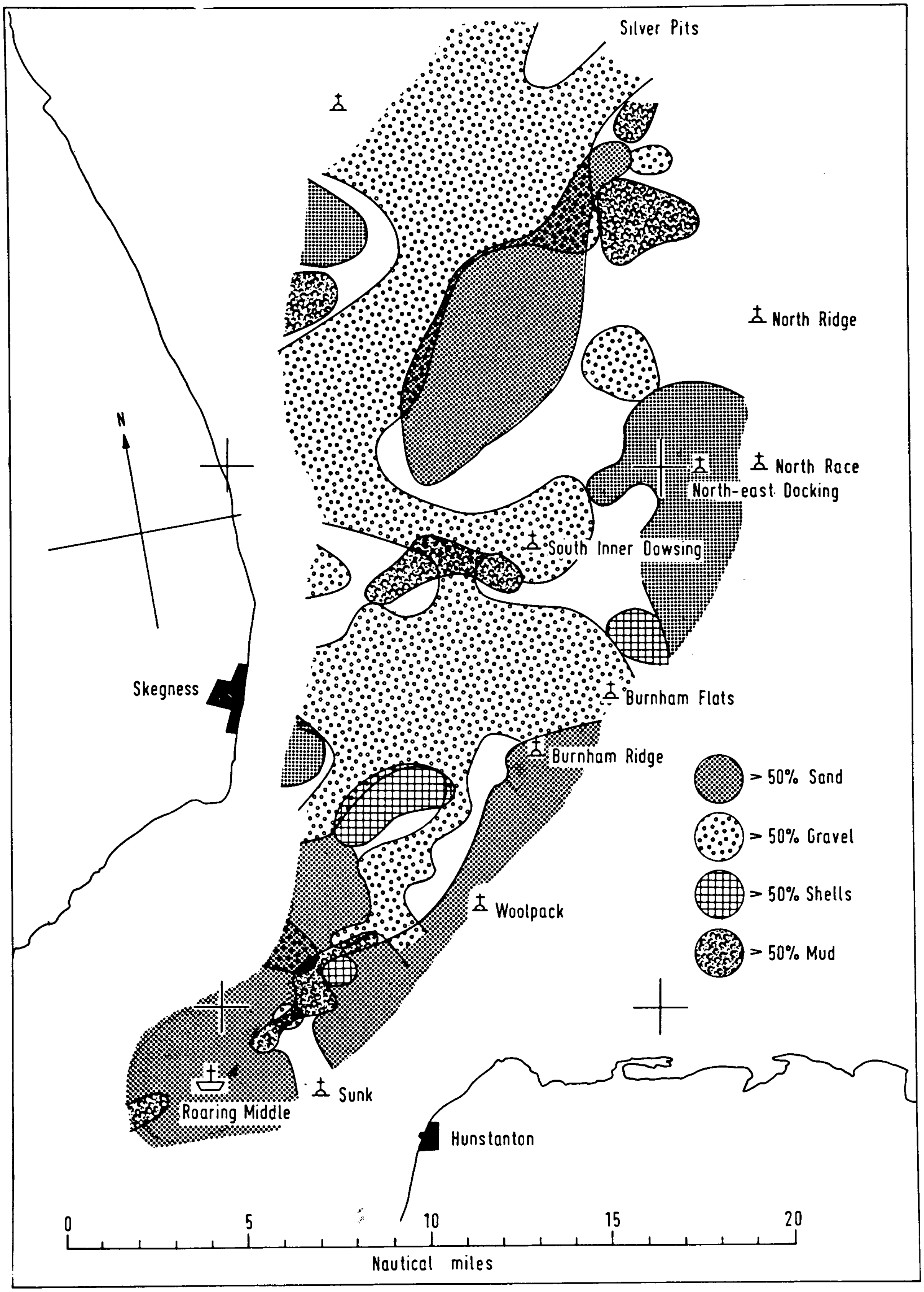

Figure 13 Types of bottom deposit in the Wash. Samples containing more than 50 per cent of four bottom deposits have been grouped together.

c Shrimp feeding

Before discussing the food of the shrimp, it is necessary to consider the nature of the sea bed of the Wash, for this affects the distribution of the food of the pink shrimp.

In order to obtain information about the bottom deposits in the Wash, a sediment survey was undertaken and samples of the substrate were taken at 168 stations to determine the main features of the area. The results are summarized in Figure 13. It can be seen that the fishery for pink shrimps takes place on the mixed but mainly hard substrate in the central area. This hard substrate consists of mixtures of gravel, sandy mud and stones, which in some areas are large enough to make trawling hazardous. Mud is present in the deep water of the Lynn Deeps, and in other small areas the bottom is soft where mud occurs in sufficient quantities. Occasional very heavy settlements of seed mussels occur in central areas of the fishery; these shells, together with oyster, clam and cockle shells, form the majority of the shell component in the substrate. Trawling for pink shrimps extends into areas of shell and mud, but not where the substrate is composed entirely of clean sand. Clean and muddy sand forms extensive banks at the southern inshore end of the Wash and brown shrimps are fished in these areas. Along the eastern side of the Wash, the sand continues well offshore in the form of extensive shallow-water-covered shoals. Little is known of the movement of sand along the eastern edge, but further offshore in the deep water between the North-East Docking and South Inner Dowsing Buoys, there is an area where sandwaves are formed on the sea bed by water movements and subsequently flattened during periods of bad weather.

Examination of the stomach contents of considerable numbers of pink shrimps has shown that they eat a wide variety of foods, including segmented worms, small crustaceans (copepods and small shrimps and their larvae), molluscs (tiny mussels and periwinkles) and algae (weed). In addition to obvious food material, many stomachs contain small fragments of shell, and sand grains are often present in high concentrations. Although there is little evidence, it has been suggested that sand is taken in with other food to assist digestion, but when it forms a major part of the stomach contents the reason for its presence is even less certain. In most samples of shrimps, the stomachs of between one quarter and one half of those examined were empty.

For many years fishermen have been aware of a probable feeding relationship between pink shrimps and Sabellaria ('ross' or 'cod'). Sabellaria is a species of segmented worm which builds characteristic colonial honeycomb structures from sand grains, which in time may become extended to form raised reefs of tubes over a sandy substrate. Because such colonies of ross consist of a great many intertwined tubes, the concentration of worms can be very high, and it has been estimated that a ross reef measuring 40 square metres may contain one million worms. Thus, although pink shrimps will accept a wide variety of food types, their preference for ross may be simply due to the fact that, in a ross colony, suitable food is available in very high concentrations. Laboratory observations have shown that pink shrimps walk over the surface of ross colonies and feed by probing the tubes to extract fragments of worm with their claws.

In recent years ross has been found in only small clumps in the Wash where the bottom is predominantly sandy, particularly toward the offshore end of the fishery. No reefs of ross are known to exist. In the main area of the fishery the abundance of ross is insufficient of itself to feed the whole of the shrimp population, and various alternative foods are taken. Thus, shrimp stomachs usually contain the food which is most readily available at the time. Recently-settled mussels may be taken. In August 1963 a haul with commercial gear in 15 fathoms (30 m) near the Lynn Knock buoys took 26 gallons of pink shrimps at about low slack water. Stones and shells in the cod-end were covered with recently-settled mussel spat. When 103 large shrimps from the haul were subsequently examined, it was found that the stomachs of 39 (38 per cent) were empty; of the remainder, one stomach contained 3 seed mussels, 18 contained mussel shells and a further 27 contained mussel shell fragments, making a total of 48 shrimps (46.5 per cent) which had been actively feeding upon mussel spat.

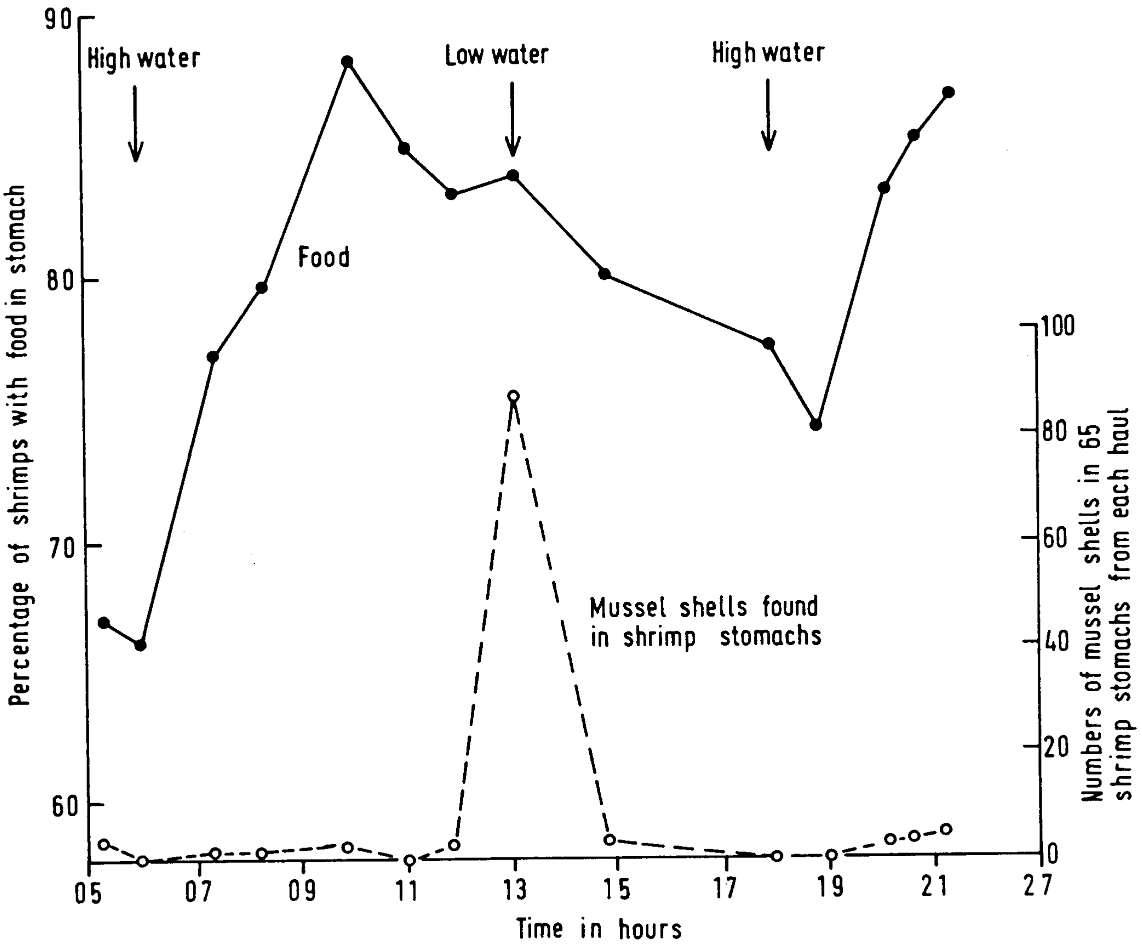

Figure 14 Variation of food intake by shrimps with the state of the tide, based on the analysis of the stomach contents of 65 shrimps from each of 14 consecutive hauls over a tidal cycle.

In April 1963, a series of trawl hauls was carried out near the South Inner Dowsing buoy to examine a possible relationship between shrimp feeding and the state of the tide. The stomach contents of 65 shrimps were examined from each of 14 consecutive hauls over a tidal cycle. Results (Figure 14) showed that the intake of food varied with the state of the tide, feeding activity increasing during the ebb tide and decreasing during the flood. The number of shrimps with food in their stomachs was lowest at high water. At low water, there was a sudden increase in the number of stomachs containing mussel shells; 88 complete shells and shell fragments were found in 65 stomachs at low water, compared with a maximum of 6 during the remainder of the tidal cycle.

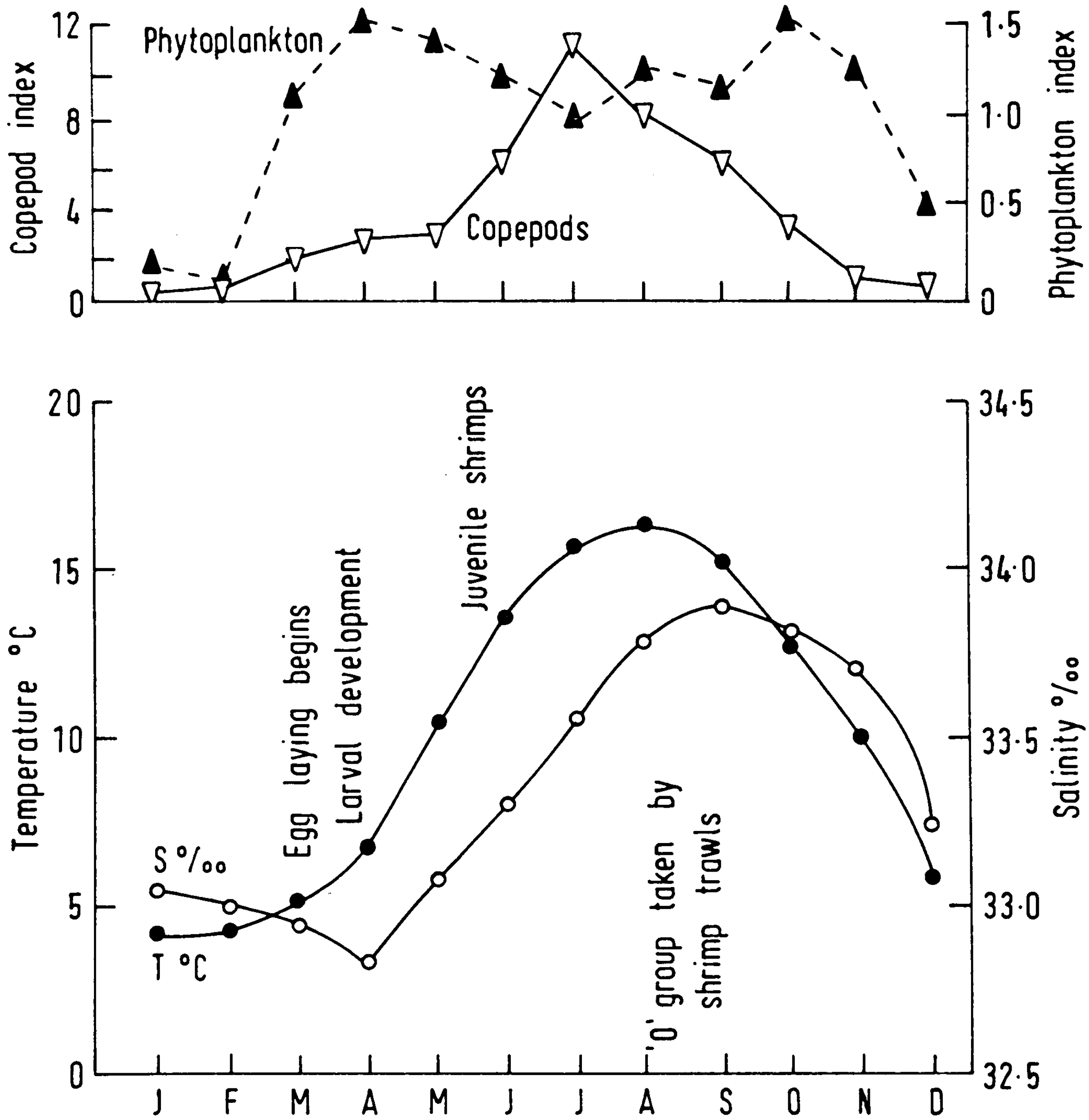

Figure 15 Plankton production cycles in area D2, southern North Sea, (Colebrook and Robinson 1965), and mean temperature and salinity in the Wash, 1963-68, (Johnson 1970), compared with growth of 0-group (first year) pink shrimps.

When shrimp eggs are hatched, the resulting larvae are carried by the tides and not confined to the sea bed for their food supply. As they develop and grow, their food requirement changes, but is governed mainly by the maximum size of food which they can ingest. At the time of hatching, the larvae (which measure about 3-4 mm) are released into the water at a time when suitable food, in the form of phytoplankton (small floating plants), is reaching its annual peak of abundance (Figure 15). The size of the phytoplankton taken probably does not exceed 100 micrometres (0.01 mm). Subsequently, juvenile shrimps are present when concentrations of copepods (small crustacea) are reaching their annual peak and it is probable that these copepods may be taken with other suitable sources of food. Six months after hatching, young shrimps are first taken by bottom trawls in the commercial fishery, and it is assumed that from then on their food is similar to that of the remainder of the population.

d Vertical migration

In the Wash, as elsewhere, commercial fishing for shrimps is confined to bottom trawling and there can be no doubt that pink shrimps stay close to the sea bed for most of the time. However, concentrations of shrimps have been taken in midwater, particularly by vessels trawling for sprats. Scientific observations on the deep-water shrimp (Pandalus borealis) and on the ocean shrimp (Pandalus jordani) in other countries have shown that vertical migrations are regularly undertaken by both species. P. borealis has been caught in strings of baited pots suspended between the surface and the sea bed in 45 fathoms (82 m) of water, and P. jordani has been taken by trawl at least twice this height above the sea bed. At the Burnham laboratory, tank observations have shown that pink shrimps swim readily and will feed at a source of food suspended 6 feet (2 m) from the bottom, and even this is above the height of a commercial trawl beam.

In February 1965, a midwater trawl was fished in various areas of the Wash, to obtain information on the possible vertical distribution of pink shrimps. This trawl had a horizontal spread of 30 feet (9 m) and a vertical spread of 12 feet (4 m), and the mesh size was graded from 100 mm at the mouth to 20 mm at the cod-end. A headline transducer recorded its position in the water column. The results gathered from 29 hauls established that small numbers of pink shrimps, and occasionally brown shrimps, were found as high as 10 fathoms (18 m) above the sea bed in water depths of 12-23 fathoms (22-42 m). Pink shrimps were caught nearer the surface in darkness than in daylight. In most hauls shrimps were taken with large quantities of sprats, and subsequent examination showed that sprat scales were present in the stomachs of many of these shrimps. From counts made at the completion of each haul, there was clear evidence that fewer berried female shrimps occurred in midwater than on the sea bed; of 3 400 shrimps examined from 15 hauls, midwater samples contained 21 per cent berried females, while bottom samples contained 50 per cent.

In the fishery, observations made on research and commercial vessels over a number of years have established that, for a period during the summer months, pink shrimps rise to the surface, riding on the trawl warps and the outer surface of the net. In calm conditions, several thousand pink shrimps may be seen to leave the warps and cover of the trawl as the gear breaks surface. The change in behaviour is well known to shrimp fishermen, who refer to these shrimps as 'floaters', because they remain in the surface waters for a short period after leaving the gear.

Although a growing volume of scientific evidence from other fisheries records increased shrimp activity off the sea bed at night, in the Wash the process appears often to be reversed, when commercial trawling carried out during the summer nights proves much more profitable than in daylight. This improvement is not consistent, but a tenfold increase in landings is possible as a result of changing from daylight to night fishing.

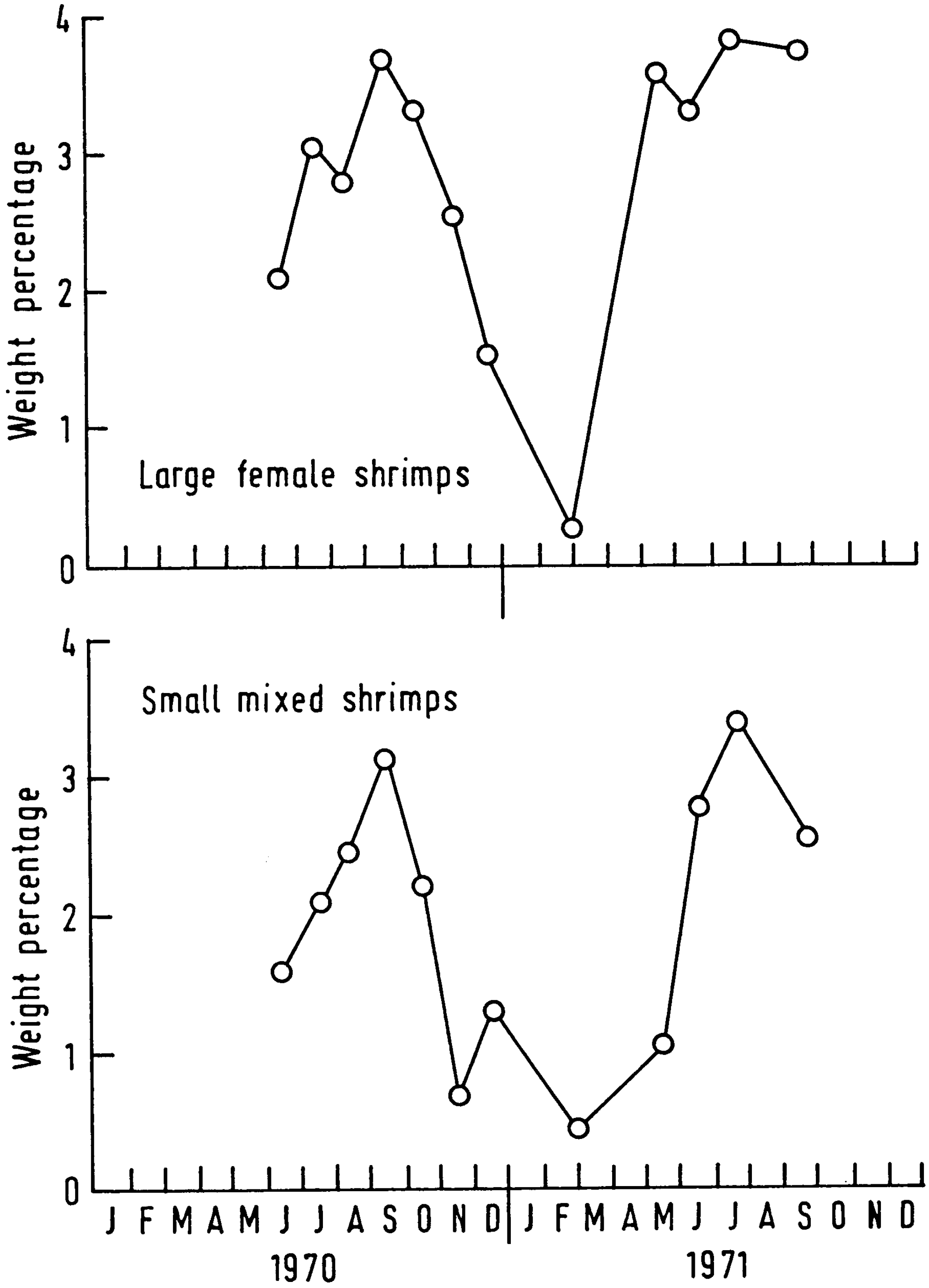

Figure 16 Oil storage by pink shrimps, the Wash, 1970-71.

The mechanism controlling the vertical movements of shrimps has not been properly described. Many fish species use air-bladders to control their buoyancy in water; herrings and sharks are reported to maintain buoyancy control by adjusting the amount of oils or fats stored within their bodies. Similar oil is a normal component of shrimps, and the oil stored by fish and shrimps is positively buoyant, having a density of 0.924 compared with about 1.024 for sea water. During the summer months, the quantity of oil stored by pink shrimps reaches its highest annual level and, although swimming is a normal part of shrimp activity, the ability of shrimps to move off the sea bed is probably assisted by this high oil content, as well as by the casting of the shell, which accounts for a notable part of the shrimp's weight in water. During 1970-71, a series of monthly observations determined the level of stored oil in large female shrimps and small shrimps of mixed sexes (Figure 16). Results showed that over two years there was a tenfold variation in the amount of oil stored by pink shrimps, the amount varying between 0.3 and 3.8 per cent. The samples of both large and small shrimps contained most oil in late summer, following the period of active feeding, but before egg-laying had started. Thereafter, the oil content decreased until March, when a sudden increase took place, probably connected with the start of active feeding. Most oil was stored in the digestive gland, situated behind the stomach. In mid-October 1970, before egg-laying began, one sample of digestive gland contained 33 per cent of stored oil by wet weight, but in subsequent samples taken in mid-November and mid-December the levels of stored oil had fallen to 14 and 2 per cent respectively. In July 1971 the level of stored oil in a sample of digestive gland had risen again to 44 per cent by wet weight.

It is possible that the effect of storing oil is to make it easier for shrimps to swim up from the sea bed to the level where planktonic food is more plentiful and when this happens to millions of shrimps, the volume of landings taken by commercial trawling is reduced for a period. The ability of shrimps to move readily through the water column, even in relatively deep water, might also have some significance in their migratory behaviour. Similarly, the increased density of shrimps which occurs in winter might possibly provide a protective mechanism to ensure that they remain in the deep water where they are not subject to extremes of salinity, temperature or wave exposure.

e Fish by-catch: conservation and predation

From observations which have been made on the by-catch, it is clear that the number and variety of market fish taken by shrimp trawlers is usually small and the majority of by-catch fish are normally flatfish species. White fish are rarely taken in quantities which would justify their landing for sale. This is perhaps not surprising since beam trawls are towed slowly (at about 2 knots) and at these speeds they are probably inefficient at capturing white fish. While it is true that relatively few saleable fish are caught, very considerable numbers of small flatfish are a normal seasonal feature of the catch. Most of these are killed while the catch is being sorted and very few are returned live to the sea. The pink shrimp fleet normally operates outside the main concentrations of small flatfish, but taken together with the brown shrimp boats the losses of immature fish are considerable. In 1875, Buckland estimated that 20 000-30 000 young flatfish, mainly soles, were caught and killed each day during the summer as a by-catch of the shrimp fishery. During the summer of 1970, a series of estimations was made by the present author which suggested that the shrimping fleet might be responsible for daily mortalities of 15 000-37 000 small flatfish such as soles, plaice, flounders and dabs. However, without an extensive knowledge of the total numbers of small flatfish in the Wash the significance of these estimates cannot be assessed. Nevertheless, the loss of small fish attributable to shrimp trawling is clearly considerable and may amount to one million fish per month.

At the same time, the number of larger fish in the by-catch is not an accurate indication of those present on the grounds, and gives no clue as to the losses of shrimps taken as food by fish species. Some estimates of the loss of shrimps due to fish predation have, however, been obtained by examining the stomachs of white-fish species in the by-catch. Both pink and brown shrimps are commonly found in white-fish stomachs, the larger fish containing up to six or more shrimps at one time.

In the German brown shrimp fishery, within recent years the total annual loss of shrimps attributable to predation by fish has been calculated to exceed the quantity of shrimps landed by all the commercial shrimp vessels in their fishery. The loss of shrimps due to fish predation has been calculated to be about twice the total annual landings from the fishery and may possibly reach thirteen times as much. Most of this predation occurred among young 'brood' shrimps (up to one year old). The main fish predator in the German fishery is the sea snail (Liparus vulgaris), a small tadpole-shaped fish, with a sucker pad beneath its head, which is a normal fèature of the catches of shrimp boats in the Wash.

f Note

Finally, in a fishery like that of the Wash, a good deal of fishing lore has been handed down from the past, and a number of curious observations may be encountered. Among these is one which concerns the possible detection of pink shrimps by their smell. Although this is clearly a very subjective area for scientific observation, in calm sea conditions it is sometimes possible to detect a faint odour when the gear is first brought to the surface. Whether this odour originates from the shrimps is a moot point, but it is intriguing that the possibility of a specific shrimp smell has not been discounted by fishermen.

5 ACKNOWLEDGEMENTS

My thanks are due to many people in their official capacities. I also record my pleasure at the time spent in the company of fishermen whose observations on the present fishery were accurate and valuable, and whose recollections of the past fishery were always interesting.

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Laboratory addresses

Fisheries Laboratory, Lowestoft, Suffolk.
Fisheries Laboratory, Burnham-on-Crouch, Essex, CM0 8HA.
Fisheries Experiment Station, Castle Bank, Conwy, Caernarvonshire.